Richness of tiger moths (Lepidoptera: Arctiidae) in the Brazilian Cerrado: how much do we know?

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ABSTRACT. The Cerrado biome is located in the central region of Brazil and consists mainly of savanna vegetation. In this study we assessed the richness of tiger moths (Arctiidae) of the Brazilian Cerrado. Specifically, we 1) assessed species richness in one-degree cells in the biome, 2) identified areas where these moths are poorly known, and 3) tested if similarities in species composition are related to geographical distance in the relatively well-sampled areas. We obtained the data mainly from specimens deposited in museums, but we also included additional information from the literature. We compiled 2,321 records belonging to 723 species. Specimens were recorded in 108 localities distributed in 67 one-degree cells. Species occurring exclusively in one or two one-degree cells represented 64% of the total number of species. Sample effort was not uniform in the biome, as there were very few records in the northern region of the Cerrado. The best-sampled one-degree cell had 239 species. Species assemblages were structured in space with a clear trend of localities near one another presenting more similarities in faunal composition than distant localities. This distance decay in similarity was slightly more pronounced along the longitudinal than along the latitudinal distances. We conclude that the Cerrado still remains poorly inventoried for tiger moths, particularly in its northern portion, where many unrecorded species may be found in the future. Despite of this limited knowledge, the best-sampled region indicates that richness of tiger moths in the Cerrado is comparable to the species-rich forest biomes in the Neotropical region.

KEY WORDS. Arctiinae; distance decay in similarity; Lithosiinae; museum data; sample effort.
Ferro & Diniz 2008). Moths of the families Arctiidae, Saturniidae, and Sphingidae, in particular, are commonly used as indicators in ecosystem monitoring programs (Hilty &Merenlender 2000).

The arctiids, commonly known as tiger moths, include almost 11,000 species (Scole 1995). A total of 5,931 described species was recorded in the Neotropical region (Watson &Goodiger 1986, Heppner 1991) and Brown Jr &Freitas (1999) estimated that there are nearly 2,000 species in Brazil. According to Jacobson &Weller (2002), the family contains three subfamilies: Arctiinae, Lithosiinae, and Syntominae. The Arctiinae are small-to-medium sized moths (Scole 1995) that occur worldwide, but are specially rich in the neotropics, comprising 73% of the 6,523 described species (Heppner 1991). The Lithosiinae are cosmopolitan small-sized moths, but only 34% of the 3,445 species occur in the neotropics (Heppner 1991, Scole 1995). The Syntominae are small-to-medium sized moths (Scole 1995) and include 977 species, none in the New World (Heppner 1991).

In the present study we assessed Arctiidae richness in the Brazilian Cerrado biome for the first time. Specifically, we 1) map and describe the species-richness in the biome, as currently known, 2) highlight areas where these moths are poorly known, and 3) investigate the spatial relationship in similarities among the 14 best-sampled regions.

MATERIAL AND METHODS

The Cerrado region, located in altitudes ranging from 300 to 900 m, has a high diversity of soils, geomorphology, climate, and vegetation types (Durigan et al. 2003, Silva et al. 2006). Nearly 95% of the climate in this biome is classified as Aw, according to the Köppen system, with an annual temperature average between 18 and 28°C, and precipitation ranging from 600 to 2,200 mm per year. Moreover, the climate is highly seasonal, so that 80% of the biome has five to seven months of dry season during the winter (Dias 1996). The soils in 90% of the region are nutrient-poor, highly acidic, and aluminum-rich latosols and quartzsols. The flora is very heterogeneous, presenting a gradient that ranges from evergreen forest with closed canopy (gallery forest) to a total absence of woody vegetation (“campo limpo”) (Durigan et al. 2003, Silva et al. 2006).

Most of our data on the geographic distribution of the Cerrado tiger moths were obtained from specimens deposited in Brazilian museums, plus a few records from the literature. We visited the 10 most important arctiid collections in the country: Coleção Becker, Coleção Entomológica da Universidade de Brasília, Coleção Entomológica do Instituto Nacional de Pesquisas da Amazônia, Coleção Entomológica Padre Jesus Santiago Moura da Universidade Federal do Paraná, Fundação Instituto Oswaldo Cruz, Museu Paraense Emílio Goeldi, Museu Entomológico Ceslu Biezanco da Universidade Federal de Pelotas, Museu de Zoologia da Universidade Estudal de Campinas Adão José Cardoso, Museu de Zoologia da Universidade de São Paulo, and Museu Nacional da Universidade Federal do Rio de Janeiro. The individuals were identified using information available in the literature (Pinas Rubio et al. 2000, Pinas Rubio &Manzano 2003, Watson &Goodiger 1986) and by comparison with digital images of identified specimens in the Coleção Becker. This is the best collection of arctiid of the Cerrado and most of its specimens were identified by comparison with types found in museums. Additionally, Bendix &Minet (1999) was used to identify the Lithosiinae tribes.

Our data set contained only species that could be identified with certainty by using the adult external morphology (head and leg characters, wing venation, and coloration). We did not consider individuals with doubtful provenance. Individuals of the same species collected on multiple dates at the same locality were considered as a single record. Most of the museum specimens did not contain information on the geographic coordinates of the sampled site. In such cases, we used the coordinates of the nearest city where the specimen was collected, obtained from the “splink” information system available at the Reference Center on Environmental Information (http://splink.cria.org.br/geoloc). We also obtained data on species records from literature (Ferreira et al. 1995, Ferro &Diniz 2007c), but did not include records when information about the sampling sites was inaccurate and a few taxonomical and ecological publications dealing with the fauna of eucalyptus plantations.

The Cerrado biome boundary was defined according to the coordinates available from the Instituto Brasileiro de Geografia e Estatística (2008). We used a grid containing one-degree latitude/longitude cells to map tiger moth richness in the core region of the Brazilian Cerrado. Most species were recorded in one or two localities only, precluding the use of minimum convex polygons of occurrence to estimate species richness in cells.

We selected the 14 best-sampled cells (i.e., those containing more than 61 species). These 14 cells represent a compromise between the minimum sampling effort in the cells and the maximum number of cells to evaluate resemblance among regions. We used the ordination and Mantel tests to evaluate whether similarities in species composition were related to spatial distance. We calculated a dissimilarity matrix using the Simpson beta-diversity index (Koleff et al. 2003a), which is related to Jaccard and Sorensen indices, but has less sensitivity to sample size (Koleff et al. 2003a, Baselga 2007). In our study, the 14 best-sampled cells differed greatly in species richness and this was the main reason for selecting the Simpson beta-diversity index. We also used the dissimilarity matrix to obtain the ordination of the 14 cells on two axes using a Non-Metric Multidimensional Scaling (NMDS).

Additionally, we employed Mantel tests to assess whether dissimilarities in species composition among cells were related to: 1) geographical distances, 2) differences in latitude, and 3)
differences in longitude among cells. We used the same dis-
similarity matrix used in the NMDS ordination. The Mantel
tests were done using the Spearman coefficient of correlation
and 1,000 permutations to assess statistical significance. The
choice for the Spearman coefficient was based on previous work
indicating the non-linearity of the distance decay relationship
(NEKOLA & WHITE 1999). We wrote routines and used functions
available in the packages ‘MASS’ (VENABLES & RIPLEY 2002) and
‘vegan’ (OKSANEN et al. 2008) of the R environment (R DEVEL-
OPMENT CORE TEAM 2007) to data analyses.

RESULTS

About 30% of the specimens examined were not included
in our data set due to doubtful provenance or difficulties in
sorting among morphospecies (hereafter treated as ‘species’).
A total of 16 species could not be identified to genus, and 14
could not be identified to species. A portion of this unidenti-
ified material likely represents new species or genera. The re-
mainng specimens might correspond to species already de-
described but for which we were not able to identify. The data set
included a total of 2,321 records belonging to 723 species, and
to 256 genera. Out of the 723 species, 621 belonged to the
Arctiinae (86%). Although all six Arctiinae tribes occur in the
Cerrado region, the Phaegopterini and Ctenuchini were domi-
nant, comprising 53.5% of the total arctiid species (Tab. I). The
remaining 102 species were Lithosiinae, and belonged mostly
to the tribes Cisthenini and Lithosiini (Tab. I).

Table I. Number of species of tiger moth subfamilies and tribes
occurring in the Cerrado region.

<table>
<thead>
<tr>
<th>Taxa</th>
<th>Number of identified species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arctiinae</td>
<td>621</td>
</tr>
<tr>
<td>Phaegopterini</td>
<td>254</td>
</tr>
<tr>
<td>Ctenuchini</td>
<td>133</td>
</tr>
<tr>
<td>Euchromiini</td>
<td>76</td>
</tr>
<tr>
<td>Pericopini</td>
<td>39</td>
</tr>
<tr>
<td>Arctiini</td>
<td>33</td>
</tr>
<tr>
<td>Callimorphini</td>
<td>2</td>
</tr>
<tr>
<td>Undetermined Tribe</td>
<td>84</td>
</tr>
<tr>
<td>Lithosiinae</td>
<td>102</td>
</tr>
<tr>
<td>Cisthenini</td>
<td>53</td>
</tr>
<tr>
<td>Lithosiini</td>
<td>34</td>
</tr>
<tr>
<td>Eudesmini</td>
<td>4</td>
</tr>
<tr>
<td>Undetermined Tribe</td>
<td>11</td>
</tr>
<tr>
<td>Arctiidae (Total)</td>
<td>723</td>
</tr>
</tbody>
</table>

Species were recorded in 108 localities of the Cerrado dis-
tributed in 67 one-degree cells. The number of species sampled
exclusively in one and two cells was 315 and 146, respectively.
Collectively, they represented 64% of all species (Fig. 1). Only
eight species were recorded in more than 15 cells (Fig. 1).

Our sampling effort was not homogeneously distributed
in the biome (Fig. 2). For instance, we do not have records for
vast regions of the northern part of the Cerrado. Most records
were concentrated in the southeastern portion (Fig. 2), which
is the most populated region and is close to the largest Brazil-
ian museums and universities. The cell containing the most
records (261) and species (239) included Brasília (capital of Bra-
zil), in the central part of the biome.

The ordination of the 14 best-sampled cells containing
more than 61 species revealed that nearby areas harbor similar
sets of species (Fig. 3). Also, a gradient was found in the first
axis, with western and northern cells scored in the right side of
the diagram (Fig. 3). Consistent with the NMDS ordination,
the Mantel tests revealed that dissimilarities in species composi-
tion were strongly correlated with geographical distances ($r =
0.71, p < 0.001$). The main component contributing to this
strong correlation was longitude ($r = 0.56, p < 0.001$), although
the correlation with latitude was also relatively high ($r = 0.44,
p < 0.001$).

DISCUSSION

The richness of arctiid recorded in this study for the
Cerrado represents 36% of the 2,000 species estimated to oc-
cur in Brazil according to BROWN JR & FREITAS (1999), and 12% of
the 5,931 Neotropical species (HEPPNER 1991). Similarly, CAMARGO
& BECKER (1999) observed that Saturniidae moths in the Cerrado
represented 42% of the Brazilian and 12% of the New World
fauna. Despite the similarity found between our data and
CAMARGO & BECKER’S (1999), it is not yet clear whether the rela-
tive proportions of Brazilian and Neotropical arctiid and satar-
niid moths occurring in the Cerrado can be generalized to other lepidopterans. There is no published information on other moth families and our data indicate that many arctiid species may be found in future inventories of the northern Cerrado.

The sampling effort was not homogenously distributed in the Cerrado area. Instead, museum records were concentrated in the southern part of the biome, and there were several areas in the biome with no or few species records, especially in the northeastern region. For instance, there were no records in the Cerrado regions of the states of Bahia and Maranhão. In the states of Piauí and Tocantins there were records from only one and three sites, respectively. The southern portion of the Cerrado, which includes most of the arctiid records, also includes regions that are poorly inventoried. For instance, there are only a few records in Cerrado areas of the state of Mato Grosso do Sul, and in the southeastern portion of the biome (borders of São Paulo and Paraná states). These poorly inventoried regions are in the most disturbed part of the biome.

In the state of São Paulo, for example, the vegetation has been reduced from 33,929 km² to 2,379 km² in the last 30 years (Durigan et al. 2003). The northeastern region of the biome, for which only a few records are available, includes the lesser-disturbed areas of Cerrado. However, this area is currently threatened by the expansion of the agricultural frontier and subsequent development of infrastructures (Cavalcanti & Joly 2002). Future collections of arctiid in the northern portion of the Cerrado should increase the total species richness in the biome. Additionally, these inventories may allow better estimates of species ranges and evaluation of endemism in the biome.

The cell containing most species and records was located in the central portion of the Cerrado (Brasília) and included 33% of all species recorded in the entire biome. Bridgewater et al. (2004) found similar results for wood plants and reported

Figure 2. Brazil map including the Cerrado biome polygon and tiger moths richness in one-degree cells. Areas of the Cerrado without cells indicate lack of records. Some cells included areas outside the biome, but records were restricted to localities that could be certainly assigned to the Cerrado vegetation.
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Figure 3. Non-Metric Multidimensional Scaling (NMDS) ordination using the Simpson beta-diversity index of the 14 best-sampled cells. Cells are indicated by coordinates (longitude, latitude) of their left-hand inferior corner. Stress = 16.4%.

that 25% of all Cerrado plants were recorded in 13 sites around Brasília. The region of Brasilia also harbors the highest known richness of Mimosa L. legumes (SIMON & PROENÇA 2000) and anurans (DINIZ-FILHO et al. 2007) in the Cerrado. This repeated pattern of highest richness around Brasilia is probably due to concentrated sampling effort in this region, where the largest and oldest university (Universidade de Brasília) of the core region of the Cerrado is located. Tiger moth species richness in the Brasilia region (239 species) is only slightly lower than that observed in well-inventoried Neotropical moist sites. FEIJO & DINIZ (2007b), for instance, compiled about 4,800 museum records accumulated during decades of arctiid (mostly Arctiinae) sampling at Estação Biológica de Boracéia, a southeastern Brazilian Atlantic Rain Forest site, and found 256 species. Moreover, ZIKÁN & ZIKÁN (1968) listed 306 currently valid arctiid species in a high-altitude site in the Atlantic forest, and HILT & FRIEDLER (2005) found 287 species in an inventory of a 2 km² area of montane cloud forest in Ecuador. Together, these values indicate that local species richness in the Cerrado is similar to those in moist forests. This result does not imply, however, that total (regional) species richness in the Cerrado is similar to values observed in other biomes. Too few localities were well inventoried in the Cerrado and many areas remain mostly unsampled, precluding a reliable estimation of total diversity.

The multivariate analyses of species composition in the 14 best-sampled cells revealed that those cells closest to one another share more similar sets of species than those localities that are farther apart, a pattern that had been previously reported for other groups of organisms, such as plants and parasite communities of vertebrate hosts (NEKOLA & WHITE 1999, POULIN 2003). This trend, known as distance decay of similarity, can be caused by differences in environmental conditions or by the dispersal restrictions of certain organisms (NEKOLA & WHITE 1999, BECK & KHEN 2007). Unfortunately, the limited number of cells used in our analyses preclude our ability to draw conclusions on the role played by these two factors in our data. However, the results of our study, carried out in an area encompassing 17 degrees of longitude and 13 degrees of latitude, are consistent with the expectation that distance decay patterns are most likely to be revealed by large-scale studies (NEKOLA & WHITE 1999).

Given the existence of latitudinal gradients in species richness and environmental conditions (e.g., HAWKINS et al. 2003), one might expect that the slope of the distance decay relationship would be steepest along latitudinal distances (see KOLEFF et al. 2003b). Instead, we observed steepest decreasing similarity along longitudinal distances and this gradient deserves further investigation in other taxonomic groups. RATTER et al. (2003), for instance, identified five floristic regions within the core region of the Cerrado arranged both along the latitudinal and longitudinal gradients. In the east portion of the biome they identified three provinces (namely North & Northeastern, Central & Southeastern, and Southern) and, in the western portion, they identified two provinces (namely Central & Western and Far Western Mesotrophic). Thus, the spatial gradient observed in our arctiid data should be a consequence of differences in host-plant composition between the floristic regions in the Cerrado (RATTER et al. 2003).

How much do we know about Arctiidae richness in the Cerrado? The biome includes an expressive proportion of the richness in Brazil and in the Neotropical region. The identification of many regions without records and the high proportion of rare species indicate that many more species should be found in further inventories. The local richness of the most intensively sampling region (Brasilia) was similar to values from intensively sampled sites of moist forests in the Neotropical region. Lastly, we found that the resemblance in species composition among the best-sampled cells followed a pattern of distance decay in similarity, particularly along the longitudinal gradient. The importance of this longitudinal gradient deserves further studies to test, for instance, whether arctiid assemblages in the Cerrado at large spatial scales is determined by the distribution of their host plants.

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