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Research article

Do economic activities in the Barra do Rio Mamanguape Environmental Protection Area impact snake communities?

¿Las actividades económicas realizadas en el Área de Protección Ambiental Barra do Rio Mamanguape impactan en la comunidad de serpientes?

Vanesa do Nascimento Barbosa[1], Jéssica Monique da Silva Amaral[2], Adrian Antonio Garda[3], Frederico Gustavo Rodrigues França[2]

[1] Universidade Federal da Paraíba, Campus I Lot. Cidade Universitaria, João Pessoa, Brazil, nascimentob.vn@gmail.com
[2] Universidade Federal da Paraíba, Av. Santa Elisabete, s/n, Centro, Rio Tinto, Brazil, jessica_monique.amaral@hotmail.com, frederico.franca@academico.ufpb.br
[3] Universidade Federal do Rio Grande do Norte, Campus Universitário Lagoa Nova, Natal, Brazil, pseudis@gmail.com
[*] *For correspondence: nascimentob.vn@gmail.com*

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ABSTRACT

Brazil ranks among the top three countries worldwide in reptile diversity, boasting more than 435 species of snakes. Snakes play a pivotal ecological role in maintaining ecosystem balance and offer potential for the bioprospecting of venom peptides for pharmaceutical applications. Despite their ecological significance, snakes continue to face indiscriminate killing, often due to widespread lack of knowledge about these animals. Consequently, protected areas assume paramount importance in snake conservation efforts, safeguarding both their populations and their habitats. Access restrictions coupled with enhanced fauna and flora protection measures within these areas mitigate adverse interactions between humans and snakes. This study aims to assess the impact of economic activities within the Environmental Protection Area of Barra do Rio Mamanguape, in northeast Brazil, on the snake community. Data documenting roadkill incidents indicate a potential rise in snake-vehicle collisions attributed to increased tourist traffic within the protected area. Additionally, events of snakes preying on domestic animals, such as chickens or small cats, heighten the risk of retaliatory killings by residents attempting to protect their pets. Thus, proactive environmental education initiatives are imperative to foster awareness among both visitors and residents regarding the vital role of snakes within the local ecosystem and the importance of their conservation.

Keywords: biodiversity conservation, environmental impact, Human-wildlife conflicto, protected areas, reptile ecology.

RESUMEN

Brasil se encuentra entre los tres países con mayor diversidad de reptiles del mundo, con más de 435 especies de serpientes. Estas desempeñan un papel ecológico fundamental en el mantenimiento del equilibrio del ecosistema y ofrecen potencial para la bioprospección de péptidos de su veneno para aplicaciones farmacéuticas. A pesar de su importancia ecológica, las serpientes siguen enfrentándose a una muerte indiscriminada, a menudo debido a la falta de conocimiento sobre esta especie. En consecuencia, las áreas protegidas adquieren una importancia primordial en los esfuerzos de conservación de las serpientes, salvaguardando sus poblaciones y hábitats. Restricciones de acceso y medidas mejoradas de protección de la fauna y la flora dentro de estas áreas mitigan las interacciones adversas entre los seres humanos y las serpientes. Este estudio tuvo como objetivo evaluar el impacto de las actividades económicas dentro del Área de Protección Ambiental Barra do Rio Mamanguape (Brasil) sobre la comunidad de serpientes. Los datos que documentan los incidentes de atropellos indican un posible aumento de las colisiones entre vehículos y serpientes atribuidas al aumento del tráfico turístico dentro del área protegida. Además, los casos de serpientes que atacan a

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animales domésticos, como pollos o gatos pequeños, aumentan el riesgo de muertes en represalia por parte de los residentes que intentan proteger a sus mascotas. Las iniciativas proactivas de educación ambiental son urgentes para fomentar la conciencia entre los visitantes y los residentes sobre el papel vital de las serpientes dentro del ecosistema local y la importancia de su conservación.

Palabras clave: áreas protegidas, conflicto entre humanos y fauna silvestre, conservación de la biodiversidad, ecología de reptiles, impacto ambiental.

INTRODUCTION

Brazil ranks as the third country globally in terms of reptile diversity, and currently, hosts more than 435 snake species (Guedes *et al.,* 2023). Snakes play a critical role in ecosystem dynamics and are key species in trophic structures of ecological communities, they can be bioindicators of environmental quality and hold significant medical and economic importance in the pharmaceutical industry (Melgarejo, 2013; Bernarde, 2014; Hoang *et al.,* 2021). However, habitat fragmentation and urbanization have led to snake population declines (Fernandes-Ferreira *et al.,* 2012). Encumbered by pervasive legends and entrenched popular beliefs passed through generations, snakes evoke a spectrum of human emotions, ranging from admiration to aversion (Alves *et al.,* 2010; Fraga *et al.,* 2013). However, these emotions tend to be negative, with snakes being the most feared animal among zoophobias, where ophidiophobia can occur without requiring any traumatic experience (Polák *et al.,* 2016). In addition, insufficient information and limited access to environmental education perpetuates the indiscriminate killing of snakes (Fernandes-Ferreira *et al.,* 2012; Fraga *et al.,* 2013; Barbosa *et al.,* 2020a). The accident risks with venomous species fuel the conflict, as people perceive all snakes as potential threats to human life in an encounter (Argôlo, 2004; Alves *et al.,* 2010). Therefore, environmental education plays a key role in demystifying the cultural bias surrounding these animals, including in informal environments (Rocha and Luna, 2019), and is a tool that can help in the conservation of snakes and other species (Junior, 2024).

Protected Areas (PA) remain pivotal in species conservation and habitat preservation efforts (Hassler, 2005). In Brazil, PAs encompass two main categories: Integral Protection (e.g., National, State, or Municipal Parks) aimed at conserving ecologically significant natural ecosystems, and Sustainable Use (e.g., Environmental Protection Areas – EPAs, Extractivist Reserves, National Forests) facilitating the sustainable utilization of natural resources while maintaining biodiversity, social equity, and economic viability (Hassler, 2005; Henry-Silva, 2005). Ecotourism, while often lauded for its contributions to human well-being and nature conservation, can also exert adverse environmental impacts (Swarbrooke, 2002; Souza and Martos, 2008). Factors such as improper waste disposal within PAs and the introduction or proliferation of exotic pets (e.g., domestic dogs and cats) directly threaten native fauna (Vilela and Lamim-Guedes, 2014; Seymour *et al.,* 2020). The presence of Felis catus is one of the main threats to wildlife within and around Conservation Units (Sampaio and Schmidt, 2013), even impacting snake species (Santos *et al.,* 2020; Assis *et al.,* 2023). Nevertheless, Sustainable Use PAs hold promise in fostering environmental, social, and economic sustainability in Brazil (Acosta *et al.,* 2018), and although they should not be considered the only or main form of reptile conservation, Conservation Units are vital for the conservation of species in the reptile group, including snakes (Marques *et al.,* 2010).

The Barra do Rio Mamanguape Environmental Protection Area is a Sustainable Use Protected Area of 14,640 ha in northeastern Brazil. The area is occupied by some human populations and its creation aimed to control land use, protect biodiversity, foster ecotourism, and ensure sustainable use of natural resources (ICMBio, 2014). The area harbors a considerable snake diversity, boasting 24 species across six families, representing 42 % of the species in Paraíba State. These snakes inhabit diverse habitats including restingas, mangroves, rainforests, and anthropized areas, thus rendering the area crucial for snake conservation efforts (Barbosa *et al.,* 2022). This study aims to catalog the economic activities within the Barra do Rio MEPA and assess their potential impacts on the snake community within the area.

MATERIALS AND METHODS

Study site

The Barra do Rio Mamanguape Environmental Protection Area (Fig. 1, hereafter MEPA) was established on September 10, 1993, along the northern coast of Paraíba state, within the Zona da Mata mesoregion (6°45' S and 34°56' W) in northeastern Brazil. Its primary objective is the conservation of the West Indian manatee, *Trichechus manatus* (Perazzo *et al.,* 2013; ICMBio, 2014). Encompassing an area of 14,460 ha, MEPA features a diverse Atlantic Forest vegetation comprising fragments of natural rainforest, mangrove, and coastal restinga, interspersed with sugarcane fields (ICMBio, 2014). The MEPA is bordered by the Atlantic Ocean, encompasses the municipalities of Rio Tinto, Marcação, Baía da Traição, and Lucena, and includes the estuaries of the Miriri, Mamanguape and Estivas rivers. (Perazzo *et al.,* 2013; Luna *et al.,* 2016). The region's climate is hot and humid (As type) according to the Köppen climate classification, with rainfall occurring predominantly between March and September, and an average annual temperature of 28 °C.

Annual precipitation ranges between 1,200 mm and 1,800 mm (Lima and Heckendorff, 1985).

Snakes community. Over a two-year period, we conducted an extensive snake inventory in the MEPA. Collections were carried out for seven consecutive days per month from May 2019 to August 2021, with interruptions between April and September 2020 due to the COVID-19 pandemic. Our efforts included both day and night searches using visual surveys and passive 20 pitfall trap grids each consisting of four 60-L buckets buried at ground level interconnected by 5m canvas guide fences (50 cm high). Additionally, we employed tracking techniques using ecdysis, records of animals found dead on roads and decumented chance encounters (Barbosa *et al.,* 2022).

Interaction of snakes with the human community

Through a literature review in March 2022, we compiled a list of economic activities conducted within the MEPA by searching three platforms: SciELO, Google Scholar, and Web of Science. We searched for articles using the following keywords in English and Portuguese (Barra de Mamanguape and pesca/fishing; Barra de Mamanguape and marisco/seafood; Barra de Mamanguape and caranguejo/crab; Barra de Mamanguape and camarão/shrimp). We used 16 publications: nine articles, five theses, one book chapter and one technical report. We excluded 11 manuscripts (n = 11) that dealt with ethnozoology based on local knowledge and other scientific research carried out in the study area using the searched keywords. We divided activities into three categories: tourism-related, subsistence, and mixed-use.

Field data collection was part of a larger project and included snake capture and monitoring techniques. For further details on the methodology, see Barbosa *et al*. (2022). For this study, we collected data on snakes found dead and assessed possible causes of death by observing environmental characteristics where the animal was found, such as tire tracks crossing the snake's body or blood-stained stones near the carcass, which may indicate predation. We considered some specimens in perfect condition (no external injuries) to have died of natural causes. Residents contacted us to report witnessed snake deaths, to report dead individuals, or to request rescue of live animals during the sampling months. However, when the team was not in the field, residents recorded snake species found in the MEPA area through videos or photos.

RESULTS

The snake assemblage within the Barra do Rio Mamanguape Environmental Protection Area (MEPA) encompasses 24 species covering six families (Barbosa *et al.,* 2022; Supplementary material). Among these, three species hold medical significance due to their venomous nature: the elapids *Micrurus bonita* (formerly *M. ibiboboca*), *M. potyguara* and the viperid *Bothrops leucurus*. However, our findings reveal low abundance for *M. potyguara* (n=1) and *B. leucurus* (n=2), with only *M. bonita* (n=14) being common in the area. Additionally, *Philodryas olfersii*, a colubridae species with opisthoglyphous dentition generally considered of low medical importance, nevertheless warrants attention because there are records of mild to severe snakebite (Barbosa *et al.,* 2020a). Five species are endemic to Brazil: *Amerotyphlops*

Table 1. Economic activities carried out in the Environmental Protection Area of Barra do Rio Mamanguape divided into categories.

Economic activities	References
Tourism-related	
Ecotourism	Barbosa *et* al., 2015; Cruz, 2015; Temoteo *et* al., 2018; Valencia, 2021; Personal observation
Handicrafts (vine, painting, shells, coconut, reed, stuffed animals, banana leaf, bamboo and wood)	Riul, 2015; Neto and Silva, 2017; Personal observation
Homestay accommodations	Personal observation
Construction of guesthouses	Personal observation
Subsistence-related	
Agriculture (banana, coconut, papaya, cassava, pineapple, broad beans, and sugarcane cultivation)	Rodrigues *et al*., 2007; Rodrigues *et al*., 2008; Personal observation
Artisanal fishing (fish)	Trindade, 2013; Silva, 2018; Personal observation
Shrimp farming	Rodrigues *et al*., 2007; Personal observation
Collection of crustaceans and mollusks (Shellfish, oysters and crabs)	Rodrigues *et al*., 2007; Ferreira, 2010; Rocha, 2010; Santos, 2021; Personal observation
Livestock	Rodrigues *et al*., 2007
Mixed character	
Trade	Personal observation
Transportation	Personal observation

paucisquamus, *Epicrates assisi*, *Dibernardia affinis*, *Micrurus bonita*, and *M. potyguara*. Terrestrial habits (including use of the ground) predominated in 14 species, followed by arboreal (four species), semi-arboreal (seven species), fossorial (two species), cryptozoic (four species), and semi-aquatic (one species). Furthermore, diurnal activity characterizes twelve species, while five are nocturnal, and four are active during both periods (see supplementary material).

The analysis of economic activities within the study area identified a total of eight distinct activities, which were classified into three main categories: those primarily associated with tourism (such as tourism services, handicrafts, homestay accommodations and the construction of guesthouses), those related to subsistence (including agriculture, artisanal fishing, shrimp farming and the collection of crustaceans and mollusks), and those of mixed character, which serve both local needs and tourism demands (e.g., trade and transportation) (Table 1). Moreover, ecotourism activities carried out by hiking, by car or by boat, contribute to the local economy, resulting in an increase in guesthouses and summer homes, consequently leading to habitat fragmentation in Barra de Mamanguape.

During subsistence activities, residents may encounter snakes sheltering or foraging in plantations, livestock farms, shrimp ponds, and even in the sandbanks near the river and sea (Fig. 2a). In tourism-related activities, these encounters can occur during trails, while traveling (walking or driving) between lodging and businesses, and along rivers and seashores. They may even occur inside tourist residences (Fig. 2b).

A total of 25 individuals of 11 species were found dead in the study area, representing 45.8 % of the species richness recorded in the MEPA. Of the 25 specimens, 18 were sighted by community residents and seven during field searches. Of these, three possibly died of natural causes. Some deaths were assisted by researchers or residents who helped with the transfer of the animals to the research team. A local resident handed over a live 'cobra-capim' (*Adelphostigma occipitalis*) that had been hit by a car; the snake was injured and later died. We witnessed a resident beat to death a Patagonia Green Racer, *Philodryas patagoniensis*, that was on his street. Some individuals presented severe injuries, such as a crushed head, lacerated body and organs protruding from the body cavity (Fig. 3). Some residents reported two Chicken Snake (*Spilotes pullatus*) and a Wagler's Snake

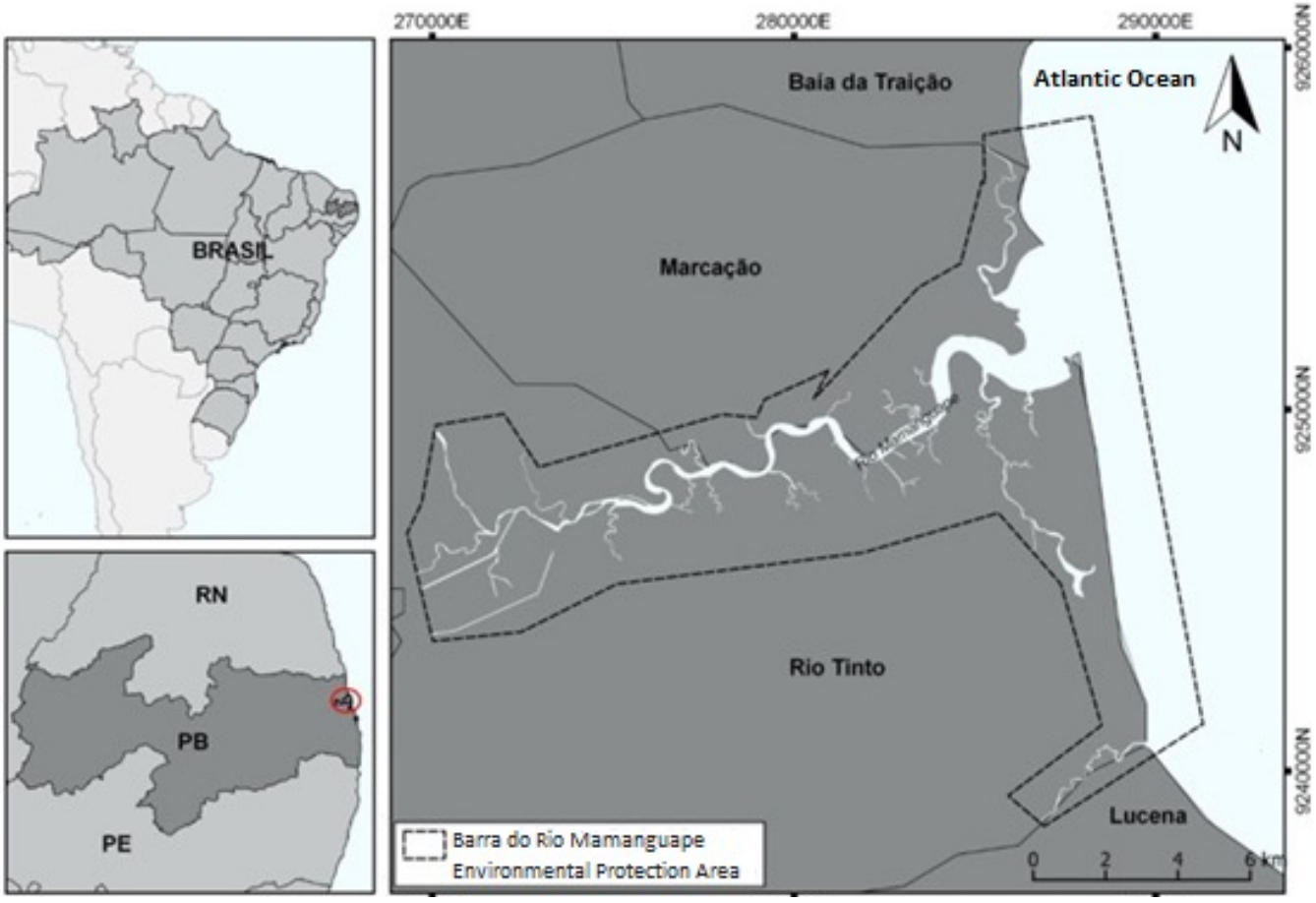

Figure 1. Map of Brazil with enlargement and focus on the State of Paraíba, highlighting Barra do Rio Mamanguape Environmental Protection Area - MEPA.

(*Xenodon merremii*) were killed by other community members for preying on chicks in plantations.

After learning about the research on MEPA snakes, many residents began avoiding killing the animals and instead reported sightings to the research team. In total, there were 33 reports from residents, including 28 supported by photos or videos and five involving live animal rescues.

DISCUSSION

Snake encounters can occurred during various economic activities in the MEPA region in all categories mentioned in (Table 1). Throughout the inventory period, found dead snakes throughout the study area, representing more than half of the species recorded in the MEPA. Most of these species were not venomous or medically significant. While these records aided in comprehensively assessing species richness (Barbosa *et al*., 2020b), they also underscore the ongoing conflict between humans and these animals. Our observations revealed deliberate killings and deaths from vehicle collisions on unpaved roads, as well as fatal encounters in agricultural fields and residential areas where snakes were sometimes crushed by sticks or stones. Additionally, accidental deaths resulting from activities such as fires and harvesting were noted. It was also necessary to highlight the possibility of natural death and that some run-overs may have been accidental. Three individuals were found deceased within crops after preying on chickens raised by locals from nearby residences (Fig. 2e-2f); others were found disemboweled near tire tracks on unpaved roads, indicating fatal collisions (Fig. 2a-2b). Additionally, we documented a burnt specimen of a common boa (*Boa constrictor*) due to an illegal fire (Fig. 2d). Fortuitous encounters human-animals encounters, occurred during leisure and work activities in protected regions such as the MEPA, had mostly negative impacts on native fauna (including herpetofauna), emphasizing the urgent need for rigorous environmental conservation measures (Webb and Shine, 2008; Tomas *et al*., 2021).

The deliberate killing of snakes by humans, often due to the aversion and fear they provoke, was largely influenced by prevalent myths and a lack of understanding within society (Alves *et al*., 2010; Fraga *et al*., 2013). These killings were extremely harmful to snake populations, causing population declines and even local extinction. Among the species found dead, eight were categorized as regionally threatened (França *et al*., 2024; see supplementary material), with the caninana *Spilotes pullatus*, the common boa *Boa constrictor*, and the vinesnake *Oxybelis aeneus* classified as vulnerable to extinction, and six species deemed near threatened (França *et al*., 2024). Moreover, limited appreciation of snakes' ecological roles exacerbated their persecution, despite their

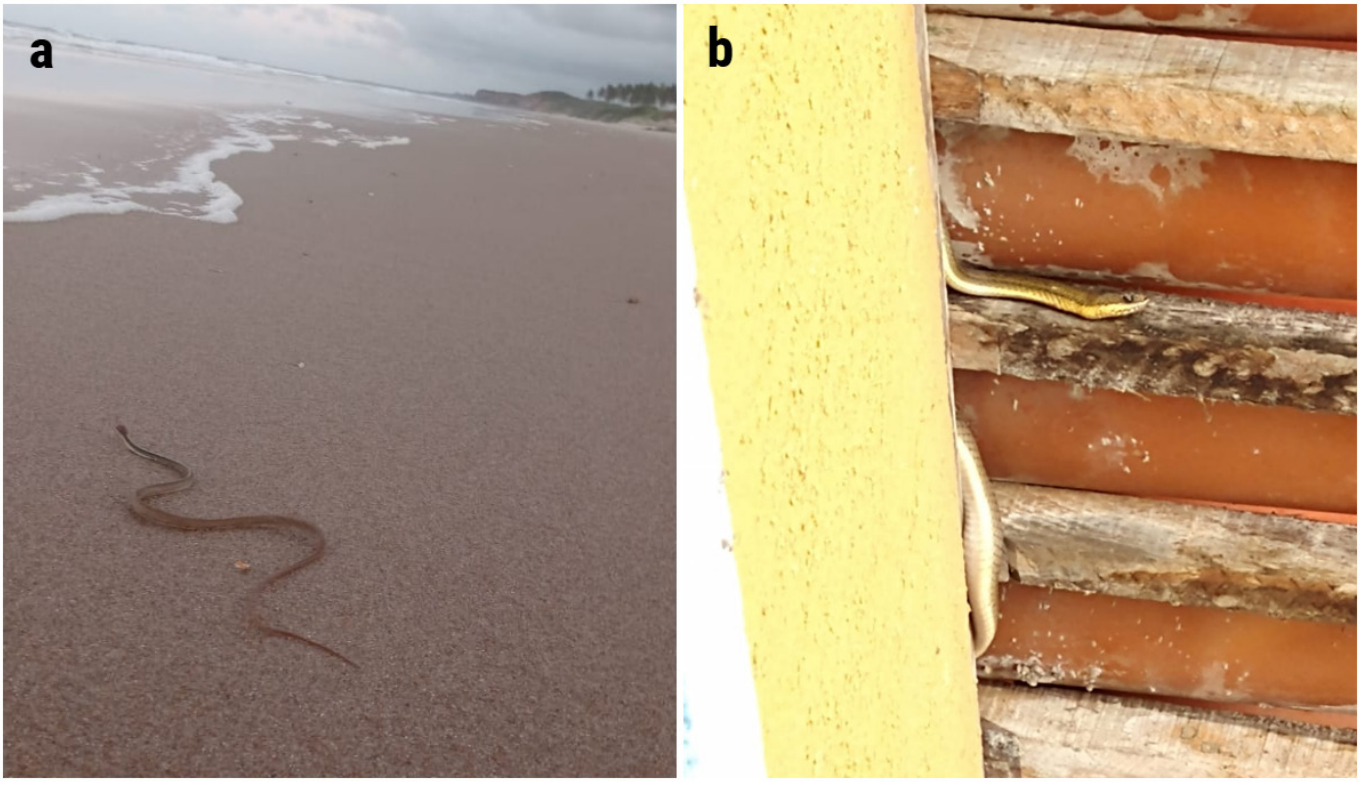

Figure 2. Example of snake specimens found in the Barra do Rio Mamanguape Environmental Preservation Area, highlighting the potential for human encounters with snakes anywhere within the MEPA. a) Adult *Chironius flavolineatus* recorded in a restinga area; b) *Philodryas nattereri* on the roof of a residence in the study area.

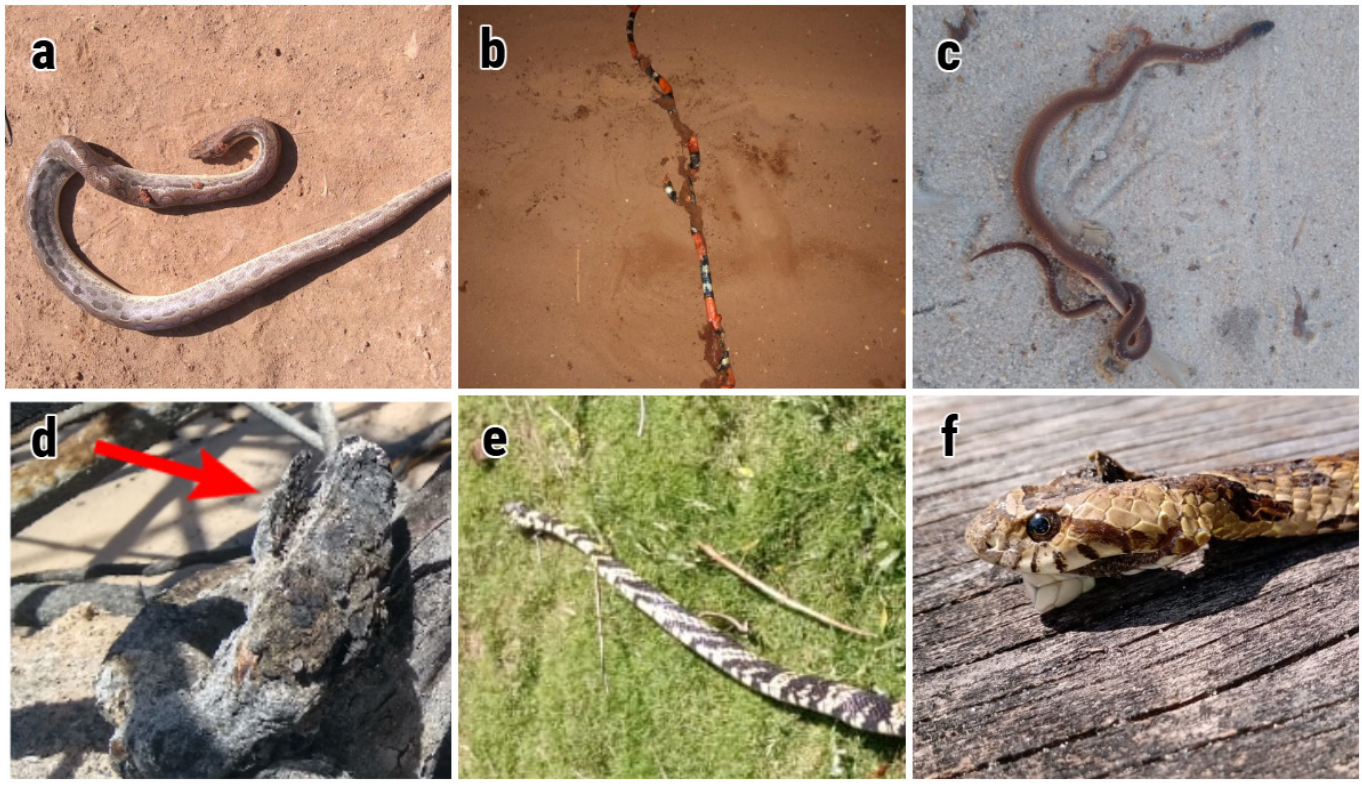

Figure 3. Records of snake species found dead in study area. a: rainbow boa *Epicrates assisi* – roadkill; b: coral snake (*Micrurus bonita)* - roadkill; c: (*Tantilla melanocephala)* – crushed by stick or stone; d: common boa (*Boa constrictor)* with the arrow indicating the head - burn; e: caninana (*Spilotes pullatus)* - crushed by stick or stone; f: boipeva (*Xenodon merremii)* - crushed by stick or Stone.

contribution to controlling crop pests such as rodents. Additionally, the high volume of vehicular traffic associated with tourist activities in the MEPA posed a direct threat to the snake community, elevated the risk of accidental or deliberate roadkill incidents (Rodrigues *et al*., 2002; Turci and Bernardes, 2009).

Other human-related causes, such as domestic animal predation, mainly by cats and dogs, further exacerbated threats to the snake assemblage within MEPA. These pets were known hunters of native fauna, pose significant risks to wildlife populations and highlight the need for responsible pet ownership and targeted interventions by environmental agencies to control stray animals (Whitaker and Shine, 2000; Woods *et al*., 2003; Vilela and Lamim-Guedes, 2014; Santos *et al*., 2020).

Residents reported more live than dead snakes, demonstrating that environmental education and citizen science can be essential for MEPA snake conservation. The combination of environmental education and partnerships with collaborators from a university in Pernambuco resulted in a massive reduction in the indiscriminate killing of snakes on the university campus (Barbosa *et al.,* 2020b). This demonstrated that environmental education was essential to reduce persecution of animals driven by human fear and misconceptions. Heightened awareness and conservation efforts were imperative to mitigate these threats and ensure the long-term survival of the snake community within MEPA.

CONCLUSIONS

The Barra do Rio Mamanguape Environmental Protection Area (MEPA) is a critical stronghold for the conservation of northeastern Atlantic Forest herpetofauna. Within this habitat, one can encounter endemic (*Micrurus bonita, M. potyguara*), medically significant (the families Viperidae and Elapidae), and rare species (*Drymarchon corais, Phimophis guerini*). However, the area experiences consistent tourist visitation, increasing the likelihood of snake encounters. Therefore, prioritizing environmental education and implementing targeted conservation strategies are imperative actions to dispel misconceptions surrounding these animals and foster awareness about the importance of preserving the snake community. Such efforts are essential for ensuring that MEPA continues to serve as a faunal sanctuary while simultaneously contributing to the local community's livelihood through sustainable economic activities.

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SUPPLEMENTARY MATERIAL

Table 2. Species recorded in study area from 2019 to 2021. Inside parenthesis in No = is number of individuals dead; H = Habits (AB = arboreal, AQ = aquatic, C = cryptozoic, FO = fossorial, T = terrestrial); A = Activity (N = nocturnal and D = diurnal) (Marques *et al.*, 2019). Dve = degree of vulnerability to extinction (LC – Little concern; NT- Near threatened; VU – Vulnerable) (França *et al.*, 2024); Apparent death = CB – carbonized; SS – crushed by stick or stone; PET – domestic animals; RO – ran over.

Family/Species	No	H	A	Dve	Apparent death
Typhlopidae					
Amerotyphlops brongersmianus (Vanzolini, 1976)	6	FO	N	NT	-
Amerotyphlops paucisquamus (Dixon & Hendricks, 1979)	2	FO	N	NT	-
Boidae					
Boa constrictor Linnaeus, 1758	27(7)	T; AB	D, N	VU	CB, PC, RO
Epicrates assisi Machado, 1945	1(1)	T; AB	N	NT	RO
Colubridae					
Chironius flavolineatus (Boettger, 1885)	114	AD	D	NT	-
Drymarchon corais (Boie, 1827)	1(1)	T, AB	D	NT	RO
Oxybelis aeneus (Wagler, 1824)	2(1)	AB	D	VU	RO
Leptophis dibernardoi Albuquerque, Santos, Borges-Nojosa, Ávila, 2022	3	AB	D	-	-
Spilotes pullatus (Linnaeus, 1758)	5(3)	T; AB	D	VU	PC
Tantilla melanocephala (Linnaeus, 1758)	11(1)	T; C	D; N	LC	RO
Dipsadidae					
Adelphostigma occipitalis (Jan, 1863)	1	T	D	NT	RO
Boiruna sertaneja Zaher, 1996	1	T	N	NT	-
Dibernardia affinis (Günther, 1858)	2	T	D	NT	-
Helicops angulatus (Linnaeus, 1758)	1	AQ; T	D	LC	-
Hydrodynastes gigas (Duméril, Bibron & Duméril, 1854)	1	AQ; T	D	NT	-
Oxyrhopus trigeminus Duméril, Bibron and Duméril, 1854	10(2)	T	D; N	LC	RO; SS
Philodryas nattereri (Steindachner, 1870)	13(3)	T	D	NT	RO, SS
Philodryas olfersii (Liechtenstein, 1823)	3	T; AB	D	NT	-
Philodryas patagoniensis (Girard, 1858)	12(3)	T	D	NT	PET; RO; SS
Phimophis guerini (Duméril, Bibron & Duméril, 1854)	1	T; C	N	NT	-
Xenodon merremii (Wagler, 1824)	5(1)	T	D	LC	SS
Elapidae					
Micrurus bonita (Merrem, 1820)	14(3)	T; C	D; N	LC	RO; SS
Micrurus potyguara Pires *et al.,* 2014	1	T; C	D; N	VU	-
Viperidae					
Bothrops leucurus Wagler, 1824	2(2)	T	N	NT	RO; SS