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Sphingidae (Lepidoptera: Bombycoidea) assemblage in the State Ecological Station of Wenceslau Guimarães, Bahia, Brazil

Eduarda Mendes Malheiros[1*], Willian Rogers Ferreira de Camargo[2], Amabílio José Aires de Camargo[2] and Márlon Paluch[1]

[1]Laboratório de Sistemática e Conservação de Insetos, Setor de Ciências Biológicas, Centro de Ciências Agrárias, Ambientais e Biológicas, Universidade Federal do Recôncavo da Bahia, Rua Rui Barbosa, 710, 44380-000, Cruz das Almas, Bahia, Brazil. [2]Empresa Brasileira de Pesquisa Agropecuária, Embrapa Cerrados, Planaltina, Distrito Federal, Brazil. *Author for correspondence. E-mail: eduarda_malheiros@hotmail.com

ABSTRACT. The diversity of hawkmoths (Lepidoptera: Sphingidae) is poorly known in the biomes of the Bahia state. However, studies were carried out in other states of the northeastern region with species inventories in the Atlantic Forest, Caatinga and Cerrado. In order to broaden the knowledge on of the richness and diversity of hawkmoths in the Atlantic Forest of the state of Bahia, six monthly sampling sessions were carried out in the State Ecological Station of Wenceslau Guimarães. Hawkmoths were captured using a 250-watt mercury-vapor light trap set against a white cloth panel, for two nights a month, between 6:00 p.m. and 6:00 a.m. A total of 266 specimens were collected, distributed across 17 genera and 41 species. The most abundant and dominant species were *Isognathus swainsoni* C. Felder, 1862, with a relative abundance of 12.41%, and *Xylophanes amadis* (Cramer, 1782) and *Xylophanes anubus* (Cramer, 1777), both with 7.9%. Our study represents the second inventory of hawkmoths for the state, totaling 59 species known for the Atlantic Forest of Bahia. *Isognathus excelsior* (Boisduval, [1875]) and *Manduca lucetius* (Cramer, 1780) represented new records for the biome. The accumulated number of species indicates the need for further sampling in order to safely reach the curve asymptote.

Keywords: hawkmoths; neotropical; conservation; richness; Atlantic Forest.

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Introduction

Sphingidae (hawkmoths) is worldwide acknowledged for its important role in pollination, interactions with plants and as bioindicators (Camargo, Camargo, Corrêa, Vilela, & Amorim, 2018). They are found in all continents except for Antarctica and Greenland (D'Abrera, 1986; Kitching & Cadiou, 2000; Hilty & Merenlender, 2000; Darrault & Schlindwein, 2002; Motta & Xavier-Filho, 2005; Duarte, Marconato, Specht, & Casagrande, 2012; Amorim, Wyatt, & Sazima, 2014; Lourido, Motta, Graça, & Rafael, 2018; Conceição & Teston, 2020).

Worldwide, the hawkmoths are a family comprising approximately 1,608 species, distributed across 213 genera, grouped in three subfamilies: Sphinginae, Macroglossinae and Smerinthinae (Camargo et al., 2018). An analysis of their phylogeny based on 5 nuclear genes revealed a strongly supported monophyly of the family, although the position of Smerinthinae *sensu lato* within the family deserves further investigation, because some of its genera remain *incertae sedis* (Kawahara, Mignault, Regier, Kitching, & Mitter, 2009).

Approximately 302 species are estimated for South America and among those, 196 occur in Brazil (Haxaire & Mielke, 2019). They are mainly nocturnal, except for some genera, such as *Aellopos*, Hübner [1819], and *Eupyrrhoglossum*, Grote 1865, which show diurnal and crepuscular activity (Marinoni, Dutra, & Mielke, 1999; Kitching & Cadiou, 2000).

In northeastern Brazil, the hawkmoths are known chiefly by species inventories, distributed in the biomes Caatinga, Atlantic Forest and Cerrado (Cardoso, 1949; Silva, 1967; Duarte Jr, Motta, & Varela-Freire, 2001; Darrault & Schlindwein, 2002; Gusmão & Creão-Duarte, 2004; Duarte Jr & Schlindwein, 2005a, 2005b, 2008; Lopes, Medeiros, Aguiar-Neto, & Machado, 2005; Primo, Duarte, & Machado, 2013; Mielke & Haxaire, 2013; Rafael et al., 2017; Câmara, Rocha, & Pereira, 2018; Vila-Verde & Paluch, 2019).

Although Sphingidae is considered to be the best-inventoried family among nocturnal moths (Kitching & Cadiou, 2000), very little is known about them in Bahia, a priority state for lepidopterans inventories in the Northeast (Freitas & Marini-Filho, 2011).

This study aimed to contribute to the knowledge of Sphingidae assemblage within a protected area located to the northwest of the central corridor of the Atlantic Forest in the Bahia state, known as *Estação Ecológica Estadual de Wenceslau Guimarães* (State Ecological Station of Wenceslau Guimarães), in order to improve the understanding of diversity and distribution of hawkmoths in northeastern Brazil.

Material and methods

Study area

The State Ecological Station of Wenceslau Guimarães (SESWG) (13°35'43''S and 39°43'10''W) located in the municipality of Wenceslau Guimarães, Bahia is a priority area for conservation in the full protection category (SNUC Law 9985/2000 and Decree 4340/2002). Currently, it comprises a total area of 2,418 ha of protected forests. It was created by the State Decree 6228/1997 and later expanded by the Decree 7791/2000. It is inserted in the Atlantic Forest biome, and it is composed exclusively of the Submontane Ombrophilous Dense Forest phytophysiognomy (Figure 1) (Rigueira et al., 2012).

The region presents a humid and sub-humid climate. Climatology of the municipality, based on 30 years of observation, shows precipitation varying from 103 mm to 153 mm, maximum temperature from 27 to 29ºC and the minimum temperature from 19 to 20ºC, between October and March (Rigueira et al., 2012; Climatempo, 2020).

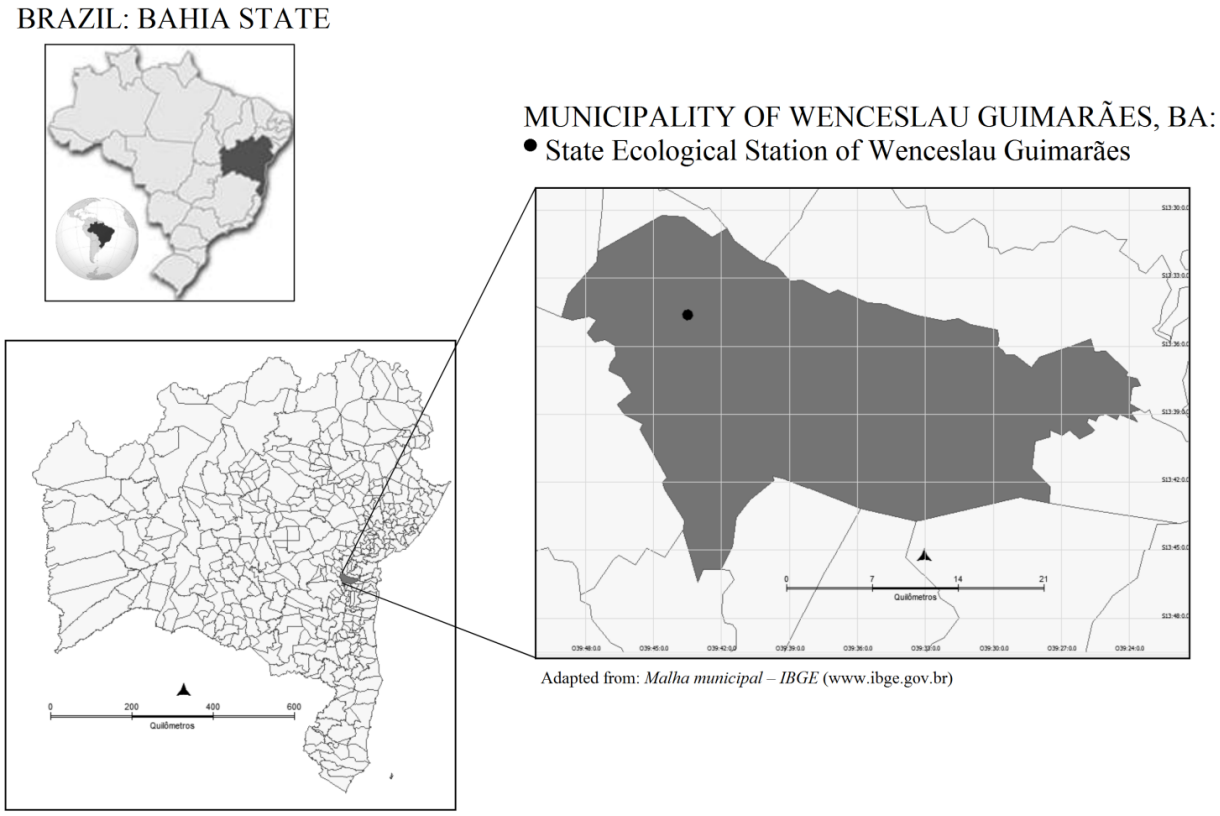

Figure 1. Location of sampling point in area of Atlantic Forest in the State Ecological Station of Wenceslau Guimarães, Bahia, Brazil.

Sampling

One sampling event per month consisting of two consecutive nights was carried out from October 2013 to March 2014. We made a total of 12 nights and 144 hours of sampling in two seasons: spring and summer. Sampling was carried out in the waning or new moon phases, between 6:00 p.m. and 6:00 a.m. (12 hours). The sampling period (October-March) was determined based on the fact that the richness and abundance of Sphingidae respond positively to the increase in rainfall after the driest period (Amorim, Ávila Jr, Camargo, Vieira, & Oliveira, 2009; Duarte Jr & Schlindwein, 2005a, 2005b). The pluriannual precipitation of Wenceslau Guimarães shows September (108 mm) and October (103 mm) with the lowest averages of the year, with a increase in November (136 mm), reaching the highest summer average in March (153 mm) (Climatempo, 2020).

We used a light trap consisting of a rectangle of white cotton cloth measuring 1.5x2.0 m, illuminated by a 250 watts mercury vapor mixed light lamp. Hawkmoths were collected manually or using an entomological net. The specimens were then sacrificed by lethal injection composed of ethyl ether 35% ($v\ v^{-1}$), through a fine needle ventrally inserted between the thorax and abdomen, and then put in individual entomological envelopes with the specimen information. In the laboratory, the collected specimens were numbered and identified, and their sampling date was entered in a database. The specimens were prepared and deposited in the collection of the *Laboratório de Sistemática e Conservação de Insetos, Setor de Ciências Biológicas, Centro de Ciências Agrárias, Ambientais e Biológicas, Universidade Federal do Recôncavo da Bahia,* Cruz das Almas, Bahia. Duplicates were deposited in the *Embrapa Cerrados* entomological collection, Planaltina, Distrito Federal.

Taxonomic identification and data analysis

Sphingidae nomenclature and classification followed Carcasson and Heppner (1996), Camargo et al. (2018) and Haxaire and Mielke (2019). The species were identified based on information and illustrations obtained in Martin, Soares, and Bizarro (2011), Camargo et al. (2018) and through consultation to the insect *Embrapa Cerrados* entomological collection, Planaltina, Distrito Federal.

Following Santos, Casagrande, and Mielke (2015), the richness and dominance were chosen to describe and depict the structure of the Sphingidae assemblage that was also qualitatively compared with other areas from Northeast Brazil, using only data from works with species level identification. These areas belong to the states of Maranhão, Ceará, Rio Grande do Norte, Paraíba, Pernambuco, Alagoas, and Bahia. For richness estimates based on abundance, we chose to use Chao1 estimator, which also considers the relationship between the number of singletons (rare species) and doubletons, and the ACE estimator that uses species with ten or less individuals per sample (Lee & Chao, 1994; Ferraz, Gadelha, & Aguiar-Coelho, 2009). We also used the Bootstrap estimator, which is based on species incidence, using data from all collected species (Ferraz et al., 2009). To obtain an estimated species richness, and in order to provide an accumulation curve, we used the statistical software EstimateS version 9.1 (Colwell, 2013).

Results and discussion

During the study, 266 specimens (N) were collected, distributed across 17 genera and 41 species (S). The average number of captures per hour was 1.85 individuals (Table 1).

The hawkmoth assemblage consists of the three subfamilies: Macroglossinae, Smerinthinae and Sphinginae. Macroglossinae was represented by two tribes: Dilophonotini, distributed across 20 species of 11 genera, represented 39.5% of the individuals collected (N = 105), and Macroglossini with 10 species of two genera accounted for 29.7% of the individuals collected (N = 79). Smerinthinae was represented by the only tribe that occurs in the Neotropical region, Ambulycini, with four species of two genera that represented 12.8% of the individuals collected (N = 34). Sphinginae was represented by the tribe Sphingini with seven species of two genera, which amounted to 18% of the individuals collected (N = 48) (Table 2).

Comparison of the SESWG species richness with that of published inventories in the northeastern Brazil indicated that SESWG occupies the third place in the ranking, after Balsas (BLS) and Feira Nova of Maranhão (FNM), two localities in the state of Maranhão that added 48 species to the region (Mielke & Haxaire, 2013). The Private Natural Heritage Reserve Frei Caneca (PNHRFC), Jaqueira, Pernambuco, with 50 species (Duarte Jr & Schlindwein, 2008), remains as the locality with the greatest species richness in northeastern Brazil (Table 3).

Among the species recorded in SESWG, seven were the most abundant with a total of ten or more individuals: *Isognathus swainsoni* Felder & Felder, 1862, *Pachylia darceta* Druce, 1881, *Xylophanes amadis* (Stoll, 1782), *Xylophanes anubus* (Cramer, 1777), *Protambulyx strigilis* (Linnaeus, 1771), *Manduca florestan* (Cramer, 1782) and *Manduca lucetius* (Cramer, 1780). Together they corresponded to 47.4% of the abundance and 17.1% of the richness. Seven species were represented by a single individual (singleton) and four by two individuals (doubletons) accounting for 26.8% of the richness in the SESWG (Table 1). Novotný and Basset (2000) state that these species may appear to be rare in inventories due to inadequate sampling. However, they can also represent transient species or specialists with genuinely low population levels. Among the collected singletons, five species were recorded previously in two or three northeastern biomes. Thus, we might conclude that they are common species widely distributed and that their low abundance in the SESWG was probably affected by the sampling technique (Table 1). Seasonality studies including the four seasons may elucidate the real abundance of these species in the SESWG.

Table 1. Checklist of the species of Sphingidae recorded in the State Ecological Station of Wenceslau Guimarães, Bahia. Previous records of the species in other inventories of the Northeast, abundance (N), relative abundance % (RA), months of occurrence and biomes. *New occurrence in northeastern Brazil; C: Caatinga; AF: Atlantic Forest; Ce: Cerrado. The numbers (1-14) represent the studies carried out in northeastern Brazil cited in Table 3.

Subfamily / Tribe / Species	N	RA	Months	Biomes
Macroglossinae (30)				
Dilophonotini (20)				
Callionima nomius (Walker, 1856)[9,14]	7	2.63	Nov, Jan-Mar	AF
Callionima parce (Fabricius, 1775)[4-5,9-10,12,14]	6	2.26	Jan-Mar	C, AF
Enyo lugubris lugubris (Linnaeus, 1771)[1-3,5-7,9,11-14]	1	0.38	Dec	C, AF, Ce
Erinnyis alope alope (Drury, 1770)[1-2,5-7,9-14]	1	0.38	Dec	C, AF, Ce
Erinnyis ello ello (Linnaeus, 1758)[1-14]	8	3	Jan-Feb	C, AF, Ce
Eumorpha anchemolus (Cramer, 1780)[1,7,9,10]	3	1.13	Jan	AF
Eumorpha capronnieri (Boisduval, 1875)[14]	4	1.50	Dec-Jan, Mar	AF
Eumorpha phorbas (Cramer, 1775)*	1	0.38	Jan	AF
Hemeroplanes triptolemus (Cramer, 1779)[7,9-11,14]	3	1.13	Feb-Mar	AF, Ce
Isognathus allamandae Clark, 1920[2-3,7,9,11-13]	3	1.13	Jan	C, AF, Ce
Isognathus excelsior (Boisduval, [1875])*	3	1.13	Jan-Feb	AF
Isognathus leachii (Swainson, 1823)[2,9,13]	8	3	Nov-Mar	C, AF, Ce
Isognathus swainsoni Felder & Felder, 1862[9,14]	33	12.41	Nov-Feb	AF
Oryba kadeni (Schaufuss, 1870)*	1	0.38	Feb	AF
Pachylia darceta Druce, 1881*	10	3.76	Nov-Dec, Mar	AF
Pachylia ficus (Linnaeus,1758)[1-2,4,8-11,13-14]	2	0.75	Jan	C, AF, Ce
Pachylioides resumens (Walker, 1856)[9,11-12,14]	3	1.13	Dec, Feb-Mar	C, AF, Ce
Perigonia stulta Herrich-Schäffer, [1854][10]	2	0.75	Jan	AF
Perigonia pallida Rothschild & Jordan, 1903[4-5,10-13]	1	0.38	Jan	C, AF, Ce
Pseudosphinx tetrio (Linnaeus,1771)[2,4-7,9-14]	5	1.88	Nov, Jan-Feb	C, AF, Ce
Macroglossini (10)				
Hyles euphorbiarum (Guérin-Méneville & Percheron, 1835)[1-6]	1	0.38	Nov	C, AF
Xylophanes amadis (Stoll, 1782)[9]	21	7.9	Nov-Mar	AF
Xylophanes anubus (Cramer, 1777)[9,11,14]	21	7.9	Dec-Mar	AF, Ce
Xylophanes chiron nechus (Cramer, 1777)[1-2,9-14]	3	1.13	Jan-Mar	C, AF, Ce
Xylophanes crenulata Vaglia & Haxaire, 2009[14]	2	0.75	Nov	AF
Xylophanes epaphus (Boisduval, [1875])[14]	3	1.13	Dec-Jan	AF
Xylophanes loelia (Druce, 1878)[7,9-10]	9	3.38	Dec-Jan, Mar	AF
Xylophanes pluto (Fabricius, 1777)[5,9-11,14]	3	1.13	Dec	C, AF, Ce
Xylophanes tersa tersa (Linnaeus, 1771)[1-14]	8	3	Nov, Jan-Mar	C, AF, Ce
Xylophanes thyelia thyelia (Linnaeus, 1758)[9]	8	3	Nov, Jan, Mar	AF
Smerinthinae (4)				
Ambulycini (4)				
Adhemarius gannascus (Stoll, 1790)[7-9]	6	2.26	Nov, Mar	AF
Adhemarius palmeri (Boisduval, [1875])[4,8,14]	7	2.63	Nov, Jan, Mar	AF
Protambulyx astygonus (Boisduval, [1875])[1,7-9,14]	6	2.26	Nov, Jan	AF
Protambulyx strigilis (Linnaeus, 1771)[1-14]	15	5.64	Nov-Mar	C, AF, Ce
Sphinginae (7)				
Sphingini (7)				
Cocytius antaeus (Drury, 1773)[2,4,6-7,9-10,14]	7	2.63	Dec-Feb	C, AF
Manduca diffissa tropicalis (Rothschild & Jordan, 1903)[4,9-10,12-13]	2	0.75	Nov, Jan	C, AF, Ce
Manduca florestan (Cramer, 1782)[1,9,11]	14	5.26	Oct-Jan, Mar	AF, Ce
Manduca hannibal hamilcar (Boisduval, [1875])[1,7-10,14]	8	3	Nov-Dec, Mar	AF
Manduca lefeburii lefeburii (Guérin-Méneville, [1844])[8,10-12]	1	0.38	Jan	C, AF, Ce
Manduca leucospila (Rothschild & Jordan, 1903)*	4	1.50	Nov-Dec	AF
Manduca lucetius (Cramer, 1780)[2]	12	4.50	Nov-Dec, Feb	C
Total	266	100		

Table 2. Species richness and abundance of Sphingidae by tribe in the State Ecological Station of Wenceslau Guimarães, Bahia.

Tribe	Species richness - Percentage		Abundance - Percentage	
Dilophonotini	20	48.8%	105	39.5%
Macroglossini	10	24.4%	79	29.7%
Ambulycini	4	9.7%	34	12.8%
Sphingini	7	17.1%	48	18%
Total	41	100%	266	100%

Table 3. Comparison of species richness of Sphingidae recorded in northeastern Brazil in the states of Maranhão, Ceará, Rio Grande do Norte, Paraíba, Pernambuco, Alagoas, and Bahia.

Biome - State	Number species	Number individuals	Sampling effort	Author (year)	Sampling technique
1. Atlantic Forest - Alagoas	32	Unknown	Unknown	Cardoso (1949)	Unknown
2. Caatinga - Ceará	32	Unknown	Bibliographic review	Silva (1967)	Unknown
3. Caatinga - Rio Grande do Norte	14	83	6 consecutive nights (72 hours)	Duarte Jr et al. (2001)	White panel with mixed lamp
4. Atlantic Forest (Enclave of Cerrado) - Paraíba	24	136	14 months (indefinite hours)	Darrault and Schlindwein (2002)	White panel with black light, mixed lamp and entomological net
5. Caatinga (Highland humid forest (Brejo) and a Caatinga area) - Paraíba	19	326	1 year (576 hours)	Gusmão and Creão-Duarte (2004)	Luiz de Queiroz trap
6. Caatinga - Rio Grande do Norte	20	593	14 months (308 hours)	Duarte Jr and Schlindwein (2005a)	White panel with mercury-vapor light
7. Atlantic Forest - Pernambuco	23	89	1 year (264 hours)	Duarte Jr and Schlindwein (2005b)	White panel with mixed lamp
8. Atlantic Forest - Border between Pernambuco and Alagoas	14	52	5 months (64 hours)	Lopes et al. (2005)	White panel with black light
9. Atlantic Forest - Pernambuco	50	379	1 year (264 hours)	Duarte Jr and Schlindwein (2008)	White panel with mercury-vapor light
10. Atlantic Forest (Semi-deciduous Seasonal Rainforest) - Pernambuco	31	277	27 months (486 hours)	Primo et al. (2013)	White panel with mercury-vapor light
11. Cerrado - Maranhão	48	Unknown	wet season	Mielke and Haxaire (2013)	White panel with mercury-vapor light
12. Caatinga - Ceará	35	287	5 months (indefinite hours)	Rafael et al. (2017)	Panel and with light
13. Cerrado - Maranhão	33	254	23 months (276 hours)	Câmara et al. (2018)	White panel with mixed lamp
14. Atlantic Forest (Tabuleiro Forest) - Bahia	40	208	6 months (192 hours)	Vila-Verde and Paluch (2019)	White panel with mixed lamp and other techniques
15. Atlantic Forest (Submontane Ombrophilous Dense Forest) - Bahia	41	266	6 months (144 hours)	Present study	White panel with mixed lamp

Seven species were collected exclusively in spring (October to December) and 14 only in summer (January to March). Thirteen species (31.7% of the richness and 8.3% of the abundance) occurred in a single month. Nineteen species were recorded in at least three months of sampling, of these ten species contributed with approximately 56% of abundance and 24.4% of richness: *Callionima nomius* (Walker, 1856) (N = 7; RA = 2.63%), *Isognathus leachii* (Swainson, 1823) (N = 8; RA = 3%), *Isognathus swainsoni* (N = 33; RA = 12.41%), *Pachylia darceta* (N = 10; RA = 3.76%), *Xylophanes amadis* (N = 21; RA = 7.9%), *Xylophanes anubus* (N = 21; RA = 7.9%), *Xylophanes tersa tersa* (Linnaeus, 1771) (N = 8; RA = 3%), *Protambulyx strigilis* (N = 15; RA = 5.64%), *Manduca florestan* (N = 14; RA = 5.26%) and *Manduca lucetius* (N = 12; RA = 4.5%) (Table 1).

Among the hawkmoths of SESWG, *Isognathus swainsoni* (N = 33), *Xylophanes amadis* (N = 21), *Xylophanes anubus* (N = 21) and *Manduca florestan* (N = 14) scored the highest abundance throughout the sample period. In the spring (October-December) we recorded 29 species of which *Isognathus swainsoni* (N = 19) and *Manduca florestan* (N = 10) had the highest dominance. One hundred and fourteen individuals were collected during the season, which corresponds to 43% of the specimens sampled. In summer (January-March) 35 species were found, of which three were dominant: *Isognathus swainsoni* (N=14), *Xylophanes amadis* (N = 13), and *Xylophanes anubus* (N = 13). One hundred and fifty two individuals were collected during the season, representing 57% of the total sampled. However, these species are not frequently recorded in northeastern Brazil. Cardoso (1949) collected *Manduca florestan* in the Atlantic Forest of Alagoas state; Duarte Jr and Schlindwein (2008) recorded the four species in the PNHRFC, Mielke and Haxaire (2013) collected *Xylophanes anubus* and *Manduca florestan* in BLS-FNM and Vila-Verde and Paluch (2019) collected *Isognathus swainsoni*, *Xylophanes anubus* in the *Campus* Sosígenes Costa (CSC), Porto Seguro, Bahia (Table 1 and 3).

Erinnyis ello ello (Linnaeus, 1758), *Protambulyx strigilis* and *Xylophanes tersa tersa* are quite common in northeastern Brazil, occurring in the Caatinga, Atlantic Forest and Cerrado biomes (Table 1). Pollination studies found 22 pollen types in mouth parts of *Erinnyis ello ello* and ten types in *Xylophanes tersa tersa*, which shows that these subspecies visit several plants and have great ecological importance (Darrault & Schlindwein, 2002).

The estimated richness was very close to the one observed with the estimators based on abundance Chao1 = 47.1 and ACE = 44.5 and also in the species incidence with Bootstrap = 46.23 (Figure 2). The highest estimate was obtained with Chao 1, probably as a function of the number of singletons and doubletons that represented 26.8% of the richness in the SESWG (Ferraz et al., 2009). The sampling efficiency was 87% with Chao1; 92.1% with ACE; and 88.7% with Bootstrap.

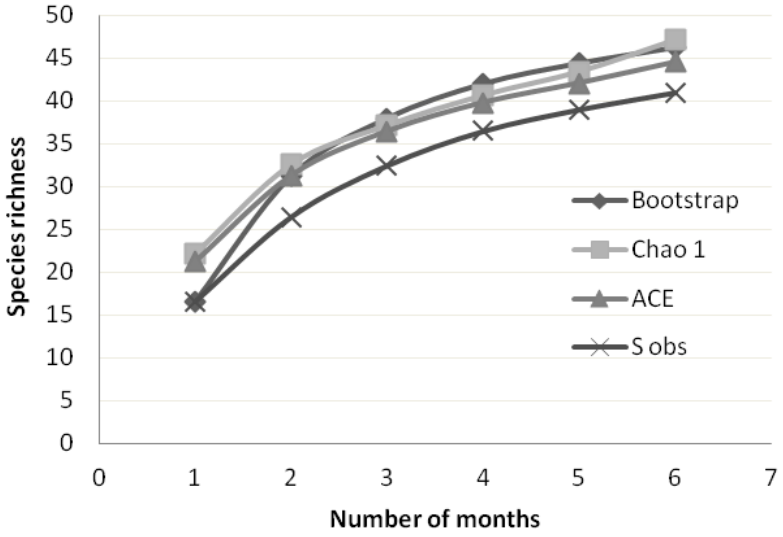

Figure 2. Richness estimation curves of Sphingidae species in the State Ecological Station of Wenceslau Guimarães, BA. S_{obs}: observed richness.

The total of hawkmoths species collected was considered high for the sampling effort. The SESWG showed a significantly higher species richness than the localities where one year or more of sampling effort with luminous attraction was carried out, as for example, two areas of Atlantic Forest in Pernambuco with records of 23 species in the Gurjaú Biological Reserve (GBR), Cabo de Santo Agostinho (Duarte Jr & Schlindwein, 2005b) and 31 species in the Tapacurá Ecological Station (TES), São Lourenço da Mata (Primo et al., 2013). The estimate of 47.1 species (Chao 1) for SESWG is consistent with the highest richness known for northeastern Brazil, with 50 species in the PNHRFC, a reservation that harbors one of the best-preserved Atlantic Forest fragments of Pernambuco state (Duarte Jr & Schlindwein, 2008) (Table 3).

The accumulated number of species throughout the six sampling periods in SESWG resulted in a curve close to the asymptote (Figure 3). In other areas of Atlantic Forest in northeastern Brazil, as the GBR, the species accumulation curve showed stabilization as of the sixth sampling (six months) (Duarte Jr & Schlindwein, 2005b). However, in PNHRFC, the curve reached the asymptote point and stabilization in the tenth sampling (ten months) (Duarte Jr & Schlindwein, 2008). Similarly, in TES, the curve showed an apparent stabilization after the fourteenth sampling (14 months) effort, but there was an increment of 11 species at the end of the sampling (total of 27 months) (Primo et al., 2013).

Analyzing geographic distribution of the species recorded in the SESWG, 19 species have only been sampled in the Atlantic Forest and one species in the Caatinga, three species were collected in the Caatinga and Atlantic Forest biomes, three species in the Atlantic Forest and Cerrado, and fifteen species are broadly distributed across the three biomes (Table 1 and 3).

In the SESWG the genera with highest species richness were *Xylophanes* Hübner, [1819], *Manduca* Hübner, [1807], *Isognathus* Felder & Felder, 1862 and *Eumorpha* Hübner, [1807]. This result is probably a direct function of the number of species in each genus, since these are the richest of them. The same pattern was also observed in the PNHRFC; in this area however, the genera *Callionima* Lucas, 1857, *Erinnyis* Hübner, [1819] and *Eumorpha* together correspond to 30% of the richness, with a total of 15 species (Duarte Jr & Schlindwein, 2008).

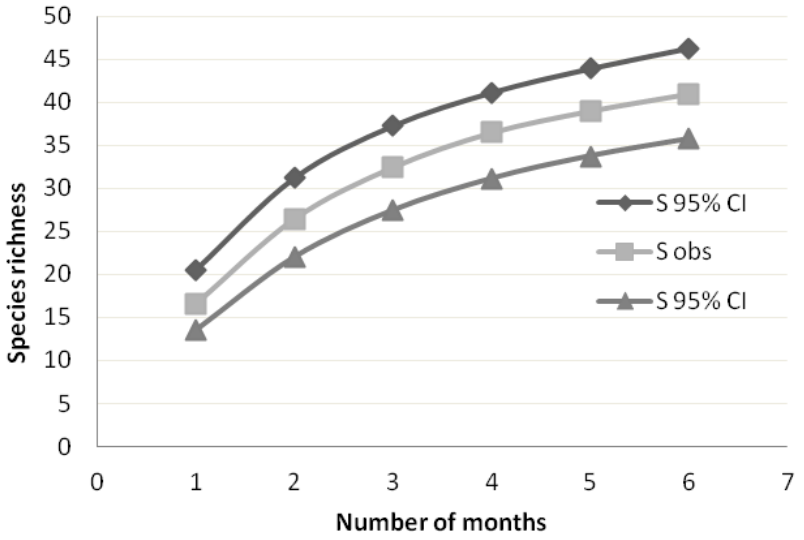

Figure 3. Species richness accumulation curve of Sphingidae recorded from October 2013 to March 2014 in the State Ecological Station of Wenceslau Guimarães, BA. S_{obs}: observed richness.

Five species, *Eumorpha phorbas* (Cramer, 1775), *Isognathus excelsior* (Boisduval, [1875]), *Oryba kadeni* (Schaufuss, 1870), *Pachylia darceta* and *Manduca leucospila* (Rothschild & Jordan, 1903) are recorded for the first time in the northeastern region. These species were recorded previously mainly in the Amazon biome (Motta, Ferreira, & Aguiar, 1991; Motta, Aguilera-Peralta, & Andreazze, 1998; Motta & Andreazze, 2001; Motta & Xavier-Filho, 2005; Lourido et al., 2018; Conceição & Teston, 2020). Martin et al. (2011) also recorded *Oryba kadeni*, *Eumorpha phorbas* and *Manduca leucospila* in the Atlantic Forest of Serra dos Órgãos, Rio de Janeiro State; Camargo et al. (2018) recorded *Pachylia darceta* in the Cerrado in the states of Maranhão and Minas Gerais, and according to Haxaire and Mielke (2019) this species also occur in the state of Santa Catarina.

In the *Catálogo dos Lepidoptera Cearenses*, Silva (1967) cited the only reference of the *Manduca lucetius* (Cramer, 1780) in the Northeast. The state of Ceará has most of its territory in the Caatinga phytogeographical domain. Thus, two species, *Isognathus excelsior* and *Manduca lucetius* found mainly in the Amazonian rainforest (Haxaire & Mielke, 2019) represent new records for the Atlantic Forest biome.

The present study is the second Sphingidae inventory undertaken in the state of Bahia. Among the 41 species recorded in the SESWG, 22 species were also recorded in the Tabuleiro Forest of the *Campus* Sosígenes Costa (CSC), Porto Seguro, Bahia, that now holds the fourth place in hawkmoths richness in northeastern Brazil with 40 species. Together, SESWG and CSC add up to a total of 59 species for the Atlantic Forest of Bahia. The following species were recorded only in the CSC: *Callionima inuus* (Rothschild & Jordan, 1903), *Enyo gorgon* (Cramer, 1777), *Enyo ocypete* (Linnaeus, 1758), *Erinnyis obscura obscura* (Fabricius, 1775), *Eumorpha fasciatus fasciatus* (Sulzer, 1776), *Isognathus australis* Clark, 1917, *Isognathus menechus* (Boisduval, [1875]), *Madoryx plutonius* (Hübner, [1819]), *Nyceryx coffaeae* (Walker, 1856), *Perigonia lusca* (Fabricius, 1777), *Phryxus caicus* (Cramer, 1777) (Macroglossinae: Dilophonotini); *Adhemarius daphne daphne* (Boisduval, 1875, *Adhemarius gagarini* (Zikán, 1935), *Protambulyx eurycles* (Herrich-Schäffer, [1854]) (Smerinthinae: Ambulycini); *Cocytius lucifer* Rothschild & Jordan, 1903, *Cocytius duponchel* (Poey, 1832), *Neococytius cluentius* (Cramer, 1775) (Sphinginae: Sphingini); *Agrius cingulata* (Fabricius, 1775) (Sphinginae: Acherontiini) (Vila-Verde & Paluch, 2019; Haxaire & Mielke, 2019).

The results obtained in this study after six months of samplings corroborate the high species richness expected for the Atlantic Forest and encourage new studies in SESWG, including other taxonomic groups. Species Inventories are important tools for assessing the local diversity and for allowing the promotion of conservation actions and policies (Santos, Mielke, & Casagrande, 2008; Freitas & Marini-Filho, 2011).

Conclusion

The richness found in the SESWG evidences the need for further studies in order to increase the sampling effort. It is important to note that most inventories carried out in the northeastern Atlantic Forest lasted a year or more, but the richness recorded was lesser or similar than the richness found in the SESWG after a six month sampling period.

The sampling efficiency obtained with the estimators Chao1= 87%, ACE= 92.1% and Bootstrap= 88.7% was higher than 80%. Notwithstanding, the accumulated number of species collected demonstrates the need for further sampling, including seasonality studies in order to better approach the curve asymptote.

The present study contributes to broaden the knowledge on richness and distribution of Sphingidae in northeastern Brazil. Together, SESWG and CSC add up a checklist of 59 species for the Atlantic Forest of Bahia. *Isognathus excelsior* and *Manduca lucetius* represented new records for the Atlantic Forest biome.

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References

Amorim, F. W., Ávila Jr, R. S., Camargo, A. J. A., Vieira, A. L., & Oliveira, P. E. (2009). A hawkmoth crossroads? Species richness, seasonality and biogeographical affinities of Sphingidae in a Brazilian Cerrado. *Journal of Biogeography 36*(4), 662-674. DOI: http://dx.doi.org/10.1111/j.1365-2699.2008.02033.x

Amorim, F. W., Wyatt, G. E., & Sazima, M. (2014). Low abundance of long-tongued pollinators leads to pollen limitation in four specialized hawkmoth-pollinated plants in the Atlantic Rain forest, Brazil. *Naturwissenschaften*, *101*(1)*,* 893-905. DOI: http://dx.doi.org/10.1007/s00114-014-1230-y

Câmara, J. T., Rocha, J. R. B., & Pereira, S. (2018). Sphingidae (Lepidoptera) ocorrentes no leste do Maranhão, Brasil. *EntomoBrasilis, 11*(3), 209-215. DOI: http://dx.doi.org/10.12741/ebrasilis.v11i3.793

Camargo, A. J. A., Camargo, W. R. F., Corrêa, D. C. V., Vilela M. F., & Amorim, F. W. (2018). *Mariposas polinizadoras do cerrado: identificação, distribuição, importância e conservação: Família Sphingidae (Insecta - Lepidoptera).* Brasília, DF: Embrapa Cerrados.

Carcasson, R. H., & Heppner, J. B. (1996). Sphingoidea, Sphingidae. In J. B. Heppner (Ed.), *Atlas of neotropical lepidoptera. checklist: part. 4B. Drepanoidea, Bombycoidea, Sphingoidea* (p. 50-60). Gainesville, FL: Association for Tropical Lepidoptera, Scientific Publishers.

Cardoso, A. (1949). Lepidópteros de Alagoas. *Revista de Entomologia, 20*(1-3), 427-436.

Climatempo, (2020). *Climatologia: Wenceslau Guimarães, BA*. Retrieved from http://www.climatempo.com.br/climatologia/5354/wenceslauguimaraes-ba

Colwell, R. K. (2013). *EstimateS: statistical estimation of species richness and shared species from samples. Version 9.1.0, user's guide and application*. Retrieved from http://purl.oclc.org/estimates

Conceição, A. C. W., & Teston, J. A. (2020). Temporal variation and ecological parameters of hawkmoths (Lepidoptera: Sphingidae) in savannahs in the Alter do Chão protection area, Santarém, Pará, Brazil. *Acta Scientiarum. Biological Sciences, 42*(1), 1-12. DOI: http://dx.doi.org/10.4025/actascibiolsci.v42i2.49064

D'Abrera, B. (1986). *Sphingidae mundi: hawk moths of the world.* Faringdon, UK: E. W. Classey.

Darrault, R. O., & Schlindwein, C. (2002). Esfingídeos (Lepidoptera, Sphingidae) no Tabuleiro Paraibano, nordeste do Brasil: abundância, riqueza e relação com plantas esfingófilas. *Revista Brasileira de Zoologia*, *19*(2), 429-443. DOI: http://dx.doi.org/10.1590/S0101-81752002000200009

Duarte Jr, J. A., & Schlindwein, C. (2005a). The highly seasonal hawkmoth fauna (Lepidoptera, Sphingidae) of the Caatinga of northeast Brazil: a case study in the state of Rio Grande do Norte. *Journal of the Lepidopterists' Society, 59*(4), 212-218. DOI: http://dx.doi.org/10.1590/S0001-37652013000300017

Duarte Jr, J. A., & Schlindwein, C. (2005b). Riqueza, abundância e sazonalidade de Sphingidae (Lepidoptera) num fragmento de Mata Atlântica de Pernambuco, Brasil. *Revista Brasileira de Zoologia, 22*(3), 662-666. DOI: http://dx.doi.org/10.1590/S0101-81752005000300022

Duarte Jr, J. A., & Schlindwein, C. (2008). Hawkmoth fauna of a northern Atlantic Rain Forest remnant (Sphingidae). *Journal of the Lepidopterists' Society, 62*(2), 71-79.

Duarte Jr, J. A., Motta, C. S., & Varela-Freire, A. A. (2001). Sphingidae (Lepidoptera) da estação ecológica do Seridó, Serra Negra do Norte, Rio Grande do Norte, Brasil. *Entomología y Vectores, 8*(3), 341-347.

Duarte, M., Marconato, G., Specht, A., & Casagrande, M. M. (2012). Lepidoptera Linnaeus, 1758. In J. A. Rafael, G. A. R. Melo, C. J. B. Carvalho, S. A. Casari & R. Constatino (Eds.), *Insetos do Brasil: diversidade e taxonomia* (p. 625-682). Ribeirão Preto, SP: Holos.

Ferraz, A. C. P., Gadelha, B. Q., & Aguiar-Coelho, V. M. (2009). Análise faunística de Calliphoridae (Diptera) da Reserva Biológica do Tinguá, Nova Iguaçu, Rio de Janeiro. *Revista Brasileira de Entomologia 53*(4), 620-628. DOI: http://dx.doi.org/10.1590/S0085-56262009000400012

Freitas, A.V.L., & Marini-Filho, O. J. (2011). *Plano de ação nacional para conservação dos lepidópteros ameaçados de extinção.* Brasília, DF: Instituto Chico Mendes de Conservação da Biodiversidade.

Gusmão, M. A. B., & Duarte, A. J. C. (2004). Diversidade e análise faunística de Sphingidae (Lepidoptera) em área de brejo e caatinga no estado da Paraíba, Brasil. *Revista Brasileira de Zoologia, 21*(3), 491-498. DOI: http://dx.doi.org/10.1590/S0101-81752004000300011

Haxaire, J., & Mielke, C. G. C. (2019). A revised and annotated checklist of the Brazilian Sphingidae with new records, taxonomical notes, and description of one new species (Lepidoptera Sphingidae). *The European Entomologist, 11*(3-4), 101-187.

Hilty, J., & Merenlender, A. (2000). Faunal indicator taxa selection for monitoring ecosystem health. *Biological Conservation, 92*(2), 185-197. DOI: http://dx.doi.org/10.1016/S0006-3207(99)00052-X

Kawahara, A. Y., Mignault, A. A., Regier, J. C., Kitching, I. J., & Mitter, C. (2009). Phylogeny and Biogeography of Hawkmoths (Lepidoptera: Sphingidae): Evidence from Five Nuclear Genes. *Plos One, 4*(5), p. 1-11. DOI: http://dx.doi.org/10.1371/journal.pone.0005719

Kitching, I. J., & Cadiou, J.-M. (2000). *Hawkmoths of the world: an annotated and illustrated revisionary checklist (Lepidoptera: Sphingidae)*. New York, NY: Cornell University Press.

Lee, S.-M., & Chao, A. (1994). Estimating population size via sample coverage for closed capture-recapture models. *Biometrics 50*(1),88-97. DOI: http://dx.doi.org/10.2307/2533199

Lopes, A. V., Medeiros, P. C., Aguiar-Neto, A. V., & Machado, I. C. (2005). Esfingídeos. In K. C. Porto, J. S. Almeida-Cortez, & M. Tabarelli (Orgs.), *Diversidade biológica e conservação da floresta Atlântica ao norte do Rio São Francisco* (p. 228-235). Brasília, DG: Ministério do Meio Ambiente.

Lourido, G. M., Motta, C. S., Graça, M. B., & Rafael, J. A. (2018). Diversity patterns of hawkmoths (Lepidoptera: Sphingidae) in the canopy of an ombrophilous forest in Central Amazon, Brazil. *Acta Amazonica, 48*(2), 117-125. DOI: http://dx.doi.org/10.1590/1809-4392201704721

Marinoni, R. C., Dutra, R. R. C., & Mielke, O. H. H. (1999). Levantamento da fauna entomológica no estado do Paraná. IV. Sphingidae (Lepidoptera). Diversidade alfa e estrutura de comunidade. *Revista Brasileira de Zoologia*, *16*(Supl 2), 223-240. DOI: http://dx.doi.org/10.1590/S0101-81751999000600023

Martin, A., Soares, A., & Bizzaro, J. (2011). *Guia dos Sphingidae da Serra dos Órgãos, sudeste do Brasil.* Oxford, UK: Information Press.

Mielke, C. G. C., & Haxaire, J. (2013). A hawk moths fauna of southern Maranhão state, Brazil, with description of a new species of *Orecta* Rothschild & Jordan, 1903 and the female of *Nyceryx mielkei* Haxaire, 2009 (Lepidoptera: Sphingidae). *Nachrichten des Entomologischen Vereins Apollo, N. F., 34*(3), 109-116.

Motta, C. S., & Andreazze, R. (2001). Esfingofauna (Lepidoptera, Sphingidae) do Parque Nacional do Jaú e arredores, Amazonas, Brasil. *Acta Amazonica, 31*(4), 643-654. DOI: http://dx.doi.org/10.1590/1809-43922001314654

Motta, C. S., & Xavier-Filho, F. F. (2005). Esfingídeos (Lepidoptera, Sphingidae) do município de Beruri, Amazonas, Brasil. *Acta Amazonica*, *35*(4), 457-462. DOI: http://dx.doi.org/10.1590/S0044-59672005000400010

Motta, C. S., Aguilera-Peralta, F. J., & Andreazze, R. (1998). Aspectos da Esfingofauna (Lepidoptera, Sphingidae), em área de terra-firme, no estado do Amazonas, Brasil. *Acta Amazonica, 28*(1), 75-92. DOI: http://dx.doi.org/10.1590/1809-43921998281092

Motta, C. S., Ferreira, R. L. M., & Aguiar, N. O. (1991). Sobre a esfingofauna da Ilha de Maracá e da Serra de Pacaraima, Roraima (Lepidoptera, Sphingidae). *Acta Amazonica*, *21*(único), 319-324. DOI: http://dx.doi.org/10.1590/1809-43921991211324

Novotný, V., & Basset, Y. (2000). Rare species in communities of tropical insect herbivores: pondering the mystery of singletons. *Oikos 89*(3), 564-572. DOI: http://dx.doi.org/10.1034/j.1600-0706.2000.890316.x

Primo, L. M., Duarte, J. A., & Machado, I. C. (2013). Hawkmoth fauna (Sphingidae, Lepidoptera) in a semi-deciduous rainforest remnant: composition, temporal fluctuations, and new records for northeastern Brazil. *Anais da Academia Brasileira de Ciências, 85*(3), 1177-1188. DOI: http://dx.doi.org/10.1590/S0001-37652013000300017

Rafael, J. A., Oliveira, M. L., Souza, U. R. M., Galileo, M. H. M., Silva, A. S., Mello, F. V., ... Limeira-de-Oliveira, F. (2017). Insetos dos Parques Nacionais de Sete Cidades e de Ubajara. In W. Mantovani, R. F. Monteiro, L. Anjos, M. O. Cariello (Orgs.), *Pesquisas em unidades de conservação no domínio da caatinga: subsídios à gestão* (p. 301-388). Fortaleza, CE: Edições UFC.

Rigueira, D. M. G., Molinari, A. L. M., Mariano, D. L. S., Reis, R. M., Portugal, A. B., Santana, N. S., & Santos, R. A. (2012). Influência da distância da borda e do adensamento foliar sobre a abundância de plantas pioneiras em um fragmento de floresta tropical submontana na Estação Ecológica de Wenceslau Guimarães (Bahia, Brasil). *Acta Botanica Brasilica, 26*(1), 197-202. DOI: http://dx.doi.org/10.1590/S0102-33062012000100019.

Santos, E. C., Mielke, O. H. H., & Casagrande, M. M. (2008). Butterfly inventories in Brazil: the state of the art and the priority-areas model for research aiming at conservation. *Natureza & Conservação, 6*(2), 176-198.

Santos, F. L., Casagrande, M. M., & Mielke, O. H. H. (2015). Saturniidae and Sphingidae (Lepidoptera, Bombycoidea) assemblage in Vossoroca, Tijucas do Sul, Paraná, Brazil. *Anais da Academia Brasileira de Ciências, 87*(2), 843-860. DOI: http://dx.doi.org/10.1590/0001-3765201520140368

Silva, A. G. (1967). Catálogo dos Lepidoptera Cearenses. *Revista do Instituto do Ceará, 1*(1), 91-112.

Vila-Verde, G., & Paluch, M. (2019). Fauna de Esfingídeos (Lepidoptera; Bombycoidea; Sphingidae) em um fragmento de Mata Atlântica no Sul do estado da Bahia. *EntomoBrasilis, 12*(3), 113-117. DOI: http://dx.doi.org/10.12741/ebrasilis.v12i3.870