

**UNIVERSIDADE ESTADUAL PAULISTA
FACULDADE DE MEDICINA VETERINÁRIA E ZOOTECNIA**

**POWER-LINE COLLISIONS: GROSS POSTMORTEM FINDINGS AND CAUSES
OF MORTALITY IN *Sterna* spp. IN NORTHEASTERN BRAZIL**

Gabriela Coleta Ferreira

**BOTUCATU – SP
2025**

**UNIVERSIDADE ESTADUAL PAULISTA
FACULDADE DE MEDICINA VETERINÁRIA E ZOOTECNIA**

**POWER-LINE COLLISIONS: GROSS POSTMORTEM FINDINGS AND CAUSES
OF MORTALITY IN *Sterna* spp. IN NORTHEASTERN BRAZIL**

Gabriela Coleta Ferreira

Dissertation submitted to the Graduate Program
in Wildlife Animals as part of the requirements
for the degree of Master of Science.

Advisor: Prof. Dr. José Luiz Catão Dias

Co-advisor: Dr. Daphne Wrobel Goldberg

F383p Ferreira, Gabriela Coleta
Power-line collisions: : gross postmortem findings and causes of mortality in
Sterna spp. in northeastern Brazil / Gabriela Coleta Ferreira. -- , 2025
108 f.

Dissertação (mestrado) - Universidade Estadual Paulista (UNESP),
Faculdade de Medicina Veterinária e Zootecnia, Botucatu,
Orientador: José Luíz Catão Dias
Coorientadora: Daphne Wrobel Goldberg

1. Medicina veterinária. 2. Patologia animal. 3. Aves marinhas. 4. Impactos
antrópicos em aves marinhas. 5. Linhas de energia. I. Título.

Autor: Gabriela Coleta Ferreira

Title: Power-line collisions: Gross postmortem findings and causes of mortality in *Sterna* spp. in northeastern Brazil

EXAMINING COMMITTEE

Prof. Dr. José Luíz Catão Dias
Orientador
Departamento de Patologia
FMVZ – UNESP – Botucatu

Silvia Neri Godoy
Membro titular da banca
Cemave/ICMBio

Larissa Donida Biasotto
Membro titular da banca
BirdLife International

Data da Defesa: 28 de Outubro de 2025

FERREIRA, G.C. Power-line collisions: Gross postmortem findings and causes of mortality in *Sterna* spp. in Northeastern Brazil. Botucatu, 2025. 108p. Dissertation (Master of Science) – Faculdade de Medicina Veterinária e Zootecnia, Campus Botucatu, Universidade Estadual Paulista.

RESUMO

As aves marinhas vêm enfrentando declínio populacional significativo, impulsionado por atividades humanas e degradação ambiental. Dentre os impactos, destaca-se a colisão com linhas de energia. Neste contexto, foi registrado um aumento expressivo na mortalidade de *Sterna dougallii*, *Sterna hirundo* e *Sterna hirundinacea* no litoral do Rio Grande do Norte, com indivíduos apresentando amputações, fraturas e escoriações. Este estudo teve como objetivo identificar as principais alterações macroscópicas observadas em indivíduos de *Sterna* spp. encalhados no âmbito do Projeto de Monitoramento de Praias da Bacia Potiguar (PMP-BP), entre 2020 e 2023. Foram analisados 143 indivíduos, com descrição e classificação das alterações conforme diretrizes da ABPV, ACVP e ECVP. Na Bacia Potiguar, 97,2% dos registros ocorreram em Galinhos (RN), com predomínio de resgates pela manhã (84,6%). O sistema musculoesquelético (SME) foi o mais afetado (88,8%), com fraturas (91,3%) e amputações (30,7%). O sistema respiratório (SR) foi o segundo mais comprometido (87,2%), principalmente os pulmões (90,6%), com hemorragia (95,6%). O sistema digestivo (SD) também foi frequentemente afetado (69,8%), especialmente fígado (88,3%), por congestão (49,1%) e necrose (34%), e o trato gastrointestinal (55%), por congestão (57,6%) e hipotrofia (24,4%). Alterações nos sistemas cardiovascular (50%), endócrino (44,2%), tegumentar (65%) e musculares internos (68,6%) também foram observadas. Quanto ao estado geral (EG), 48,9% apresentavam escore corporal magro (88,6%) ou caquético (11,4%). As análises sugerem interdependência nas lesões em SME e SR ($p=0$), SCV ($p<0,2$), ST ($p=0$) e EG ($p=0$), sugerindo lesões sistêmicas decorrentes do trauma. As lesões nas asas comprometem o voo e a alimentação, contribuindo para a debilidade. Os resultados reforçam que a colisão com linhas de energia é uma importante causa de óbito dessas aves no RN. No entanto, estudos complementares, como a histopatologia, são necessários para melhor elucidação da causa mortis e fatores predisponentes, como debilidade prévia, doenças ou esforço migratório.

Palavras chave: linhas de energia; colisão; aves marinhas; interação antrópica; necropsia

FERREIRA, G.C. Power-line collisions: Gross postmortem findings and causes of mortality in *Sterna* spp. in northeastern Brazil. Botucatu, 2025. 108p. Dissertation (Masters) – Faculty of Veterinary Medicine and Animal Science, Campus Botucatu, Universidade Estadual Paulista.

ABSTRACT

Seabirds have been facing a significant population decline, driven by human activities and environmental degradation. Among these impacts, collisions with power lines are considered a significant threat. In this context, a sharp increase in mortality of *Sterna dougallii* and *Sterna hirundo* has been recorded along the coast of Rio Grande do Norte, with individuals presenting amputations, fractures, and abrasions. This study aimed to identify the main macroscopic changes observed in *Sterna* spp. individuals stranded under the Beach Monitoring Project of the Potiguar Basin (PMP-BP) between 2020 and 2023. A total of 143 carcasses were analyzed in the Potiguar Basin, with alterations described and classified according to the guidelines of the ABPV, ACVP, and ECVP. In the Potiguar Basin, 97.2% of the records occurred in Galinhos (RN), with a predominance of morning rescues (84.6%). The musculoskeletal system (MSS) was the most affected (88.8%), with fractures (91.3%) and amputations (30.7%). The respiratory system (RS) was the second most compromised (87.2%), particularly the lungs (90.6%), with hemorrhage (95.6%). The digestive system (DS) was also frequently affected (69.8%), especially the liver (88.3%), with congestion (49.1%) and necrosis (34%), and the gastrointestinal tract (55%), with congestion (57.6%) and hypotrophy (24.4%). Alterations in the cardiovascular (50%), endocrine (44.2%), integumentary (65%), and internal muscular systems (68.6%) were also recorded. Regarding general condition (GC), 48.9% presented a thin (88.6%) or cachectic (11.4%) body score. The analyses suggest interdependence of lesions in the MS and RS (p-value = 0), CVS (p-value < 0.2), IS (p-value = 0), and GC (p-value = 0), indicating systemic lesions resulting from trauma. Wing injuries impair flight and feeding, contributing to debilitation. The results reinforce that collisions with power lines are a significant cause of death for these birds in RN. However, complementary studies such as histopathology are needed to better elucidate the cause of death and predisposing factors such as prior debilitation, concurrent diseases, or migratory effort.

Key words: power lines; collision; seabirds; anthropogenic interaction; necropsy

TABLES

Table 1. Classification of cadavers preservation codes. Adapted from Geraci & Lounsbury (2005).....47

Table 2. Main external gross pathological findings in *Sterna* spp. with signs of collision in the Potiguar Basin between 2020 and 2023.....53

Table 3. Main internal macroscopic pathological findings in *Sterna* spp. with signs of collision in the Potiguar Basin between 2020 and 2023.....61

Table 4. Classification of fractures observed in radiographed carcasses of *Sterna* spp.....70

Table 5. Main radiological findings in *Sterna* spp. with evidence of collision with power lines in the Potiguar Basin.....7

LIST OF FIGURES

Figure 1. Offshore wind potential along the Brazilian coast (World Bank, 2019) and location of projects under environmental licensing (IBAMA, 2022).....	14
Figure 2. Area where fractured <i>Sterna</i> spp. were found between 2010 and 2017.....	15
Figure 3. <i>Sterna hirundo</i> individual feeding.....	17
Figure 4. Morphological comparison between <i>Sterna dougallii</i> and <i>Sterna hirundo</i>	18
Figure 5. Morphological comparison between <i>Sterna paradisea</i> breeding and non-breeding plumage.....	19
Figure 6. Morphological comparison between <i>Sterna hirundinacea</i> breeding and non-breeding plumage.....	22
Figure 7. Record of an <i>Ara chloropterus</i> specimen caught in power distribution wires in Campo Grande, Brazil.....	34
Figure 8. Map of the study area between the municipalities of Aquiraz (CE) and Caiçara do Norte (RN).....	40
Figure 9. Individuals of <i>Sterna</i> spp. found with collision signs near power lines.....	43
Figure 10. Comparison of the final outcomes of birds found alive.....	49
Figure 11. Comparison between deaths recorded prior to rescue and those occurring after rescue.....	50
Figure 12. Number of <i>Sterna</i> spp. records per month in the Potiguar Basin between 2020 and 2023.....	51

Figure 13. Annual distribution of <i>Sterna</i> spp. records in the Potiguar Basin between 2020 and 2023.....	53
Figure 14. Severe bilateral hypotrophy of the pectoral musculature in a <i>Sterna</i> spp. individual.....	55
Figure 15. Complete open fracture in the proximal portion of the right humerus of <i>Sterna dougallii</i>	57
Figure 16. Traumatic amputations in <i>Sterna</i> spp.....	57
Figure 17. Relationship between the time interval until death and the severity of bone lesions.....	58
Figure 18. Macroscopic lesions in the integumentary system observed in <i>Sterna</i> spp. stranded in the Potiguar Basin.....	60
Figure 19. Gross pathological findings in the left pectoral musculature of <i>Sterna</i> spp.....	64
Figure 20. Presence of hematoma in the right pectoral musculature.....	64
Figure 21. Gross pathological findings in the respiratory system of <i>Sterna</i> spp.....	65
Figure 22. Gross pathological findings in the digestive system of <i>Sterna</i> spp.....	66
Figure 23. Gross pathological findings in the digestive system of <i>Sterna</i> spp.....	66
Figure 24. Gross pathological alterations in the heart of <i>Sterna</i> spp.	67
Figure 25. Gross pathological findings in the genitourinary system of <i>Sterna</i> spp...68	
Figure 26. Comparison between radiographic and necropsy findings in the carcasses of <i>Sterna</i> spp.....	71
Figure 27. Coracoid bone alterations identified through radiographic evaluation....	73

LIST OF ABBREVIATIONS

- ABPV** – Associação Brasileira de Patologia Veterinária
- ACVP** – American College of Veterinary Pathologists
- APLIC** – Avian Power Line Interaction Committee
- BP** – Bacia Potiguar
- CEPRAM** – Centro de Pesquisa e Reabilitação de Animais Marinhos
- CEMAM** – Centro de Estudos e Monitoramento Ambiental
- CRDA** – Centro de Reabilitação e Despetrolização de Araruama
- CRF-AB** – Centro de Reabilitação de Fauna de Areia Branca
- ECVP** – European College of Veterinary Pathologists
- EG** – Estado Geral
- FMVZ** – Faculdade de Medicina Veterinária e Zootecnia
- IBAMA** – Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis
- ICMBio** – Instituto Chico Mendes de Conservação da Biodiversidade
- LMBM** – Laboratório de Monitoramento de Biota Marinha
- MAD** - Membro anterior direito
- MAE** - Membro anterior esquerdo
- NESC** – National Electrical Safety Code
- PCCB-UERN** – Projeto Cetáceos da Costa Branca da Universidade do Estado do Rio Grande do Norte
- PMP** – Projeto de Monitoramento de Praias
- PMP-BP** – Projeto de Monitoramento de Praias da Bacia Potiguar
- PMP-BC** – Projeto de Monitoramento de Praias da Bacia de Campos
- PMP-BS** – Projeto de Monitoramento de Praias da Bacia de Santos
- RN** – Rio Grande do Norte
- SCV** – Sistema Cardiovascular
- SD** – Sistema Digestivo
- SD (espécie)** – *Sterna dougallii*
- SE** – Sistema Endócrino

SGU – Sistema Geniturinário (forma alternativa encontrada no texto)

SH – *Sterna hirundo*

SIMBA – Sistema de Informação de Monitoramento da Biota Aquática

SME – Sistema Musculoesquelético

SR – Sistema Respiratório

ST – Sistema Tegumentar

TGI – Trato Gastrointestinal

UFERSA – Universidade Federal Rural do Semiárido

UNESP – Universidade Estadual Paulista

USFWS – United States Fish and Wildlife Service

Table of Contents

INTRODUCTION	12
1. Introduction	13
OBJECTIVES	18
2. Objectives	19
LITERATURE REVIEW	20
3. Literature review	21
3.1. Seabirds	21
3.2. Main anthropogenic interactions	27
3.2.1. Collision	28
3.2.1.1. Collisions with power lines	29
3.2.1.1.1. Factors Influencing Collision Risk	30
3.2.1.1.1.1. Frequency of Flights Near Power Lines	30
3.2.1.1.1.2. Wire Detectability	32
3.2.1.1.1.3. Collision Avoidance Capacity	33
3.2.2. Mitigation of power line impacts on birds	36
MATERIALS AND METHODS	38
4. Materials and Methods	39
4.1. Study Area	39
4.1.1. Potiguar Basin and the States Rio Grande do Norte and Ceará	39
4.1.1.1. Presence of Power Lines: The Case of Galinhos (RN)	40
4.2. Data Collection	41
4.2.1. Radiographic Evaluation	44
4.2.2. Necropsy Evaluation	45
4.2.3. Data Evaluation	47
RESULTS	48
5. Results	49
5.1. Main Gross Pathological Findings	52
5.1.1. External Alterations	52
5.1.1.1. General Condition	55
5.1.1.2. Musculoskeletal System	56
5.1.1.3. Integumentary System	58
5.1.2. Internal Alterations	60
5.1.2.1. Musculoskeletal System	63
5.1.2.2. Respiratory System	64
5.1.2.3. Digestive System	65
5.1.2.4. Cardiovascular System	67
5.1.2.5. Endocrine System	67
5.1.2.6. Genitourinary System	67
5.2. Statistical Evaluation	68
5.3. Radiographic Study	69
DISCUSSION	75

6. Discussion	76
CONCLUSIONS	84
7. Conclusions	85
REFERENCES	86
8. References	87

INTRODUCTION

1. Introduction

Brazil holds the second largest number of bird species globally threatened with extinction (BIRDLIFE INTERNATIONAL, 2020; PACHECO et al., 2021). In addition to natural selective pressures such as limited food resources, predation, and adverse climatic conditions (HAMER et al., 2002; BELL, 2008), seabird species face numerous anthropogenic threats. These include ingestion of solid waste, entanglement in fishing gear (MARIANI, 2016; GARBELOTO & PEREIRA, 2021; NASCIMENTO et al., 2022), and collisions with vessels (MARIANI, 2016) and power transmission and distribution lines (PALACÍN et al., 2017; BERNARDINO et al., 2018; REVORÊDO, 2021).

Other threats—such as hunting and aircraft collisions—are more frequently reported among terrestrial birds (LYNE et al., 1998; SHEEHY et al., 2005; SILVA et al., 2018), but they should also be considered potential risks in marine and coastal settings given the ongoing expansion of human activities.

In this context, fixed structures such as wind turbines and power lines are of particular concern for migratory birds because they can act as barriers, displace flight paths, and increase collision risk (PALACÍN et al., 2017).

The expansion of wind energy in Brazil has been driven by government incentives, notably Law No. 10.438/2002, which established the Program for the Incentive of Alternative Electric Energy Sources (PROINFA) and created favorable conditions for sector growth. Negligible before 2005, wind power now accounts for about 10% of the national electricity mix, with average annual growth of roughly 36% over the past decade (ABEEólica, 2021).

IBAMA (2022) reports that wind-energy developments undergoing environmental licensing in Brazil are concentrated in three coastal sectors: (a) the northeastern coast, from Piauí to Rio Grande do Norte; (b) the southeastern coast, from southern Espírito Santo to northern Rio de Janeiro; and (c) the southern coast, along the central and northern littoral of Rio Grande do Sul (Figure 1). These clusters overlap regions of high ecological value and high concentrations of migratory birds, highlighting the need for targeted studies and rigorous assessment of potential impacts on coastal avifauna.

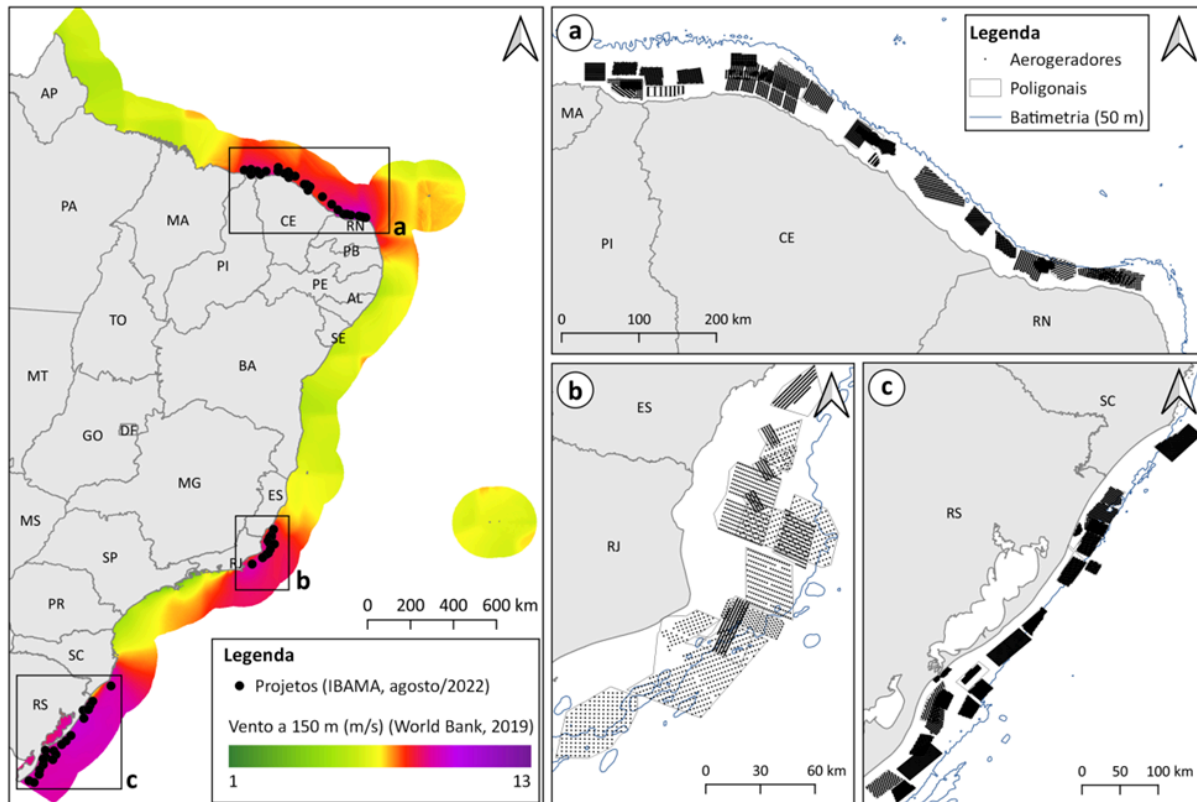


Figure 1. Offshore wind potential along the Brazilian coast (World Bank, 2019) and location of projects under environmental licensing (IBAMA, 2022), detailed for the three areas of greatest wind potential: a) Northeastern coast; b) Southeastern coast; c) Southern coast. Source: BUGONI et al. (2022).

Within this context, an increase in mortality among two tern species of the family Sternidae—*Sterna dougallii* (MONTAGU, 1813) and *Sterna hirundo* (LINNAEUS, 1758)—has been observed along the northeastern coast of Brazil, especially in the municipality of Galinhos (Rio Grande do Norte) (REVORÊDO, 2021).

Since 2009, the Projeto Cetáceos da Costa Branca at the Universidade do Estado do Rio Grande do Norte (PCCB-UERN) has carried out the Beach Monitoring Project in the Potiguar Basin (*Projeto de Monitoramento de Praias na Bacia Potiguar* – PMP-BP), generating a systematic database on the marine fauna assisted. Beginning in 2014, PCCB-UERN field teams documented a marked increase in injured terns (FARFÁN et al., 2017; GARTHE et al., 2017; REVORÊDO, 2021), coincident with the commencement of operations at a wind farm in the region (Figure 2). This temporal overlap prompted the hypothesis that wind turbines may be altering avian flight paths and increasing the risk of collisions with power lines (PCCB/UERN/CEMAM Technical Note No. 01/17, 2017)..

Revorêdo (2021) subsequently corroborated this hypothesis, documenting an association between the commissioning of the wind farm and increased avian collisions with overhead electrical infrastructure. Collision risk is amplified where these structures occur near feeding and roosting sites and when conductors are of small diameter, which reduces their detectability to birds (Beaulaurier, 1981).



Figure 2. Area where fractured *Sterna* spp. were found between 2010 and 2017. A. Satellite image of layers showing impacted birds and power lines in Galos Beach, municipality of Galinhos; B. *S. dougallii* found stranded after suspected collision with power lines. Source: Joint Technical Note PCCB-UERN/CEMAM No. 01/20 (2020) and Aquatic Biota Monitoring Information System, respectively.

Physical obstacles such as wind farms and overhead power lines can alter avian flight trajectories by inducing avoidance behavior (PALACÍN et al., 2017). These deviations may have important conservation implications for migratory species, including the two noted above, which migrate annually to the Southern Hemisphere during the boreal winter and rely on northeastern Brazil as a key stopover site (HAYS, HELEN et al., 1999; LIMA et al., 2004b; CERQUEIRA LIMA et al., 2005).

Furthermore, the conservation of these birds is directly related to the protection of their resting, feeding, and breeding areas. Therefore, the development and expansion of monitoring efforts for populations visiting Brazil is of utmost importance, as the country holds critical areas for the survival of these animals (CORDEIRO, 1996).

Currently, there is a body of research addressing the effects of habitat anthropization on the behavior and distribution of these animals, as well as environmental quality assessments and the threats present in these ecosystems

(VALENTE et al., 2011; REVORÊDO, 2021; ROCHA, 2021). However, there remains a gap regarding their clinical, pathological, and epidemiological conditions, as well as the description of traumatic injuries resulting from collisions with physical structures and hunting artifacts.

Although the primary objective of the Beach Monitoring Project is to assess the impacts of oil and gas production and transportation activities on marine tetrapods—through beach monitoring, veterinary care for live animals, and collection and analysis of materials from deceased animals—the data it generates also allow us to understand other impacts affecting these animals and their causes of death.

In Brazil, the Northeast serves as a migratory route for the common tern (*Sterna hirundo*) and a wintering area for the roseate tern (*Sterna dougallii*) (LIMA et al., 2004a,b; DE LUCA et al., 2006). At the same time, this region stands out as a leader in renewable energy generation, especially wind power, which accounts for nearly 90% of regional consumption (NEOENERGIA, 2018; ETENE, 2019). Rio Grande do Norte was a pioneer in commercial wind energy production in the country and currently leads national production (PETROSOLGAS, 2023).

To meet national demand, the energy generated in the Northeast is transmitted via high-voltage lines to other regions of the country. However, the overlap between this energy infrastructure and priority areas for Sternidae has resulted in significant impacts on these birds.

In this context, a concerning situation involving these birds has been documented along the northern coast of Rio Grande do Norte, particularly in the municipality of Galinhos. According to the Joint Technical Note PCCB-UERN/CEMAM (2020), *Sterna* spp. were frequently found with clinical signs and postmortem findings consistent with collisions with power distribution lines, totaling 320 recovered terns in this area between 2011 and 2020 (CENTRO DE ESTUDOS E MONITORAMENTO AMBIENTAL, 2021).

As migratory animals monitored both during the wintering period in Brazil by the Beach Monitoring Project and during the breeding season in the Northern Hemisphere by Mass Audubon and the United States Fish and Wildlife Service (USFWS) (source), such information represents an important contribution to the assessment of the health status of the birds found, and the effectiveness of the

mitigation measures currently adopted, in addition to the creation of new public policies aimed at the conservation of these species.

Accordingly, this study aimed to systematically characterize the necropsy lesions of *Sterna* spp. recovered in the Potiguar Basin after suspected power-line collisions, in order to document collision-related trauma patterns and inform mitigation efforts. In addition to guiding the evaluation of current mitigation measures, the detailed description of these lesions may also support the identification of similar collision patterns in other seabird species, contributing to a broader understanding of trauma mechanisms associated with power-line interactions and strengthening diagnostic and monitoring efforts in wildlife conservation programs.

OBJECTIVES

2. Objectives

This study aims to characterize necropsy and radiographic findings in terns (family *Sternidae*) with a documented history of collision, recovered by the Potiguar Basin Beach Monitoring Project (PMP-BP) from January 2020 through December 2023, to identify trauma patterns associated with overhead power-line strikes and inform mitigation strategies in the region.

2.1. Specific objectives

- Profile the sample by sex, age class, species, carcass condition, stranding location, and the presence or absence of overhead power lines in the stranding area.
- Describe and classify collision-associated traumatic injuries based on gross necropsy and radiographic evaluation, including events involving electrical distribution and transmission lines.

LITERATURE REVIEW

3. Literature review

3.1. Seabirds

Seabirds comprise a group of species adapted to coastal and oceanic environments, exhibiting a wide morphological and physiological diversity that supports their survival and reproduction in these specific habitats (SCHREIBER & BURGER, 2002). Among their various adaptations are differences in beak shape, wings, tails, legs, plumage coloration, and salt glands (EFE, 1999; SCHREIBER & BURGER, 2002).

This group is divided into five orders: Procellariiformes, Sphenisciformes, Pelecaniformes, Suliformes, and Charadriiformes. The latter is the focus of the present study..

3.1.1. Order Charadriiformes and terns

Within the order Charadriiformes, the family Laridae includes the genus *Sterna*, commonly known as terns (SIBLEY, AHLQUIST & MONROE, 1988). These birds have narrow wings, forked tails, and straight, pointed beaks, which are angled downward in flight. They also exhibit distinct plumage in breeding and non-breeding seasons (SICK, 2001) and lack sexual dimorphism (NACINOVIC, 2005).

Terns are distributed across all continents, occurring primarily in coastal and marine habitats, with diverse foraging behaviors focused on aquatic prey (ARNOSO, 2019). Their diet consists mainly of squid and bony fish (Figure 3), captured either at the water's surface or through shallow plunge-diving. They are considered opportunistic kleptoparasites, although this behavior is most often observed during periods of low food availability (GARCIA et al., 2014).



Figure 3. *Sterna hirundo* individual feeding. Source: MACAULAY LIBRARY. Available at: <https://macaulaylibrary.org/asset/585547691>. Accessed on: 5 Jan. 2025.

Of the 13 existing species within the genus *Sterna*, four occur in the state of Rio Grande do Norte: the Common Tern (*Sterna hirundo* Linnaeus, 1758), Roseate Tern (*Sterna dougallii* Montagu, 1813), Arctic Tern (*Sterna paradisaea* Pontoppidan, 1763), and South American Tern (*Sterna hirundinacea* Lesson, 1831).

The first two species can be differentiated (Figure 4) by examining the outer margins of the primary flight feathers: *S. dougallii* exhibits a continuous white border reaching the tips of the first three or four primaries, whereas *S. hirundo* has a dark gray or black border, and if a pale line is present, it does not reach the feather tips (U.S.F.W.S., 1999). Additionally, *S. dougallii* has shorter wings and a longer tail than *S. hirundo*, and its breast is pure white rather than the pale gray seen in *S. hirundo*.

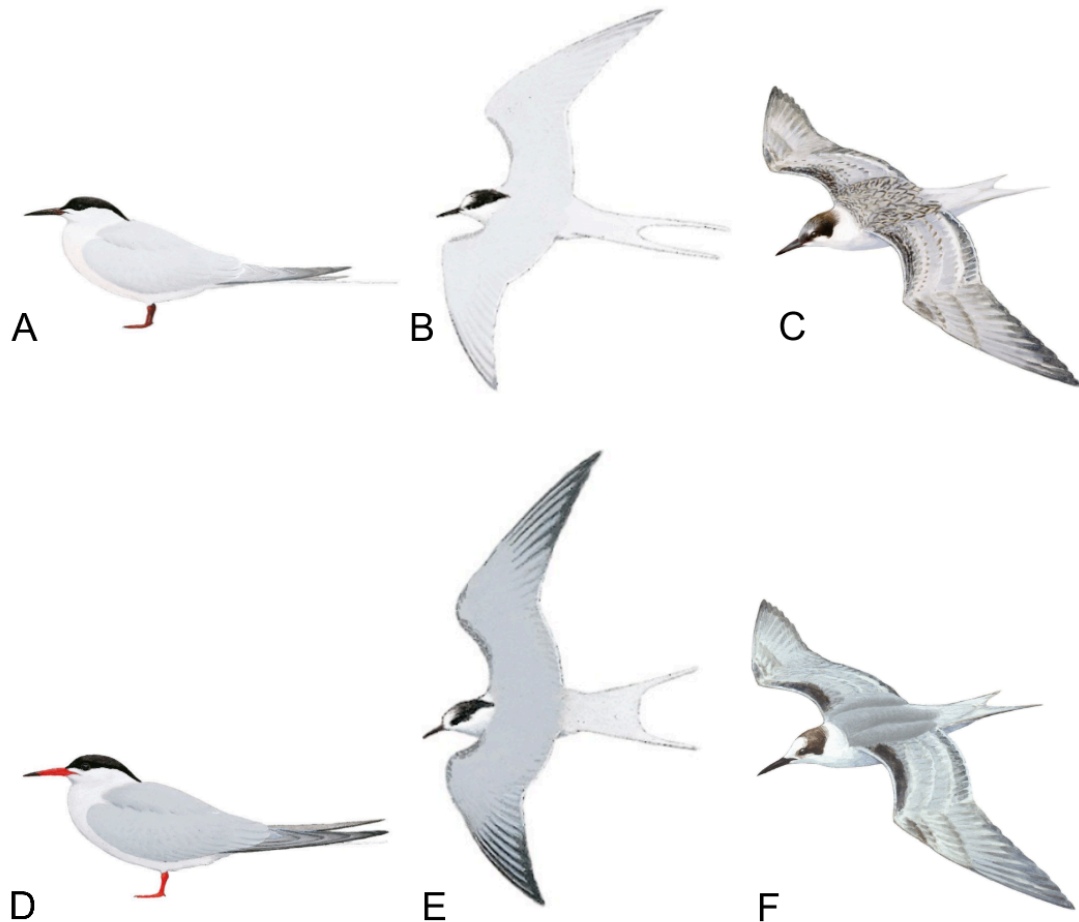


Figure 4. Morphological comparison between *Sterna dougallii* and *Sterna hirundo*. (A–C) Adult *S. dougallii* at rest (A), dorsal view (B), and juvenile (C). (D–F) *S. hirundo* in the same positions: at rest (D), dorsal flight (E), and juvenile (F). Source: Adapted from Birds of the World (2025). Accessed at: <https://birdsoftheworld.org/bow/species/roster/cur/multimedia?media=illustrations> and <https://birdsoftheworld.org/bow/species/comter/cur/introduction>.

Both species have broad distribution ranges, breeding in temperate regions of Europe, Asia, and North America, and wintering along tropical and subtropical coasts of Africa and South America (LIMA, 2018; CAMBOIN, 2020).

In Brazil, these terns are predominantly migrants from North America, especially the United States (NISBET, 1989; U.S.F.W.S., 1999; AZEVEDO JUNIOR, LARRAZÁBAL & PENA, 2004; ICMBIO/MMA, 2018a), with primary wintering grounds in Rio Grande do Sul and Bahia (CORDEIRO, FLORES & NACIMENTO, 1996; SOMENZARI et al., 2018). They have also been recorded at several other locations along the Brazilian coast, including Rio Grande do Norte (AZEVEDO JUNIOR, LARRAZÁBAL & PENA, 2004; MESTRE, 2007; MACEDO MESTRE, 2010).

The Arctic Tern (*S. paradisaea*) has pelagic habits, occurring both in open ocean and at ice edges (BURGER & GOCHFELD, 1996; HATCH, 2002). Its plumage resembles that of *S. hirundo*, but it has a paler body, a longer, more deeply forked tail, and an entirely red beak during the breeding season (Figure 5). The upperwing surfaces are pale gray with translucent outer primaries (KENN KAUFMAN, H.G.S.; 2005). In the non-breeding season, the beak becomes darker.



Figure 5. Morphological comparison between *Sterna paradisaea* breeding (A) and non-breeding (B) plumage. Source: Adapted from Birds of the World. Available at: <https://birdsoftheworld.org/bow/species/arcter/cur/multimedia?lang=es&media=illustrations>. Accessed on: 15 Jul. 2025.

The fourth species, *S. hirundinacea*, has red beak and legs, light gray upperparts, and white underparts when adult; juveniles have a black beak and darker gray mottling on dorsal and wing feathers. In breeding plumage, the forehead, crown, and nape are black; in non-breeding plumage, only the nape remains black, with the forehead and crown turning white (Figure 6). This species is restricted to the

Atlantic Ocean, from Tierra del Fuego (Argentina) to Santa Catarina (Brazil) (ANTAS, 1991; SICK, 1997; BRANCO, 2003a,b; FRACASSO, 2005).

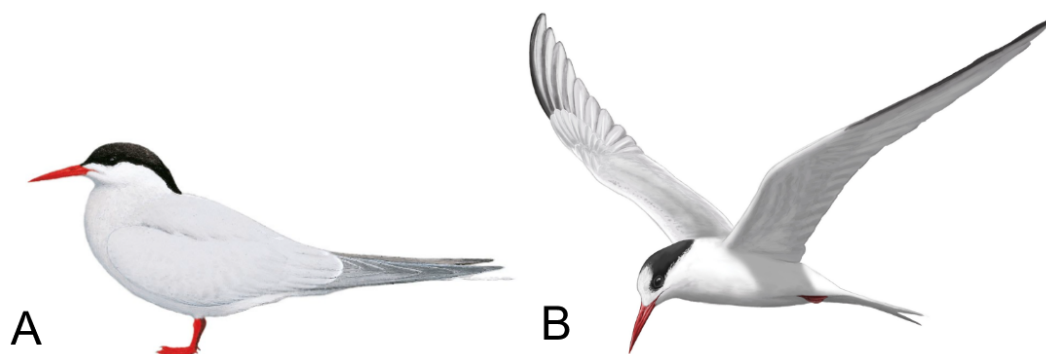


Figure 6. Morphological comparison between *Sterna hirundinacea* breeding and non-breeding plumage. (A) Breeding phase. (B) Non-breeding phase. Source: Adapted from *Birds of the World*. Available at: <https://birdsoftheworld.org/bow/species/soater1/cur/multimedia?media=illustrations>. Accessed on January 5, 2025.

3.1.1.1. *Sterna dougallii*

S. dougallii, commonly known as the Roseate Tern, is named for the faint pink wash on the breast during the breeding season (SICK, 2001). In Brazil, the species is classified as Vulnerable (VU), mainly due to its small known area of occupancy and the aggregation of individuals in a limited number of sites (ICMBIO/MMA, 2018b). According to Tavares et al. (2013), the first documented occurrence of the species on the southeastern coast of Brazil was only in 2011. At the global level, however, the species is classified as Least Concern (LC) by the IUCN Red List (BirdLife International, 2018).

Adult individuals reproduce from early May to early July. At the end of this period, breeding areas are abandoned, and fledglings accompany their parents to other locations in search of food.

In general, migration to non-breeding areas begins in September, and North American populations remain in South America until mid-April, when they begin the return to breeding sites, thus restarting the annual cycle (NISBET, 1989; HAYS et al., 1999b; U.S.F.W.S., 1999; ICMBIO/MMA, 2018b; DAVIS et al., 2019).

3.1.1.2. *Sterna hirundo*

S. hirundo, known as the Common Tern, is the most frequent migrant of the family *Sternidae* along the Brazilian coast (NASCIMENTO & SANTOS, 2010). They

are regular visitors to Brazil during the non-breeding season, when they show a white forehead and crown (SICK, 2001). Regarding conservation status, the species is listed as Least Concern (LC) both in Brazil and in the United States (BIRDLIFE INTERNATIONAL, 2019).

These individuals begin their return to breeding grounds in April and early May (NASCIMENTO & SANTOS, 2010), and after the breeding season, around July, post-breeding dispersal occurs as they prepare for southbound migration, restarting the cycle.

The species experienced two major population declines: in the late 19th century due to hunting for the fashion industry, and in the mid-20th century due to nesting site competition with gulls and chemical contamination. In the late 20th century, breeding populations increased along the Atlantic coast due to conservation measures such as pollution control, waste management, protection of breeding areas, predator control, and habitat restoration. These factors highlight the importance of continuous monitoring to maintain stable populations (ARNOLD et al., 2020).

3.1.1.3. *Sterna paradisaea*

S. paradisaea, known as the Arctic Tern, undertakes the longest known migration of any species, with extreme seasonal movements between the Northern and Southern Hemispheres. Migrating individuals have a broad distribution and have even been recorded inland, far from coastal areas (HATCH, 2002).

The species breeds primarily in Arctic and subarctic regions during the boreal summer months, migrating to the Antarctic Ocean during the Northern Hemisphere winter, reaching pack ice zones (BURGER & GOCHFELD, 1996; HATCH, 2002). Its occurrence in Brazil is rare, but there are scattered records along the coast (SAUNDERS & SALVIN, 1896; PINTO, 1964; SICK, 1997; LIMA et al., 2004; DIAS et al., 2012), including the state of Ceará (GIRÃO et al., 2008).

During the breeding season, which takes place between May and August in the Arctic regions of Europe, Asia, and North America, they display fully red beaks, white breasts, pale wings, and a long, deeply forked tail extending beyond the wing tips when at rest. After breeding, they disperse to the Southern Hemisphere for the

non-breeding season in areas near the Antarctic continent (EGEVANG et al., 2010; FIJN et al., 2013) before starting their return migration between April and May.

Globally, the species is classified as Least Concern (LC) by BirdLife International (2019), but faces increasing threats from climate change, particularly in the Arctic, which may affect food availability and breeding habitats.

3.1.1.4. *Sterna hirundinacea*

S. hirundinacea, commonly known as the South American Tern or Red-billed Tern, is one of the most widely distributed *Sterna* species, completing its entire life cycle exclusively in South America. It is currently listed as Vulnerable (VU) in the Brazilian Red Book of Threatened Fauna (ICMBIO/MMA, 2018b). However, at the global level, BirdLife International/IUCN (2019) classifies the species as Least Concern (LC).

Two distinct breeding populations occur along the South American Atlantic coast. The population breeding in southern Uruguay and Argentina initiates reproduction between December and February, during the austral summer, later migrating to Brazil between April and May to spend the winter, possibly between the coasts of Rio de Janeiro and southern Bahia. The Brazilian population, distributed between Santa Catarina and Espírito Santo, begins breeding between April and May (ANTAS, 1987), with records also in coastal islands of Rio de Janeiro (COELHO et al., 1990) and Santa Catarina (BRANCO, 2003a). Studies in Brazil indicate that the breeding period for this species in the country may extend from May to November (SICK, 1997; EFE et al., 2000; BRANCO, 2003a; 2003b).

Nesting sites have been identified in several locations, including the Itacolomis, Deserta, Moleques do Sul, and Cardos Islands in Santa Catarina (BRANCO, 2003a), Laje de Santos and Ilha Comprida in São Paulo, as well as Guanabara Bay, Rio das Ostras, and Macaé in Rio de Janeiro (COELHO et al., 1990), and in the state of Pará. In Espírito Santo, the species nests on several islands, including the largest known breeding colony in Brazil.

3.2. Main anthropogenic interactions

Seabirds have experienced sharp population declines over the past decades, affecting around 80% of their species. Among the main factors associated with this decrease are infectious diseases, toxicosis, and various anthropogenic interactions (MARIANI, 2016; REVORÊDO, 2021).

Among these threats, the most notable are oil contamination, ingestion of solid waste, interaction with fishing gear, habitat loss, and ocean pollution by chemical substances (e.g., organochlorines, heavy metals, and hydrocarbons) (KETTRUP; MARTH, 1998; SANTOS, 2006; PELANDA, 2007; FERREIRA; HORTA, 2010; SALVAGNI, 2013; SERAFINI; LUGARINI, 2014; MARIANI, 2016). According to Erickson et al. (2005) and Loss et al. (2015), collision with physical structures that are part of the urban environment is considered one of the main anthropogenic causes of mortality among wild birds, potentially resulting in the death of hundreds of millions of individuals each year.

3.2.1. Collision

Large linear constructions, such as highways, railways, canals, pipelines, and power lines, are essential for urban infrastructure and the country's economic development. However, while they ensure the transportation of people and the supply of energy, fuel, and water, these structures also generate significant impacts on natural ecosystems through habitat loss and fragmentation, spread of invasive species, and direct mortality by collision and electrocution (RIOUX et al., 2013; LOSS et al., 2015; REVORÊDO, 2021), which can lead to significant population reductions (LOSS et al., 2015; SCHAUB et al., 2010; SCHAUB & PRADEL, 2004).

In this context, bird populations have been significantly affected by collisions with structures such as power lines, communication towers, wind turbines, and poles (DREWITT & LANGSTON, 2008; SILVA et al., 2018; REVORÊDO, 2021).

Other linear structures, such as fiber-optic cables used in communications, guy wires supporting towers, and those present in gondolas, cable cars, and zip lines, also increase the risk of collision for these animals (BECH et al., 2012).

In addition, contact with structures that make up the electrical distribution system can cause electrocution (CHEVALLIER et al., 2015; GODINO et al., 2016; BIASOTTO et al., 2021; TINOCO et al., 2022). Birds are the most affected group, as many species use these structures as hunting perches, resting spots, and nesting

sites (Figure 7). Most individuals die or suffer irreversible injuries that prevent them from returning to the wild (APLIC, 2012; CHEVALLIER et al., 2015).



Figure 7. Record of an *Ara chloropterus* specimen caught in power distribution wires in Campo Grande, Brazil. Source: TINOCO et al. (2022).

Years of research on the impact of power lines on birdlife have indicated that the presence of these structures inevitably results in collisions (BEVANGER, 1994, 1995; SAVERENO et al., 1996; JANSSE, 2000; BEVANGER & BROSETH, 2004; ERICKSON et al., 2005; DREWITT & LANGSTON, 2008; JENKINS et al., 2010; APLIC, 2012; RIOUX et al., 2013; LOSS et al., 2014, 2015; MURPHY et al., 2016b; BERNARDINO et al., 2018; MARCELINO et al., 2021; SHAW et al., 2021).

3.2.1.1. Collisions with power lines

It is estimated that global energy demand will increase by about 30% by 2040, leading to the construction of new overhead power lines (GELLINGS, 2015), with an estimated growth rate of 5% per year (ERICKSON et al., 2005; JENKINS et al., 2010; INTERNATIONAL ENERGY AGENCY, 2016).

Furthermore, the increase in renewable energy production will promote its decentralization, with projects being developed in remote regions rich in natural resources (LIENERT et al., 2015; SMITH & DWYER, 2016; ØSTERGAARD et al., 2023). This will result in the expansion of transmission lines to connect these production areas to urban centers (LIENERT et al., 2015), increasing collision risk for other species (SMITH & DWYER, 2016).

The orders most susceptible to power line collisions include Anseriformes, Podicipediformes, Charadriiformes, Falconiformes, and Gruiformes (BROWN; DREWIEN, 1995), with threatened species and those at greater collision risk facing the loss of their already small populations (MCNEIL et al., 1985; BEVANGER, 1998; JANSSE, 2000; REAL et al., 2001; SUNDAR & CHOUDHURY, 2005).

Among seabirds, collisions with power lines have already been documented in species such as *Bulweria bulwerii*, *Calonectris borealis* (GARCIA-DEL-REY; RODRIGUEZ-LORENZO, 2011; GÓMEZ-CATASÚS et al., 2020), *Phaethon lepturus*, *Ardeana pacifica*, *Puffinus bailloni* (BUREAU D'ETUDES ENVIRONNEMENT AGRONOMIE, 2008; VERBEKE et al., 2020), *Sterna dougallii*, and *Sterna hirundo* (REVORÊDO, 2021). A study by Travers et al. (2021) indicated that collisions with power lines are the main anthropogenic cause of mortality for species such as *Puffinus newelli* and *Pterodroma sandwichensis*.

In general, species show different levels of susceptibility to collision (MARTIN, 2011). This phenomenon is influenced by several factors; for example, flight speed can affect birds' ability to detect and react to obstacles (ORLOFF & FLANNERY, 1992). In addition, seasonal movements, flight behavior, and morphological characteristics also play significant roles. Weather conditions at the time of flight are equally relevant (ALERSTAM, 1990; BEVANGER, 1994; ANNUAL REPORT ON MIGRATORY BIRD CONCENTRATION AREAS IN BRAZIL, 2014).

3.2.1.1.1. Factors Influencing Collision Risk

Seabirds are particularly vulnerable to collisions with power lines due to their behavior of breeding, transiting, and/or landing in areas where such infrastructure is present. Travers (2022) identified three primary factors that influence the risk of collision: (1) frequency of flights near power lines, (2) detectability of the wires, and (3) ability to avoid collisions upon detection. Each of these factors is influenced by species-specific biological traits, environmental conditions, and characteristics of the electrical infrastructure, and are discussed in detail below.

3.2.1.1.1.1. Frequency of Flights Near Power Lines

From a biological perspective, species that routinely traverse areas with electrical networks are at greater risk of collision. This includes seabirds that breed within or near power line corridors and regularly fly across these lines during

commutes between breeding colonies and foraging areas at sea (TRAVERS et al., 2021; VERBEKE et al., 2020).

While local movements can present significant collision risks, migratory events are also associated with elevated collision rates (SHAW, 2013; VAN ROOYEN & DIAMOND, 2008). Migratory birds often cover long distances across unfamiliar landscapes, frequently in large flocks and at lower altitudes, particularly near stopover sites (FAANES, 1987; STEHN & WASSENICH, 2008).

During the breeding season, they tend to fly closer to the ground as an effort to save energy (HENDERSON et al., 1996). In certain species, males are disproportionately affected during the breeding period (ANDERSON, 1978; FAANES, 1987; BEVANGER, 1995b; JENKINS et al., 2011; PONCE et al., 2010)

From an environmental standpoint, flight routes that minimize energetic costs may lead to a significant increase in localized seabird traffic over power lines (COOPER & DAY, 1998; DAY & COOPER, 1995; DAY et al., 2017a,b; TRAVERS et al., 2014), thereby increasing the collision risk.

Migratory species are particularly exposed, as they encounter multiple power lines and anthropogenic structures along their routes (MARTIN, 1990; BEVANGER, 1994; DIXON et al., 2020; HAMER et al., 2021). Species that spend more time in flight also face a higher risk compared to more terrestrial or ground-dwelling species (BEVANGER, 1994).

Another important factor is the presence of landscape elements, which can either reduce or increase collision risk. For example, tall trees that exceed the height of power lines may induce birds to fly at higher altitudes, reducing risk, whereas open areas with low vegetation or those where trees have been removed may elevate it (BEVANGER, 1994; BEVANGER & BRØSETH, 2001, 2004; JENKINS et al., 2010).

Wind resistance is another influential factor, as birds tend to fly at lower altitudes when flying against headwinds, thereby increasing exposure to wires and structures (AINLEY et al., 2015; TRAVERS et al., 2014).

Power lines constructed on hilltops or ridgelines present particularly high risks, especially when bird flight paths intersect perpendicularly with the slope, as the infrastructure often becomes the most prominent vertical feature in the landscape (D'AMICO et al., 2018).

With respect to infrastructure characteristics, vertically oriented structures—often required by regulatory standards for electrical safety (NATIONAL ELECTRICAL SAFETY CODE®, 2017)—are associated with increased collision risks (BERNARDINO et al., 2018). Higher voltage transmission lines typically require greater ground clearance and structural height (NATIONAL ELECTRICAL SAFETY CODE® (NESC®) C2-2017, 2017), making high-voltage lines especially concerning from an avian conservation perspective (WARD & ANDERSON, 1988; BERNARDINO et al., 2018; TRAVERS et al., 2021).

3.2.1.1.1.2. **Wire Detectability**

The ability of birds to visually detect power lines is critical for collision avoidance. Thus, the time of day when birds fly near power lines is an important factor in their ability to detect the wires. Wire visibility is reduced during nighttime (BROWN; DREWITT, 1995; DENG E FREDERICK, 2001; MURPHY et al., 2016a,b) and in conditions of poor visibility, such as fog or rain (JENKINS et al., 2010; BERNARDINO et al., 2018).

Behavioral factors also affect detectability (BERNARDINO et al., 2018; DREWITT & LANGSTON, 2008). For instance, juvenile birds are more susceptible to artificial light attraction (RODRÍGUEZ et al., 2012), while behaviors such as pre-breeding courtship near power lines increase the risk of collision (TRAVERS et al., 2023).

Sensory perception is also important, as birds with laterally positioned eyes have a wider visual field (MARTIN, 1985, 1990, 2011; FERNÁNDEZ-JURICIC et al., 2008; ROGERS, 2008), but may be unable to accurately estimate the distance to a specific object and may have blind spots that limit obstacle detection (MARTIN, 2011, 2012; MARTIN & SHAW, 2010).

Wire configuration is another important factor. Thicker wires, as used in high-voltage transmission lines, are more visually conspicuous (JENKINS et al., 2010). Collision risk has also been correlated with the number of vertical wire levels and the spacing between them (BEVANGER, 1994; DREWITT & LANGSTON, 2008; JENKINS et al., 2010).

Studies indicate that most collisions involve ground wires (FAANES, 1987; BEAULAURIER, 1981; BROWN et al., 1987). However, their removal is unfeasible

due to their essential role in protecting power lines from lightning strikes and ensuring service reliability (APLIC, 2012).

In addition, power lines are generally designed vertically by engineers in order to minimize lateral ground occupation. However, this design increases the height of the top wire and the number of wires within the airspace used by birds, thereby increasing their exposure to collision risk (PODOLSKY et al., 1998; BEVANGER & BRØSETH, 2001; DREWITT & LANGSTON, 2008; BERNARDINO et al., 2018; JENKINS et al., 2010).

In contrast, horizontally arranged lines, where all conductors are aligned at the same height, reduce the number of potential collision surfaces and may limit birds' exposure to a single obstacle, thereby lowering the risk of multiple collisions (TRAVERS et al., 2023).

The spacing between poles may also be relevant (JENKINS et al., 2010), as collision rates tend to be lower near the poles compared to the middle of the span (WARD & ANDERSON, 1992; NEVES et al., 2005; PANDEY et al., 2008).

The relationship between wire diameter and height makes it difficult to isolate the effect of each individual factor, since ground wires are thinner and positioned at the top, whereas conductors are thicker and located below.

3.2.1.1.1.3. Collision Avoidance Capacity

Once a bird detects a power line, its ability to avoid impact depends on its flight speed and maneuvering ability, both influenced by morphological traits such as body mass and wing morphology (PENNYCUICK, 1987; ALERSTAM et al., 1993; BEVANGER, 1998).

Flight speed determines the distance and time available for the bird to perform an avoidance maneuver from the moment of detection, while maneuvering ability determines the extent to which the bird can alter its course within this distance-time window (BEVANGER, 1998; JANSS, 2000).

Diving birds tend to have greater difficulties maneuvering due to their heavier bodies and reduced agility, such as Anseriformes, Podicipediformes, Gruiformes, and Charadriiformes (BEVANGER, 1998; CROWDER, 2000; JANSS, 2000; RUBOLINI et al., 2005; RIOUX et al., 2013), whereas surface-feeding species with weaker flight power tend to be more successful in evasive maneuvers (ALERSTAM et al., 1993; BEVANGER, 1998).

Gregarious species, which have reduced individual vision within flocks, tend to collide more frequently than solitary species (SCOTT et al., 1972; ALONSO & ALONSO, 1999; DREWITT & LANGSTON, 2008; APLIC, 2012). However, larger flocks may respond better to power lines (CROWDER, 2000), adjusting their flight paths and avoiding power lines more efficiently.

Another relevant biological factor is age, with younger individuals being more vulnerable to collisions than adults (KRAPU, 1974; ANDERSON, 1978; WARD & ANDERSON, 1992; BROWN & DREWIEN, 1995; HALLEY et al., 1995; COOPER & DAY, 1998; SUNDAR, 2005). This is attributed to their lower maneuverability and lack of familiarity with the areas they traverse. Henderson et al. (1996) observed that juvenile *Sterna hirundo* fly closer to wires than adults and reported a higher probability of collision in juveniles due to lower flight skills and reflexes.

Environmental conditions can also affect a seabird's ability to avoid power lines. Flying against the wind reduces approach speed, providing more time for evasive maneuvers (SAVERENO et al., 1996; WARD & ANDERSON, 1988).

Regarding power line configuration, those with a higher number of wires or greater vertical profile increase obstacles, elevating the risk of secondary collisions (BEVANGER, 1994; PODOLSKY et al., 1998).

3.2.1.2. Impacts of Power Lines on Avifauna

The impacts of linear infrastructures on avifauna can be classified as: 1) Direct physical impacts and electrocution, 2) Impacts from emissions and radiation, and 3) Habitat alteration impacts (WYLIE & BELL, 1973; MURCIA, 1995; GOOSEM, 2007; JENKINS et al., 2010; MORÓN et al., 2014; D'AMICO et al., 2018).

In addition, collisions with power lines have indirect effects such as abandoned breeding attempts (DAY et al., 2017a,b), increased mortality of dependent chicks due to the death of breeding adults (DAY et al., 2017a,b), and lost breeding years until the surviving adult establishes a new breeding pair.

3.2.1.2.1. Direct physical impacts

Direct impacts on avifauna primarily result from collisions with power lines, with over one billion birds dying annually from this cause (MCNEIL et al., 1985; BEVANGER, 1994; RIOUX et al., 2013; LOSS et al., 2014).

Such incidents can cause total or partial amputation, fractures, bruises, and abrasions (TECHNICAL NOTE PCCB-UERN/CEMAM, 2020; REVORÊDO, 2021), as well as feather loss on the skull, eye injuries, and blood in the oral cavity and nostrils (TRAVERS et al., 2021).

At the same time, Travers et al. (2021) demonstrated that one-fifth of stranded and examined individuals showed no visible injuries. These unseen traumas in the cranial or cervical regions may be detected through other clinical signs, such as neurological alterations, which can lead to delayed mortality during rehabilitation.

In the aforementioned studies, only a minority of stranded birds were found alive, and some died during rehabilitation. This underlines that failure to provide prompt care almost certainly results in death by dehydration, malnutrition, or predation (RODRÍGUEZ et al., 2017).

One challenge in collision cases is the high probability that incidents occur undocumented, as monitoring the entire length of power lines is difficult (BARRIENTOS et al., 2018; BEVANGER, 1995; LOSS et al., 2014; TRAVERS et al., 2021), which can erroneously obscure the need for conservation interventions (TRAVERS et al., 2021) and result in underestimation of collisions (SAVERENO et al., 1996; MURPHY et al., 2016b; TRAVERS et al., 2021).

3.2.1.2.2. Impacts from emissions and radiation

Radiation and emission impacts affect birds in various ways, including noise, lights, vibrations, and electromagnetic radiation associated with linear infrastructures. Electromagnetic radiation, for example, has been shown to impair reproductive performance by reducing egg hatchability (FERNIE et al., 2000).

Most reported impacts involving power lines are related to electrocution rather than collision (REBOLO-IFRÁN et al., 2023), likely because electrocutions are more visible and tend to result in greater economic losses, including potentially significant damage such as forest fires (GUIL et al., 2018). Collisions that do not result in electrocution may not be fatal, or birds may die far from power lines, making these events less frequently recorded (REBOLO-IFRÁN et al., 2023).

Electrocution victims may exhibit external injuries, burns, and hemorrhage (TINOCO et al., 2022). Burns typically show immediate necrosis of affected tissues, muscles, and organs, along with carbonization, causing structural and functional alterations (BRUNETTA et al., 2024). Electric discharge damages the interior of

blood vessels, causing edema and blood clot formation, which may result in immediate or delayed thrombosis (BRUNETTA et al., 2024).

3.2.1.2.3. Habitat alteration impacts

The construction of linear infrastructures causes habitat loss, degradation, and fragmentation, affecting microclimate, soil, vegetation, and biodiversity, as well as reducing available habitat area and isolating populations (FORMAN & ALEXANDER, 1998; GOOSEM, 2007; EIGENBROD et al., 2009).

Fragmentation creates smaller and isolated habitats that limit gene flow and the maintenance of viable populations, increasing local extinction risk, especially in edge areas that act as barriers to their movement and survival (FAHRIG, 2003; NEWMARK & STANLEY, 2011).

Power lines represent specific risks, particularly collisions in areas of great importance to migratory birds and habitats with high population density (APLIC, 2012; SHOBRAK, 2012). They are especially hazardous in sites where birds form breeding and wintering colonies, use stopover sites during migration, and congregate in high densities, significantly increasing collision risk.

3.2.2. Mitigation of power line impacts on birds

After identifying seabird collisions with power lines, it is essential to implement preventive solutions to avoid further impacts. There are three main approaches to reduce collisions: (1) removal of power lines from avian airspace, (2) implementation of strategies to influence seabirds to alter their flight paths and avoid collisions, and (3) prior planning of power line installation routes to avoid high-risk areas.

The first approach includes underground cabling, which, in this case, is the only solution that completely eliminates collisions and is also effective in improving safety and reliability for human populations (RAAB, 2012; LARSEN, 2016; GLASS & GLASS, 2019). However, this approach may not be economically feasible everywhere due to high costs (LARSEN et al., 2018; FREEMAN et al., 2019; GLASS & GLASS, 2019).

Habitat management is another important strategy. Altering land use or modifying habitats near power lines can help divert birds from collision routes (THOMPSON, 1978; APLIC, 2012). Although such modifications may be difficult to implement, they have the potential to reduce collision risks (HARNESS, 2001).

Additionally, creating foraging areas may encourage birds to land before reaching the power lines (MARTIN, 2011; APLIC, 2012).

Another alternative is the reconstruction of existing lines by reducing wire height (BEVANGER, 1994; BERNARDINO et al., 2018), replacing vertically exposed wires with a single horizontal layer (BEVANGER, 1994; BERNARDINO et al., 2018), and substituting power lines with insulated aerial cables, which decrease the risk of electrocution and increase detectability due to larger diameter (BEVANGER, 1994; JENKINS et al., 2010), as well as keeping the spans as short as possible (JENKINS et al., 2010; SHAW et al., 2010; APLIC, 2012).

Physical barriers such as trees, deflector poles, flight diverters, or noise barriers can also be used in these situations to minimize bird collisions with power lines (JENKINS et al., 2010; KOCIOLEK et al., 2015; ZUBEROGOITIA et al., 2015).

Strategic route planning (D'AMICO et al., 2018) is another approach that can be carried out by selecting paths that avoid sensitive areas for migratory birds, such as nesting and foraging sites (BEVANGER, 1994; FAANES, 1987; HARNESS, 2001; SNH, 2016; THOMPSON, 1978). The use of collision risk maps and species distribution models can support this decision-making (SHAW et al., 2010; QUINN et al., 2011; AUSTRALIAN GOVERNMENT, DEPARTMENT OF THE ENVIRONMENT, 2015; SILVA et al., 2014; ALLINSON, 2017).

Furthermore, increasing the detectability of power lines through visibility devices such as markers and flight diverters has proven to be an effective measure (MORKILL & ANDERSON, 1991; ALONSO et al., 1994; JANSS, 2000), although its effectiveness varies depending on the surrounding environment, target species, and device characteristics (JENKINS et al., 2010). Devices such as spirals and reflectors are frequently used, with those showing higher contrast and mobility being more effective (MARTIN, 2011; BARRIENTOS et al., 2011).

In summary, effective management of power line impacts on seabirds depends on strategic planning based on robust data and the implementation of appropriate mitigation measures. Ongoing research and monitoring are crucial to ensure the sustainability of energy infrastructures and bird conservation (ASHWIN et al., 2023).

MATERIALS AND METHODS

4. Materials and Methods

This study was based on the availability of data and the collection of samples from birds of the genus *Sterna*, covering the period from January 1, 2020 to December 31, 2023. The data originated from the Beach Monitoring Project of the Potiguar Basin (PMP-BP), implemented by the Cetaceans of the Costa Branca Project (PCCB-UERN) and required as an environmental condition by the Brazilian Institute of the Environment and Renewable Natural Resources (IBAMA) for oil and gas exploration and production by Petrobras in Brazil.

The study was approved by the Ethics Committee on the Use of Animals of the School of Veterinary Medicine and Animal Science, UNESP Botucatu, and registered under protocol number 0538/2023.

4.1. Study Area

The PMP-BP is conducted from Caiçara do Norte (RN) (05°04'01.15"S; 36°04'36.41"W) to Aquiraz (CE) (03°49'20.9"S; 38°24'07.8"W), and the study encompassed animals and carcasses found throughout the PMP-BP area.

4.1.1. Potiguar Basin and the States of Rio Grande do Norte and Ceará

In the Potiguar Basin, the monitored area covers an extension of 325 km, encompassing eastern Ceará and the northern coastline of Rio Grande do Norte (Figure 8), and is divided into five segments. Segment A covers 61 km, from Grossos/RN to Icapuí/CE; Segment B, 51 km, from Areia Branca/RN to Porto do Mangue/RN; Segment C, 53 km, from Macau/RN to Guamaré/RN; Segment D, 30 km, from Galinhos/RN to Caiçara do Norte/RN; and Segment E, 137 km, from Aquiraz/CE to Aracati/CE. Monitoring is conducted daily, except for Segment E, which is monitored every 20 days (CORREIA; SANTOS; MOURA, 2016).

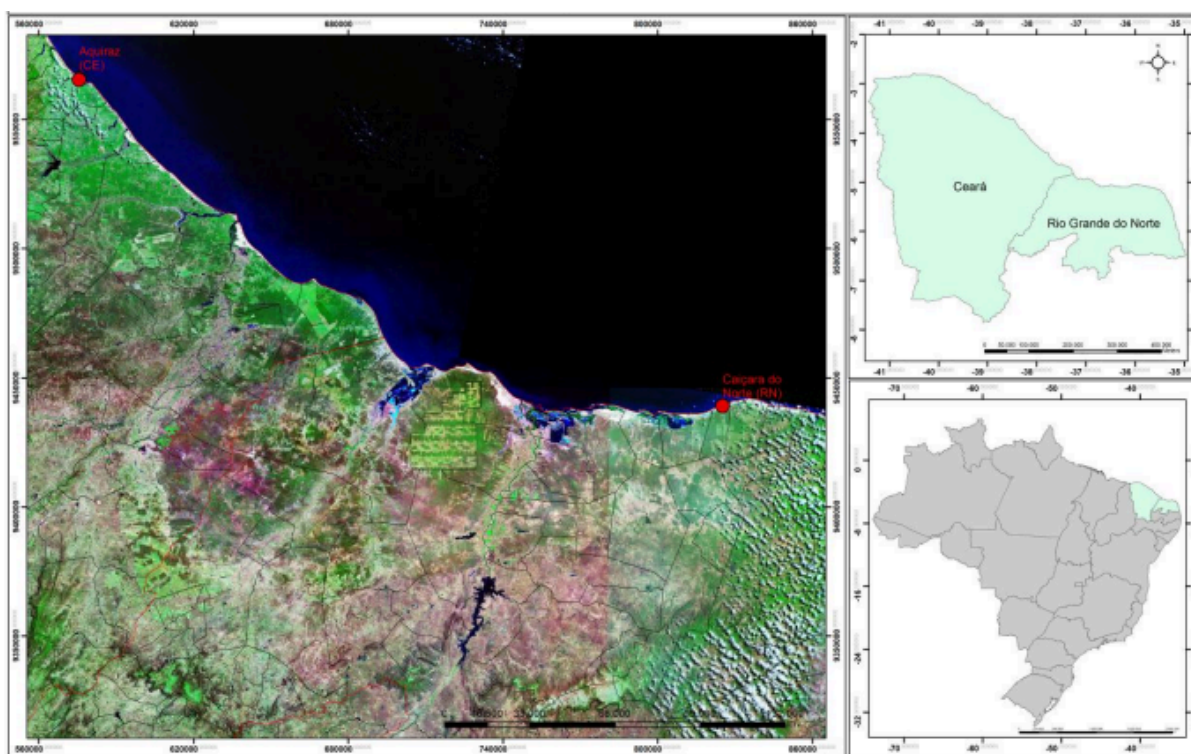


Figure 8. Map of the study area between the municipalities of Aquiraz (CE) and Caiçara do Norte (RN). Source: MAIA (2016).

Live and dead animals were sent to the Areia Branca Wildlife Rehabilitation Center (CRF-AB) and/or to the Necropsy Sector of the Marine Biota Monitoring Laboratory (LMBM) in Mossoró (RN). These facilities receive cases from the entire potiguar region, which hosts concentrations of migratory birds and lies along the migratory route of the species studied here (VALENTE et al., 2011; REVORÊDO, 2021).

4.1.1.1. Presence of Power Lines in the Area: The Case of Galinhos (RN).

Within the monitored area, the municipality of Galinhos ($05^{\circ}05'30.75''\text{S}$; $36^{\circ}16'32.90''\text{W}$) stands out due to the presence of electrical distribution lines running parallel to the beach over the dunes (TEIXEIRA, 2022). These features have proven relevant, as the region records the highest number of seabird incidents with signs of trauma (REVORÊDO, 2021).

The issue was first identified in 2011 by the PCCB-UERN team during the execution of the Potiguar Basin Beach Monitoring Project. Numerous individuals of the genus *Sterna* were found dead or debilitated near the power line in Galinhos (RN), with injuries consistent with collisions against these structures (U.S.F.W.S., 2020).

The power line in question corresponds to the final section (about 2.8 km) of a project named SBN-01S3, which totals 127.35 km and was installed in 1982. It is a three-phase medium-voltage network (13.8 kV), with copper wiring (35 mm² cross-section), installed on 11 m-high poles, either circular fiberglass or “double T” concrete types, spaced approximately 70 m apart. This line supplies energy to about 677 consumers and is located over the dunes of Galinhos Beach (REVORÊDO, 2021).

In 2013, the area underwent modifications due to the construction of a wind farm at Galos Beach, located about 3.5 km east of the start of the line. It began operating in the second half of 2014, under the responsibility of a different company from the power line concessionaire. In October 2018, in response to notifications made by PCCB-UERN and the Environmental Studies and Monitoring Center (CEMAM), the agency responsible for the line installed “spiral”-type visual markers on approximately 100 m of the line (-36.2506318, -5.0963736) to mitigate collisions. The yellow markers, 21 cm in length, were installed at 8 m intervals on alternating phases of the network, totaling 15 units (REVORÊDO, 2021).

Studies by Revorêdo (2021) evaluated the impacts of these changes on collision patterns, comparing three periods: before the installation of the wind farm (2011–2014), after it began operation (2014–2018), and after the installation of the markers (2018–2020). The results showed that collision frequency increased significantly with the installation of the wind farm, suggesting shifts in bird flight routes and a negative synergy between the two infrastructures. However, no significant reduction in collisions was observed after the installation of the markers.

These data demonstrate that the energy infrastructure in the Galinhos region plays an important role in the dynamics of collisions involving migratory birds (REVORÊDO, 2021). Although not part of the results of the present study, this contextualization is essential for understanding the local landscape and the recurrence of collision events in one of the most critical areas of the Potiguar Basin.

4.2. Data Collection

In the Potiguar Basin, all specimens found beached and collected during the regular beach monitoring mentioned earlier, between January 1, 2020, and

December 31, 2023, were analyzed. They were identified to the lowest possible taxonomic level, and information related to the rescue — including date, time, geographic coordinates, sea and sky conditions, tide, wind speed, and wind direction — was recorded on a Rescue Form and analyzed.

Clinical information for live individuals (N = 118) was also analyzed through the admission clinical examination available in the “Clinical History” section registered in SIMBA. Data selected included level of consciousness (alert, depressed, unconscious, or in shock), degree of dehydration (normohydrated, dehydrated, or severely dehydrated), mucous membrane coloration (pale, normal, cyanotic, or icteric), body condition score (optimal, good, thin, or cachectic), heart rate (HR, bpm), respiratory rate (RR, mrm), and peripheral temperature (°C). These parameters were analyzed to assess the animals’ condition upon arrival at the Rehabilitation Center, in order to initiate the stabilization process. Based on Kolesnikovas et al. (2020), cloacal temperature was considered low when below 38.5 °C and high when above 41 °C.

In the present study, a beached bird occurrence was defined as any case in which animals were found on the beach, in mangroves, on rocks, or on coral reefs, with reduced ability to move and/or escape, staggering, defenseless, weak, or deceased (GERACI & LOUNSBURY, 1993).

Since the exact moment of collision was, in most cases, not observed, for this study only birds showing collision-related signs and found within a maximum distance of 500 m from the physical structure (Figure 9) were considered. These signs included: (1) fracture or amputation, total or partial, of at least one limb; (2) characteristic bruises, abrasions, or lacerations; (3) contusions, bruises, or fractures to the skull; and (4) impaired mobility in at least one limb, limiting or preventing flight.



Figure 9. Individuals of *Sterna* spp. found with collision signs near power lines. A: *S. dougallii* with open fracture in the right wing. B: *S. dougallii* with complete amputation of the right wing. C: *S. dougallii* with open fracture in the left wing. D: *S. hirundinacea* with open fracture in the left wing.

Cadavers found on the beach or that died during rehabilitation were sent to the Diagnostic Imaging Department of the Veterinary Hospital of the Federal Rural University of the Semi-Arid (UFERSA) for radiographic description of traumatic lesions. Subsequently, macroscopic evaluation was performed at the Necropsy Sector of the Marine Biota Monitoring Laboratory (LMBM).

Macroscopic alterations were described, classified, and tabulated according to the standards recommended by the “*Associação Brasileira de Patologia Veterinária*”, the American College of Veterinary Pathologists, and the European College of Veterinary Pathologists.

Data from the submission forms — such as species, origin, age, and sex — along with the results of macroscopic alterations, were compiled in spreadsheets for statistical analysis. Observed alterations were presented descriptively through tables and graphs.

For binary comparison of qualitative variables, the binomial test was applied, and for paired comparison of macroscopic findings, McNemar’s test was used. All analyses were performed with a significance level of 5%.

4.2.1. Radiographic Evaluation

Radiographic examination was performed on all cadavers of beached birds from the Potiguar Basin during 2023, aiming to provide a detailed description of the macroscopic findings in these animals.

Since radiography is not recommended for critically ill patients due to the risk of death caused by excessive handling during the procedure (SILVERMAN, 1987; SMITH & SMITH, 1997; RUPLEY, 1999), and considering that most of these animals were found in this condition, radiographs were taken only of the cadavers of those that died, in order to contribute to the characterization of lesions for this study.

Laterolateral and ventrodorsal projections were used to ensure accurate radiographic interpretation. When necessary, additional projections such as oblique views were included.

For the laterolateral projection, the cadaver was positioned in right and/or left lateral recumbency, with the wings extended dorsally and the pelvic limbs positioned caudoventrally (BEREGI et al., 1999; CRACKNELL, 2004a), aiming to avoid overlap of osseous structures within the coelomic cavity (SILVERMAN, 1987).

For the ventrodorsal projection, the cadaver was placed in dorsal recumbency, with the head, wings, and pelvic limbs extended cranially, laterally, and caudally, respectively.

Fractures were classified according to anatomical location, displacement, and exposure, based on Fossum et al. (2008) and Piermattei et al. (2009). First, fractures

were categorized by their anatomical location (proximal, middle, or distal portions of the affected bone). They were further grouped according to fracture line orientation into five distinct types: transverse, oblique, spiral, comminuted, and multiple. Additionally, fractures were classified according to the degree of exposure to the external environment as either open or closed (PIERMATTEI & FLO, 1999; FOSSUM et al., 2008).

Open fractures were further subdivided according to severity into three types: type I, with minimal soft tissue perforation near the fracture site; type II, with variable-sized soft tissue wounds associated with the fracture, presence of foreign bodies, and laceration of soft tissues; and type III, with extensive soft tissue damage adjacent to the fracture, with a high risk of contamination, infection, and tissue necrosis (PIERMATTEI & FLO, 1999).

4.2.2. Necropsy Evaluation

Animals that died during treatment and cadavers found on beaches with preservation codes 2 or 3 were subjected to a detailed necropsy evaluation, according to the classification presented in the table below, based on the marine mammal carcass classification by Geraci & Lounsbury (2005) and adapted for marine tetrapods (Table 1).

Table 1. Classification of cadavers preservation codes. Adapted from Geraci & Lounsbury (2005).

Code	Description	Characteristics
1	<i>Live animal</i>	<i>Live animals, which may be healthy or debilitated.</i>
2	<i>Fresh cadaver</i>	<i>Recent death; normal appearance with minimal damage; intact viscera; bright eyes and mucous membranes; mild odor and absence of bloating.</i>
3	<i>Moderately decomposed cadaver</i>	<i>Carcass intact; evident bloating; moderate odor; dry eyes and mucous membranes; further damage due to scavenger interaction; discoloration of organs caused by hemoglobin imbibition but overall good appearance; intestine distended with gas.</i>
4	<i>Severely decomposed cadaver</i>	<i>Carcass may still be intact but shows severe damage; strong odor; viscera often liquefied; bones may be disarticulated; large amounts of gas in intestinal loops and organs; internal organs may be externalized; body parts removed by scavengers.</i>
5	<i>Mummified remains or bones</i>	<i>Carcass completely decomposed, with only skin remnants and skeleton remaining.</i>

Source: *PMP Activities Protocol*. (2017). *Field activities for beach monitoring: vessel-based and land-based (Revision 03)*. BR 00000000/00.

Collision-induced lesions were described following the terminology recommended by Ressel et al. (2016). The integumentary, musculoskeletal, cardiovascular, respiratory, digestive, genitourinary, and endocrine systems were evaluated, as well as the general condition of the cadavers. The nervous system was

not considered in the present study due to the advanced degree of autolysis observed in all brains examined.

The alterations observed were divided into external and internal lesions. External lesions were those affecting the surface of the cadaver and systems accessible without opening the body, such as the integumentary system, sensory organs, and parts of the musculoskeletal (bones and joints) and vascular systems. Internal lesions, on the other hand, involved alterations in organs and internal systems, which required opening the cadaver for direct evaluation, such as the respiratory, cardiovascular, digestive, renal, nervous, endocrine, and hematopoietic systems, as well as parts of the musculoskeletal system (muscles).

During necropsy, a standardized necropsy form was completed by the veterinarian in order to ensure uniformity of the collected information.

4.2.3. Data evaluation

This study includes data from January 2020 to July 2023 on birds stranded along the Potiguar Basin. All the systems listed above were also considered, and the gross findings and causes of death were tabulated, with statistical tests deemed appropriate to the scope of the study applied.

Statistical analyses were performed to evaluate whether the frequency of certain qualitative characteristics or macroscopic lesions differed between categories or anatomical systems. For binary qualitative variables, such as sex, age class, or presence/absence of specific lesions, the binomial test was applied to assess whether the observed proportions differed from an expected 50:50 distribution. For the comparison of paired macroscopic findings within the same individual, McNemar's test was used, as this test is appropriate for evaluating asymmetries in paired binary outcomes. These analyses allowed us to investigate whether certain lesions tended to occur more frequently in one category than another, and whether lesions in one anatomical system were associated with lesions in another system within the same bird. All analyses were performed with a significance level of 5%

RESULTS

5. Results

A total of 148 *Sterna* spp. individuals were recorded in the Potiguar Basin between 2020 and 2023. Among these, 146 (98.6%, 146/148) showed evidence of collision. However, 143 were considered in the analyses, since one corresponded to a code 5 carcass and two had no necropsy records available, although they had been found near power lines and in close proximity to each other.

In terms of taxonomy, three species were identified: *Sterna dougallii* (82.5%, 118/143), *Sterna hirundo* (17.3%, 24/143), and *Sterna hirundinacea* (0.2%, 1/143). All individuals were adults, comprising 44.1% males (63/143), 33.9% females (47/143), and 23.1% of undetermined sex (33/143). Body condition was classified as good in 51% (73/143), thin in 43.4% (62/143), and cachectic in 5.6% (8/143).

Most of the animals were found alive (84.6%; 121/143); however, they died during veterinary stabilization (89.3%; 108/121), either naturally (40.7%; 44/108) or through euthanasia (59.3%; 64/108), due to their inability to be released back into the wild. Among those that survived (10.7%; 13/121), 69.2% (9/13) were released, while 30.8% (4/13) were transferred to animal care institutions due to their inability to fly (Figure 10).

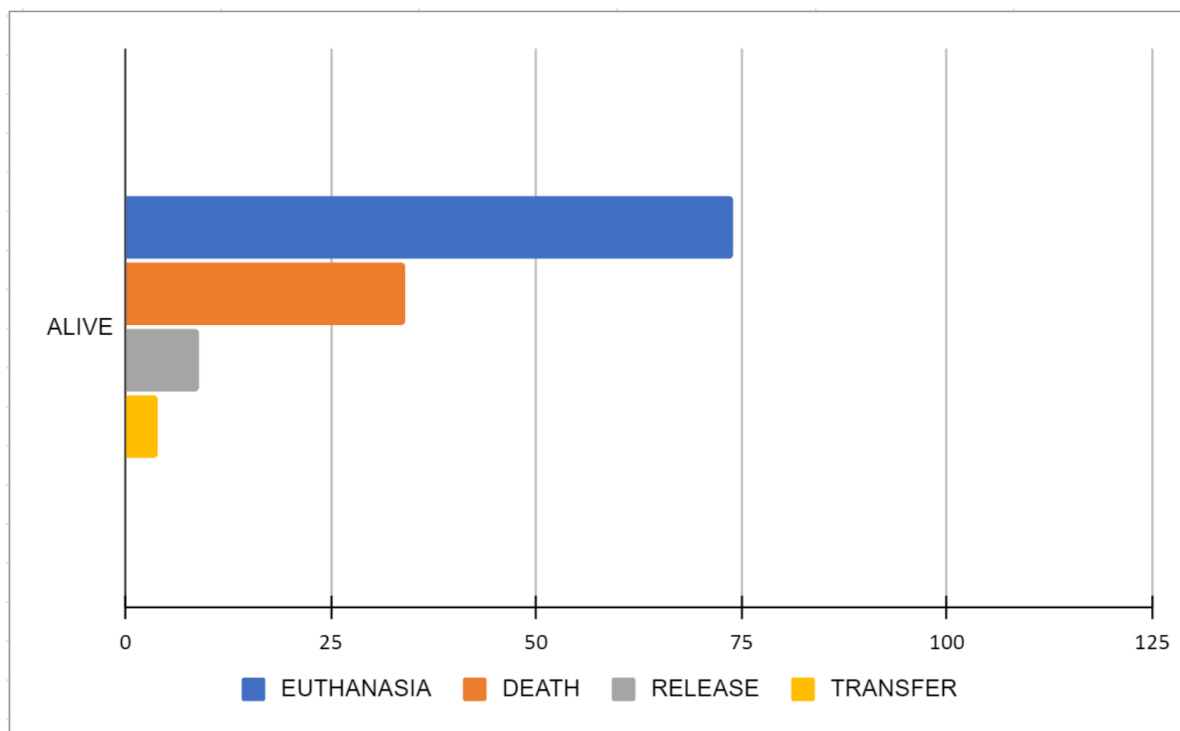


Figure 10. Comparison of the final outcomes of birds found alive.

Overall, 90.9% of the evaluated specimens (130/143) died, of which 17% (22/130) occurred prior to rescue and 83.1% (108/130) after rescue. Among the 130 deceased birds, 50.8% (66/130) died naturally, whereas the remaining individuals were euthanized (49.2%, 64/130) due to the severity of their clinical condition, as determined by the attending veterinary team.

Since monitoring was conducted daily in the morning, beginning around 7:00 a.m., individuals found dead during monitoring were considered to have died within the previous 24 hours. Otherwise, they would likely have been detected during the previous day's monitoring or reported by collaborators outside monitoring hours. These cases accounted for 39.3% of natural deaths (22/56). Among the remaining individuals initially found alive (60.7%, 34/56), 55.9% of deaths occurred within the first 24 hours post-rescue (19/34), 8.8% between 24 and 48 hours (3/34), 14.7% between 48 and 72 hours (5/34), and 20.6% more than 72 hours after rescue (7/34). This comparison is illustrated in Figure 11.

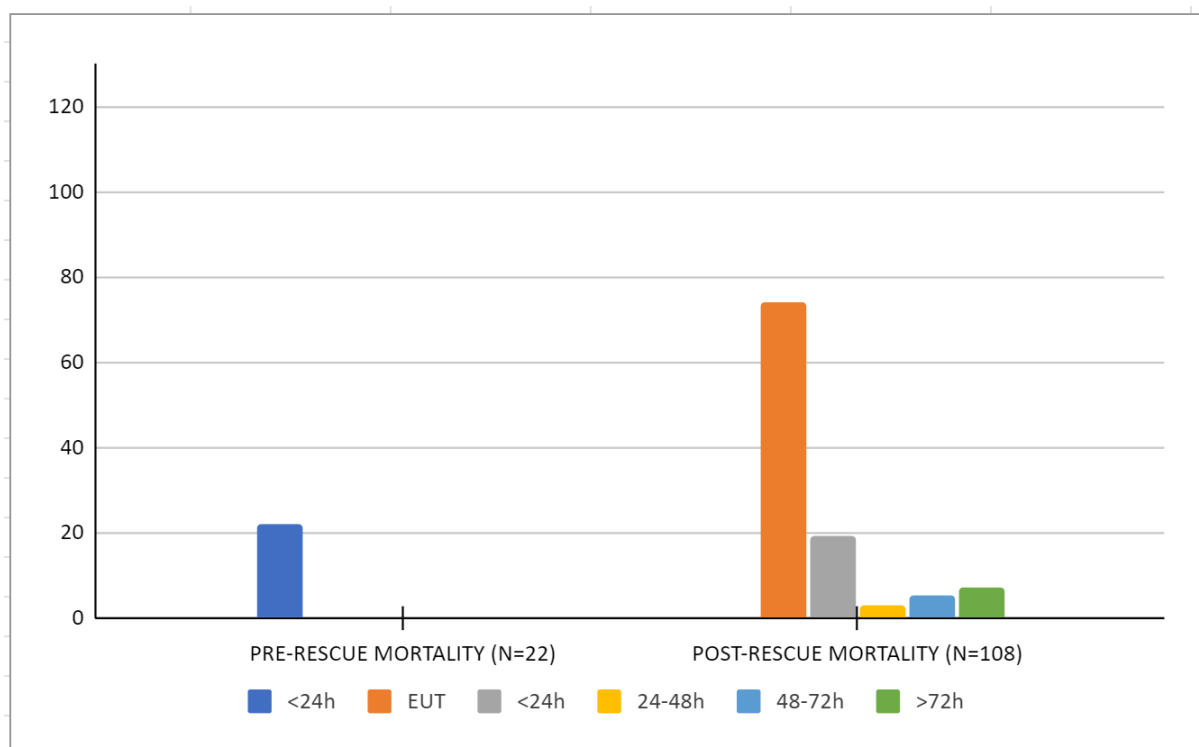


Figure 11. Comparison between deaths recorded prior to rescue and those occurring after rescue, classified according to the time elapsed until death (<24 h, 24–48 h, 48–72 h, and >72 h), and cases of euthanasia (EUT).

These individuals showed signs of collision and, in most cases, died due to the severity of traumatic injuries sustained during incidents with power lines, with lesions primarily involving bone fractures and extensive damage to multiple organs.

Regarding the study area, the region with the highest number of occurrences was Galinhos (RN) (97.2%; 139/143), followed by Areia Branca (RN) (1.4%; 2/143) and Icapuí (CE) (1.4%; 2/143). Animals were found predominantly in the morning (06:01–12:00) (84.6%; 121/143), but occurrences were also recorded during the early morning (00:00–06:00) (7.7%; 11/143), afternoon (12:01–18:00) (5.6%; 8/143), and night (18:01–23:59) (2.1%; 3/143).

The months with the highest number of records were March (76.2%; 109/143) and February (14%; 20/143), although sporadic occurrences were also observed in November (2.1%; 3/143), October (1.4%; 2/143), December (1.4%; 2/143), and January (1.4%; 2/143), as illustrated in Figure 12.

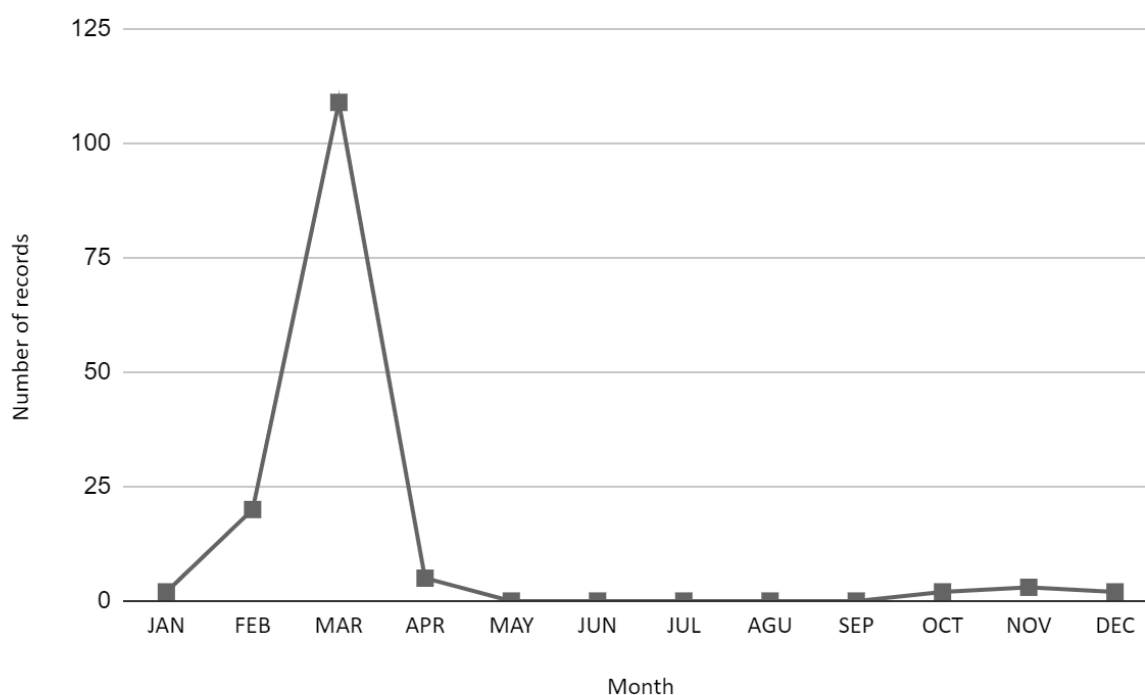


Figure 12: Number of *Sterna* spp. records per month in the Potiguar Basin between 2020 and 2023.

Regarding the year of *Sterna* spp. records (Figure 13), the highest number occurred in 2020, which accounted for 59.4% of the cases (85/143), followed by 2022 (19.6%, 28/143), 2023 (12.6%, 18/143), and 2021 (8.4%, 12/143). It is worth noting that the first case of highly pathogenic avian influenza (HPAI) in Brazil was

confirmed in wild birds in May 2023. As of June 2023, necropsies in the region were suspended by the PCCB-UERN team, in accordance with MAPA and IBAMA guidelines. However, since most strandings in 2023 occurred in March, as in previous years, the performance of necropsy evaluations was not compromised.

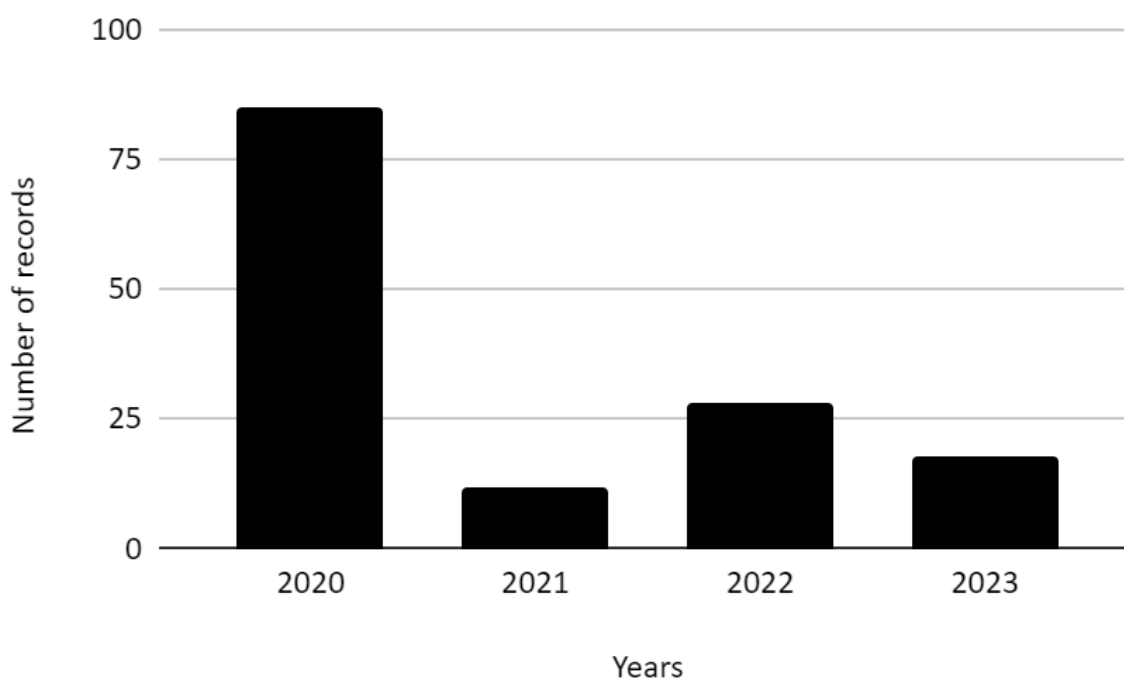


Figure 13. Annual distribution of *Sterna* spp. records in the Potiguar Basin between 2020 and 2023.

5.1. Main gross pathological findings

The alterations observed were divided into external and internal lesions. These findings are presented below.

5.1.1. External alterations

Alterations identified in the musculoskeletal system, such as bones and joints, and in the integumentary system, including skin and appendages, were analyzed and are presented in Table 2.

Table 2. Main external gross pathological findings in *Sterna* spp. with signs of collision in the Potiguar Basin between 2020 and 2023.

Site of lesion	Absolute frequency (n)	Relative frequency (%)
Musculoskeletal System	127	88.8
Amputation	39	30.7
Fracture	116	91.3
Open fracture	97	83.6
Left humerus	28	28.9
Right humerus	37	38.1
Left ulna	8	8.2
Right ulna	16	16.5
Left radius	10	10.3
Right radius	16	16.5
Left carpometacarpus	5	51.5
Right carpometacarpus	4	4.1
Left phalanx	1	1
Right phalanx	0	0
Left tibia	2	2.1
Right tibia	0	0
Closed fracture	22	19
Left humerus	8	36.4
Right humerus	3	13.6
Left ulna	5	22.7
Right ulna	1	4.5
Left radius	6	27.3

Right radius	1	4.5
Left carpometacarpus	2	9.1
Right carpometacarpus	1	4.5
Right coracoid	2	9.1
Beak	1	4.5
Clavicle	1	4.5
Dislocation	6	4.7
Left scapulohumeral joint	2	33.3
Right scapulohumeral joint	1	16.7
Left humeroradioulnar joint	2	33.3
Right humeroradioulnar joint	1	16.7
Rotation	4	31.5
Left scapulohumeral joint	0	0
Right scapulohumeral joint	1	25
Left humeroradioulnar joint	2	50
Right humeroradioulnar joint	1	25
Integumentary System	93	65
Laceration	60	64.5
Contusion	21	22.6
Apteria	11	11.8
Abrasion	5	5.4
Presence of ectoparasites	57	61.3
General Condition	70	48.9
Altered body condition	70	100
Poor BCS	62	88.6

Very poor BCS	8	11.4
TOTAL individuals	143	

Legenda: BCS= Body condition score.

5.1.1.1. General Condition

Alterations in general condition (GC) were observed in 48.9% of the evaluated specimens (70/143), of which 88.6% presented a thin body condition score (62/70) and 11.4% a cachectic score (8/70), as shown in Figure 14.



Figure 14. Severe bilateral hypotrophy of the pectoral musculature in a *Sterna* spp. individual.

Among the 121 live individuals, 69 had a complete admission clinical examination, including information on level of consciousness, degree of dehydration, and mucous membrane coloration; 22 had data on heart rate; 23 on respiratory rate; and 48 on peripheral temperature.

Regarding hydration status, 46.4% (32/69) were dehydrated and 53.6% (37/69) normohydrated. As for level of consciousness, 8.7% (6/69) were classified as depressed and 91.3% (63/69) as alert. Mucous membrane assessment indicated

that 42% (29/69) of individuals had pale mucous membranes, whereas 58% (40/69) had normal coloration.

The mean HR recorded was 320 beats per minute (bpm), while the mean RR was 34 breaths per minute (brpm). With respect to peripheral temperature, among the 48 individuals evaluated, 14.6% (7/48) were hypothermic, 82.2% (39/48) normothermic, and 4.2% (2/48) hyperthermic. The mean temperature of normothermic individuals was 39.9 °C.

5.1.1.2. Musculoskeletal System

The musculoskeletal system (MSS) was the most affected among those evaluated, with a predominance of bone alterations (88.1%; 126/143). The main lesions observed were fractures (92.1%; 116/126), followed by amputations (30.9%; 39/126) and dislocations (4.8%; 6/126).

Among the fractures, most were open, with bone exposure (83.6%; 97/116). The right humerus was the most frequently affected bone (38.5%; 37/97), followed by the left humerus (28.9%; 28/97), right radius (16.5%; 16/97), and right ulna (16.5%; 16/97) (Figure 15). In 40.2% (39/97) of these open fractures, traumatic amputation of the affected segment was observed, as illustrated in Figure 16.

Amputations also occurred predominantly in one of the humeri (79.5%; 31/39), but were also recorded in the radius and ulna (15.4%; 6/39), phalanx (2.6%; 1/39), and tibia (2.6%; 1/39), though less frequently.

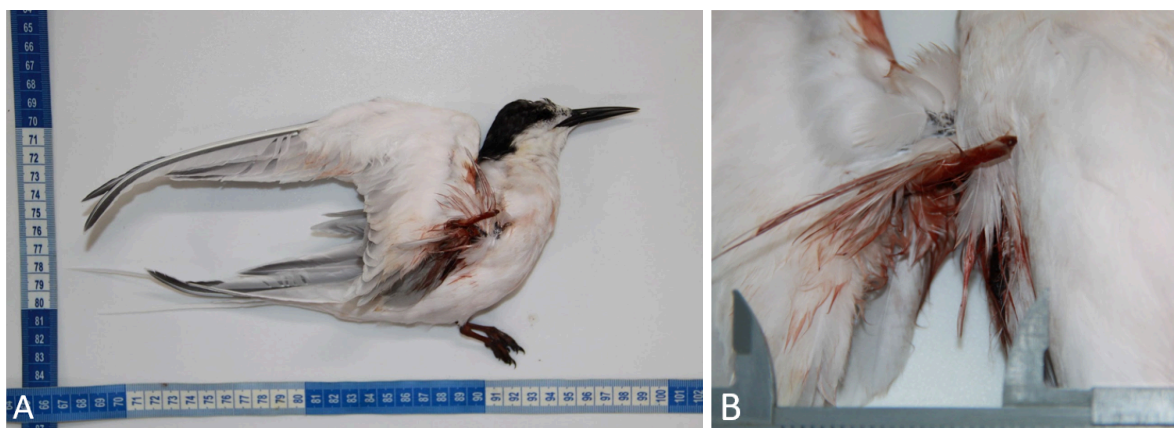


Figure 15. Complete open fracture in the proximal portion of the right humerus of *Sterna dougallii*. (A) Right lateral view of the bird showing the exposed lesion. (B) Magnification of the injured region, evidencing bone exposure.



Figure 16. Traumatic amputations in *Sterna* spp. A: Amputation of the left humerus in *Sterna hirundo*. B: Amputation of the left radius and ulna in *Sterna dougallii*. C: Amputation of the left humerus in *Sterna dougallii*.

Closed fractures were less frequent (18.9%; 22/116), predominantly affecting the left humerus (36.4%; 8/22), followed by the left radius (27.3%; 6/22), left ulna (22.7%; 5/22), and right humerus (13.6%; 3/22).

Overall, the forelimbs were the most affected region. Of the 116 recorded fractures, 97.4% (113/116) involved forelimb bones, predominantly the humeri. Additional cases included fractures of the shoulder girdle — coracoid (2/116) and clavicle (1/116) — as well as fractures of the hindlimbs (tibia, 2/116) and beak (1/116). In total, six individuals presented fractures in regions other than the forelimbs; in three of these cases, such fractures occurred together with forelimb fractures, whereas in the other three they were restricted to these alternative regions only.

Dislocations were also concentrated in the forelimbs, occurring in equal proportions in the scapulohumeral (50%; 3/6) and humeroradioulnar (50%; 3/6) joints, reinforcing the predominant involvement of the anterior locomotor segments.

Regarding the outcomes, most animals that died naturally presented fractures (73.2%; 41/56). Among these, there was a significantly higher frequency of open fractures in at least one bone (75.6%; 31/41). Moreover, as illustrated in Figure 17, the number of individuals with open fractures was substantially greater among those found dead or that died following rescue (71%, 22/31).

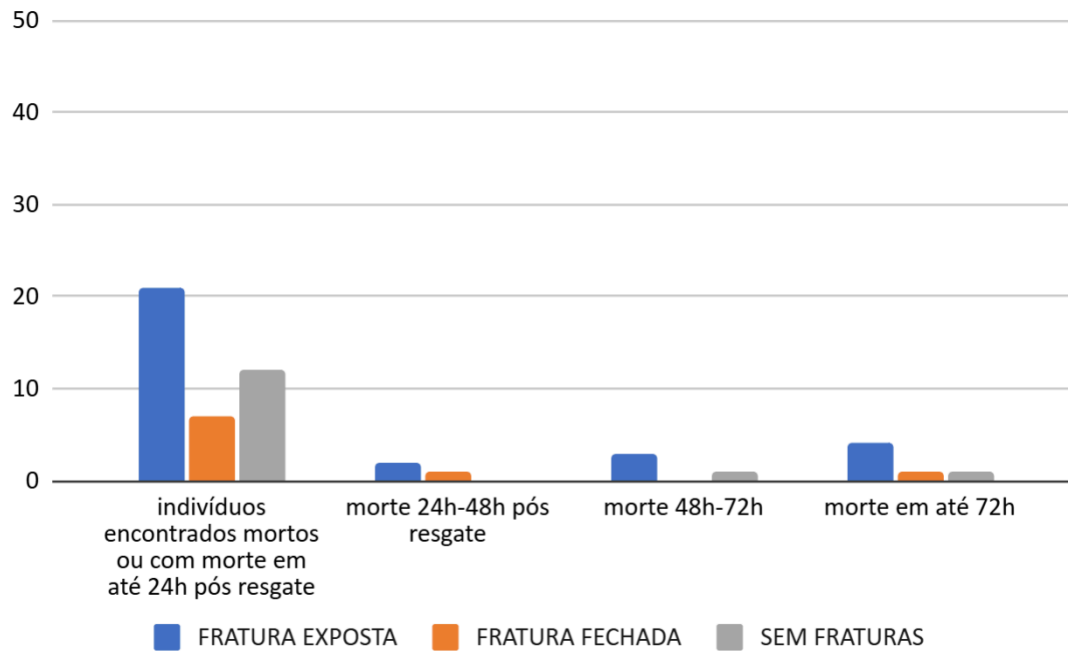


Figure 17. Relationship between the time interval until death and the severity of bone lesions.

Of the 27 individuals without identified fractures (18.9%; 27/143), 11 (40.7%, 11/27) exhibited lesions consistent with trauma, including contusion (18.5%, 5/27), dislocation (14.8%, 4/27), laceration (7.4%, 2/27), and abrasion (3.7%, 1/27). In one case (3.7%, 1/27), no detectable lesions were observed radiographically, although the individual presented impaired extension of the right forelimb.

5.1.1.3. Integumentary System

The integumentary system (IS) was also considerably affected (65%, 93/143), and the main alterations observed were the presence of laceration (64.5%; 60/93), ectoparasites (61.3%; 57/93), contusion (22.6%, 21/93), abrasion (5.4%; 5/93), and avulsion (1.1%; 1/93), represented in Figure 18.

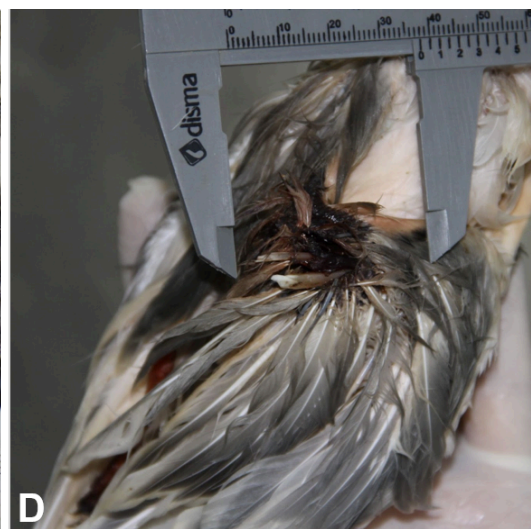
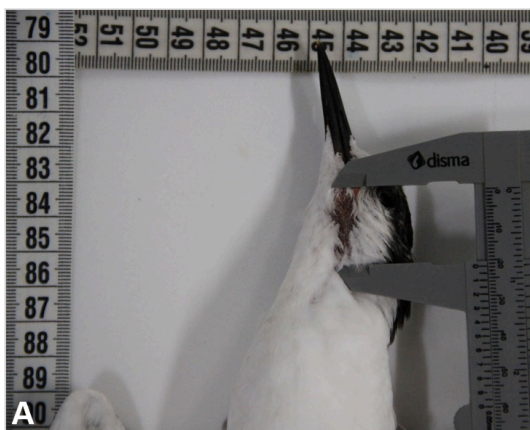




Figure 18. Macroscopic lesions in the integumentary system observed in *Sterna* spp. stranded in the Potiguar Basin. A: Abrasion in the left lateral-cervical region. B: Laceration of the left beak commissure. C: Laceration in the proximal third of the left radius and ulna region. D: Extensive laceration of the skin and adjacent musculature, with exposure of the radius and ulna bones. E: Laceration in the skull. F: Abrasion in the skull. G: Laceration in the left wing (LWF) with blood adhered to feathers near the lesion and exposure of musculature. H: Laceration with the presence of a blood clot adhered to feathers near the lesion in the right wing (RWF). I: Laceration at the base of the beak. J: Avulsion in the distal third of the ventral-cervical region with exposure of trachea, esophagus, and cervical vertebrae.

5.1.2. Internal alterations

Internal alterations were evaluated in 86 individuals selected with signs of collision, as described in Table 3.

Table 3. Main internal macroscopic pathological findings in *Sterna* spp. with signs of collision in the Potiguar Basin between 2020 and 2023.

Location of alteration	Absolute frequency (n)	Relative frequency (%)
MSS	55	63.9
LPM	17	30.9
Hematoma	17	100
Hemorrhage	2	11.8
Hypotrophy	2	11.8
RPM	14	27.2
Hematoma	10	71.4
Hemorrhage	3	21.4
PMs	23	41.8
Congestion	5	21.7
Hypotrophy	19	82.6
Emphysema	1	4.3
CM	1	3.4
Hematoma	1	100
RS	75	87.2
Air sacs	16	21.3
Hemorrhage	5	31.2
Rupture	4	25
Opacity	5	31.2
WSF (whitish spherical foci)	3	18.75
Trachea	18	24
Congestion	18	100

Bronchi	16	21.3
Bloody secretion	5	31.25
Congestion	15	93.75
Lungs	68	90.6
Hemorrhage	65	95.6
Fibrosis	1	1.5
Pallor	1	1.5
WSF (whitish spherical foci)	1	1.5
DS	60	69.8
GIT	33	55
Hypotrophy	8	24.4
Pallor	6	18.2
Congestion	19	57.6
WSF (whitish spherical foci)	3	9,1
Esophagus	5	8.3
Congestion	4	80
Liver	53	88.3
Congestion	26	49.1
Necrosis	18	34
Fibrosis	5	9.4
WSF (whitish spherical foci)	2	3.8
Pallor	5	9.4
Dilatation	12	22.6

Hypotrophy	2	3.8
Gallbladder	3	5
Rupture	3	100
Tongue	1	1.6
Laceration	1	100
Cloaca	1	1.6
Prolapse	1	100
Cavities	7	8.1
Oral cavity	1	14.3
Bloody secretion	1	100
Coelomic cavity	6	85.7
Bloody secretion	6	100

Legend: MSS = musculoskeletal system; LPM = left pectoral muscle; RPM = right pectoral muscle; PMs = pectoral muscles; CM = cervical muscle; RS = respiratory system; WSF = whitish spherical foci; DS = digestive system; GIT = gastrointestinal tract.

5.1.2.1. Musculoskeletal System

In the internal evaluation, muscular alterations (63.9%, 55/86) were predominantly observed in the pectoral musculature (PM), with generalized distribution (41.8%, 23/55). These included hypotrophy (82.6%, 19/23), congestion (21.7%, 5/23), and emphysema (4.3%, 1/23).

Alterations in the left pectoral muscle (LPM) (30.9%, 17/55) consisted of hematoma (100%, 17/17), hemorrhage (11.8%, 2/17), and focal hypotrophy (11.8%, 2/17). There was also one case of superficial laceration (5.9%, 1/17), in which a bone fragment from a fractured humerus perforated the left pectoral musculature. Some of these findings are illustrated in Figure 19.



Figure 19. Gross pathological findings in the left pectoral musculature of *Sterna* spp. (A) Generalized hypotrophy with a severe focal area in the left pectoral muscle. (B) Superficial laceration in the left pectoral muscle caused by perforation from a fractured humeral bone fragment. (C) Hematoma in the left pectoral musculature.

Regarding alterations in the right pectoral musculature (27.2%, 14/55), hematoma was observed in 71.4% (10/14), hemorrhage in 21.3% (3/14), and congestion in 7.1% (1/14) of the cases. Some of these findings are illustrated in Figure 20.

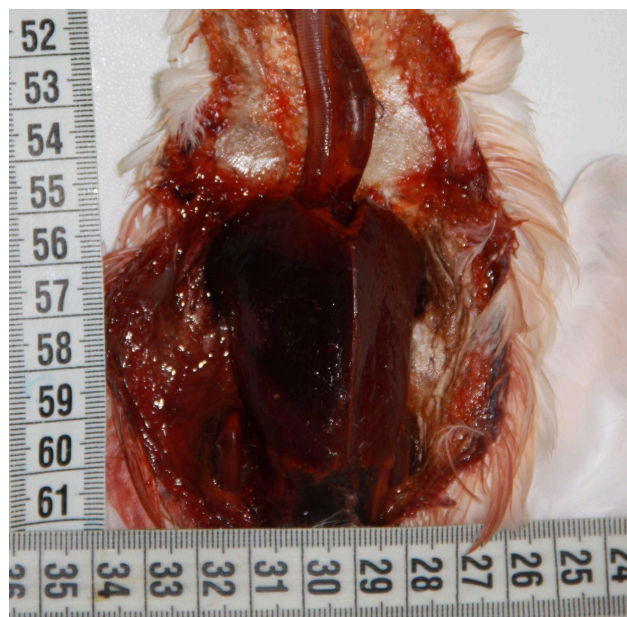


Figure 20. Presence of hematoma in the right pectoral musculature.

Alterations in the cervical musculature were recorded in only one case (3.4%, 1/59), consisting of hematoma (100%, 1/1).

5.1.2.2. Respiratory System

The respiratory system (RS) exhibited alterations in 87.2% (75/86) of the cases (Figure 18). The lungs were the most frequently affected organs (90.6%,

68/75), with the predominant finding being hemorrhage (95.6%, 65/68). Other alterations included fibrosis (1.5%, 1/68), pallor (1.5%, 1/68), and the presence of whitish spherical foci (1.5%, 1/68). Representative examples are shown in Figure 21.



Figure 21. Gross pathological findings in the respiratory system of *Sterna* spp. (A) Severe generalized congestion of the RS. (B) Hemorrhagic lung with intraparenchymal cruoric clots.

5.1.2.3. Digestive System

The digestive system (DS) was also widely affected (69.8%, 60/86), with the liver being the most frequently involved organ (88.3%, 53/60), followed by the gastrointestinal tract (GIT) (55%, 33/60).

The main alterations observed in the liver were congestion (51.1%, 26/53), necrosis (36.2%, 18/53), hypertrophy (22.6%, 12/53), fibrosis (9.4%, 5/53), and discoloration characterized by pallor (9.4%, 5/53). Some of these findings are illustrated in Figure 22. The gallbladder was also affected in 5% of the cases (3/53), with rupture observed in all of them (100%, 3/3).

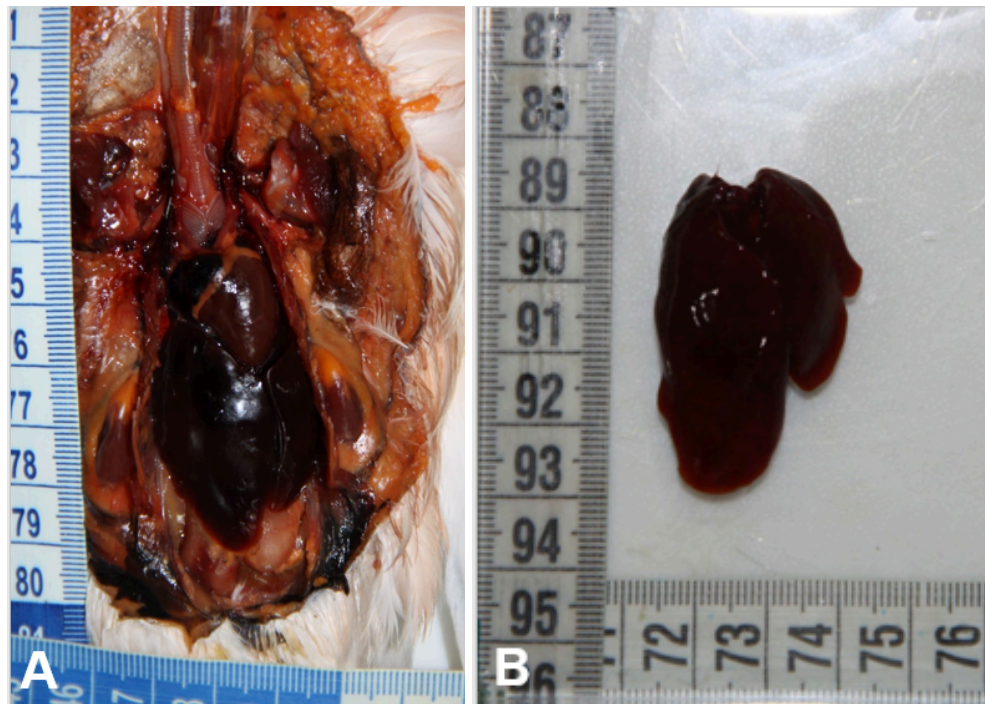


Figure 22. Gross pathological findings in the digestive system of *Sterna* spp. (A) Congestion and hypertrophy of the liver. (B) Congested and hypertrophic liver with rounded edges and areas of necrosis.

In the GIT, the main alterations observed were congestion (57.6%, 19/33), hypotrophy (24.4%, 8/33), pallor (18.2%, 6/33), and the presence of whitish spherical foci (9.1%, 3/33). Representative examples are shown in Figure 23.

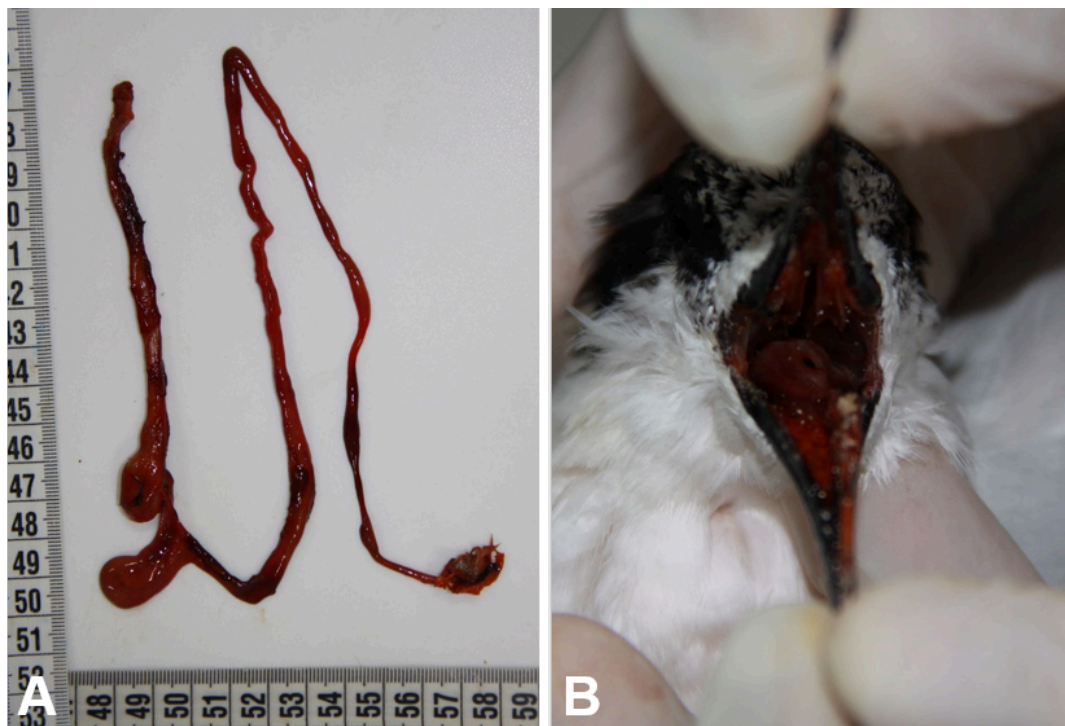


Figure 23. Gross pathological findings in the digestive system of *Sterna* spp. (A) Generalized congestion in the GIT. (B) Leftward deviation of the tongue, consistent with traction or traumatic injury.

5.1.2.4. Cardiovascular System

The cardiovascular system (CVS) also exhibited significant alterations (50%, 43/86), all of which were observed in the heart (100%, 43/43), as shown in Figure 24. The main findings included congestion (90.7%, 39/43), dilation (16.3%, 7/43), and hypotrophy (7%, 3/43).

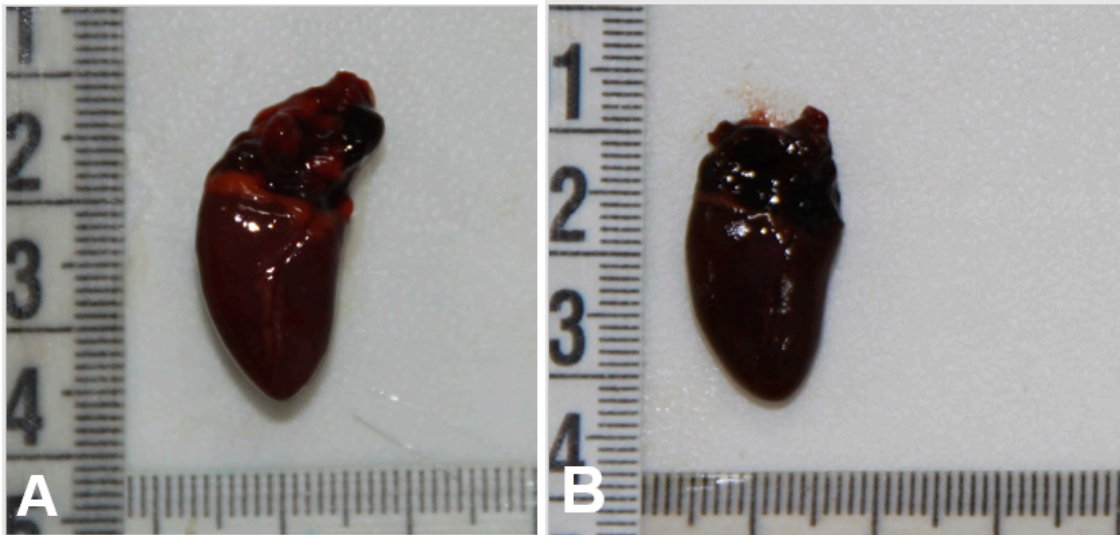


Figure 24. Gross pathological alterations in the heart of *Sterna* spp. (A) Moderate congestion, with adherent blood clots and cardiac dilation. (B) Severe cardiac congestion.

5.1.2.5. Endocrine System

Alterations were also recorded in the endocrine system (44.2%, 38/86). The main organs affected were the pancreas (76%, 29/38), with congestion (97%, 28/29), dilation (27.6%, 8/29), or hypotrophy (6.9%, 2/29), and the thyroid gland (39.5%, 15/38), with congestion (73.3%, 11/15), pallor (26.7%, 4/15), enlargement (13.3%, 2/15), or hypotrophy (6.7%, 1/15).

5.1.2.6. Genitourinary System

Lesions in the genitourinary system (GUS) were observed in 44.2% (38/86) of the cases, all of which were localized in the kidneys (100%, 38/38). These renal lesions included hemorrhages (81.6%, 31/38), cortical pallor (10.5%, 4/38), reduced renal volume (7.9%, 3/38), presence of whitish spherical foci (5.3%, 2/38), and nephromegaly (2.6%, 1/38). Some of these alterations are shown in Figure 25.

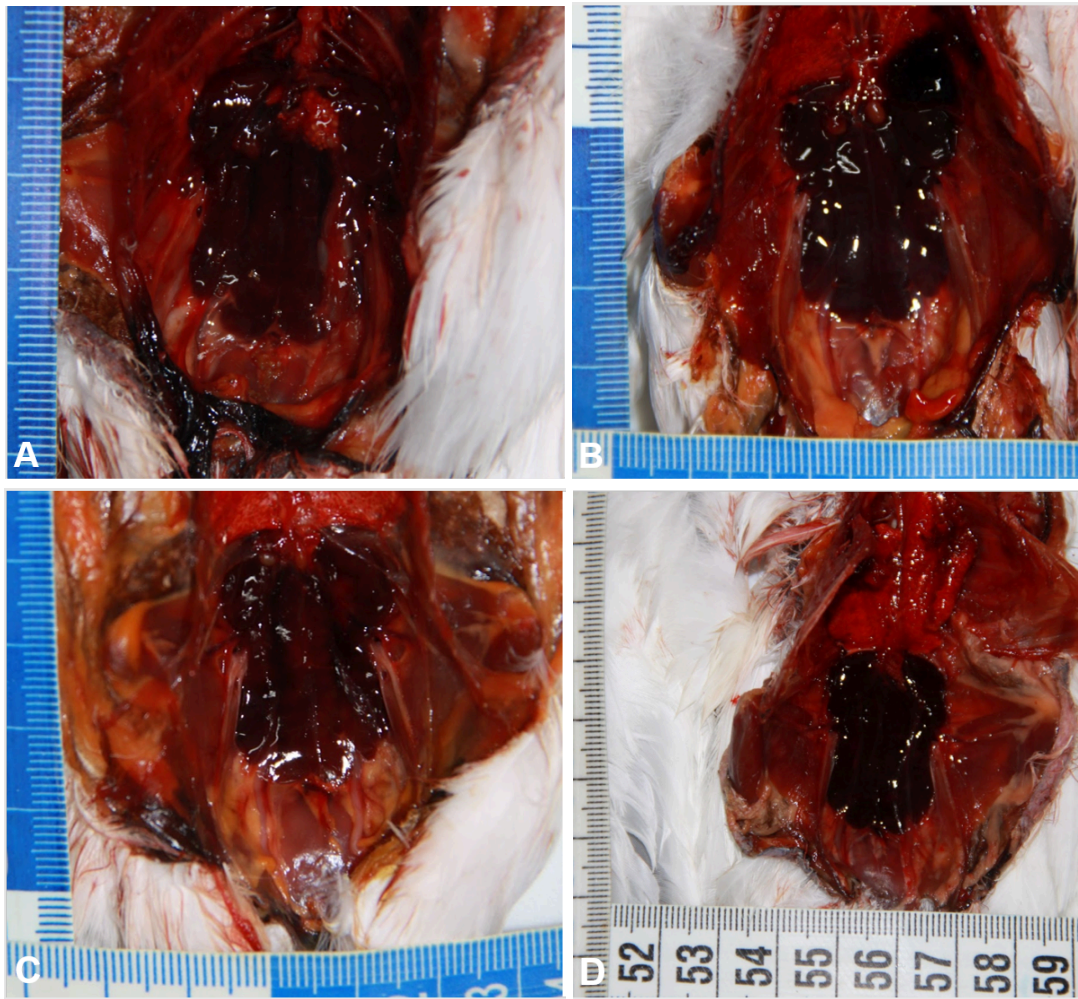


Figure 25. Gross pathological findings in the genitourinary system of *Sterna* spp A: Diffuse severe renal congestion. B: Diffuse severe renal congestion. C: Diffuse severe renal congestion with focal areas of necrosis. D: Diffuse severe renal congestion.

5.2. Statistical Evaluation

Based on the statistical analysis of the results, an interdependent relationship can be suggested between the occurrence of lesions in the musculoskeletal system (MSS) and the respiratory system (RS) ($p\text{-value} = 0$), as well as between the MSS and the genitourinary system (GUS) ($p\text{-value} < 0.04$), the MSS and the integumentary system (IS) ($p\text{-value} = 0$), and the MSS and the gastrointestinal system (GIS) ($p\text{-value} = 0$) in the individuals from the BP group, according to McNemar's test.

Additionally, the binomial test was used to analyze the proportion of deaths in birds in relation to the time elapsed after their rescue. To meet the assumption of a dichotomous variable, deaths recorded after 24 hours were grouped into a single category. Considering only birds that were rescued alive and not euthanized, the test

revealed that the proportion of deaths within 24 hours was significantly higher (p-value = 0.044) than after that period.

The binomial test was also applied to assess the difference in sex ratio among the individuals analyzed in the BP group, excluding cases with undetermined sex. The results indicated that this difference was not statistically significant (p-value = 0.061).

5.3. Radiographic Study

Radiographic examinations were performed on 17 carcasses, revealing that 11 of them (64.7%) exhibited bone lesions indicative of fractures. The fractures were distributed as follows: humerus and radius in five cases each (45.5%), ulna in four cases (36.4%), and coracoid in two cases (18.2%).

Fractures involved more than one bone in 45.4% of the cases (5/11), including bilateral humeral fractures in one case (1/5; 20%), left humerus, radius, and ulna in one case (1/5; 20%), right radius and ulna in one case (1/5; 20%), and left radius and ulna in two cases (2/5; 40%). Simple fractures were present in 54.6% of the cases (6/11), involving the humerus in three cases (3/6; 50%), the radius in one case (1/6; 16.7%), and the coracoid in two cases (2/6; 33.3%). Fracture classification is described in Table 4, and some cases are shown in Figure 26.

Table 4. Classification of fractures observed in radiographed carcasses of *Sterna* spp.

Fracture Classification	N
Simple Fractures in Forelimb	4
Closed transverse fracture in the proximal third of the left humerus	1
Closed transverse fracture in the proximal third of the left radius	1
Grade III open fracture with amputation in the proximal third of the left humerus	1
Grade III open segmental fracture of the left humerus	1
Multiple Fractures in Forelimb	5
Grade III open comminuted fracture in the proximal third of the left humerus and closed oblique fracture in the proximal third of the left radius and ulna	1
Grade II open comminuted fracture in the proximal third of the left radius and ulna	1
Closed transverse fracture in the proximal third of the right radius and ulna	1
Grade III open transverse fracture in the mid third of the left radius and ulna	1
Grade III open oblique fracture in the proximal third of the right humerus and mid third of the left humerus	1
Simple Fractures in Shoulder Girdle	2
Closed transverse fracture in the proximal third of the right coracoid	1
Closed transverse fracture in the mid third of the right coracoid	1

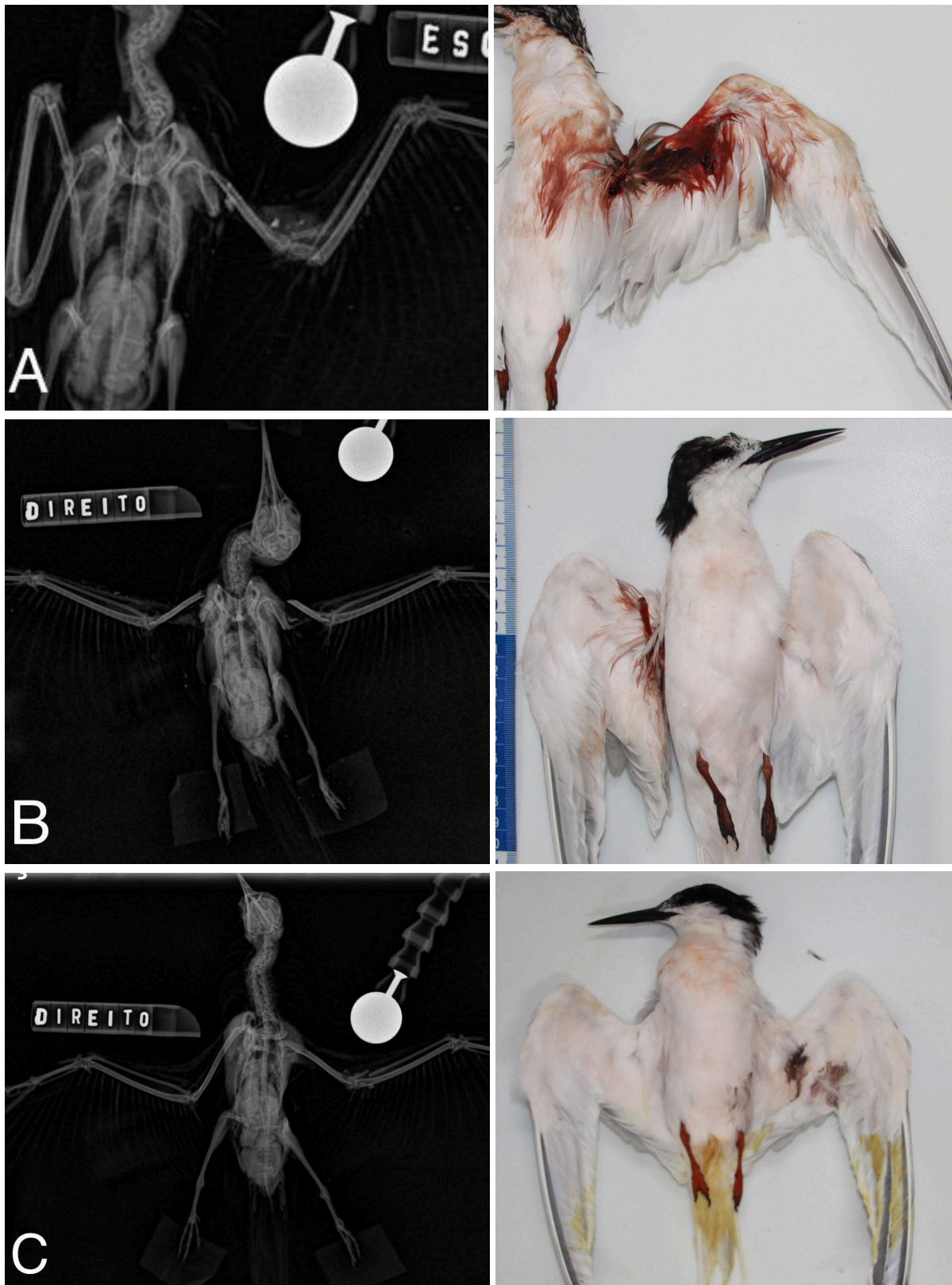


Figure 26. Comparison between radiographic and necropsy findings in the carcasses of *Sterna* spp.
 A: Comminuted open fracture in the proximal third of the left humerus and closed oblique fracture in the proximal third of the left radius and ulna. B: Open oblique fracture in the proximal third of the right humerus and in the midshaft of the left humerus. C: Closed oblique fracture in the proximal third of the left radius.

The anatomical distribution of the fractures revealed a predominance in the forelimbs (81.8%, 9/11), while the shoulder girdle was affected in only two cases (18.2%, 2/11). No lesions were detected in the hindlimbs, ribs, or pelvic girdle bones in any of the analyzed specimens.

Radiographic evaluation also revealed joint alterations in two cases (2/17): in one case, dislocation of the articulations between the sternum and the coracoid, as well as the left scapulocoracoid-humeral joints, was observed, with asymmetry of the shoulder girdle and widening of the humeral–shoulder girdle joint space; in the other case, a coracoid fracture was associated with dislocation of the right scapulocoracoid-humeral joint (Figure 27).



Figure 27. Coracoid bone alterations identified through radiographic evaluation. A: Complete transverse fracture of the proximal portion of the right coracoid. B: Closed transverse fracture in the midshaft of the right coracoid.

Among the 12 cases of individuals with osteoarticular lesions detected by radiographic examination, the left antimeres was significantly more affected, with

lesions observed in 8 cases (66.7%, 8/12), while the right antimer was affected in 3 cases (25%, 3/12), and only one case showed bilateral involvement (8.3%, 1/12).

In addition, visceral alterations were identified, particularly hepatomegaly in 47.1% (8/17) of the cases and cardiomegaly in 23.5% (4/17). The main radiographic findings are presented in Table 5.

Table 5. Main radiological findings in *Sterna* spp. with evidence of collision with power lines in the Potiguar Basin.

Radiological findings	SH	SD	TOTAL (casos)
Dislocation	1	1	2
Dislocation of the left sternocoracoid joint	1	0	1
Dislocation of the right scapulocoracohumeral joint	1	0	1
Dislocation of the left scapulocoracohumeral joint	0	1	1
Fracture	1	10	11
Fracture of the right humerus	0	1	1
Fracture of the left humerus	0	5	5
Fracture of the right radius	0	1	1
Fracture of the left radius	1	3	4
Fracture of the right ulna	0	1	1
Fracture of the left ulna	1	2	3
Fracture of the right coracoid	0	2	2
Volume alteration	1	9	10
Hepatomegaly	1	7	8
Hepatic atrophy	0	1	1
Cardiomegaly	1	3	4
Cardiac atrophy	0	1	1

SH=*Sterna hirundo*; SD=*Sterna dougallii*

DISCUSSION

6. Discussion

The predominance of *Sterna dougallii* among the birds analyzed in the present study was substantially higher than that of *Sterna hirundo*. This result is consistent with the findings of Revorêdo (2020), who, during systematic monitoring in the Galinhos region from 2010 to 2020, recorded 273 birds: 73.6% (201/273) *Sterna dougallii*, 23.1% (63/273) *Sterna hirundo*, and 3.3% (9/273) other *Sterna* spp. This distribution is similar to that observed among birds involved in collisions from 2020 to 2023.

This disparity in collision rates may first reflect the lower abundance of *S. hirundo* in the study area, resulting in fewer individuals exposed to collision risk. Additionally, differences in flight performance may contribute to this pattern. The superior flight capabilities and greater maneuverability of *S. hirundo* naturally reduce its susceptibility to collisions, leading to a lower frequency of accidents. This enhanced agility has been reported by Henderson et al. (1996), who observed a significantly lower collision rate for this species at the Shotton Steel Works industrial complex in northern Wales, Great Britain, UK.

In this context, higher occurrences of *Sterna* spp. were recorded in February and March, with occasional cases during the remaining summer months and late spring. This seasonal pattern is consistent with the migratory ecology of the species analyzed, as both *Sterna dougallii* and *Sterna hirundo* use the Brazilian coast during the non-breeding period. The marked increase in strandings in March and April may reflect the onset of northward migration, when a greater number of individuals begin long-distance movements toward the Northern Hemisphere. During this phase, birds tend to maintain more sustained and directionally focused flight, which may reduce their ability to detect and avoid anthropogenic obstacles such as power lines, thereby increasing collision susceptibility.

Additionally, a considerable proportion of the individuals recovered at this time presented poor or very poor body condition, suggesting that environmental factors in the region may be limiting food availability. Such reduced foraging opportunities could impair the birds' energetic reserves prior to migration, increasing vulnerability to collision events as well as to general mortality. Although these interpretations are

biologically plausible, dedicated studies are needed to clarify the link between migration phenology, environmental quality, and collision risk in these species.

Regarding the predominance of adults observed in this study, Teixeira (2022) also reported a high proportion of adults (83.5%, 259/310) in the Galinhos (RN) region between 2010 and 2021, supporting the current findings. Conversely, several studies indicate that juveniles tend to be more prone to collisions due to lower flight proficiency and greater energy expenditure during migration (Bayle, 1999; Sundar et al., 2005; Bernardino et al., 2018). However, *S. hirundo* predominantly migrates in the adult phase, which may explain the higher representation of adults in our sample (Rotics et al., 2016; Marcelino et al., 2021).

The high mortality rate among adults is particularly concerning, as the premature loss of individuals in this age group compromises the reproductive segment of the population, adversely affecting reproductive success (Pérez-García et al., 2011). This phenomenon might have negative consequences for the population migrating to the Northern Hemisphere during the breeding season.

Although most collided birds were initially found alive, 59.4% died within 24 hours of rescue. This early mortality likely reflects the severity of their injuries, which were predominantly grade II or III open fractures with substantial hemorrhage. Prior studies indicate that fracture severity and blood loss are key prognostic determinants in affected birds (SUNDAR et al., 2005; BERNARDINO et al., 2018). Acute hemorrhage can rapidly cause hypovolemia, characterized by a reduction in circulating blood volume and consequent decreases in venous return and cardiac output, which compromise tissue oxygen delivery, and trigger hypovolemic shock, multi-organ dysfunction, and death; in birds, relatively small circulating blood volumes and high metabolic demands make even moderate losses potentially fatal.

The predominance of incidents in the Galinhos region of Rio Grande do Norte (97.8%; 136/139) is likely linked to the presence of power line infrastructure, as previously reported by Revorêdo (2021) and Teixeira (2022). Our findings are consistent with Beaulaurier (1981) and Erickson et al. (2005), who identify collisions with overhead lines as a major threat to birds, particularly where these structures traverse wetlands used as habitat or lie along migratory routes.

Furthermore, Drewitt and Langston (2008) highlight interspecific differences in collision susceptibility, which may help explain the recurrence of cases observed here. Likewise, Larsen and Clausen (2002) report that situations involving large numbers of birds moving through the same area increase the likelihood of power-line strikes, particularly when many individuals are in simultaneous flight, reinforcing the association between this infrastructure and the high collision rates documented in this study.

According to the 2021 Report on Concentration Areas of Migratory Birds in Brazil, a species' biogeographic origin strongly influences its seasonal occurrence in Brazilian waters and should be considered when designing sampling and monitoring programs. Understanding these migratory patterns is essential to guide conservation measures and to plan coastal developments, particularly during critical periods of peak occurrence. The higher number of birds found in the morning likely reflects detection shortly after impact: although the exact time of collision cannot be determined, the fact that most individuals were still alive at rescue suggests that impacts occurred shortly before they were found. A similar pattern was reported by Teixeira (2022), who recorded 70% of individuals alive between 06:00 and 10:59 h. Because monitoring is conducted primarily in the early hours, this temporal clustering of detections may indicate that collisions occur in the late afternoon or at dawn, when reduced or changing light decreases cable conspicuity. These findings highlight the need for rapid-response protocols and early-morning patrols to minimize the consequences of collisions and improve recovery prospects for affected birds.

Interpreting ground-based monitoring data is challenging because the true number of collisions is likely much higher than the number detected. Although systematic searches for carcasses or incapacitated birds beneath or near the structures are the most commonly used method (SAVERENO et al., 1996; JENKINS et al., 2010; RIOUX et al., 2013), such surveys typically recover only a fraction of events (SAVERENO et al., 1996; JENKINS et al., 2010). After impact, birds may glide or be carried by wind or currents and land far from the strike point; injured individuals can also move away before dying. Dense vegetation, water, difficult terrain, limited access, scavenger removal between search intervals, and imperfect observer detection further depress recovery rates. Consistent with these limitations,

Travers et al. (2021) reported that only 13% of impacted birds were found within standard search distances, with many carcasses landing more than one kilometer from the strike location and therefore remaining undetected by conventional searches. Consequently, uncorrected ground-search counts should be treated as minimum estimates unless augmented with broader search methods (e.g., telemetry, radar, drones, among others).

Importantly, the daily monitoring carried out by the PMP substantially reduces many of these detection biases. By conducting searches every morning, carcass persistence issues are minimized and the probability of detecting injured birds while still alive is markedly increased. This high-frequency monitoring enhances detection reliability compared to studies relying on wider search intervals, in which scavenger removal and observer limitations have greater impact. Thus, although undetected events undoubtedly remain, the continuous patrolling characteristic of this program provides a more robust basis for interpreting collision patterns.

Building on these constraints, remote and autonomous approaches can help close the detection gap. Impact sensors mounted on conductors or shield wires (e.g., accelerometer/strain- or acoustic-based systems) can register and time-stamp strikes directly, including on spans that are difficult to access (HARNESS et al., 2003; PANDEY et al., 2008). Networked devices with solar power and telemetry enable continuous coverage and rapid alerts, while AI-assisted optical or thermal cameras at selected spans can corroborate events and, in some cases, identify taxa.

When combined with statistical corrections derived from searcher-efficiency and carcass-persistence trials within appropriate modeling frameworks, these tools can yield more realistic mortality estimates and more precisely target mitigation—such as span-specific line marking, routing refinements, or operational adjustments—thereby strengthening conservation strategies.

In the present study, a predominance of injuries was observed in the forelimbs, particularly in the humerus, contrasting with the findings of Travers et al. (2021), who analyzed *Puffinus newelli* and *Pterodroma sandwichensis* following collisions with power lines. In that study, only 10% of individuals presented wing injuries—also involving humeral fractures and damage to the elbow and carpal

joints—while most lesions were cranial, including skull and beak fractures, ocular injuries, feather loss on the head, and nasal or oral bleeding.

These contrasting injury patterns are likely related not only to wing loading but also to broader aerodynamic and behavioral differences between these groups. *Puffinus* and *Pterodroma* are dynamic/glide flyers specialized for high-speed, energy-efficient travel, with relatively high wing loading and long, narrow, stiff wings optimized for sustained forward motion. These characteristics reduce maneuverability and limit rapid last-moment changes in flight trajectory. As a result, individuals are more prone to frontal impacts, which commonly lead to cranial injuries.

By contrast, terns possess much lower wing loading and proportionally longer, more tapered wings with greater aerodynamic responsiveness, enabling tighter turns, rapid deceleration, and abrupt evasive maneuvers. This increased agility may allow birds to redirect their body at the last moment and avoid a direct head-on collision. However, such evasive actions can cause the wings—especially the extended primaries—to strike the wires instead, which would explain the predominance of wing fractures observed in the present study.

Radiographic analysis was essential for the characterization and classification of lesions, enabling the identification of fractures not externally visible but with potential to compromise adjacent soft tissues (FOSSUM et al., 2008; PIERMATTEI et al., 2009), thus expanding the understanding of case severity.

The internal injury patterns observed reinforce the hypothesis of blunt trauma, with relevant visceral alterations that often do not manifest clinically at first. These findings highlight the need for comprehensive clinical and diagnostic approaches that account for both external and internal injuries, the latter frequently being fatal.

McNemar's test indicated an association between musculoskeletal (MSS) and integumentary (IS) lesions, and between MSS lesions and poorer general condition (GC): when the MSS was affected, IS injuries and compromised GC were more likely to co-occur. This pattern aligns with previous reports in seabirds involved in collisions (SILVA et al., 2018; REVORÊDO, 2021; TRAVERS et al., 2021). Mechanistically, wing and shoulder injuries impair flight, limiting foraging and movement and rapidly

leading to exhaustion, dehydration, and loss of body condition; hemorrhage and pain further increase physiological stress. Integumentary damage often occurs simultaneously—either directly from the impact (lacerations, abrasions) or from subsequent contact with the ground or water and struggling after the fall. Collectively, these findings support collision as the primary driver of the observed alterations and the proximate cause of stranding in the individuals examined.

Systematic monitoring, combined with the analysis of collision patterns, can support public policies aimed at the conservation of affected species, particularly in more sensitive regions. Investigations into the morphophysiological characteristics of the species involved, as well as the specific features of local infrastructures, are essential to identify vulnerable groups and propose targeted conservation actions (BERNARDINO et al., 2018).

In addition, the assessment of the environment and adjacent areas is crucial to identify overlapping impacts (CEMAVE/ICMBio, 2021), such as that recorded in Galinhos/RN, where the installation of a wind farm in close proximity to a power distribution line intensified bird collisions with these structures, and no significant reduction in such events was observed even after the installation of line markers (REVORÊDO, 2021). This scenario highlights the importance of considering the cumulative effects of neighboring projects at the population, community, or guild level, particularly in light of the formation of continuous barriers in the coastal environment (GOODALE & MILMAN, 2020; GOODALE et al., 2019), which impact both navigation and the conservation of sensitive species.

If left unmitigated, recurrent collisions can become a major driver of population decline in vulnerable species (Travers et al., 2021), highlighting the urgency of effective intervention. A priority measure is line marking: installing high-contrast, moving, or reflective devices on conductors or (especially) shield wires along migratory corridors and in key feeding or roosting areas to increase cable conspicuity, particularly under low light or poor weather. Targeted deployment at documented hotspots and during peak-use periods, coupled with monitoring to evaluate efficacy (e.g., before–after/control–impact designs), can substantially reduce collision rates and better safeguard at-risk populations. One of the greatest challenges in research on avian mortality from collisions is assessing the

population-level impact of this mortality (LOSS et al., 2015). To achieve this, it is essential to investigate key demographic parameters that allow population viability analysis (JENKINS et al., 2011), in addition to developing appropriate modeling approaches that clarify whether anthropogenic mortality is compensatory—meaning that some of the individuals killed would likely have succumbed to other natural causes—or additive, when individuals die exclusively as a result of collisions (LOSS et al., 2015). Furthermore, biases such as carcass persistence and detectability rates (COSTANTINI et al., 2017; PONCE et al., 2010), as well as birds that collide but die or are detected only after moving away from power lines (MURPHY et al., 2016b), must be taken into account.

The predominance of open fractures (83.6%) among the affected individuals, with 40.2% (39/97) of these associated with amputations, highlights the severity of injuries resulting from collisions with power lines. These findings indicate that musculoskeletal trauma caused by such impacts is, in most cases, severe and irreversible, significantly compromising the physical integrity and rehabilitation potential of the affected animals. This may be related to the fact that mortality within 24 hours after rescue occurred at higher rates according to the binomial test. In addition, open fractures are associated with greater contamination, delayed bone healing, and higher risk of complications compared with closed fractures, as described by Piermattei et al. (2009), reinforcing the critical nature of these injuries.

This severity may be linked to the high flight speed of these birds, which are otherwise known for their aerial agility, when colliding with structures. It is also possible that such collisions occur during periods of reduced visibility, such as late in the day, making it more difficult to visually detect wires and avoid them in time. This hypothesis is supported by the fact that most individuals were found in the early morning hours.

Notably, 40.7% of individuals without radiographically detectable fractures still exhibited trauma-related lesions. Thus, the absence of fractures does not rule out clinically significant injury and broadens our understanding of the spectrum of effects caused by collisions with anthropogenic structures. This is consistent with Travers et al. (2021), who reported that about 20% of birds had no externally visible injuries yet likely sustained occult trauma. Such non-fracture injuries can include intracranial

trauma, internal hemorrhage, thoracic or abdominal contusions (e.g., pneumothorax/hemothorax), and severe soft-tissue damage. Clinically, these may present as neurological deficits, respiratory distress, arrhythmias, shock, or rapid deterioration, and can be fatal even after rehabilitation has begun. The internal injuries identified in the analyzed carcasses also revealed patterns consistent with high-energy trauma, compatible with collisions with the studied structures. The respiratory system was the most affected, with a predominance of pulmonary hemorrhage, which may result from direct impact capable of causing vascular rupture. Such alterations can lead to acute respiratory failure as a possible immediate cause of death in many cases.

Hepatic and renal congestion, which were also frequent, are best interpreted as passive congestion secondary to trauma-induced hemodynamic instability—acute hemorrhage and shock leading to hypotension, reduced cardiac output, tissue hypoxia, and impaired venous return. The universal finding of cardiac congestion in birds with cardiovascular lesions reinforces this interpretation, indicating systemic circulatory failure precipitated by the impact itself (e.g., myocardial contusion or arrhythmia) and potentially exacerbated by pre-existing debilitation.

Internal muscle injuries, particularly in the pectorals, together with the high prevalence of muscle hypotrophy and congestion, point to multiple impact sites and concurrent energy depletion. Long-distance migration imposes substantial metabolic stress; as fat reserves are exhausted, birds catabolize muscle, resulting in atrophy and diminished strength. This nutritional compromise likely amplified the effects of trauma by reducing the ability to absorb impact, maintain adequate perfusion, and mount an effective physiological response, thereby worsening clinical outcomes.

During the compilation and review of records for this study, we identified notable limitations in SIMBA data quality. Clinical histories were often incomplete, with key parameters missing and no documented justification, which hampers interpretation of the animals' condition. In addition, many examinations were conducted under emergency conditions, and, as previously shown, 55.9% of deaths occurred within the first 24 hours after rescue, indicating the severe debilitation of the animals. In such situations, it is likely that rapid care with minimal handling was

prioritized to reduce stress and increase the chances of survival, which may have limited the full collection of clinical parameters at admission.

However, the lack of explicit notes to that effect introduces uncertainty into the analysis. We also observed the absence of photographic documentation for some postmortem (necropsy) examinations—an essential means of corroborating written findings—as well as gaps in the completeness of gross (macroscopic) lesion descriptions.

Although the present study does not aim to evaluate or validate SIMBA, it is essential to consider that the quality and standardization of the data entered directly influence the reliability of analyses developed from this database. Continued improvement of data entry procedures—such as implementing clearer guidelines, more standardized protocols, and broader use of visual documentation—would further enhance the robustness and applicability of the information generated. Despite the challenges inherent to large collaborative databases, SIMBA represents an invaluable tool for wildlife research and conservation, and its ongoing refinement will undoubtedly strengthen future studies based on its data.

CONCLUSIONS

7. Conclusions

The findings of the present study demonstrate that collisions with power lines constitute one of the main causes of stranding and mortality of *Sterna* spp. along the Northeastern coast of Brazil, particularly in the region of Galinhos (RN).

The most frequent alterations were related to the musculoskeletal system, with a predominance of open fractures in the forelimbs, mostly associated with amputations, reflecting the severity of the impact.

Radiographic analysis proved to be essential for characterizing and classifying these lesions and serves as a key diagnostic tool in studies aimed at characterizing traumatic injuries. Used alongside gross (macroscopic) examination, it enables a more accurate assessment of lesion extent, particularly in collision scenarios. Moreover, the observed patterns of internal injury support the hypothesis of collision-related blunt-force trauma and reveal systemic injuries that may not be evident from anamnesis and/or external inspection.

The study shows that the injuries caused by interaction with power lines are severe and often irreversible, significantly affecting flight capacity and, consequently, the feeding and survival rates of these birds. These results highlight that collisions with human infrastructures represent a critical threat factor for migratory species, requiring special attention in conservation strategies.

Furthermore, the importance of complete clinical and radiographic protocols is emphasized, as they enable more accurate interventions during rehabilitation. Finally, considering the complexity of the findings, it is necessary to integrate macroscopic evaluation with complementary examinations, such as histopathological analysis, in order to more precisely elucidate the cause of death and investigate potential predisposing or aggravating factors, such as concomitant diseases, previous debilitation, or physiological disorders related to migratory effort.

REFERENCES

8. References

AINLEY, D. G.; PORZIG, E.; ZAJANC, D.; SPEAR, L. B. Seabird flight behavior and height in response to altered wind strength and direction. *Marine Ornithology*, [S.l.], v. 43, n. 1, Art. 4, 2015. Available at: https://digitalcommons.usf.edu/marine_ornithology/vol43/iss1/4. Accessed on: 24 jun. 2023. DOI: <https://doi.org/10.5038/2074-1235.43.1.1098>.

ALERSTAM, T. *Bird migration*. Cambridge: Cambridge University Press, 1990.

ANDERSON, W. L. Waterfowl collisions with power lines at a coal-fired power plant. *Wildlife Society Bulletin*, [S.l.], v. 6, p. 77–83, 1978.

ANTAS, P. T. Z. Status and conservation of seabirds breeding in Brazilian waters. In: CROXALL, J. P. (Ed.). *Seabird status and conservation: a supplement*. Cambridge, UK: International Council for Bird Preservation, 1991. Technical Publication 11. p. 141–158.

Antas, P.T.Z. Migração de aves no Brasil In: Anais (ed.) *2º Encontro Nacional de Anilhadores de Aves*. Rio de Janeiro, Editora da Universidade Federal do Rio de Janeiro, 1987. pp. 153-187.

APLIC – Avian Power Line Interaction Committee. *Reducing avian collisions with power lines: the state of the art in 2012*. Washington: Edison Electric Institute/APLIC/California Energy Commission, 2012. 184 p.

ARNOLD, Jennifer M.; OSWALD, Stephen A.; NISBET, Ian C. T.; PYLE, Peter; PATTEN, Michael A. Common Tern (*Sterna hirundo*). *Birds of the World*, 2020. Available at: <https://birdsoftheworld.org/bow/species/comter/cur/introduction>. Accessed on: 05 jan. 2025.

ARNOSO, G. S. P.; CARLOS, J. C.; PEREIRA, M. J. Osteologia do aparato alimentar em trinta-réis-de-bico-vermelho: *Sterna hirundinacea* (Aves: Charadriiformes). 2019. Available at: lume.ufrgs.br/bitstream/handle/10183/191000/Resumo_58304.pdf?sequence=1. Accessed on: 05 ago. 2022.

AZEVEDO JUNIOR, S. M.; LARRAZÁBAL, M. E.; PENA, O. Aves aquáticas de ambientes antrópicos. In: *Aves marinhas e insulares brasileiras: bioecologia e conservação*. Itajaí, SC: UNIVALI, 2004. p. 255–266. E-book.

BARRIENTOS, R.; ALONSO, J. C.; PONCE, C.; PALACÍN, C. Meta-analysis of the effectiveness of marked wire in reducing avian collisions with power lines. *Conservation Biology*, [S.l.], v. 25, p. 893–903, 2011. Available at: <https://doi.org/10.1111/j.1523-1739.2011.01699.x>. Accessed on: 24 jun. 2024.

BASSO, M. et al. Sedimentology and petrophysical analysis of pre-salt lacustrine carbonate reservoir from the Santos Basin, southeast Brazil. *International Journal of Earth Sciences*, [S.l.], v. 110, n. 7, p. 2573–2595, 1 oct. 2021.

BEAULAURIER, D. L. Mitigation of birds collisions with transmission lines. Bonneville Power Administration, US Department of Energy, Boulder, Colorado, 1981.

BELL, G. *Selection: the mechanism of evolution*. New York: Oxford University Press, 2008.

BEREGI, A.; MOLNÁR, V.; FELKAI, F.; BÍRÓ, F.; SZENTGÁLI, Z. Diagnostic radiology of pet and wild birds: a review. *Acta Veterinaria Hungarica*, v. 47, n. 4, p. 395–408, 1999.

BERNARDINO, J.; BEVANGER, K.; BARRIENTOS, R.; DWYER, J. F.; MARQUES, A. T.; MARTINS, R. C.; SHAW, J. M.; SILVA, J. P.; MOREIRA, F. Bird collisions with power lines: state of the art and priority areas for research. *Biological Conservation*, v. 222, p. 1–13, 2018. DOI: <https://doi.org/10.1016/j.biocon.2018.02.029>.

BEVANGER, K. Bird interactions with utility structures: collision and electrocution, causes and mitigating measures. *Ibis*, v. 136, p. 412–425, 1994.

BEVANGER, K. Tetraonid mortality caused by collisions with power lines in boreal forest habitats in central Norway. *Fauna Norvegica*, Series C, Cinclus, [S.l.], v. 18, p. 41–51, 1995b.

BEVANGER, K. Biological and conservation aspects of bird mortality caused by electricity power lines: a review. *Biological Conservation*, v. 86, p. 67–76, 1998.

BEVANGER, K.; BRØSETH, H. Impact of power lines on bird mortality in a subalpine area. *Animal Biodiversity and Conservation*, v. 27, n. 2, p. 67–77, 2004.

BIASOTTO, L. D.; KINDEL, A. Power lines and impacts on biodiversity: a systematic review. *Environmental Impact Assessment Review*, v. 71, p. 110–119, 2018. DOI: <https://doi.org/10.1016/j.eiar.2018.04.010>.

BIASOTTO, L. D.; MOREIRA, F.; BENCKE, G. A.; D'AMICO, M.; KINDEL, A.; ASCENSÃO, F. Risk of bird electrocution in power lines: a framework for prioritizing species and areas for conservation and impact mitigation. *Animal Conservation*, v. 25, n. 2, p. 285–296, set. 2021. DOI: 10.1111/acv.12736.

BIRDLIFE INTERNATIONAL. *Sterna dougallii*. 2018. *The IUCN Red List of Threatened Species*. Available at: <https://www.iucnredlist.org/species/22694601/132260491>. Accessed on: 10 nov. 2025.

BIRDLIFE INTERNATIONAL. *Sterna hirundinacea*. 2018. Available at: <https://www.iucnredlist.org/species/22694618/132562410>. Accessed on: 10 nov. 2025.

BIRDLIFE INTERNATIONAL. *Sterna hirundo*. 2019. Available at: <https://www.iucnredlist.org/species/22694623/155537726>. Accessed on: 03 jul. 2023.

BIRDLIFE INTERNATIONAL. BirdLife Data Zone. [S.l.], 2020. Available at: <http://datazone.birdlife.org/species/search>. Accessed on: 10 fev. 2023.

BRADBURY, M. A.; DUPUY, L. F. *Clinical avian medicine*. Philadelphia: Saunders, 1986. Capítulo 5: Selected Physiology for the Avian Practitioner, p. 71.

BRANCO, J. O. Aves marinhas das ilhas de Santa Catarina. In: BRANCO, J. O. (Org.). *Aves marinhas e insulares brasileiras: biologia e conservação*. Itajaí: Ed. Univali, 2014. p. 266.

BRANCO, J. O. Avifauna aquática do Saco da Fazenda (Itajaí, Santa Catarina, Brasil): uma década de monitoramento. *Revista Brasileira de Zoologia*, [S.l.], v. 24, n. 1, p. 97–108, 2007. Available at: https://www.scielo.br/j/rbzool/a/pgy4bVpwxWCQhqSYPR4Mycw/?utm_source=chatgpt.com. Accessed on: 1 jan. 2025.

BRANCO, J. O. Reprodução das aves marinhas nas ilhas costeiras de Santa Catarina, Brasil. *Revista Brasileira de Zoologia*, Curitiba, v. 20, n. 4, p. 619–623, 2003a.

BRANCO, J. O. Reprodução de *Sterna hirundinacea* Lesson e *S. eurygnatha* Saunders (Aves, Laridae), no litoral de Santa Catarina, Brasil. *Revista Brasileira de Zoologia*, Curitiba, v. 20, n. 4, p. 655–659, 2003b.

BRASIL. Instituto Chico Mendes de Conservação da Biodiversidade. **Relatório de Áreas de Concentração de Aves Migratórias no Brasil – 4ª edição**. CEMAVE/ICMBio, 2021. 192 p.

BRUNETTA, G. M.; DE SOUZA, E. H. B.; GOMES, S. A. Choque elétrico em arara-canindé (*Ara ararauna*). In: COLÓQUIO ESTADUAL DE PESQUISA MULTIDISCIPLINAR & CONGRESSO NACIONAL DE PESQUISA MULTIDISCIPLINAR, 2024, [S.l.]. Anais... [S.l.], set. 2024. ISSN 2527-2500.

BUGONI, L.; VOOREN, C. M. Feeding ecology of the Common Tern *Sterna hirundo* in a wintering area in southern Brazil. *Ibis*, v. 146, p. 438–453, 2004.

BUGONI, L.; CORMONS, T. D.; BOYNE, A. W.; HAYS, H. Waterbirds, v. 28, n. 4, p. 468–477, 2005.

BUREAU D'ÉTUDES ENVIRONNEMENT AGRONOMIE. *Cyathea_EDF: rapport suivi avifaune – bras de la Plaine*. [S.l.], 2008.

BURGER, J. Family Sternidae (Terns); p. 624-667 In J. del Hoyo, A. Elliott and J. Sargatal (ed.). Handbook of the birds of the world. Volume 3. Hoatzin to auks. Barcelona: Lynx Edicions, 1996.

CAMBOIN, T. Trinta-réis-róseo (*Sterna dougallii*) | WikiAves - A Enciclopédia das Aves do Brasil, 2020. Available at: <https://www.wikiaves.com.br/wiki/trinta-reis-roseo>. Accessed on: 03 jul. 2023.

CERQUEIRA LIMA, P.; HAYS, H.; ROCHA, R. C. A.; CORMONS, T.; CORMONS, G.; SAMPAIO, S. Recuperações de *Sterna hirundo* (Linnaeus, 1758) na Bahia, Brasil, entre 1995 e 2004, 2005.

CHEVALLIER, C.; HERNANDEZ-MATIAS, A.; REAL, J.; VICENT-MARTIN, N.; RAVAYROLS, A.; BESNARD, A. Retrofitting of power lines effectively reduces mortality by electrocution in large birds: an example with the endangered Bonelli's eagle. *Journal of Applied Ecology*, Londres, v. 52, n. 6, p. 1465-1473, 2015.

Coelho, E.P., Alves, V.S., Soneghet, M.L.L. & Carvalho, F.S. (1990) Levantamento das aves marinhas no percurso Rio de Janeiro - Bahia (Brasil). *Boletim do Instituto Oceanográfico*. 38 (2), 161--167.

COOPER, B. A.; DAY, R. H. Summer behavior and mortality of Dark-rumped Petrels and Newell's Shearwaters at power lines on Kauai. *Colonial Waterbirds*, [S.l.], v. 21, p. 11–19, 1998. Available at: <https://doi.org/10.2307/1521726>. Accessed on: 24 jun. 2024.

CORDEIRO, P. H. C.; FLORES, J. M.; NASCIMENTO, J. L. X. Análise das recuperações de *Sterna hirundo* no Brasil entre 1980 e 1994. *Ararajuba*, v. 4, p. 3–7, 1996.

CRACKNELL, J. Avian radiography and radiology in practice. *Veterinary Times*, v. 34, n. 4, p. 6-7, 2004.

DA SILVA, G. L.; DOURADO, M. S.; CANDELLA, R. N.; SHARPLES, D. J. Estudo preliminar da climatologia da ressurgência na região de Arraial do Cabo, RJ. [s.l.], 2006.

DAVIS, K. L. et al. Residency, recruitment, and stopover duration of hatch-year roseate terns (*Sterna dougallii*) during the premigratory staging period. *Avian Conservation and Ecology*, [S.l.], v. 14, n. 2, 2019.

DAY, R. H.; COOPER, B. A. Patterns of movement of Dark-rumped Petrels and Newell's Shearwaters on Kauai. *The Condor*, [S.I.], v. 97, p. 1011–1027, 1995.

DE LUCA, A.; DEVELEY, P.; OLMOS, F. Final report - Waterbirds in Brazil 2006 - BirdLife International. São Paulo: [s.n.], 2006. Available at: <https://www.yumpu.com/en/document/read/7897484/final-report-waterbirds-in-brazil-2006-birdlife-international>. Accessed on: 27 dez. 2022.

DIAS, Rafael A.; AGNE, Carlos Eduardo; BARCELOS-SILVEIRA, André; BUGONI, Leandro. *New records and a review of the distribution of the Arctic Tern *Sterna paradisaea* Pontoppidan, 1763 (Aves: Sternidae) in Brazil*. Check List, v. 8, n. 3, p. 563–567, 2012. Disponível em: <http://www.checklist.org.br>. Acesso em: 15 jul. 2025.

DREWITT, A. L.; LANGSTON, R. H. W. Collision Effects of Wind-power Generators and Other Obstacles on Birds. *Annals of the New York Academy of Sciences*, Medford, v. 1134, n. 1, p. 233–266, 2008.

EFE, M. A. Características morfológicas das aves e seus ambientes: Guia prático de observação de aves. Proaves, 1999.

EFE, M. A.; NASCIMENTO, J. L. X.; NASCIMENTO, I. L. S.; MUSSO, C. Distribuição e ecologia reprodutiva de *Sterna sandvicensis eurygnatha* no Brasil. *Melopsittacus*, Belo Horizonte, v. 3, n. 3, p. 110–121, 2000.

EIGENBROD, F.; HECNAR, S. J.; FAHRIG, L. Quantifying the road-effect zone: threshold effects of a motorway on anuran populations in Ontario, Canada. *Ecology and Society*, [S.I.], v. 14, n. 1, art. 24, 2009. Available at: <http://www.ecologyandsociety.org/vol14/iss1/art24/>. Accessed on: 24 jun. 2024.

ERICKSON, W. P.; JOHNSON, G. D.; YOUNG Jr., D. P. A summary and comparison of bird mortality from anthropogenic causes with an emphasis on collisions. *USDA Forest Service Gen. Republica Tcheca, PSW-GTR-191*, p. 1029-1042, 2005.

EGEVANG, C.; STENHOUSE, I. J.; PHILLIPS, R. A.; PETERSEN, A.; FOX, J.W; SILK, J. R. D. Tracking of Arctic terns *Sterna paradisaea* reveals longest animal migration. **Proceedings of the National Academy Sciences**, v.107, n.5, p. 2078 - 2081, 2010.

FAANES, C. A. Bird behavior and mortality in relation to power lines in prairie habitats: Technical report. Washington, DC: U.S. Fish and Wildlife Service, 1987.

FAHRIG, L. Effects of habitat fragmentation on biodiversity. *Annual Review of Ecology, Evolution, and Systematics*, [S.l.], v. 34, p. 487–515, 2003.

FARFÁN, M. A.; DUARTE, J.; REAL, R.; MUÑOZ, A. R.; FA, J. E.; VARGAS, J. M. Differential recovery of habitat use by birds after wind farm installation: A multi-year comparison. *Environmental Impact Assessment Review*, v. 64, p. 8–15, 2017. <https://doi.org/10.1016/j.eiar.2017.02.001>

FERREIRA, A. P.; HORTA, M. A. P. Avaliação das concentrações de metais pesados no sedimento, na água e nos órgãos de *Nycticorax nycticorax* (Garça-da-noite) na Baía de Sepetiba, RJ, Brasil. *Journal of Integrated Coastal Zone Management*, v. 10, p. 229–241, 2010.

FIJN, R. C.; HIEMSTRA, D.; PHILLIPS, R. A.; WINDEN, J. Arctic Terns *Sterna paradiseae* from the Netherlands migrate record distances across three oceans to Wilkes Lands, East Antarctica. *Ardea*, v. 101, p. 3-12, 2013.

FORMAN, R. T. T.; ALEXANDER, L. E. Roads and their major ecological effects. *Annual Review of Ecology and Systematics*, [S.l.], v. 29, p. 207–231, 1998.

FOSSUM, T. W. Cirurgia de pequenos animais. Rio de Janeiro: Elsevier, 2008.

FRACASSO, H. A. A. Ecologia reprodutiva de *Sterna hirundinacea* Lesson (Laridae, Aves) na Ilha dos Cardos, Florianópolis, SC. 2005. Dissertação (Mestrado) — Universidade Federal de Santa Catarina, Florianópolis, SC, 2005.

GARBELOTO, M. C.; PEREIRA, N. T. Frequência de interação antrópica em aves marinhas encalhadas no município de Florianópolis - litoral de Santa Catarina. *Revista Multidisciplinar de Educação e Meio Ambiente*, v. 2, n. 4, p. 13, 2021. <https://doi.org/10.51189/rema/2274>

GARCIA-DEL-REY, E.; RODRIGUEZ-LORENZO, J. Avian mortality due to power lines in the Canary Islands with special reference to the steppe-land birds. *Journal of*

Natural History, [S.I.], v. 45, p. 2159–2169, 2011. Available at: <https://doi.org/10.1080/00222933.2011.589916>. Accessed on: 20 jan. 2025.

GARCÍA, G.; RIECHERT, J.; FAVERO, M.; BECKER, P. Stealing food from conspecifics: spatial behavior of kleptoparasitic Common Terns (*Sterna hirundo*) within the colony site. *Journal of Ornithology*, 2014. Available at: <https://doi.org/10.1007/s10336-014-1066-4>. Accessed on: 24 jun. 2024.

GARTHE, S.; MARKONES, N.; CORMAN, A. M. Possible impacts of offshore wind farms on seabirds: a pilot study in Northern Gannets in the southern North Sea. *Journal of Ornithology*, v. 158, n. 1, p. 345–349, 2017. <https://doi.org/10.1007/s10336-016-1402-y>

GERACI, J. R.; LOUNSBURY, V. J. Marine Mammals Ashore: A Field Guide for Strandings. Galveston, Texas: Texas A&M Sea Grant Publication, 1993. 372 p.

GODINO, A.; GARRIDO, J. A.; EL KHAMLI, R.; BURAN, D.; MACHADO, C.; AMEZIAN, M.; IRIZI, A.; NUMA, C.; BARRIOS, V. Identificación de mortalidade por electrocución de aves rapaces en el sudoeste del Marruecos. Málaga: UICN, 2016. 76 p.

GÓMEZ-CATASÚS, J.; CARRASCAL, L. M.; MORALEDA, V.; COLSA, J.; GARCÉS, F.; SCHUSTER, C. Factors affecting differential underestimates of bird collision fatalities at electric lines: a case study in the Canary Islands. *Ardeola*, v. 68, n. 1, p. 71–94, 2020. Available at: <https://doi.org/10.13157/arla.68.1.2021.ra5>. Accessed on: 20 jan. 2025.

GRECIAN, W. K.; WITT, M. J.; ATTRILL, M. J.; BEARSHOP, S. Seabird diversity hotspot linked to ocean productivity in the Canary Current Large Marine Ecosystem. *Biology Letters*, [S.I.], v. 12, p. 20160024, 2016.

GROSE, Alexandre; FINK, Daniela; CREMER, Marta. Revisão bibliométrica de estudos da avifauna no Ecossistema Babitonga, Santa Catarina, Brasil. *Revista CEPSUL - Biodiversidade e Conservação Marinha*, v. 8, p. 1, 2019. Available at: <https://doi.org/10.37002/revistacepsul.vol8.676eb2019005>. Accessed on: 24 jun. 2025.

HAMER, K. C.; SCHREIBER, E. A.; BURGER, J. Breeding biology, life histories, and life history–environment interactions. In: SCHREIBER, E. A.; BURGER, J. (eds.). *Biology of marine birds*. New York: CRC Press, 2002. p. 217–261.

HARNESS, R. E. Effectively retrofitting power lines to reduce raptor mortality. In: CARLTON, R. G. (ed.). *Avian interactions with utility and communication structures: proceedings of a workshop in Charleston, SC, December 2–3, 1999*. [S.l.]: [s.n.], 2001a. p. 29–45.

HARRINGTON, B. A.; ANTAS, P. T. Z.; SILVA, F. Observation of Common Terns in Southern Brazil, 29 April–03 May 1984. *Journal of Field Ornithology*, v. 57, p. 222–224, 1986a.

HARRINGTON, B. A.; ANTAS, P. T. Z.; SILVA, F. Northward shorebird migration on the Atlantic coast of southern Brazil. *Vida Silvestre Neotropical*, v. 1, n. 1, p. 45–54, 1986b.

HATCH, J.J. Arctic Tern (*Sterna paradisaea*); p. 01–40 In A. Poole and F. Gill (ed.). *The Birds of North America* (n. 707). Philadelphia: The Birds of North America Inc., 2002.

HAYS, H.; LIMA, P.; MONTEIRO, L.; DICOSTANZO, J.; CORMONS, G.; NISBET, I. C. T.; SALIVA, J. E.; SPENDELOW, J. A.; BURGER, J.; PIERCE, J.; GOCHFELD, M. A nonbreeding concentration of Roseate and Common Terns in Bahia, Brazil. *Journal of Field Ornithology*, v. 70, n. 4, p. 455–464, 1999.

HENDERSON, I. G.; LANGSTON, R. H. W.; CLARK, N. A. The response of common terns (*Sterna hirundo*) to power lines: an assessment of risk in relation to breeding commitment, age and wind speed. *Biological Conservation*, v. 77, p. 185–192, 1996. Accessed on: [https://doi.org/10.1016/0006-3207\(95\)00144-1](https://doi.org/10.1016/0006-3207(95)00144-1). Available at: 20 fev. 2025.

INSTITUTO CHICO MENDES DE CONSERVAÇÃO DA BIODIVERSIDADE (ICMBIO); MINISTÉRIO DO MEIO AMBIENTE (MMA). *Livro Vermelho da Fauna Brasileira Ameaçada de Extinção*. 1. ed. Brasília: ICMBio/MMA, 2018a. v. 3. E-book.

INSTITUTO CHICO MENDES DE CONSERVAÇÃO DA BIODIVERSIDADE (ICMBIO); MINISTÉRIO DO MEIO AMBIENTE (MMA). *Livro Vermelho da Fauna Brasileira Ameaçada de Extinção*. 1. ed. Brasília: ICMBio/MMA, 2018b. v. 3. E-book.

JANSS, G. Avian mortality from power lines: a morphologic approach of a species-specific mortality. *Biological Conservation*, v. 95, p. 353–359, 2000.

JENKINS, A.; SMALLIE, J.; DIAMOND, M. Avian collisions with power lines: a global review of causes and mitigation with a South African perspective. *Bird Conservation International*, v. 20, p. 263–278, 2010. Available at: <https://doi.org/10.1017/S0959270910000122>. Accessed on: 24 jun. 2024.

JENKINS, A. R.; SHAW, J. M.; SMALLIE, J. J.; GIBBONS, B.; VISAGIE, R.; RYAN, P. G. Estimating the impacts of power line collisions on Ludwig's Bustards (*Neotis ludwigii*). *Bird Conservation International*, v. 21, p. 303–310, 2011. Available at: <https://doi.org/10.1017/S0959270911000128>. Accessed on: 23 mar. 2024.

KENN KAUFMAN, H. G. S. GUIA de Campo Kaufman a las aves de Norte-america: A las aves norteamericanas. *Publicado por HMCo Field Guides*, 2005; pág 88. ISBN 0-618-57424-7

KETTRUP, A.; MARTH, P. Specimen banking as environmental surveillance tool. In: SCHÜÜRMAN, G.; MARKERT, B. (eds.). *Ecotoxicology - ecological fundamentals, chemical exposure and biological effects*. New York: John Wiley & Sons, 1998.

KOLESNIKOVAS, C. K. M. et al. Reabilitação de Procellariiformes (albatrozes, petréis, pardelas). In: HURTADO, R.; SAVIOLLI, J. Y.; VANSTREELS, R. E. T. (eds.). Santos, SP: Editora Comunnicar, 2020. 5 MB. ISBN 978-85-8136-138-3.

LIMA, P. C. *Sterna dougallii* Montagu, 1813. In: INSTITUTO CHICO MENDES DE CONSERVAÇÃO DA BIODIVERSIDADE (Org.). *Livro Vermelho da Fauna Brasileira Ameaçada de Extinção: Volume III - Aves*. Brasília: ICMBio, 2018. p. 158–160.

LIMA, P. C.; GRANTS AU, R.; LIMA, R. C. F. R. Occurrence and mortality of seabirds along the Northern coast of Bahia, and the identification key to the Procellariiformes order and the Stercorariidae family. *Atualidades Ornitológicas On-line*, p. 63, 2004a.

LIMA, P. C.; HAYS, H.; LIMA, R. F. C. R.; CORMONS, T.; CORMONS, G.; DICOSTANZO, J.; SANTOS, S. S. Recuperações de *Sterna dougallii* (Montagu, 1813) na Bahia, Brasil, entre 1995 e 2004. *Ararajuba*, v. 12, n. 2, p. 147–149, 2004b. Available at: <https://www.academia.edu/download/31211378/ara122not5.pdf>.

Accessed on: 30 ago. 2022.

LOSS, S. R.; WILL, T.; MARRA, P. P. Refining estimates of bird collision and electrocution mortality at power lines in the United States. *PLoS ONE*, v. 9, n. 7, e101565, 2014.

LOSS, S. R.; WILL, T.; MARRA, P. P. Direct mortality of birds from anthropogenic causes. *Annual Review of Ecology, Evolution, and Systematics*, v. 46, p. 99–120, 2015.

LYNE, K.; GASSNER, I.; BOLGER, R.; KELLY, T. C. Is there a bird strike syndrome? Preliminary results from autopsy findings. *International Bird Strike Committee*, Stara Lesna, Slovakia, p. 14–18, 1998.

MACEDO MESTRE, L. A. Análise das recuperações no Brasil de aves anilhadas no exterior entre 1927 e 2006. [S.l.], 2010.

MAIA, C. E. P. Predição do tamanho corpóreo em tartarugas-verdes (*Chelonia mydas*, Linnaeus 1758) do nordeste brasileiro utilizando medidas do úmero. 2016.

MARCELINO, J.; MOREIRA, F.; FRANCO, A. M. A.; SORIANO-REDONDO, A.; ACÁCIO, M.; GAULD, J.; CASTRO REGO, F.; SILVA, J. P.; CATRY, I. Flight altitudes of a soaring bird suggest landfill sites as power line collision hotspots. *Journal of Environmental Management*, v. 294, p. 113149, 2021. ISSN 0301-4797. Available at: <https://doi.org/10.1016/j.jenvman.2021.113149>. Accessed on: 20 jun. 2025.

MARIANI, D. B. Causas de encalhes de aves marinhas no nordeste do Brasil. Dissertação (Mestrado) — Universidade Federal Rural de Pernambuco, Recife, PE, Brasil, 2016.

MARTIN, G. R. Understanding bird collisions with man-made objects: a sensory ecology approach. *Ibis*, v. 153, p. 239–254, 2011.

MESTRE, L. A. M. Registros das migrações de trinta-réis-boreal *Sterna hirundo*: análise das recuperações de indivíduos marcados na América do Norte (1928-2005) e Brasil (1983-2005). *Ornithologia*. [S.l.: s.n.], 2007.

MURPHY, R. K.; DWYER, J. F.; MOJICA, E. K.; MCPHERRON, M. M.; HARNESS, R. E. Reactions of Sandhill Cranes approaching a marked transmission power line. *Journal of Fish and Wildlife Management*, v. 7, n. 2, p. 480–489, 2016. Available at: <https://doi.org/10.3996/052016-JFWM-037>. Accessed on: 24 jan. 2025.

NACINOVIC, B. Aves marinhas na Bacia de Campos. 2005.

NASCIMENTO, G. D.; PEREIRA, A.; BRITO, G. R.; KOLESNIKOVAS, C. K.; SERAFINI, P. P. Prevalência e tipos de plásticos em albatrozes e petréis (Aves: Procellariiformes): recorte espacial da costa Sudeste e Sul do Brasil, de 2015 a 2019. *Biodiversidade Brasileira*, v. 12, n. 1, p. 15–24, 2022. DOI: 10.37002/biobrasil.v12i1.1855.

NASCIMENTO, J. L. X.; SANTOS, P. J. P. Preparação pré-migratória de *Sterna hirundo* (Charadriiformes, Sternidae) no Parque Nacional da Lagoa do Peixe, Rio Grande do Sul. *Revista Brasileira de Ornithologia*, v. 18, n. 4, p. 307–314, 2010. Available at: <http://www.revbrasilornitol.com.br/BJO/article/view/4103>. Accessed on: 23 jul. 2024.

NEOENERGIA. Energia eólica: ventos do Nordeste. 2018. Available at: <https://institucional.neoenergia.com/pt-br/te-interessa/meio-ambiente/Paginas/energia-eolica-ventos-do-nordeste.aspx>. Accessed on: 10 mar. 2025.

NEWMARK, W. D.; STANLEY, T. R. Habitat fragmentation reduces nest survival in an Afrotropical bird community in a biodiversity hotspot. *Proceedings of the National Academy of Sciences*, v. 108, p. 11488–11493, 2011.

NISBET, I. C. T. Status and biology of the northeastern population of the Roseate Tern *Sterna dougallii*: a literature survey and update: 1981–1989. Newton Corner, Massachusetts: U.S. Fish and Wildlife Service, 1989. E-book. Available at: <https://books.google.com.br/books?hl=pt-BR&lr=&id=K7VPAAAAYAAJ&oi=fnd&pg=P13&dq=Biology+AND+Ecology+%22Sterna+dougallii%22&ots=99eEWCb534&sig=>

[J1z3IYSzFVPMGuCMRNdnRUQWG0#v=onepage&q=Biology%20AND%20Ecology%20%22Sterna%20dougallii%22&f=false](https://doi.org/10.1111/cobi.12758). Accessed on: 30 jun. 2024.

NICOLAS BECH; SOPHIE BELTRAN; JÉRÔME BOISSIER; JEAN-FRANÇOIS ALLIENNE; J. RESSEGUIER, et al. Bird mortality related to collisions with ski-lift cables: do we estimate just the tip of the iceberg? *Animal Biodiversity and Conservation*, v. 35, n. 1, p. 95–98, 2012.

OLROG, C. C. Nueva lista de la avifauna argentina. *Opera Lilloana*, v. 27, p. 1–324, 1979.

ØSTERGAARD, P. A.; DUIC, N.; NOOROLLAHI, Y.; KALOGIROU, S. Advances in renewable energy for sustainable development. *Renewable Energy*, v. 219, pt. 1, p. 119377, 2023. ISSN 0960-1481. Available at: <https://doi.org/10.1016/j.renene.2023.119377>. Accessed on: 20 jan. 2025.

ORLOFF, S.; FLANNERY, A. Wind turbines effects on avian activity, habitat use, and mortality in Altamont Pass and Solano County Wind Resource Areas 1989–1991 – Final Report. California: Biosystems Analysis, Inc.; California Energy Commission, 1992.

PACHECO, J. F.; SILVEIRA, L. F.; ALEIXO, A.; AGNE, C. E.; BENCKE, G. A.; BRAVO, G. A.; BRITO, G. R. R. Lista comentada das aves do Brasil pelo Comitê Brasileiro de Registros Ornitológicos – segunda edição. *Ornithology Research*, v. 29, n. 2, 2021.

PALACÍN, C.; ALONSO, J. C.; MARTÍN, C. A.; ALONSO, J. A. Changes in bird-migration patterns associated with human-induced mortality. *Conservation Biology*, v. 31, n. 1, p. 106–115, 2017. Available at: <http://doi.wiley.com/10.1111/cobi.12758>. Accessed on: 4 jul. 2023.

PELANDA, A. A. Impactos humanos sobre aves associadas a ecossistemas marinhos na costa paranaense. 2007. 39 f. Dissertação (Graduação) — Universidade Federal do Paraná, Pontal do Paraná.

PETROSOLGAS. Quais estados brasileiros produzem mais energia eólica e solar? Disponível em: <https://petrosolgas.com.br/estados-energia-eolica/>. Acesso em: 10 mar. 2023.

PIERMATTEI, D. L.; FLO, G. L. Manual de ortopedia e tratamento das fraturas de pequenos animais. 3. ed. São Paulo: Manole, 1999.

PONCE, C.; ALONSO, J. C.; ARGANDOÑA, G.; GARCÍA FERNÁNDEZ, A.; CARRASCO, M. Carcass removal by scavengers and search accuracy affect bird mortality estimates at power lines. *Animal Conservation*, v. 13, p. 603–612, 2010. Available at: <https://doi.org/10.1111/j.1469-1795.2010.00387.x>. Accessed on: 24 jun. 2024.

RAAB, Rainer et al. Underground cabling and marking of power lines: Conservation measures rapidly reduced mortality of West-Pannonian Great Bustards *Otis tarda*. *Bird Conservation International*, [s. l.], v. 22, n. 3, p. 299–306, 2012. Available at: <https://www.cambridge.org/core/journals/bird-conservation-international/article/under-groundcabling-and-marking-of-power-lines-conservation-measures-rapidly-reduced-mortality-ofwestpannonian-great-bustards-otis-tarda/8174B827D0B8A037D20641D798529E99>. Accessed on: 22 Ago. 2023.

RANGEL, Danilo; ZALMON, Ilana. Composition and abundance of coastal seabirds, Arraial do Cabo, RJ, southeastern Brazil, 2020.

REBOLO-IFRÁN, N.; PLAZA, P.; PÉREZ-GARCÍA, J. M.; GAMARRA-TOLEDO, V.; SANTANDER, F.; LAMBERTUCCI, S. A. Impacts of power lines on birds: an overview of electrocution and collision events. *Perspectives in Ecology and Conservation*, [S.l.], v. 21, n. 1, p. 71–84, 2023. Available on: <https://doi.org/10.1016/j.pecon.2022.10.005>. Accessed on: 24 jun. 2024.

REVORÊDO, R. A. Colisão de aves marinhas migratórias em linha de energia no nordeste brasileiro: avaliação espaço-temporal e descrição da histologia gonadal com fins de conservação. 2021. 70 f. Dissertação (Mestrado em Biologia Estrutural e Funcional) – Universidade Federal do Rio Grande do Norte, Natal, 2021.

CEMAVE/ICMBio. Relatório anual de rotas e áreas de concentração de aves migratórias no Brasil. Cabedelo, PB: CEMAVE/ICMBio, 2014.

RIOUX, S.; SAVARD, J. P. L.; GRICK, A. A. Avian mortalities due to transmission line collisions: a review of current estimates and field methods with an emphasis on applications to the Canadian electric network. *Avian Conservation and Ecology*, [S.l.], v. 8, n. 2, p. 1–18, 2013.

ROCHA, O. C. A. Flutuações populacionais de *Sterna dougallii* Montagu, 1813 (Aves: Charadriiformes) por meio do olhar de pescadores artesanais de Paracuru (Estado do Ceará). 2021. 72 f. Trabalho de Conclusão de Curso – Universidade Federal do Ceará, Fortaleza, 2021.

RUPLEY, A. E. *Manual de clínica aviária*. São Paulo: Roca, 1999. p. 213-242, 283-332, 431-458.

SALVAGNI, T. Metais não essenciais em tecidos de *Puffinus puffinus* e *P. gravis* (Aves Procellariiformes) no litoral norte e médio leste do Rio Grande do Sul, Brasil. 2013. 69 f. Dissertação (Graduação em Biologia Marinha e Costeira) – Universidade Federal do Rio Grande do Sul, Imbé, 2013.

SANTOS, L. P. Resíduos sólidos (lixo) na praia do Balneário de Pontal do Sul, Pontal do Paraná, Paraná - BR: composição e origem. 2006. 58 f. Dissertação (Graduação em Oceanografia) – Universidade Federal do Paraná, Pontal do Paraná, 2006.

SAVERENO, A.; SAVERENO, L.; BOETTCHER, R.; HAIG, S. Avian behavior and mortality at power lines in coastal South Carolina. *Wildlife Society Bulletin*, v. 24, p. 636–648, 1996.

SCALES, K. L.; MILLER, P. I.; HAWKES, L. A.; INGRAM, S. N.; SIMS, D. W.; VOTIER, S. C. On the front line: frontal zones as priority at-sea conservation areas for mobile marine vertebrates. *Journal of Applied Ecology*, [S.l.], v. 51, p. 1575–1583, 2014.

SCHAUB, M.; AEBISCHER, A.; GIMENEZ, O.; BERGER, S.; ARLETTAZ, R. Massive immigration balances high anthropogenic mortality in a stable eagle owl

population: lessons for conservation. *Biological Conservation*, Montpellier, v. 143, n. 8, p. 1911–1918, 2010.

SCHAUB, M.; PRADEL, R. Assessing the relative importance of different sources of mortality from recoveries of marked animals. *Ecology*, v. 85, p. 930–938, 2004. DOI: 10.1890/03-0012.

SCHIEFLER, A. F.; SOARES, M. Estudo comparativo da avifauna das praias de Navegantes e Laguna, Santa Catarina. *Biotemas*, v. 7, n. 1/2, p. 31–45, 1994.

SCHREIBER, E. A.; BURGER, J. (Eds.) *Biology of Marine Birds*. Boca Raton: CRC Press, 2002. 722 p.

SERAFINI, P. P.; LUGARINI, C. Procellariiformes e outras aves de ambientes marinhos (albatroz, petrel, fragata, atobá, biguá e gaivota). In: CUBAS, P. H.; SILVA, J. C. R.; CATÃO-DIAS, J. L. *Tratado de animais selvagens*. 2. ed. São Paulo: Roca, 2014. v. 1, p. 418-439.

SOMENZARI, M. et al. An overview of migratory birds in Brazil. *Papéis Avulsos de Zoologia*, [S.l.], v. 58, 2018. Available at: <http://doi.org/10.11606/1807-0205/2018.58.03>. Accessed on: 3 mai. 2023.

SHAW, J. M.; JENKINS, A. R.; SMALLIE, J. J.; RYAN, P. G. Modelling power-line collision risk for the Blue Crane *Anthropoides paradiseus* in South Africa. *Ibis*, [S.l.], v. 152, n. 3, p. 590–599, 2010. Available at: <https://doi.org/10.1111/j.1474-919X.2010.01040.x>. Accessed on: 24 jun. 2025.

SHAW, J. M. et al. A large-scale experiment demonstrates that line marking reduces power line collision mortality for large terrestrial birds, but not bustards, in the Karoo, South Africa. *Ornithological Applications*, [S.l.], v. 123, p. duaa067, 2021. Available at: <https://doi.org/10.1093/ornithapp/duaa067>. Accessed on: 20 jun. 2025.

SHEEHY, S.; KELLY, T. C.; FENNESSY, G.; O'CALLAGHAN, M. J. A.; BOLGER, R. Bird strike syndrome: towards developing an index of bird injury. Athens: International Bird Strike Committee, 2005.

SIBLEY, C. G.; AHLQUIST, J. E.; MONROE, B. L. A. Classification of the Living Birds of the World Based on Dna-Dna Hybridization Studies. *The Auk*, [S.I.], v. 105, n. 3, p. 409–423, 1988. Available at: <https://academic.oup.com/auk/article/105/3/409/5193128>. Accessed on: 10 jul. 2023.

SICK, H. *Ornitologia Brasileira*. Rio de Janeiro: Nova Fronteira, 1997. 862 p.

SICK, H. *Ornitologia Brasileira*. 3. ed. Rio de Janeiro: Nova Fronteira, 2001. p. 331–338.

SILVA, L. T. R.; SILVA, J. S. A.; REGUEIRA, R. F. S.; ROLIM, V. P. M.; BARROS, M. R.; OLIVEIRA, A. A. F. Aspecto médico veterinário legal das lesões em aves silvestres promovidas por colisões com aeronaves. *Arquivo Brasileiro de Medicina Veterinária e Zootecnia*, v. 70, n. 1, p. 321–326, 2018. Available at: <https://doi.org/10.1590/1678-4162-9513>. Accessed on: 2 fev. 2023.

SILVERMAN, S. Técnica radiográfica para aves. In: TICER, J. W. *Técnicas radiológicas na prática veterinária*. 2. ed. São Paulo: Roca, 1987. p. 412-420.

SMITH, B. J.; SMITH, S. A. Radiology. In: ALTMAN, R. B.; CLUBB, S. L.; DORRESTEIN, G. M.; QUESENBERRY, K. *Avian medicine and surgery*. Philadelphia: W. B. Saunders Company, 1997. p. 170-199.

SOCIEDADE PARA A CONSERVAÇÃO DAS AVES DO BRASIL – SAVEBrasil. Aves Limícolas | SAVEBrasil, 2022. Available at: <https://www.savebrasil.org.br/aves-limicolas>. Accessed on: 30 ago. 2023.

STANTON, N. et al. A geophysical view of the Southeastern Brazilian margin at Santos Basin: insights into rifting evolution. *Journal of South American Earth Sciences*, [S.I.], v. 55, p. 141–154, 1 nov. 2014.

STEHN, T. V.; WASSENICH, T. Whooping Crane collisions with power lines: an issue paper. In: FOLK, M. J.; NESBITT, S. A. (eds.) *Proceedings of the 10th North American Crane Workshop*. [S.I.], 2008. p. 25–36.

SUNDAR, K. S. G.; CHOUDHURY, B. C. Mortality of sarus cranes (*Grus antigone*) due to electricity wires in Uttar Pradesh, India. *Environmental Conservation*, v. 32, n. 3, p. 260–269, 2005. DOI: 10.1017/S0376892905002341.

TAVARES, Davi Castro; MOURA, Jailson Fulgencio de; SICILIANO, Salvatore. First documented record of the Roseate Tern *Sterna dougallii* Montagu, 1813 (Aves: Sternidae) in southeast Brazil. *Check List*, v. 9, n. 4, p. 806-808, 2013. Available at: <https://checklist.pensoft.net/article/18728/>. Accessed on: 17 fev. 2025.

TEIXEIRA, G. D. Distribuição espaço-temporal e possível influência do vento no registro de aves marinhas do gênero *Sterna* e *Thalasseus* resgatadas na praia de Galinhos/RN. 2022. 32 f. Trabalho de Conclusão de Curso (Bacharel em Ciências Biológicas) – Universidade Federal do Rio Grande do Norte, Natal, 2022.

TINÔCO, L.; CALDERAN, A.; APPEL, S. C.; VICENTE, E.; GUEDES, N. M. R. Mortalidade das grandes araras por eletrocussão em área urbana, Campo Grande, Mato Grosso do Sul. *Ambiente & Sociedade*, v. 25, 2022. Available at: <http://dx.doi.org/10.1590/1809-4422asoc20200018r2vu2022L1AO>. Accessed on: 24 jun. 2025.

TOSTES, E. C. L. Bioacumulação de elementos traço em *Chelonia mydas* (Linnaeus, 1758) encalhadas no litoral sudeste do Brasil. 2019. Dissertação (Mestrado em Ecologia e Recursos Naturais) – Universidade Estadual do Norte Fluminense Darcy Ribeiro, Campo dos Goytacazes, 2019. Available at: <https://uenf.br/posgraduacao/ecologia-recursosnaturais/wp-content/uploads/sites/7/2019/10/Disserta%C3%A7%C3%A3o-2019-Elo%C3%A1-C-L-Tostes.pdf>. Accessed on: 5 mar. 2024.

TRAVERS, M. Reducing collisions with structures. In: YOUNG, Lindsay; VANDERWERF, Eric (Eds.). *Conservation of Marine Birds*. [S.l.]: Elsevier, 2023. Cap. 14, p. 379–401. <https://doi.org/10.1016/B978-0-323-88539-3.00004-2>.

TRAVERS, M. S. et al. Post-collision impacts, crippling bias, and environmental bias in a study of Newell's Shearwater and Hawaiian Petrel powerline collisions. *Avian Conservation and Ecology*, v. 16, n. 1, p. 15, 2021.

U.S. FISH AND WILDLIFE SERVICE (U.S.F.W.S). Roseate Tern. In: *SOUTH FLORIDA MULTI-SPECIES RECOVERY PLAN*. Atlanta, Georgia: Elsevier, 1999. p. 4-(429-444).

UNIVERSIDADE DO ESTADO DO RIO GRANDE DO NORTE – LABORATÓRIO DE MONITORAMENTO DE BIOTA MARINHA PROJETO CETÁCEOS DA COSTA BRANCA (PCCB-UERN) E CENTRO DE ESTUDOS E MONITORAMENTO AMBIENTAL (CEMAM). Nota técnica conjunta PCCBUERN/CEMAM No 01/20. Natal, 13 maio 2020.

VALENTE, R. M.; SILVA, J. M. C.; STRAUBE, F. C.; NASCIMENTO, J. L. X. (Orgs.). *Conservação de Aves Migratórias Neárticas no Brasil*. Belém: Conservação Internacional, 2011. 1. ed. p. 141-145. Available at: https://ppbio.inpa.gov.br/sites/default/files/Livro_Aves_migratorias_nearticas_no_brasil_Conservation_International.pdf. Accessed on: 03 mar. 2023.

VALENTIN, J. L. The Cabo Frio Upwelling System, Brazil. In: *Ecological Studies: Coastal Marine Ecosystems of Latin America*. Berlin Heidelberg: Springer-Verlag, 2001. p. 97–105.

VAN ROOYEN, C.; DIAMOND, M. Wildlife – power line interaction management. *Indwa*, [S.l.], v. 6, p. 7–16, 2008.

VERBEKE, G.; DUBOS, J.; POIRION, J. Étude du risque de collision de l'avifaune nocturne avec les infrastructures câblées. [S.l.], 2020.