

Scorpions (Arachnida, Scorpiones) at elevated altitudes of an area of conservation in the Caatinga

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ABSTRACT

This study aims to report the diversity of scorpions at elevated altitudes in the *Parque Estadual das Sete Passagens* (PESP), in an area of conservation located in the *Chapada Diamantina* within the Caatinga domain in north-eastern Brazil. Data collection occurred in December 2016 and December 2017, through the use of pitfall traps and nocturnal manual collection with the help of ultraviolet torches. 86 individuals were collected, pertaining to nine species, grouped into two families. The Bothriuridae represented 71% of samples, with *Bothriurus* sp. 1 occurring at all sample altitudes. Whereas, the Buthidae represente 29% of samples, with *Ananteris* sp, the most represented species, occurring at altitudes of 1,000m and 1,076m and *Tityus stigmurus* inhabiting areas with extensive human presence. The ample diversity found in the PESP, reveals that this location can be considered representative of the scorpiofauna of Bahia and of the Caatinga, especially due to the lack of data available on scorpions in semi-arid environments.

Keywords: Chapada Diamantina; Scorpiofauna; Parque Estadual das Sete Passagens

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1 INTRODUCTION

Scorpions are chelicerate arthropods that occur in almost all terrestrial ecosystems (POLIS, 1990). They comprise a large order within the Arachnida class, with over 2,400 described species (REIN, 2019), distributed across 17 families (FET et al., 2000) and 163 catalogued genera (BRAZIL; PORTO, 2011).

Despite their occurrence in diverse terrestrial ecosystems, applying predatory pressure on other arthropods (BROWNELL; POLIS, 2001), the group is still poorly represented in many countries (SHEHAB et al., 2011; DI et al., 2013; BRAZIL; PORTO et al., 2011) and little is known about their diversity in semi-arid environments, especially in the Brazilian Caatinga (ARAÚJO et al., 2010; CARMO et al., 2013; PORTO et al., 2014).

The Caatinga is a semi-arid ecosystem known for its high temperatures and lack of water; it also represents one of the largest savannahs in the world, whose existence is restricted to Brazilian national territory (PRADO, 2003; LEAL et al., 2005). These peculiarities result in the formation of unique environments (SILVA, 2003; SILVA et al., 2017), whose areas can reach to altitudes of over 1,000m and present considerable levels of endemism (BRASIL, 2005).

There are 28 species of scorpions in Caatinga, comprising 25% of the endemism concerning Brazilian scorpiofauna (PORTO et al., 2014). Although it is one of the most representative ecosystems for scorpions, approximately 580 thousand km² of the Caatinga has no register of species for this group, representing a very significant gap in data, especially since over 70% of its area is under-sampled (LIRA-DA-SILVA et al., 2005; PORTO et al., 2014; BARROS, 2018). This situation is directly evident through the absence of data related to the ecology and biology of species, registers of endemic elements, such as information on the occurrence and diversity of species found at elevated altitudes (LOURENÇO, 2010; PORTO et al., 2010; OTT; OTT, 2014; LIRA et al., 2019).

The current knowledge on scorpions at elevated altitudes in Brazil is basic, with a strong lack of data for the Caatinga and many ecosystems across national territory (LOURENÇO; EICKSTEDT, 2009; LOURENÇO, 1988; LIRA et al., 2016; OTT; OTT, 2014).

Moreover, studies that have approached this subject are relatively recent, and have presented information in a secondary manner (BORTOLUZZI et al., 2007; BERTANI et al., 2008; LIRA; ALBUQUERQUE, 2014).

Thus, this study aimed to register scorpion species that occur in the *Parque Estadual das Sete Passagens*, investigating the distribution of species in environments with elevated altitudes.

2 MATERIALS AND METHODS

2.1 Study area

The study area was located in the *Parque Estadual das Sete Passagens* (PESP) (11°22'S e 40°31'W), an area of conservation that stretches over 2,800 ha and is situated in the region of *Chapada Diamantina*, in the municipality of Miguel Calmon, Bahia.

Inserted in the Caatinga biome, the PESP has phytophysionomies of seasonal forest and rocky plains and is located at an elevated altitude that varies between 800m and 1,300m above sea level. The soil type is composed of Argisols and Neosols and is an area characterised by an average annual temperature of 23°C, with precipitation levels of approximately 566mm (BAHIA, 2008).

The PESP is an area of conservation that was created in the year 2000 (State Law nº 7.808), with the aim of protecting this space against illegal activities, the disappearance of endemic species and the exploration of water and gold resources. Although, two decades have almost passed since its creation, scientific research in this area is still recent.

Scorpions were collected with the permission of the *Instituto Chico Mendes da Conservação de Biodiversidade* (ICMBIO) #52972-4, and of the *Instituto do Meio Ambiente e Recursos Hídricos* (INEMA) nº 2016-007721/TEC/PES-0006.

2.2 Sample design

Two sample collections were performed, both during the dry season. The first collection occurred in December 2016, and lasted two days, and the second collection occurred in December 2017, and lasted five days.

For the sampling of scoriofauna, transects were placed at six elevated altitudes. The first elevated altitude was located at 920m above sea level, the second at 1,000m, the third at 1,024m, the fourth at 1,049m, the fifth at 1,076m and the sixth at 1,100m.

2.3 Sampling

For scorpion sampling, two collection methods were used: nocturnal manual collection and pitfall-traps.

The manual nocturnal collection was performed with the aid of ultraviolet torches at each altitude. At each altitude, four transects of 30m were placed at intervals of 50m between transects, placed at the same altitude. A pair of collectors walked along these transects for one hour, inspecting fallen trunks, burrows, bromeliads and other micro-environments, between 18:00-23:00. During the first collection, eight hours of sampling was performed and during the second collection 16 hours of sampling was performed, resulting in a total of 24 hours of sampling effort. A one-time occasional nocturnal manual collection occurred in an area designated for visitors to the PESP, an environment that did not fall within the environmental parameters established for the transects. Each individual was collected with the use of pincers and represented one sample. The captured animals were placed in plastic pots (universal collectors) with 70% alcohol.

The pitfall-traps were comprised of plastic recipients (diameter of 20cm and volume of 2 litres) buried at soil level. Liquid composed of hypersaline solution was placed in each recipient, to conserve the samples, as well as drops of detergent to reduce the superficial tension of the water. Two transects were implemented at a length of 100m per altitude, with 50m intervals between transects. For each transect, eight traps were installed, resulting in a total of 16 traps per altitude. These pitfall

traps were placed at opposite sides of the transect i.e. four traps were placed on the right side of the transect and 4 on the left. The pitfall traps located on the same side were placed at intervals of 50m and the traps on opposite sides were placed at 25m intervals. In total, 80 traps were active for five consecutive days. These traps were only implemented during the second collection (December 2017) and were not used at the first elevated altitude (920m).

Some of the collected material is available at the Zoological Collection at the Butantan Institute, São Paulo (Curator: Antônio Domingos Brescovit) and the rest can be found in the Arachnological Reference Collection of the Catholic University of Salvador, Bahia (Curator: Marcelo Cesar Lima Peres), Brazil.

2.4 Data analysis

The species richness estimate was based on the data provided by the joining of the registers collected using the two sampling methods, with the aim of obtaining information about the total number of species collected. Of the 13 estimators generated by the analysis, the Bootstrap Mean and Cole Rarefaction estimators were selected, due to the stability of their performances, as considering estimators that present curves with a greater tendency of stability and do not deviate from the observed species curve, is one of the best methods of interpreting the information obtained (TOTI et al., 2000).

Since the data for the species *Tityus stigmurus* were collected in environments out with the established sample design, they were not used in the estimated richness analysis.

3 RESULTS

Were collected 104 scorpions, belonging to nine species (Table 1). The most common species were *Bothriurus* sp1, which comprised 53.08% of the scorpions collected, followed by *Anateris* sp (19.85%), *Bothriurus asper* Pocock, 1893 (4.40%),

Bothriurus sp.2 (7.40%) and *Anateris mauryi* Lourenço 1982 (6.17%). The species *Tityus stigmurus* (Thorell, 1876) was also collected during a one-time sampling event.

Table 1 - Frequency, sampling method and altitude of scorpions collected in the *Parque Estadual das Sete Passagens*

Family	Species	Number of individuals (%)	Sampling Method	Registered Altitude(s)
Buthidae	<i>Anateris mauryi</i> Lourenço, 1982	5 (6.17%)	Manual nocturnal	920m and 1,049 m
	<i>Anateris</i> sp.	16 (19.85%)	Manual nocturnal / Pitfall-traps	1,000, 1,024, 1,049 and 1,076 m
	<i>Tityus martinpaechi</i> Lourenço, 1982	2 (2.40%)	Manual nocturnal / Pitfall-traps	929 and 1,076 m
	<i>Tityus neglectus</i> Mello-Leitão, 1932	1 (1.23%)	Manual nocturnal	1,049 m
	<i>Tityus stigmurus</i> (Thorell, 1876)	23	Manual nocturnal	-
Bothriuridae	<i>Bothriurus asper</i> Pocock, 1893	6 (7.40%)	Manual nocturnal / Pitfall-traps	920, 1,000 and 1,100 m
	<i>Bothriurus rochai</i> Mello-Leitão, 1932	2 (2.40%)	Manual nocturnal	920, 1,000 and 1,076 m
	<i>Bothriurus</i> sp.1	43 (53.08%)	Manual nocturnal / Pitfall-traps	1,000, 1,024, 1,049, 1,076 and 1,100 m
	<i>Bothriurus</i> sp.2	6 (7.40%)	Manual nocturnal / Pitfall-traps	1,000, 1,049 and 1,100m

The area with an elevated altitude of 1,049m above sea level was the most representative altitude, as the greatest number of individuals were found at this

altitude (25), as well as the greatest number of species (5). Across the altitudinal gradient, the number of individuals from the Bothriuridae family represented more than double the number collected from the Buthidae family, with 57 and 24 individuals respectively.

From the Bothriuridae family, the species *Bothriurus asper*, *B. rochai* and *Bothriurus* sp.2 were collected at three altitudes, where together they represented 17% of the samples collected. *Bothriurus* sp.1 stood out, with the highest frequency of samples collected (n=43), representing over half of the total number of scorpions collected. As well as being the most representative species, it also presented the greatest distribution between species observed in this study, occurring in five of six altitudes. Currently, this species is under description at the Butantan Institute, IBSP.

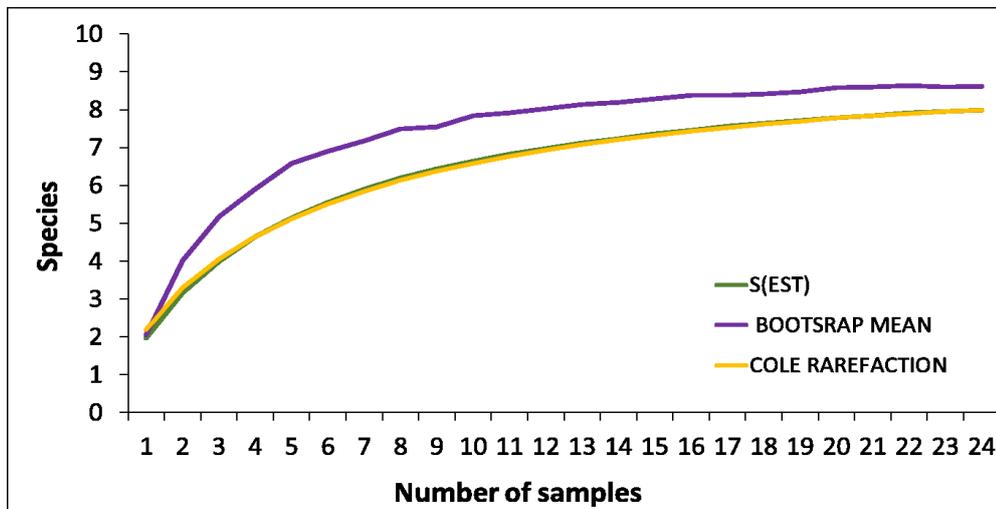
Within the Buthidae family, the species *Ananteris mauryi* and *Tityus matinpaechi* were observed at two altitudes, whereas, *T. neglectus* was found only at one altitude and where together the three species represented 10% of the samples collected. The *Ananteris* sp. occurred at four of the six altitudes and was the second most common species in this study, representing 20% of samples collected.

The species *Tityus stigmurus* was also collected in this study. However, all the individuals were observed to inhabit areas designated for tourists, that were located out-with the sample area established for this study. As such, the individuals collected were not included in the percentage of total species collected.

The majority of individuals of species *Anateris* sp. and *Bothriurus asper* were collected through manual nocturnal collection, which was also responsible for capturing all the individuals of the taxon *A. mauryi* and the only *T. neglectus* individual. On the other hand, the pitfall traps were responsible for collecting over half of the *Bothriurus* sp1. And *Bothriurus* sp. 2.

Joining together the data collected using the two sampling methods, generated estimates similar to the number of scorpion species collected in the PESP, where the accumulation curves aspired to stability. The Bootstrap Mean estimator presented better performance, estimating nine species, whereas, the Cole Rarefaction estimated eight species, demonstrating low variation between estimators (Figure 1).

Figure 1 - The number of species observed ($S(\text{obs})$) and richness observed of the scorpion species found from 24 samples in the *Parque Estadual das Sete Passagens*



4 DISCUSSION

Bahia is a state in north-eastern Brazil which houses the largest diversity of scorpion species (28 species) in Brazil (BRAZIL; PORTO, 2011) and in terms of diversity, comes second only to the Brazilian state of Amazonas (PINTO-DA-ROCHA et al., 2007; CARVALHO et al., 2017). Despite this information, Porto et al. (2010) observed the existence of an extensive sampling gap, where there were no registers of scorpions in many natural and municipal areas, resulting in a total of over 60% of under-sampling across the entire state of Bahia.

The PESP was included in this percentage of under-sampling, as there were no scientific data on the scorpiofauna that occur in this area of conservation. However, this study demonstrated the occurrence of nine species, indicating that the study area can be considered scorpion-species rich.

This richness can be considered as ample when comparing the results to other areas, where studies have been performed with greater sample efforts, such as the Ferreira Penna and Juruti Plateau Scientific Station, Pará (6 sp.) (PINTO-DE-ROCHA et al., 2007), the Caxiuna National Forest, Pará (6 sp.) (BONALDO et al., 2009), the

Marechal Newton Cavalcante Instruction Field, Pernambuco (5 sp.) (LIRA et al., 2018) and the Buraquinho Forest, Paraíba (4 sp.) (DIAS et al., 2006).

The occurrence of nine scorpion species in the PESP confirms the area as being an area of conservation, helping with the management of species, especially since several locations considered as priority areas for the conservation of invertebrates in the Caatinga do not have registers of scorpions (PORTO et al., 2014). Furthermore, there are very few studies that register a representative and/or expressive number of scorpion species in this ecosystem (ARAÚJO et al., 2010; CARMO et al., 2013; LIRA et al., 2019) which is valuable for understanding the scorpiofauna of semi-arid ecosystems.

A reflection of this can be seen in a recent study in an area of Caatinga in north-eastern Brazil. Carmo et al. (2013) required a sample effort of 216 hours to find six scorpion species. In another study carried out in a bioclimactic gradient between the Caatinga and Atlantic Forest, Lira et al. (2019) required 144 hours to find 10 scorpion species in the area of Caatinga alone. Whereas, with a sample effort of 144 hours, we registered eight species as well as one species registered during a one-time sampling event. As such, we required a lower sample effort and were still able to encounter an ample number of species.

The greatest number of individuals from the Bothriuridae family collected (70% of the total) compared to those collected from the Buthidae family, is likely due to the different foraging habitats used by the two families, which may affect their relative abundances in the study area (ARAÚJO et al., 2010). The fossorial behaviour observed for taxa of the Bothriuridae family, favours the capture of individuals by pitfall traps (SCHMIDT, 2008; LIRA et al., 2018). However, the seasonality present in the Caatinga, appears to be predominant factor influencing scorpion foraging, in terms of searching for food resources, as well as searching for sexual partners (ARAÚJO et al., 2010; CARMO et al., 2013).

Despite their fossorial behaviour, *Bothriurus asper* and *B. rochai* were collected through manual nocturnal collection, between altitudes of 920m and 1,076m. These species occur, principally, in the northeast of Brazil, with *B. asper* being restricted to

this region (BRAZIL; PORTO, 2011; SANTOS-DA-SILVA et al., 2017). It is worth mentioning, that in the latest checklist referring to scorpiofauna in Bahia, Porto et al. (2010) did not list the occurrence of *B. asper* nor *B. rochai* in Miguel Calmon. As such, our observation of the two species in this municipality, extends their known distribution.

Bothriurus sp. 1, presented the greatest spatial distribution in this study, occurring in five of the six study altitudes, varying between altitudes of 1,000m and 1,100m. Based on the results of this study, we can infer that this species presents less ecological requirements, especially due to its occurrence throughout almost the entire altitudinal gradient included in this study. Furthermore, 95% of the individuals collected of this species were males, which may indicate a period of reproduction, with this being a key factor responsible for elevating Bothriuridae activity in the soil (ARAÚJO et al., 2010; OTT; OTT, 2014).

However, this species is currently being described at the Butantan Institute, IBSP and it is therefore, necessary to wait for the conclusion of this process to further explore discussions related to this species' habitat and reproductive preferences.

Ananteris sp. was the species with the second greatest special distribution in this study, occurring between altitudes of 1,000m and 1,076m. This can be reflected through its active foraging habit, which has been previously described for other species related to this genus, such as *Ananteris mauryi* (LIRA et al., 2013; LIRA et al., 2018). As with *Bothriurus* sp. 1, this species is currently being described by the Butantan Institute, IBSP and as a result it is necessary to wait for the conclusion of this description in order to retrieve more information about its habits.

The *Ananteris mauryi* species was the fifth most common species collected in this study, occurring at altitudes of 920m and 1,049m. This species frequently inhabits micro-environments of plant litter, especially in the Atlantic Forest, occurring in the superior or inferior layers, depending on the season and maturation phase (LIRA et al., 2013; SANTOS et al., 2018; DIONISIO-DA-SILVA, 2018). The first register of occurrence of this taxon in the state of Bahia occurred almost a decade ago (BRAZIL; PORTO, 2011; PORTO et al., 2010) however, this register did not include the

municipality of Miguel Calmon and therefore, this study extends its distribution. Furthermore, its register in the Caatinga was based on data from scientific collections (PORTO et al., 2014). As such, in this study we confirm its occurrence in the Caatinga, however, this time through samples collected at elevated altitudes.

There is limited information on the species *T. neglectus*, which was collected at an altitude of 1,049m, due to the previous observation of a possible preference for the occupation of bromeliads (LOURENÇO; EICKSTEDT, 1988; LIRA; ALBUQUERQUE, 2014). This can be attributed to the preference and dependence that scorpions can present in determined micro-habitats (BROWNELL; POLIS, 2001). However, the only individual collected in this study occupied the superior region of plant litter and was not found near bromeliads (*Pers. Obs.*).

Contrary to *T. neglectus*, there is no information on *T. matinpaechi* distribution, preference or any type of specification regarding analysed habitats, which is alarming, since as well as not being considered a species important to human health, it has been reported as being responsible for cases of scorpion stings in the state of Bahia (PORTO et al., 2010b). Additionally, its occurrence in Bahia, has been previously described for three other municipalities (Canarana, Central and Salvador) (PORTO et al., 2010), with it now being registered in the municipality of Miguel Calmon, extending its distribution.

Although it has not been previously collected through the use of transects established during sampling efforts, *Tityus stigmurus* was registered in this study. This species is considered to be synanthropic and occurs in all regions across Brazil (LOURENÇO; EICKSTEDT, 2009; BRAZIL; PORTO, 2011). It is currently characterised as one of the most dangerous scorpions in the country, as it presents relative importance to public health (LIRA-DA-SILVA, 2000; RECKZIEGEL; PINTO, 2012), as well as being one of the most prevalent species in cases of scorpion stings in north-eastern Brazil and Bahai (LIRA-DA-SILVA, 2009; BATISTA et al., 2006; BRAZIL et al., 2009). The fact that we found several specimens over a short time frame in the PESP, reinforces the idea that new measures must be implemented to avoid accidents with this animal,

especially since the individuals registered in this study were found to inhabit an environment with a significant human presence.

The differences observed in terms of the capture of species between altitudes can be related to the foraging behaviour of scorpions (ARAÚJO et al., 2010; LIRA et al., 2017). However, our data differed from those of Lira et al. (2013) for the species *A. mauryi*, which despite being an active forager and therefore, has the tendency of being observed in pitfall traps, was not collected by this method.

Furthermore, despite having been previously collected by pitfall traps (DIAS et al., 2006), the only *T. neglectus* individual was collected through active searching, a method that allowed for the sampling of this species, and that also aided in discussions about the ecological preferences of scorpions. This information reinforces the importance of the use of both methods, to allow for the most reliable sampling of scorpiofauna in an area, permitting the accumulation of new information and generating discussions on the topic of the ecology and biology of the species.

The data presented here demonstrate the occurrence of nine species of scorpions in the *Parque Estadual das Sete Passagens*, resulting in an increase in the distribution for some species and therefore, the location of the PESP becomes relevant for scorpiofauna in Bahia and the Caatinga. As such, this information demonstrates the importance of semi-arid environments for scorpions, through their unique ecological characteristics. This may encourage the production of new studies which evaluate the spatial distribution of these species, as well as studies investigating the biology of populations and research aiming to understand how species respond to physical and environmental variation at elevated altitudes in this ecosystem. However, it is still necessary to intensify the production of studies focussing on the Caatinga, especially because of the large quantity of environments that have still not been sampled and may potentially provide new information.

5 CONCLUSIONS

The data presented here demonstrate the occurrence of nine species of scorpions in the *Parque Estadual das Sete Passagens*, resulting in an increase in the distribution for some species and therefore, the location of the PESP becomes relevant for scorpiofauna in Bahia and the Caatinga. As such, this information demonstrates the importance of semi-arid environments for scorpions, through their unique ecological characteristics. This may encourage the production of new studies which evaluate the spatial organisation of these species, as well as studies investigating the biology of populations and research aiming to understand how species respond to physical and environmental variation at elevated altitudes in this ecosystem. However, it is still necessary to intensify the production of studies focussing on the Caatinga, especially because of the large quantity of environments that have still not been sampled and may potentially provide new information.

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