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Activity pattern of the Black-and-White Tegu, *Salvator merianae* (Squamata, Teiidae), in an Atlantic Forest remnant in southeastern Brazil

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Abstract. Temperature is an important factor for metabolism, and lizards dispend part of their daily activity in interactions with the thermal environment. Here we aimed to determine the activity pattern (monthly and daily activity) of *Salvator merianae* in a remnant of Atlantic Forest in southeastern Brazil, and to analyse the association between activity (records/month) and local weather conditions (temperature and rainfall). The records were collected by camera traps between October/2015 and July/2017 (22 months). We obtained 162 records of *S. merianae*. The daily activity was between 8 h and 16 h (~9 hours). The species was inactive from April to September 2016 (hibernation period), with two active seasons during our sampling period. In the first activity season (October/2015 to March/2016), the local temperature varied between 26.4ºC and 27.8ºC, and the activity pattern was bimodal. In the second season (October/2016 to April/2017), ambient temperature varied between 23.8ºC and 26.8ºC, and the activity pattern was unimodal. The daily distribution of records tended to be different between activity seasons (W=5.251; p=0.072). The number of records/month was related to monthly mean temperature (rs=0.616; p=0.002; 22 pairs) and not related to total monthly rainfall (rs=0.128; p=0.570; 22 pairs). Teiid lizards need high body temperatures to perform their activities, which may explain their unimodal activity pattern. The bimodal pattern differs from that previously described to *S. merianae* and can be attributed to behavioural responses to higher temperatures during the first activity season aiming to avoid thermal stress. The activity of *S. merianae* was influenced by environment temperature, and the difference between activity seasons (bimodal or unimodal pattern) suggests behavioural plasticity in response to differences in annual temperatures.

Keywords. behavioural plasticity, circadian rhythm, hibernation, Macroteiid, Reptilia, thermoregulation, time of activity.

Introduction

Lizards are ectothermic vertebrates that use behavioural mechanisms, such as alternating movements between warm and cooler thermal microenvironments (e.g. Duran et al., 2018), and physiological mechanisms, such as enzymes regulated by hormones (e.g. John-Alder, 1990), to maintain metabolic rates and regulate body temperature. The body temperature varies from values that allow the beginning of their activities to the maximum physiologically tolerated values, establishing an optimal range in which they can develop their daily activities (Brattstrom, 1965). The body temperature influences several biological processes, such as antipredator responses (Cury de Barros et al., 2010), oxygen consumption (Beyer and Spotilat, 1994) and immunological function (Mondal and Rai, 2001).

As presented above, the temperature is a physical factor of great importance for metabolism, and lizards dispend a large part of their daily activity in interactions with the thermal environment (Rocha et al., 2009). The thermal environment influences their cycle of daily and seasonal activity (Pianka and Vitt, 2003), and in some cases leads to hibernation during the months with lower temperatures (Winck and Cechin, 2008). In general, the availability of sunlight is the most important factor for the activity of lizards, mainly the heliothermic ones, usually found in warm microhabitats where direct sunlight is available (Vitt and Caldwell, 2009).

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The Teiidae Family comprises 18 living genus of lizards (Uetz et al., 2019) distributed throughout the new world (Harvey et al., 2012). They are all terrestrial with diurnal activity (heliophiles), mainly carnivorous or insectivorous, and most of them are active foragers performing their activities within an optimal thermal range (Bauer, 1998). Most of them are lizards with large snout-vent length (SVL), as macroteiids of the genus *Salvator* (mean SVL = 416.0 ± 3.5 mm; e.g. Winck et al., 2011), but some teiids have smaller representatives, such as *Ameivula* spp. (mean SVL = 56.1 ± 4.5 mm; e.g. Menezes et al., 2008). Larger animals have more body mass to heat and lowest relative body surface (smaller surface area-to-volume ratio), than smaller ones, resulting in a lower heat loss rate to the external environment (Vitt and Caldwell, 2009). Thermal inertia is therefore different and may influence the activity pattern because larger mass can maintain body heat for a longer time compared to smaller animals.

The Black-and-White Tegu, *Salvator merianae* (Duméril and Bibron, 1839), is heliothermic (Winck et al., 2011) and has unimodal daily activity pattern (Van-Sluys and Rocha, 1999; Ferreguetti et al., 2018), with seasonal variation in activity (Van-Sluys and Rocha, 1999) and seasonal reproductive pattern (Naretto et al., 2015). Its activity is more intense in warmest months, with hibernation period in the colder months (Winck et al., 2011). Thermal preferences are similar between body sizes, sexes and reproductive condition in *S. merianae*, within a narrow range of temperature variation in thermal gradient, suggesting similar thermal requirements for a broad range of physiological processes (Cechetto and Naretto, 2015). Contradictorily, the activity pattern can be differentiated between adults and subadults, and between sexes, with males emerging from hibernation before females to establish their territories (Winck et al., 2011). Despite that, the reproductive cycle is synchronised, and both male and female concentrate their reproductive activities between October and December (Naretto et al., 2015). Species distribution models indicate mean temperature of the coldest quarter of the year, followed by annual precipitation, as the most important variables for *S. merianae* (Jarnevich et al., 2018).

Here we aimed to determine the activity pattern of *S. merianae* in an important remnant of Atlantic Forest in southeastern Brazil, considering the species monthly and daily activity pattern, and to analyse the association between activity and local weather conditions (temperature and precipitation).

Material and Methods

Study area.—The study was carried out in Reserva Natural Vale (RNV - Vale Natural Reserve; -19.1094°S, -39.9238°W; 22.711 ha) and in Reserva Biológica de Sooretama (RBS - Sooretama Biological Reserve; -19.0044°S, -40.1474°W; 27.859 ha), in the northern region of the state of Espírito Santo, southeastern Brazil. These areas, together with other small private fragments, form an important remnant of native vegetation (>53,000 ha, Bloco Florestal Linhares-Sooretama: BLS - Linhares-Sooretama Forest Block) that represents approximately 11% of the forest remaining in the state (based on data available in FSOSMA and INPE, 2019).

The BLS is composed by a mosaic of habitats, with predominance of dense lowland forest (Tabuleiro Forest), classified as Perennial Seasonal Forest (Jesus and Rolim, 2005). The regional climate is tropical with dry winter, type Aw, according to Köppen classification (Alvares et al., 2014). The region is characterized by two climatic periods throughout the year (dry and rainy season), with the dry season extending from April to September, and the rainy season from October to March (Kierulff et al., 2014). The mean annual temperature in the region is 24.3 ± 2.1°C, ranging from 18.7 ± 0.6°C to 29.9 ± 0.9°C; and the mean annual rainfall is 1,215 ± 260 mm, with high interannual variability (Kierulff et al., 2014).

Data collection.—Data were collected from October 2015 to July 2017, totalling ~22 months of sampling. For data collection, Bushnell Trophy Cam HD Aggressor Low-Glow digital camera traps (Bushnell Inc., Overland Park, USA) were used. The camera traps were installed on trails inside the forest or on unpaved roads located within the study area, totalling 14 sampling points. The equipment was attached to tree trunks (~45 cm above the ground) and operated 24 hours/day. Solar time was considered throughout the sampling period. No baits were used during the study.

Data analysis.—To ensure independent counts of lizard's detections, all records obtained within the same interval of one hour and at the same sampling point were considered as a single detection event (= independent record; Srbek-Araujo and Chiarello, 2013). The sampling effort (number of camera traps x number of sampling days) and capture success (number of independent records per sampling effort × 100) were calculated according to Srbek-Araujo and Chiarello (2005). The number of sampling days correspond to the time between first and last records in each month of sampling for each sampling point.

We recorded a period of inactivity and two distinct periods with records of *S. merianae*, which represented the active seasons between hibernation of the species during our study (see Results for details). For this reason, some of the following analyses used the activity seasons separately for comparisons.

We used line graph to illustrate the monthly distribution of *S. merianae* records over the entire study period. For this graph, we considered the proportion of records in each month (%) according to the total of records at each activity season independently.

We calculated the direction of the mean vector (mean angle = μ) and its 95% Confidence Interval (basic circular statistic) to characterize the daily activity pattern of *S. merianae*. Rose diagrams were used to illustrate the daily activity pattern (24 h = 360°), and line graphs were used to illustrate the hourly distribution of records (independent records summed in each one-hour interval). We define an activity peak when the percentage of captures in any given hour was 50% greater than the hour with the greatest number of captures (Magalhães and Srbek-Araujo, 2019). The previous analyses were performed for all study period and for each activity season separately to verify if the activity pattern of *S. merianae* displays fixed or variable pattern.

The non-parametric Mardia-Watson-Wheeler test (circular statistic) was used to verify if there was difference in the activity pattern (daily distribution of records) of *S. merianae* between the two activity seasons.

The Spearman Rank Correlation was used to analyse associations between the number of records of *S. merianae* per month and the local weather conditions considering the monthly mean temperature and the total monthly rainfall. According to data provided by the Instituto Capixaba de Pesquisa Técnica e Extensão Rural (INCAPER - Capixaba Institute for Technical Research and Rural Extension), in the period from October 2015 to April 2016, the monthly mean temperature ranged between 26.4ºC and 27.8ºC, with accumulated rainfall of 323.4 mm. In the period from October 2016 to April 2017, the monthly mean temperature varied between 23.8ºC and 26.8ºC, and the accumulated rainfall was 524.8 mm (based on data from the meteorological station of the municipality of Linhares). The monthly mean temperature was different between the two periods ($t = 3.712$; d.f. = 12; $p = 0.003$) and the monthly accumulated rainfall was similar between periods ($t = 0.792$; d.f. = 12; $p = 0.444$).

Circular statistical analyses were done in the Oriana software, version 4 (Kovach Computing Services, 2011), and the correlation in the software BioEstat, version 5.3 (Ayres et al., 2007). The level of significance was 95% ($p \leq 0.05$; Zar, 2010).

Results

We obtained 162 independent records of *S. merianae* (sampling effort = 5,268 cameras-day; capture success = 3.08). The species was inactive between April and September 2016 (hibernation period), with two active seasons during the sampling period: the first from October 2015 to March 2016, and the second from October 2016 to April 2017 (Figure 1). One isolated record was obtained in May 2016 (Figure 1). In 2017, the latest records were documented in April (Figure 1).

The lizards were active for approximately 9 hours daily, with records obtained between 08:24 h and 16:57 h. The records obtained throughout the study indicate a unimodal pattern of activity, with a concentration of records between 09 h and 15 h (Figures 2A and B). The direction of the mean vector was 12:42 h (95%IC = 12:20 h - 13:03 h; Figure 2A). In the first activity season (October 2015 to March 2016: sampling effort = 967 cameras-day; 43 records; capture success = 4.45), were observed two peaks of daily activity (bimodal pattern), with the first peak at 09-10 h and the second peak at 13-16 h (Figures 2C and D). The direction of the mean vector in the first season was 13:05 h (95%IC = 12:19 h - 13:51 h; Figure 2C). In the second activity season (October 2016 to April 2017: sampling effort = 1,739

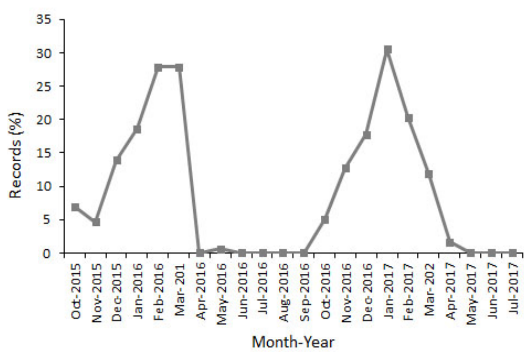

Figure 1. Monthly distribution of records of *Salvator merianae* (% according to the total of records at each activity season) in Linhares-Sooretama Forest Block, southeastern Brazil, between October 2015 and July 2017.

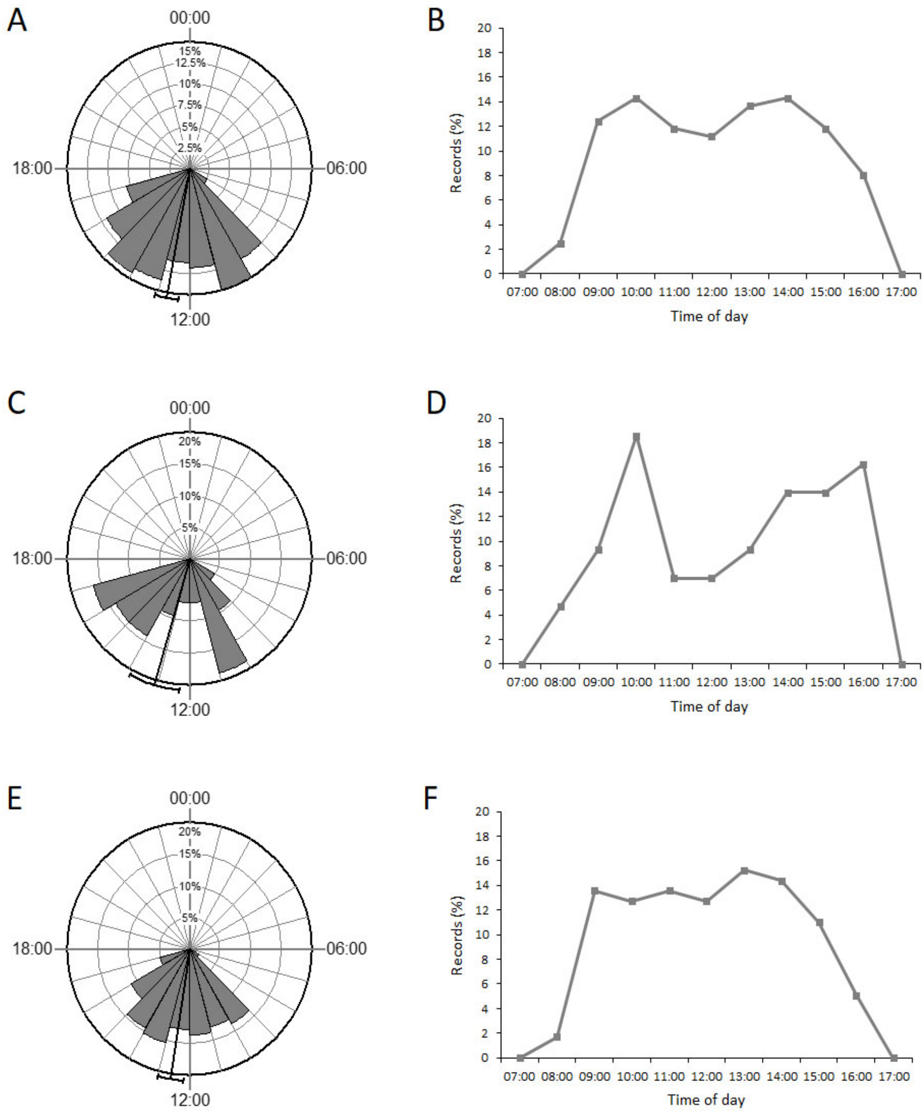

Figure 2. Daily activity pattern (left) and hourly records (right) of *Salvator merianae* in Linhares-Sooretama Forest Block, southeastern Brazil: all study period (A and B; μ = 12:42 h, 95%IC = 12:20 - 13:03 h), first activity season (October 2015 to Mach 2016 - C and D; μ = 13:05 h, 95%IC = 12:19 - 13:51 h), and second activity season (October 2016 to April 2017 - E and F; μ = 12:35 h, 95%IC = 12:12 - 12:59 h).

cameras-day; 118 records; capture success = 6.79), the activity pattern was unimodal, with more intense activity between 09 h and 15 h (Figures 2E and F). The direction of the mean vector in the second season was 12:35 h (95%IC = 12:12 h - 12:59 h; Figure 2E). The daily distribution of records of *S. merianae* tended to be different between activity seasons (W = 5.251, p = 0.072).

There was a positive and moderate association between the number of records/month and the monthly mean temperature (rs = 0.616; p = 0.002; n = 22 pairs), and no association between the records of *S. merianae* and the total monthly rainfall (rs = 0.128; p = 0.570; n = 22 pairs).

Discussion

Salvator merianae has a slightly broader daily activity patter in BLS (08 h to 16 h) than previously described for RNV (09 h to 16 h; Ferreguetti et al., 2018). In Jurubatiba region, state of Rio de Janeiro, the activity period of the species was even lower (11 h to 14 h; Hatano et al., 2001), and in Ilha Grande, also in Rio de Janeiro, the activity started even earlier (07 h to 15 h; Van-Sluys and Rocha, 1999). In Taim region, state of Rio Grande do Sul, the daily activity period was broader than in the present study (07 h to 18 h; Winck et al., 2011). We suggest activity variations between different regions of Brazil may be related to variations in latitude (which influences light intensity and day length) and ambient temperature differences between sampled environments (forest and restinga, for example). Despite the local variations in the activity pattern of *S. merianae* in Brazil, the period of activity of the species (07 h to 18 h grouping all studies) was similar to that observed for a congeneric species, *Salvator rufescens* (Günther, 1871), in the Bolivian Chaco (08 h to 18 h; Montaño et al., 2013), and for another macroteiid, *Tupinanbis teguixin* (Linnaeus, 1758), in Venezuelan flood plains (07 h to 19 h; King et al., 1994), representing a common characteristic among these teiid species.

Although the period of the day in which *S. merianae* is active is compatible with that recorded in other studies, the bimodal pattern recorded for the first activity season in BLS differs from that previously described for the species (Van-Sluys and Rocha, 1999; Winck et al., 2011; Ferreguetti et al., 2018). Active foragers lizards use the hottest hours of the day for their activities because their mean body temperature is higher than that of sedentary foragers lizards and therefore need a higher ambient temperature to start their activities (e.g. Bergallo and Rocha, 1993; Rocha et al., 2009). For Teiidae Family, the use of relatively higher ranges of body temperatures, as compared to other species, is already known (e.g. Rocha et al., 2009). The preferred temperature of *S. merianae* is 36.24 ± 1.49°C, with a narrow range of variation in its thermal gradient in laboratory conditions (Cechetto and Naretto, 2015). This, together with the fact that *S. merianae* is a large body lizard and possibly requires higher environmental temperatures to regulate its body temperature (Winck et al., 2011), may explain the unimodal pattern using the hottest hours of the day for activities. However, the ambient temperature was relatively higher in the first activity season (26.4ºC to 27.8ºC) than in the second season (23.8ºC to 26.8ºC). This difference in ambient temperature may have influenced the change in the activity pattern, alternating between bimodal and unimodal pattern. In the first activity season, there was a peak of activity in the morning and another during the afternoon, with reduced activity at hours when the ambient temperature is usually higher. It can be attributed to behavioural responses to avoid environmental temperatures considered very high (or extreme) to the thermal physiologically tolerated range by the species (Hatano et al., 2001; Cechetto and Naretto, 2015), avoiding thermal stress. The difference between the activity patterns observed in each activity season demonstrates the importance of conducting analyses considering annual sampling intervals in studies with ectothermic species and/or species more sensitive to seasonal variations in weather conditions for the suitable characterization of activity patterns. In this regard, the combination (sum) of data obtained over more than one seasonal activity cycle can hide important aspects of the species activity pattern.

Unimodal activity pattern was also recorded for the congener *S. rufescens*, with the highest activity between 11 h and 12 h (Montaño et al., 2013). In contrast, the bimodal pattern observed for *S. merianae* in the present study is similar to that found for some tropidurids lizards, such as *Tropidurus torquatus* (Wied-Neuwied, 1820), which reduces its activities in the hottest hours of the day (Hatano et al., 2001). Variation in the pattern was also observed for *Tropidurus montanus* (Rodrigues, 1987), ranging from unimodal in the dry season to bimodal in the rainy season (Filogonio et al., 2010).

The ability of *S. merianae* to adjust their behavioural response to the thermal environment can also explain variations in hours with more intense activity between studies even when the activity pattern remains unimodal (RNV: 11 h to 13 h, Ferreguetti et al., 2018; Ilha Grande: 11 h to 12 h, Van-Sluys and Rocha, 1999; Taim region: 10 h to 13 h, Winck et al., 2011). In the present study, the hours with more intense activity varied between 09 h and 15 h. The behavioural response of *S. merianae* to the environmental temperature could also help to explain the lower capture success during the first activity season (there are no population estimates for the sampling period), which may suggest a reduction in species activity when the ambient temperature is higher due to shorter time spent for thermoregulation and longer shelter use. Heliothermic lizards tend to perform behavioural strategies to adapt to the temperature of the environment, such as the use of shelters with milder temperatures, avoiding overheating (Sinervo et al., 2010).

Although annual precipitation is an important variable for *S. merianae* in species distribution models (Jarnevich et al., 2018), the total monthly rainfall during the active seasons was not associated with the number of records/month in the present study. This can be explained by the fact that total monthly rainfall was similar between activity seasons (see Data analysis for details).

The absence of record of *S. merianae* between April and September 2016 indicates a hibernation period. These months correspond to the period with lower temperatures in the study region (Kierulff et al., 2014). Periods of hibernation had already been recorded for the species, which remained inactive from May to July (Van-Sluys and Rocha, 1999; Winck and Cechin, 2008; Winck et al., 2011), suggesting a longer hibernation period in the BLS.

The monthly and daily activities of *S. merianae* are influenced by the environment temperature, and the difference between the activity seasons (bimodal or unimodal pattern) suggests behavioural plasticity in response to differences in annual temperatures. This information contributes to the knowledge about the interaction between *S. merianae* and its thermal environment, as well as its mechanisms to regulate body temperature, contributing to understanding the thermal ecology in macroteiids. We recommend using annual sampling intervals to better describe the activity pattern of ectothermic species and/or species more sensitive to cyclical variations in weather conditions due to the risk of hiding important aspects of the activity pattern when using data from sampling periods shorter or longer than one annual seasonal cycle.

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