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Butterflies of two atlantic forest conservation units from Paraíba state, northeast of Brazil

Emanoel Pereira Gualberto, Adalberto Dantas de Medeiros & Solange Maria Kerpel

Universidade Federal de Campina Grande, Patos, PB, Brazil.

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Abstract. Conservation Units are areas legally established by the government with the goal of conserving territory and its natural resources. Given the limited knowledge about the invertebrate biodiversity in the Northern Atlantic Forest, including its legally protected areas, the present study aimed to inventory butterfly species in two Conservation Units of the Northern Atlantic Forest in Paraíba, Brazil: Engenho Gargaú Private Natural Heritage Reserve (RPPN Gargaú) and Mata do Xém-xém State Park (PE Xém-xém), both located in the metropolitan region of João Pessoa. We conducted the collections every two months, over three consecutive days, in six expeditions from February 2013 to April 2014 in RPPN Gargaú and in four expeditions from August 2014 to April 2015 in PE Xém-xem. Additionally, a two-day collecting expedition was carried out in August 2021 in RPPN Gargaú. We employed two sampling methods: Van Someren-Rydon traps and entomological nets. A total of 212 species (2,841 specimens) were recorded, 158 (1,867 specimens) in RPPN Gargaú and 129 (974 specimens) in PE Xém-xém. Overall, Hesperiidae was the richest family (81 spp.), followed by Nymphalidae (70), Riodinidae (22), Lycaenidae (22), Pieridae (12), and Papilionidae (4). Out of the total species, 48 are new records for Paraíba, and seven for northeast Brazil. Notably, the record of *Morpho menelaus eberti* Weber, 1963 in RPPN Gargaú, a subspecies classified as Critically Endangered (CR), stands out. The results emphasize the need to protect the forest remnants in the region, as well as to develop management and monitoring actions for butterflies and other invertebrates.

Keywords: checklist; critically endangered; Papilionoidea; Pernambuco Endemism Center; richness.

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Corresponding author:

Emanoel Pereira Gualberto
pgmanoel.lep@gmail.com

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Conservation Units (UCs, following the Portuguese abbreviation) are areas legally established by the government with the aim of conserving territorial space and its natural resources (Brazil 2000). Currently in Brazil, there are 2,659 UCs protecting approximately 18% of the country's continental territory (MMA 2023). Out of these UCs, 1,589 are located within the Atlantic Forest, a biome globally recognized as one of the richest and most significant regions for biodiversity conservation (Myers *et al.* 2000).

In its original range, the Atlantic Forest covered a territorial area of 1,360,000 km² (MMA 2000), stretching along the entire Atlantic coast of the country, from the state of Rio Grande do Norte to Rio Grande do Sul and extending westward to the states of Goiás and Mato Grosso do Sul and reaching northern Argentina and Paraguay in its southernmost limits (Metzger 2009). However, historical exploitation of natural resources, land use for agriculture, road construction, and the development of large urban centers have had a profound impact on its ecosystems (Morellato & Haddad 2000). As a result, the Atlantic Forest retains only about 12% of its original coverage, most of it distributed in fragments of less than 50 ha (Ribeiro *et al.* 2009). Additionally, according to the Atlas of Atlantic Forest Remnants, there was a 27.2% increase in deforestation rates from 2018 to 2019 (SOS Mata Atlântica & INPE 2021).

The Northern Atlantic Forest, also known as the Endemism Center of Pernambuco or the biogeographic subregion of Pernambuco, encompasses the narrow portion of the biome located north of the São Francisco River, between the states of Alagoas and Rio Grande do Norte (Almeida & Souza 2023). The high number of threatened, rare, and endemic species makes this region extremely relevant for biodiversity preservation (Myers *et al.* 2000). However, it is relatively understudied in terms of biological diversity, especially for invertebrates. Consequently, most of the fragments in it, including those located within federal, state, or municipal conservation units or private reserves, lack basic information about their exceptional and endangered biological diversity.

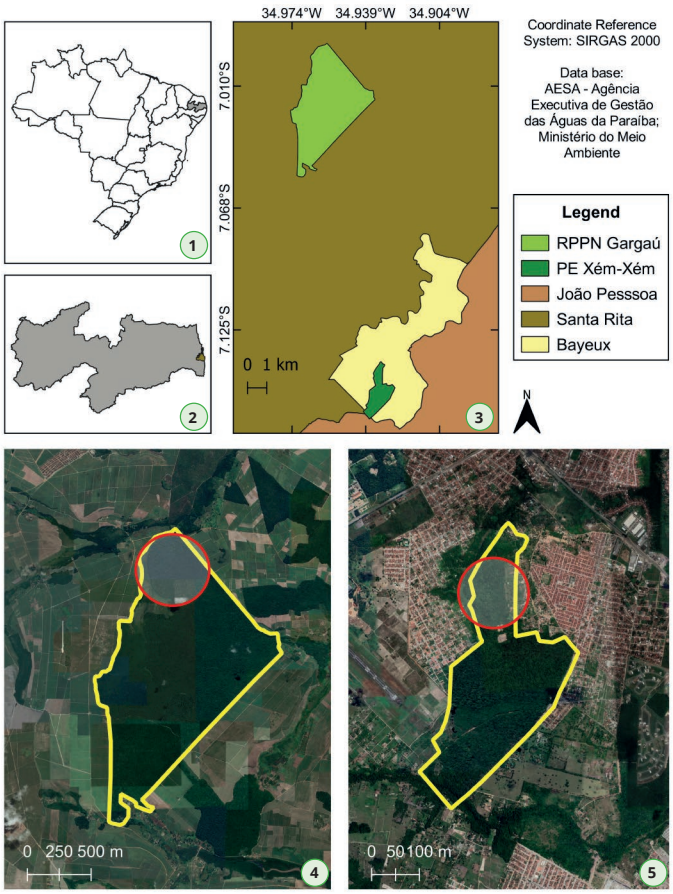
The order Lepidoptera comprises 43 superfamilies, and Papilionoidea includes butterflies (Mitter *et al.* 2017). There are approximately 18,000 species of butterflies worldwide (Espeland *et al.* 2018), distributed across seven families: Papilionidae, Hesperiidae, Pieridae, Riodinidae, Lycaenidae, Nymphalidae, and Hedylidae (Regier *et al.* 2009; Mutanen *et al.* 2010; Heikkilä *et al.* 2011; Espeland *et al.* 2018). In Brazil, more than 3,570 species have been recorded (Casagrande 2023a; 2023b; Casagrande *et al.* 2023a; 2023b; Carneiro & Casagrande 2023; Duarte *et al.* 2023; Mielke *et al.* 2023). Although butterflies constitute one of the best-known insect groups worldwide, there have been only seven inventories conducted in the Northern Atlantic Forest, of which only three were carried out in UCs (D'Almeida 1935; Cardoso 1949; Kesselring & Ebert [1982]; Melo *et al.* 2019; Bezerra *et al.* 2021; Medeiros *et al.* 2021).

Therefore, given the limited knowledge about the invertebrate biodiversity in the Northern Atlantic Forest, including its legally protected areas, the objective of this study was to inventory butterfly species in two conservation units in the state of Paraiba, Brazil: Engenho Gargaú

Private Natural Heritage Reserve (RPPN Gargaú) and Mata do Xém-xém State Park (PE Xém-xém), aiming to contribute to the knowledge of the biodiversity of the Endemism Center of Pernambuco.

MATERIAL AND METHODS

Study area. The study was conducted in two UCs located in the metropolitan region of the municipality of João Pessoa, state of Paraíba, Brazil: i) Engenho Gargaú Private Natural Heritage Reserve (RPPN Gargaú, following the Portuguese abbreviation) situated in the municipality of Santa Rita (-7.0123865,-34.9763888), and ii) Mata do Xém-xém State Park (PE Xém-xém, also following the Portuguese abbreviation) located between the municipalities of Bayeux and João Pessoa (-7.1493160010231,-34.933846316415) (Figures 1-3). These two sites, separated by approximately 11 km, are situated within the northern region of the Atlantic Forest biome and are characterized by the presence of dense ombrophilous lowland forests (Veloso *et al.* 1991), containing open environments, forest edges, interior forests, and wetlands (Figures 6-7). The climate is hot and humid (As') according to the Köppen classification, with an average annual temperature of 26 °C and an average annual relative humidity of 86% (Governo do Estado da Paraíba 1985). Both UCs are classified as areas of extremely high biological importance; therefore, they are a priority for conservation and management actions (MMA 2018).



Figures 1-5. Location of the study areas. (1) Map of Brazil with emphasis on the state of Paraíba. (2) Map of Paraíba with emphasis on the municipalities of Bayeux, Santa Rita, and João Pessoa. (3) study areas highlighted. Boundaries (yellow line) and surroundings of (4) RPPN Gargaú and (5) PE Xém-xém, showing the location where the transects were demarcated (red circle).

RPPN Gargaú, locally known as Mata Santana, was established by ordinance number 64 on June 14th, 1994 by the Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis (IBAMA). It covers an area of 1,058.62 ha. Its territory belongs to Japungu Agroindustrial LTDA, a company that is part of the Grupo Industrial Japungu, which is engaged in the production of sugar, ethanol, and electricity. PE Xém-xém was created by State Decree number 21,252 on February 28th, 2000, encompassing an area of 182 ha. These two fragments of the Atlantic Forest are under significant anthropogenic influence: while RPPN Gargaú is surrounded by sugarcane monoculture, PE Xém-xém is largely surrounded by urbanized areas (Figures 4-5), with some areas being improperly used by the population for solid waste disposal.

Sampling. We conducted the collections every two months, over three consecutive days during six expeditions conducted between February 2013 and April 2014 in RPPN Gargaú and during four expeditions between August 2014 and April 2015 in PE Xém-xém. Additionally, a two-day collection expedition was carried out in RPPN Gargaú in August 2021. The lower number of expeditions in PE Xém-xém was due to logistical difficulties and, mainly, safety concerns, as the location frequently experiences urban violence events, including during the collection period.

Figures 6-7. Landscapes of the RPPN Gargaú and PE Xém-xém, Paraíba State, Brazil, showing the open environments and forest edges, forest interior, and wetlands (from left to right). (6) RPPN Gargaú. (7) PE Xém-xém.

We performed the butterfly collection along six transects, each approximately 500 m long, established on pre-existing trails in the northern portion of both localities (Figures 4-5). We did not establish transects in the other areas of the UCs due to logistical and safety reasons. The transects were selected to contemplate the most varied environments, including open environments, forest edges, forest interior, and wetlands (Figures 6-7). We used two sampling methods: i) Van Someren-Rydon traps for frugivorous butterflies and ii) entomological nets for all butterfly guilds. To capture frugivorous butterflies, we placed five traps per transect (30 in total in each locality), each trap spaced approximately 100 m apart and suspended at a minimum height of 1.5 m above the ground. A mixture of banana and sugar cane juice, left to ferment for 48 h, was used as bait (DeVries *et al.* 1997). The traps remained active for the entire three days of each expedition, resulting in a total sampling effort of 480 h in RPPN Gargaú and 288 h in PE Xém-xém. They were inspected daily to remove captured specimens and replenish the bait. Additionally, two collectors carried out collections with entomological nets from 8:00 am to 4:00 pm, resulting in a total sampling effort of 160 h in RPPN Gargaú and 96 h in PE Xém-xém. On average, three captured specimens of each species were collected on each expedition, the others were identified, marked and released in the collection site.

Species List. The butterflies collected were identified with the assistance of literature, comparison with the material from the Laboratório de Ecologia e Interações de Insetos da Caatinga collection (CLEIIC) at the Centro de Saúde e Tecnologia Rural at the Universidade Federal de Campina Grande, Patos, Paraíba, Brazil, and consults to specialists (see acknowledgments). Higher-level classification followed Lamas (2004), updated with the modifications suggested by Wahlberg *et al.* (2009) for Nymphalidae, Seraphim *et al.* (2018) for Riodinidae, Li *et al.* (2019), Cong *et al.* (2019), Zhang *et al.* (2019a, 2020, 2021, 2022a, 2022b, 2022c, 2023) for Hesperiidae. The collected specimens were deposited in CLEIIC. We confirmed the first records for Paraíba based on lists previously published for the state (D'Almeida 1935; Kesselring & Ebert [1982]; Kerpel *et al.* 2014; Ferreira-Junior 2021; Medeiros *et al.* 2021).

Data Analysis. We generated the collector's curve using EstimateS 9.1.0 software (Colwell 2019) based on species presence and absence data, combining records obtained with entomological nets and traps for each locality. Species richness estimation for each study area was performed using CHAO 2 and Bootstrap estimators, following the criteria suggested by Magurran (2013) for non-parametric data and relying on singletons and doubletons.

RESULTS AND DISCUSSION

A total of 212 butterfly species (2,841 specimens) was recorded, with 158 (1,867 specimens) in the RPPN Gargaú and 129 (974 specimens) in the PE Xém-xém (Table 1). The species accumulation curves of none of the UCs reached the asymptote (Figures 8-9), indicating that the species richness in these areas may increase with more sampling. The richness estimate varied between 181 (Bootstrap) and 206 (Chao 2) for RPPN Gargaú and between 147 (Bootstrap) and 192 (Chao 2) for PE Xém-xém (Figures 8-9). Forty-eight of the total recorded species are new records for the state of Paraíba (Table 1). Most of the new records are of common and widely distributed species, highlighting the limited knowledge of the butterfly fauna in the Northern Mata Atlântica (Santos *et al.* 2008).

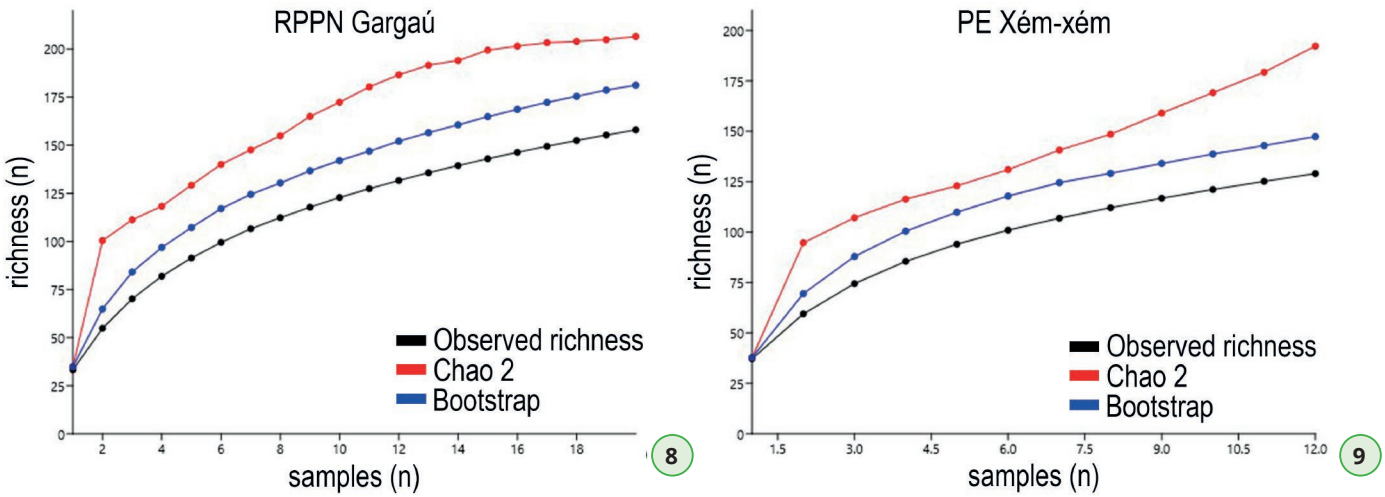
The observed richness for each of the UCs was higher than that found by Medeiros *et al.* (2021) (91 spp.) and Bezerra *et al.* (2021) (44 spp.) in urban forest fragments in the Northern Mata Atlântica, but it was lower than that found by Kesselring & Ebert ([1982]) (304 spp., according to Freitas *et al.* 2023). However, it is worth noting that the list from the latter authors is a compilation of more than five years of collections. Other studies that reported higher richness were Cardoso (1949) and, more recently, Melo *et al.* (2019), also in forest fragments of the Northern Atlantic Forest. Additionally, the observed and estimated richness was less than 300 species, which is approximately the expected number for well-sampled areas in the Northern Atlantic Forest (Freitas *et al.* 2023). This variation is largely due to the different sampling efforts and methods used in these studies (Table 2).

Considering both localities together, nectar-feeding butterflies represented 78.77% (167 spp.) and frugivorous ones, 22.17% (47 spp.). The frugivorous butterfly richness was higher than that found by Melo *et al.* (2019), which recorded 42 species, representing 14.58% of their total richness. Chronic disturbances in the forest, biomass, and richness of arboreal species are excellent predictors of taxonomic and functional changes in frugivorous butterflies, favoring species adapted to disturbances and negatively impacting forest-dependent species (Melo *et al.* 2023).

All butterfly families were represented, except Hedylidae, whose species are nocturnal (Kawahara *et al.* 2018), thus not collected by the methods employed in this study. Considering the total number of species from both UCs, Hesperiidae was the richest family (81 spp.), followed by Nymphalidae (70), Riodinidae (22), Lycaenidae (22), Pieridae (12), and Papilionidae (4). This pattern differs from what was observed in each locality separately, where Nymphalidae had the highest richness, followed by Hesperiidae, Lycaenidae, Riodinidae, Pieridae, and Papilionidae (Table 3).

According to Francini *et al.* (2011), the highest richness of Hesperiidae and Nymphalidae, followed by Lycaenidae, Riodinidae, Pieridae, and Papilionidae is the expected result for most surveys in the neotropical region. However, when comparing different studies conducted in the Northern Atlantic Forest, there is a variation in the richness pattern by family (see Table 4.1 in Freitas *et al.* 2023). This may be related to the different environmental factors in each study area, as well as the availability of host plants for the immature stages. Additionally, methodological aspects such as sampling effort and the level of expertise of the collectors are determinants as well. While Nymphalidae, Pieridae, and Papilionidae are generally large and relatively easy to sample, Hesperiidae, Lycaenidae, and Riodinidae are erratic and small, with a slow accumulation of species over the sampling period (Brown Jr. & Freitas 2000).

Papilionidae was represented by four species, three of which were exclusive to PE Xém-xém and one shared between the two UCs (Table 1). This number is similar to what was found in other areas of the Atlantic Forest in Northeast Brazil (Vasconcelos *et al.* 2009; Paluch *et al.* 2016; Melo *et al.* 2019). The higher Papilionidae richness in PE Xém-xém is because three of the four species found, *Heraclides thoas brasiliensis*



Figures 8-9. Species accumulation curve for the butterflies collected at (8) RPPN Gargaú, and (9) PE Xém-xém, Paraíba state, Brazil, with the expected number of species by CHAO 2 and Bootstrap estimators.

(Rothschild & Jordan, 1906), *Heraclides anchisiades capys* (Hübner, [1809]), and *Battus polydamas polydamas* (Linnaeus, 1758), are typical of open areas and forest edges near urban centers (Brown Jr. 1992), which are environments present in PE Xém-xém and absent in RPPN Gargaú.

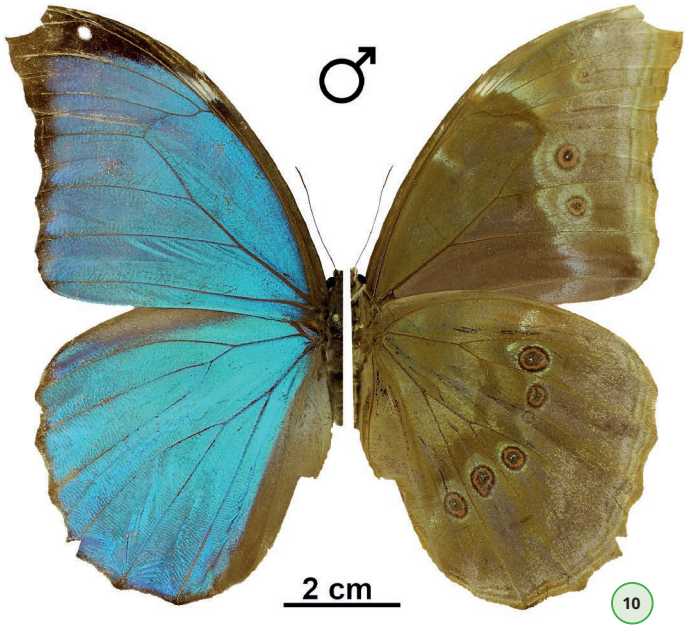
There were no new records of the Pieridae family for Paraíba. The twelve species found are widely distributed and are frequently common in forest edges and open and anthropized environments (Brown Jr. 1992; Vila-Verde *et al.* 2020; Dantas *et al.* 2021).

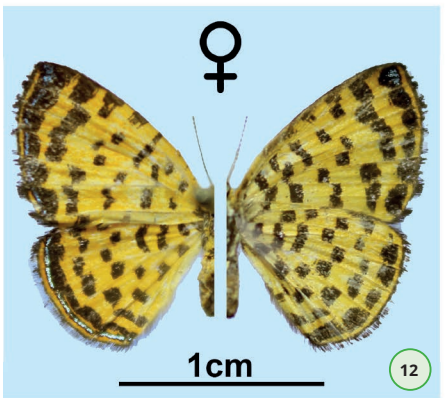
We recorded a total of 22 species of Lycaenidae (Table 1). Polyommatinae was represented by three species with a wide distribution and common in surveys conducted in Brazil (Vila-Verde & Paluch 2020; Krüger *et al.* 2021; Gonçalves *et al.* 2021; Pinheiro & Ribeiro 2022). On the other hand, Theclinae was represented by 19 species, six of which are new records for Paraíba and one for Northeast Brazil [*Ocaria ocrisia* (Hewitson, 1868)].

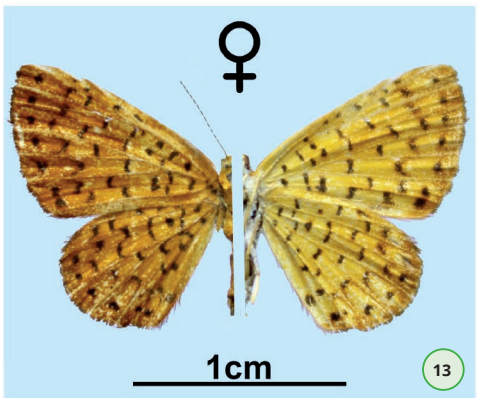
Eight Riodinidae species found in RPPN Gargaú and PE Xém-xém are new records for the state of Paraíba (Table 1). The species *Argyrogrammana* sp. deserves special mention, as it constitutes the first record of the genus for the Northern Atlantic Forest (Figure 12). This genus contains some of the rarest species of Riodinidae, with most of them being restricted to the Amazon basin (Hall & Willmott 1995; Dolibaina *et al.* 2015). Due to the lack of available data on *Argyrogrammana* species in the Northern Atlantic Forest, it was not possible to identify the single female specimen collected in RPPN Gargaú to the species level. Another significant record of Riodinidae was the sole female specimen of *Xanthosa xanthosa* (Stichel, 1910) (Figure 13). This species is only known from old female specimens without an exact sampling locality (Kaminski *et al.* 2017; Zhang *et al.* 2019b). Therefore, our record provides an initial clue about the distribution of this seemingly rare species of Riodinidae.

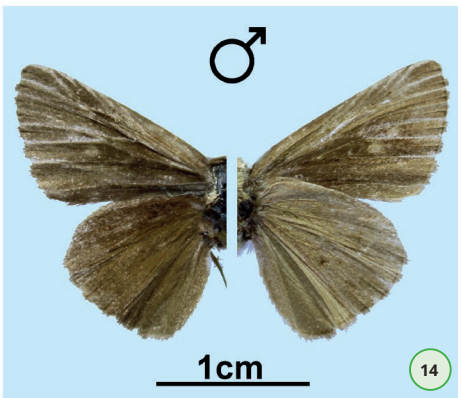
Most of the Nymphalidae species recorded in RPPN Gargaú and PE Xém-xém are common and abundant in Atlantic Forest sites (Kesselring & Ebert [1982]); Medeiros *et al.* 2021; Melo *et al.* 2019). Some of them, such as *Hamadryas februa februa* (Hübner, [1823]) and *Hamadryas feronia feronia* (Linnaeus, 1758), are potential indicators of fragmented and/or extremely disturbed environments (Brown Jr. 1992). Twelve Nymphalidae species are new records for Paraíba, most of them belonging to Satyrinae. It is important to highlight that satyrines are included in the guild of frugivorous butterflies and are mainly collected with traps, emphasizing the importance of using different sampling methods for a better characterization of the butterfly community in a locality (Freitas *et al.* 2006).

Among the satyrines, the record of *Morpho menelaus eberti* Weber, 1963, a subspecies currently classified as Critically Endangered by the Red Book of Threatened Brazilian Fauna (ICMBio 2018, 2023) stands out (Figures 10-11). This subspecies was mentioned by Kesselring & Ebert ([1982]) as abundant in the forests near the municipality of João Pessoa. We confirmed its presence in RPPN Gargaú, making it the second conservation unit where it can be found (Melo *et al.*









Figures 10-14. Dorsal (left) and ventral (right) views of some of the most important butterfly records in RPPN Gargaú and PE Xém-Xém. (10-11) *Morpho menelaus eberti* (Nymphalidae) ,(12) *Argyrogrammana* sp. (Rioinidae), (13) *Xanthosa xanthosa* (Riodinidae) e (14) *Cymaenes chapa* (Hespriidae).

Table 1. Butterflies species collected between February 2013 and April 2014 in RPPN Gargaú (additionally, a two-day collection expedition was carried out in August 2021 in RPPN Gargaú) and between August 2014 and April 2015 in PE Xém-xém in the metropolitan region of João Pessoa, Paraiba state, Brazil. The number of species for each major taxa is noted within parentheses. * = new record for Paraíba. **new record for northeast Brazil. Sha. = shared species. Nec. = nectarivorous. Fru. = Frugivorous.

TAXA	RPPN Gargaú	PE Xém-xém	Sha.	Nec.	Fru.
PAPILIONOIDEA (212)					
PAPILIONIDAE (4)					
Papilioninae (4)					
Battus polydamas polydamas (Linnaeus, 1758)		x		x	
Heraclides anchisiades capys (Hübner, [1809])		x		x	
Heraclides thoas brasiliensis (Rothschild & Jordan, 1906)		x		x	
Parides zacynthus polymetus (Godart, 1819)	x	x	x	x	
PIERIDAE (12)					
Coliadinae (10)					
Albaeis albula abula (Cramer, 1775)	x	x	x	x	
Eurema agave pallida (Chavannes, 1850)		x		x	
Eurema elathea flavescens (Chavannes, 1850)	x	x	x	x	
Phoebis argante argante (Fabricius, 1775)	x	x	x	x	
Phoebis marcellina (Linnaeus, 1758)	x	x	x	x	
Phoebis philea philea (Linnaeus, 1763)	x	x	x	x	
Phoebis statira statira (Cramer, 1777)	x			x	
Pyrisitia leuce leuce (Boisduval, 1836)	x	x	x	x	
Pyrisitia nise tenella (Cramer, 1775)	x	x	x	x	
Teriocolias deva deva (E. Doubleday, 1847)		x		x	
Pierinae (2)					
Ascia monuste orseis (Godart, 1819)	x	x	x	x	
Glutophrissa drusilla drusilla (Cramer, 1777)	x			x	
LYCAENIDAE (22)					
Polyommatinae (3)					
Hemiargus hanno hanno (Stoll, 1790)	x	x	x	x	
Leptotes cassius cassius (Cramer, 1775)	x			x	
Zizula cyna (W. H. Edwards, 1881)		x		x	
Theclinae (19)					
Aubergina vanessoides (Prittwitz, 1865)*	x	x	x	x	
Calycopis caulonia (Hewitson, 1887)	x	x	x	x	
Calycopis cissusa (Hewitson, 1877)		x		x	
Calycopis orcilla (Hewitson, 1874)	x			x	
Calycopis vesulus (Stoll, 1781)	x			x	
Celmia celmus (Cramer, 1775)		x		x	
Denivia hemon (Cramer, 1775)	x	x	x	x	
Magnastigma hirsuta (Prittwitz, 1865)*	x			x	
Ministrymon azia (Hewitson, 1873)*	x	x	x	x	
Ministrymon una (Hewitson, 1873)*	x	x		x	
Ocaria ocrisia (Hewitson, 1868)**		x		x	
Pseudolycaena marsyas (Linnaeus, 1758)	x			x	
Rekoa marius (Lucas, 1857)	x			x	
Rekoa palegon (Cramer, 1780)	x			x	
Siderus philinna (Hewitson, 1868)		x		x	
Strymon bubastus bubastus (Stoll, 1780)	x	x	x	x	
Strymon mulucha (Hewitson, 1867)	x			x	
Theclopsis sp.	x			x	
Thestius lycabas (Cramer, 1777)		x		x	
Tmolus echion (Linnaeus, 1767)	x	x		x	
Ziegleria hesperitis (Butler & H. Druce, 1872)*	x			x	
RIODINIDAE (22)					

To be continue...

Table 1. Continue...

TAXA	RPPN Gargaú	PE Xém-xém	Sha.	Nec.	Fru.
Nemeobiinae (1)					
Euselasia sp.	x			x	
Riodininae (21)					
Argyrogrammana sp.*	x			x	
Ariconias glaphyra (Westwood, 1851)	x			x	
Aricoris campestris (H. Bates, 1868)	x	x	x	x	
Calephelis braziliensis McAlpine, 1971	x	x		x	
Eurybia halimede (Hübner, [1807])*	x			x	
Helicopis cupido lindeni Grote, 1877	x			x	
Isapis agyrtus agyrtus (Cramer, 1777)		x		x	
Lemonias zygia chea Hewitson, 1863*	x			x	
Mesene phareus (Cramer, 1777)	x			x	
Mesosemia nyctea (Hoffmannsegg, 1818)	x			x	
Nymphidium azanoides azonoides A. Butler, 1867*	x			x	
Nymphidium lisimon (Stoll 1790)*	x			x	
Nymphidium mantus (Cramer, 1775)	x	x	x	x	
Parvospila lucianus (Fabricius, 1793)	x	x	x	x	
Rhetus arcius (Linnaeus, 1763)		x		x	
Sarota acanthoides (Herrich-Schäffer, [1853])*	x			x	
Symmachia (*Xenandra*) *sp.* *		x		x	
Synargis calyce (C. Felder & R. Felder, 1862)	x	x	x	x	
Theope foliorum H. Bates, 1868	x	x	x	x	
Theope leucanthe H. Bates, 1868*		x		x	
Xanthosa xanthosa (Stichel, 1910) *		x		x	
NYMPHALIDAE (70)					
Danainae (9)					
Danaus erippus (Cramer, 1775)	x	x	x	x	
Danaus gilippus (Cramer, 1775)		x		x	
Hypothyris euclea (Godart, 1819)	x			x	
Hypothyris ninonia daetina (Weymer, 1899)	x			x	
Lycorea halia discreta Haensch, 1909	x	x	x	x	
Mechanitis lysimnia nesaea (Fabricius, 1793)	x	x	x	x	
Methona themisto (Hübner, 1818)*		x		x	
Scada reckia (Hübner, [1808])		x		x	
Tithorea harmonia (Cramer, 1777)*	x			x	
Satyrinae (28)					
Brassolis sophorae dinizi R.F. D'Almeida, 1956		x			x
Deltaya probata (Weymer, 1911)*	x				x
Caligo illioneus illioneus (Cramer, 1775)	x	x	x		x
Caligo teucer (Cramer, 1758)	x	x	x		x
Emeryus aff. argulus (Godart, [1824])*	x				x
Hermeuptychia atalanta (A. Butler, 1867)*	x	x			x
Hermeuptychia hermes (Fabricius, 1775)		x			x
Hermeuptychia sp.	x	x	x		x
Magneuptychia lethra (Möschler, 1883)*	x				x
Magneuptychia libye (Linnaeus, 1767)	x	x	x		x
Malaveria affinis (A. Butler, 1867)*	x	x	x		x
Malaveria maepius (Godart, [1824])		x			x
Modestia sylvina (C. Felder & R. Felder, 1867)*	x	x	x		x
Modica myncea (Cramer, 1780)*	x				x
Moneuptychia romanina (Bryk, 1953)		x			x
Morpho helenor anakreon Fruhstorfer, 1910	x	x	x		x

To be continue...

Table 1. Continue...

TAXA	RPPN Gargaú	PE Xém-xém	Sha.	Nec.	Fru.
Morpho menelaus eberti Weber, 1963	x				x
Opsiphanes cassiae cassiae (Linnaeus, 1758)	x	x	x		x
Opsiphanes invirae pernanbucoensis Bristow, 1991	x	x	x		x
Opsiphanes quiteria meridionalis Staudinger, 1887	x				x
Pharneuptychia innocentia (C. Felder & R. Felder, 1867)		x			x
Pierella kesselring (Zacca, 2015)*	x	x	x		x
Taygetis echo (Cramer, 1775)	x				x
Taygetis laches laches (Fabricius, 1793)	x	x	x		x
Taygetis sosis Hopffer, 1874*	x				x
Taygetis thamyra (Cramer, 1779)	x				x
Taygetis virgilia (Cramer, 1776)	x				x
Yphthimoides manasses (C. Felder & R. Felder, 1867)	x	x	x		x
Charaxinae (5)					
Anaea ryphea phidile (Cramer, 1775)	x	x	x		x
Archaeoprepona demophon demophon (Linnaeus, 1758)	x	x	x		x
Archaeoprepona demophoon antimache (Hübner, [1814])	x	x	x		x
Prepona laertes laertes (Hübner, [1811])	x	x	x		x
Zaretis galanthis galanthis (Cramer, 1775)		x			x
Biblidinae (11)					
Callicore astarte (Cramer, 1779)	x				x
Catagramma pygas (Godart, [1824])	x				x
Dynamine postverta (Cramer, 1779)		x			x
Hamadryas amphinome amphinome (Linnaeus, 1767)	x	x	x		x
Hamadryas arete (E. Doubleday, 1847)	x				x
Hamadryas arinome (Lucas, 1853)	x				x
Hamadryas chloe rhea (Fruhstorfer, 1907)	x				x
Hamadryas epinome (C. Felder & R. Felder, 1867)*	x				x
Hamadryas februa februa (Hübner, [1823])	x	x	x		x
Hamadryas feronia feronia (Linnaeus, 1758)	x	x	x		x
Myscelia orsis (Drury, 1782)	x				x
Cyrestinae (1)					
Marpesia petreus petreus (Cramer, 1776)		x		x	
Nymphalinae (8)					
Anartia amathea roeselia (Eschscholtz, 1821)		x		x	
Anartia jatrophae jatrophae (Linnaeus, 1763)	x	x	x	x	
Colobura dirce dirce (Linnaeus, 1758)	x	x	x		x
Historis acheronta (Fabricius, 1775)	x				x
Historis odius odius (Fabricius, 1775)	x	x	x		x
Junonia evarete evarete (Cramer, 1779)	x	x	x	x	
Siproeta stelenes meridionalis (Fruhstorfer, 1909	x	x		x	
Tegosa claudina (Eschscholtz, 1821)	x			x	
Limenitidinae (1)					
Adelpha cytherea aea (C. Felder & R. Felder, 1867)	x	x	x	x	
Heliconiinae (9)					
Dione juno (Cramer, 1779)		x		x	
Dione maculosa Stichel, [1908]	x			x	
Dryadula phaetusa (Linnaeus, 1758)	x	x	x	x	
Dryas alcionea alcionea (Cramer, 1779)	x	x	x	x	
Eueides isabella dianasa (Hübner, [1806])		x		x	
Euptoieta hegesia meridiania Stichel, 1938	x	x	x	x	
Heliconius erato phylis (Fabricius, 1775)	x	x	x	x	
Heliconius melpomene nanna Stichel, 1899	x	x	x	x	

To be continue...

Table 1. Continue...

TAXA	RPPN Gargaú	PE Xém-xém	Sha.	Nec.	Fru.
Philaethria dido dido (Linnaeus, 1763)	x	x	x	x	
HESPERIIDAE (82)					
Eudaminae (21)					
Augiades crinisus (Cramer, 1780)	x			x	
Autochton itylus Hübner, 1823	x			x	
Autochton neis (Geyer, 1832)	x			x	
Bungalotis midas (Cramer,1775)*	x			x	
Cecropteros dorantes dorantes (Stoll, 1790)	x	x	x	x	
Chioides catillus catillus (Cramer, 1779)	x	x	x	x	
Cogia calchas (Herrich-Schäffer, 1869)		x		x	
Cogia hassan hassan A. Butler, 1870		x		x	
Cogia undulatus (Hewitson, 1867)	x			x	
Drephalys phoenice (Hewitson, 1867)	x			x	
Epargyreus exadeus exadeus (Cramer, 1779)	x			x	
Nascus phocus (Cramer, 1777)	x			x	
Phocides polybius polybius (Fabricius, 1793)		x		x	
Spicauda procne (Plötz, 1881)		x		x	
Spicauda simplicius (Stoll, 1790)	x	x	x	x	
Telegonus anaphus (Cramer, 1777)		x		x	
Telegonus fulgerator (Walch, 1775)	x			x	
Telemiades quammeni Siewert, O. Mielke & Casagrande, 2020*	x			x	
Udranomia kikkawai (Weeks, 1906)		x		x	
Urbanus proteus proteus (Linnaeus, 1758)	x	x	x	x	
Urbanus velinus (Plötz, 1881)*		x		x	
Pyrginae (17)					
Anaxas obliqua (Plötz, 1884)*	x			x	
Bunrsius orcus (Stoll, 1780)	x	x	x	x	
Chirgus veturius Plötz, 1884	x	x	x	x	
Cycloglypha thrasibulus thrasibulus (Fabricius, 1793)	x			x	
Echelatus sempiternus simplicior (Möschler, 1877)*		x		x	
Gesta gesta (Herrich-Schäffer, 1863)	x			x	
Gindanes brebisson (Latreille, [1824])	x			x	
Gorgythion begga begga (Prittwitz, 1868)	x			x	
Helias phalaenoides palpalis (Latreille, [1824])		x		x	
Heliopetes arsalte (Linnaeus, 1758)	x	x	x	x	
Heliopetes macaira (Reakirt, [1867])		x		x	
Heliopetes omrina (A. Butler, 1870)	x			x	
Heliopetes willi (Plötz, 1884)	x	x	x	x	
Nisoniades macarius (Herrich-Schäffer, 1870)		x		x	
Viola violella (Mabille, 1898)	x	x	x	x	
Xenophanes tryxus (Stoll, 1780)	x	x	x	x	
Zopyrion evenor thania Evans, 1953		x		x	
Hesperiinae (44)					
Anatrytone perfida (Möschler, 1879)*	x			x	
Anthoptus epictetus (Fabricius, 1793)		x		x	
Artonia artona (Hewitson, 1868)*		x		x	
Callimormus alsimo (Möschler, 1883)	x			x	
Callimormus corades (C. Felder, 1862)	x			x	
Callimormus corus E. Bell, 1941	x			x	
Callimormus radiola radiola (Mabille, 1878)		x		x	
Calpodes longirostris (Sepp, [1840])*	x			x	

To be continue...

Table 1. Continue...

TAXA	RPPN Gargaú	PE Xém-xém	Sha.	Nec.	Fru.
Conga chydaea (A. Butler, 1877)*		x		x	
Corticea corticea (Plötz, 1882)*	x	x	x	x	
Cymaenes alumna (A. Butler, 1877)	x	x	x	x	
Cymaenes chapa O. Mielke, 1968**	x			x	
Cymaenes tripunctus theogenis (Capronnier, 1874)	x			x	
Cynea cannae (Herrich-Schäffer, 1869)		x		x	
Damas clavus (Herrich-Schäffer, 1869)*	x			x	
Euphyes cherra Evans, 1955**	x			x	
Flaccilla aecas (Stoll, 1781)		x		x	
Hylephila phyleus phyleus (Drury, 1773)		x		x	
Justinia justinianus justinianus (Latreille, [1824])	x	x		x	
Lerema ancillaris (A. Butler, 1877)	x			x	
Lerema compta (A. Butler, 1877)	x			x	
Lerema lineosa (Herrich-Schäffer, 1865)**	x			x	
Mnaseas inca E. Bell, 1930*	x			x	
Mnasinous ina (Plötz, 1882)	x			x	
Moeris anna (Mabille, 1898)**	x			x	
Nastra chao (Mabille, 1898)*	x			x	
Niconiades xanthaphes Hübner, [1821]		x		x	
Nyctelius nyctelius nyctelius (Latreille, [1824])		x		x	
Oligoria percosius (Godman, 1900)**	x			x	
Panoquina fusina viola Evans, 1955		x		x	
Panoquina hecebolus (Scudder, 1872)*	x			x	
Papias allubita (A. Butler, 1877)		x		x	
Perichares philetes (Gmelin, [1790])	x	x	x	x	
Polites premnas (Wallengren, 1860)*		x		x	
Pompeius amblyspila (Mabille, 1898)		x		x	
Pompeius pompeius (Latreille, [1824])	x	x		x	
Quasimellana eulogius (Plötz, 1882)**	x			x	
Talides alternata E. Bell, 1941	x			x	
Talides sergestus (Cramer, 1775)	x			x	
Tigasis arita (Schaus, 1902)*	x			x	
Vehilius inca (Scudder, 1872)	x			x	
Zariaspes mys (Hübner, [1808])		x		x	
Total	**158**	**129**	**66**	**167**	**47**

Table 2. Comparison of richness and sampling effort between butterfly inventories carried out in the Northern Atlantic Forest.

Reference	Sites	Richness	Sampling effort	
			Net	Traps
Present study	PE Xém-xém (PB)	128	96 hours	288 hours
Present study	RPPN Gargaú (PB)	158	160 hours	480 hours
Cardoso (1949)	Maceio (AL)	225	-	-
Kesselring & Ebert ([1982])	Mata do Buraquinho (PB)	304*	> 5 years	-
Melo *et al*. (2019)	Parque Estadual Dois Irmãos (PE)	288	464 hours	-
Medeiros *et al*. (2021)	FLONA de Cabedelo (PB)	89	108 hours	432 hours
Bezerra *et al*. (2021)	Arboretum de Alagoas. (AL)	44	140 hours	-

2014; ICMBio 2018).

Hesperiidae had the highest number of new records for Paraíba (22 spp.), most of them belonging to Hesperiinae (Table 1). This diverse subfamily includes most of the small brown neotropical Hesperiidae species (Warren *et al.* 2008, 2009). This characteristic, along with a fast and erratic flight, make Hesperiinae more difficult to collect. Consequently, the richness of this subfamily is often underestimated, especially in short to medium-duration inventories (Brown Jr. & Freitas 2000).

Six hesperines species are new records for northeast Brazil: *Cymaenes chapa* Mielke, 1968, *Euphyes cherra* Evans, 1955, *Lerema lineosa* (Herrich-Schäffer, 1965), *Moeris anna* (Mabille, 1898), *Oligoria percosius* (Godman, 1900), and *Quasimelana eulogius* (Plötz, 1882). Until this study, *C. chapa* (Figure 14) was known only from gallery forests in the Brazilian Cerrado,

Table 3. Richness by family and number of shared butterfly species collected between February 2013 and April 2014 in RPPN Gargaú (additionally, a two-day collection expedition was carried out in August 2021 in RPPN Gargaú) and between August 2014 and April 2015 in PE Xém-xém in the metropolitan region of João Pessoa, Paraíba state, Brazil.

Families	RPPN Gargaú	PE Xém-xém	Total	Shared species (%)
Papilionidae	1	4	4	1 (25)
Pieridae	10	10	12	8 (66,67)
Lycaenidae	18	14	22	6 (27,27)
Riodinidae	17	11	22	5 (22,73)
Nymphalidae	58	49	70	33 (47,14)
Hesperiidae	54	40	81	13 (16,05)
Total	***158***	***128***	***211***	***66 (31,28)***

being considered potentially endemic to this biome (Mielke 1968; Mielke *et al.* 2008; Pinheiro *et al.* 2010). Our record extends the distribution of this species to the northern part of the Atlantic Forest.

Only 66 (31.28%) of the total species were found in both collection sites. Nymphalidae and Pieridae had the highest percentages of shared species, with 47.14% and 66.67%, respectively. Accordingly, the values were lower for Papilionidae (25%), Riodinidae (22.73%), Lycaenidae (27.27%), and Hesperiidae (16.05%) (Table 3). The low number of shared species in these last families may be a consequence of the higher number of non-resident species (i.e. migratory species) they present (Brown Jr. & Freitas 2000). Additionally, some Hesperiidae, Riodinidae, and Lycaenidae species have extremely peculiar habits and are sometimes associated with very specific environments, such as small clearings, hilltops, and even caves or holes in the ground (Mielke 1967; New 1993; Dolibaina *et al.* 2016). Only standardized ecological studies can elucidate the differences in the composition of butterfly assemblages in these two important conservation units in the Atlantic Forest of Paraíba.

This study makes an important contribution by adding 48 new records of butterfly species for the state of Paraíba and seven for northeast Brazil, providing a glimpse on how much is still unknown about the northern portion of the Atlantic Forest. In addition, it confirmed the presence of the threatened subspecies *M. m. eberti* in RPPN Gargaú, reinforcing the need to protect the forest remnants in the region, as well as to develop management and monitoring actions for butterflies and other invertebrates.

It is worth noting the absence of *M. m. eberti* in PE Xém-xém, approximately 11 km from RPPN Gargaú, where it would also be expected. Habitat loss and fragmentation can reorganize natural communities, favoring species adapted to disturbances and negatively impacting forest-dependent species (Melo *et al.* 2023), as is the case with *M. m. eberti*. Conservation, especially of PE Xém-xém, is strategic as it harbors a rich and almost unknown biodiversity and contains the source of the Marés river, which supplies the city of João Pessoa, among other water sources and relevant aspects. Therefore, greater attention to this UC by the responsible agencies is urgently needed.

This study fills one of the knowledge gaps regarding the biodiversity of the Paraiba Atlantic Forest, and such information can contribute to the planning and management of priority areas for biological conservation, aiming towards sustainable development.

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AUTHORS CONTRIBUTION

EPG: Sampling, species identification, analysis of metadata and, initial writing of the article; ADM: Sampling, species identification, analysis of metadata and, final writing of the article; SMK: Sampling design, sampling, species identification, analysis of metadata and, revision and final writing of the article.

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CONFLICT OF INTEREST STATEMENT

The authors of this article declare that there is no conflict of interest.

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