The Role of Temperature in the Use of Natural Microhabitats and Marine Debris by the Lizard *Liolaemus lutzae*

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Abstract.—We studied how the endemic and endangered Lutz's Tree Iguana (*Liolaemus lutzae*) used natural microhabitats and human caused marine debris in a Restinga area (Praia Grande, Rio de Janeiro, Brazil), evaluating the extent to which this use was influenced by the thermal environment. We recorded the frequency of use of the different microhabitats, the operative temperature of the microhabitats (T_e) and the body temperature of *Liolaemus lutzae* individuals (T_b in °C). For the Te of the microhabitats, we use data loggers. We recorded individual *L. lutzae* in seven types of microhabitats: bare sand, vegetation, footwear, styrofoam, canvas, wood, and plastic. Vegetation was the most frequently used microhabitat. Among artificial microhabitats, marine debris composed of plastic and wood were the most frequently used shelters. The frequency of natural vegetation used during the day followed the period of activity of the species. The use of plastic was higher at the beginning and at the end of the day, while the use of wood was relatively constant throughout the day. The data logger we installed in vegetation registered the highest mean T_e. The T_b of the lizards in vegetation (33.5° ± 2.2° C; range, 28.4°–38.2° C, n = 70) remained more constant throughout the day than those under plastic (32.3° ± 2.5° C; range, 27.8°–39° C, n = 47) or wood (31.3° ± 3.7° C; range, 24°–40.2° C, n = 65). Data indicated that *L. lutzae* used vegetation and marine debris of anthropic origin deposited in its habitat to maximize its thermoregulation.

Key Words.—microhabitat use; shelters; Restinga; thermal ecology; thermoregulation

Introduction

The use of different microhabitats plays an important role in the thermoregulation of ectothermic animals, such as lizards, helping to maintain body temperature within a suitable range (Andersson et al. 2010). Thus, temperature is one of the most important characteristics in microhabitat choice by these animals (Schlesinger and Shine 2004; Thierry et al. 2009). Lizards seek to maintain their body temperatures within a range suitable for carrying out their daily activities (Avery 1982). This varies between the minimum voluntary temperature (T_{min}), at which lizards interrupt their normal activities and seek refuge in shelters, and the maximum voluntary temperature (T_{max}) obtained during their normal period of activity (Brattstrom 1965). Within these boundaries, there is a more restricted temperature range, called the

set point range (T_{set}), within which field-active lizards seek to maintain themselves to maximize efficiency in normal activities, such as foraging (e.g., Huey 1982) and reproduction (e.g., Licht 1971). To remain within this optimum temperature range, in addition to physiological mechanisms, lizards use behavioral adjustments, such as postural changes, body flattening or stretching, and alternation between microhabitats with sun or shade (Gandolfi and Rocha 1998; Labra et al. 2001; Vrcbradic and Rocha 2002). Among the behavioral mechanisms, the proper choice of microhabitats that have appropriate thermal characteristics is essential for the thermoregulation process (Vrcbradic and Rocha 2002; Kerr et al. 2003). Lizards can use different structural elements (e.g., rocks, leaf litter, tree trunk, burrows, vegetation) of the habitat to thermoregulate and the choice of these elements may vary between species

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(Kerr et al. 2003; Aguilar and Cruz 2010; Corbalán et al. 2013).

In Brazil, the Restinga environment (coastal dune habitats at seaside) has been subject to intense degradation in recent years (Rocha et al. 2007; Cosendey et al. 2020). The high deposition and accumulation of marine debris on beaches is one of the causes of its degradation. The accumulation of marine debris can cause impacts to both coastal and marine wildlife. Among the most frequent impacts are ingestion of and entanglement in material, and alteration of habitat functioning (Vegter et al. 2014; Li et al. 2016).

Lutz's Tree Iguana (*Liolaemus lutzae*) has been reported to use debris as shelter (Rocha 1991; Soares and Araújo 2008). *Liolaemus lutzae* is restricted to a narrow strip of sand dune vegetation, covered with psammophilous and halophilous species in the Restingas of the state of Rio de Janeiro, southeastern Brazil (Fig. 1). Its distribution covers about 200 km of the coast of the state. Due to its restricted distribution and the environmental degradation within its range, the species has incurred some local extinctions (Rocha et al. 2009). For these reasons, the species was included in the Official Brazilian National List of Species of the Fauna Threatened with Extinction (issued in 2018 by Instituto Chico Mendes de Conservação da Biodiversidade of The Brazilian Ministry of Environment) as Critically Endangered and was also listed as Vulnerable by the International Union for Conservation of Nature (Rocha 2000).

In addition, climate change has been considered another potential risk for lizard species in different regions on earth (Foufopoulos et al. 2011; Kubisch et al. 2016). One study predicted that the extinction of lizard populations around the world caused by global warming could reach 20% by 2080, including *L. lutzae* (Sinervo et al. 2010). Lizards are having their thermal niche altered through a substantial reduction in the number of hours per day that they can remain active without reaching their critical temperature and overheating, which, consequently, decreases the number of hours available for carrying out vital activities such as obtaining food, mating, and reproducing, among other activities (Sinervo et al. 2010). In this sense, understanding the processes involved in the thermoregulation of *L. lutzae* and the thermal environment available in its habitat are essential for future management and conservation projects, especially actions to mitigate the potential effects of climate change. In this study we analyzed the frequency of use of natural and anthropogenic microhabitats as shelter by *L. lutzae*, considering whether the frequency of use was influenced by the thermal properties of these microhabitats.

MATERIALS AND METHODS

Study area.—We studied lizards in the Restinga of Praia Grande (Arraial do Cabo, 22°57'S, 42°02'W, Rio de Janeiro, Brazil; Fig. 2). The climate of this region is classified as semi-arid, with low rainfall (average 751 mm/y) and an average temperature of 25° C (minimum 22.5° C; maximum 29° C) in the rainy season and 21° C (minimum 19° C; maximum 24° C) in the dry season (Barbiére 1984). Restinga environments have different vegetation formations that extend from the ocean to the mountains (Souza et al. 2008; Araujo et al. 2009). We conducted our samplings in the beach zone within the sandy halophilous habitat of *L. lutzae*.

Methods of sampling and analysis.—We collected data from March 2011 to August 2013, with monthly campaigns of 2–4 d, from 0800 to 1700. We walked randomly through vegetation, and we searched in every potential shelter of the lizard. For every individual lizard we found, we recorded capture time, the body temperature (T_b in °C), and the microhabitat used. We measured temperatures with quick reading cloacal thermometer (accuracy of ± 0.2° C; Miller & Weber, Inc., Queens, New York, USA). To avoid pseudoreplication, we individually toe-clipped all
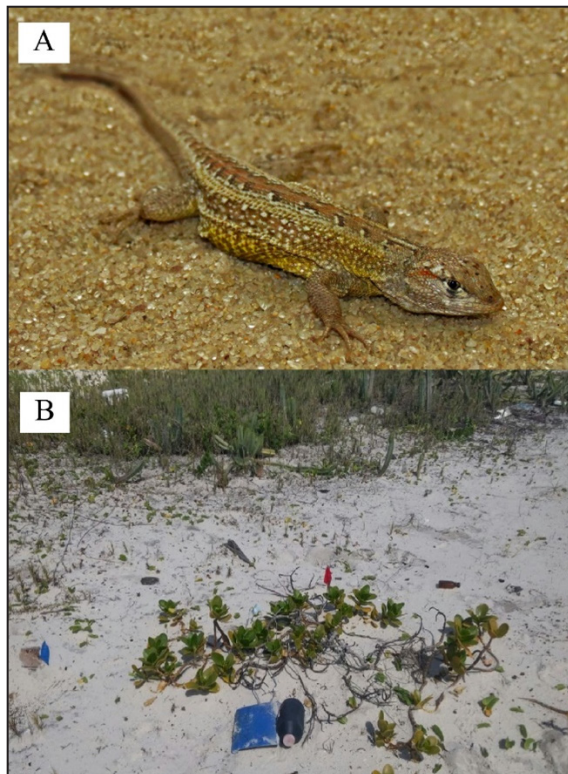

FIGURE 1. (A) A captive adult female Lutz's Tree Iguana (*Liolaemus lutzae*) from the population of Barra de Maricá, Brazil. (Photographed by Daniel Cunha-Passos). (B) Microhabitat used by *Liolaemus lutzae*. (Photographed by Beatriz Nunes Cosendey).
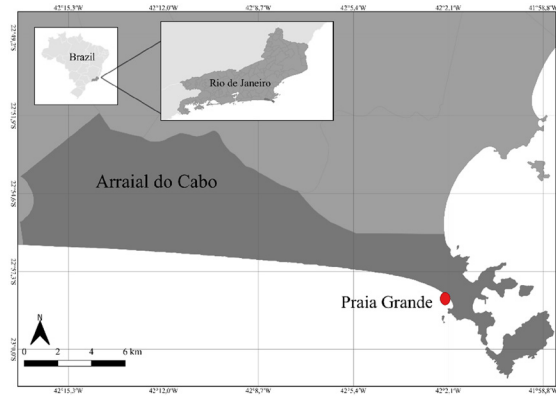
Figure 2. Location of the study site (red dot) in Praia Grande, Arraial do Cabo, Brazil.

lizards with an alphanumeric code (Waichman 1992) and we only used the first capture data in analyses.

The operative temperature (T_e) is the temperature of a model of the animal duplicating all external conductive, convective, and radiative conditions, but with no metabolism or evaporation (i.e., ectotherms animal non-thermoregulating) at a variety of randomly selected sites within a habitat (Bakken and Gates 1975; Bakken 1992; Hertz et al. 1993). To estimate T_e, we used HOBO® data loggers (Onset Computer Corporation, Bourne, Massachusetts, USA) coupled to a polyvinyl chloride (PVC) model simulating the body of the lizard (PVC tubes of about 90 mm in length and 15 mm in diameter, painted with gray spray paint). We calibrated the models previously in relation to live *L. lutzae* individuals at the same substrate and temperature conditions. The lizard and model temperatures (in °C) were recorded simultaneously, every minute for 2 h, using an Eltek Squirrel data logger (Eltek Ltd., Cambridge, UK). We performed a Pearson Product Moment Correlation test to select the best PVC model. We recorded the temperature of the models throughout 3 d in the rainy season of 2012, with measurements taken at 1 min intervals from 0800 to 1700. We placed each model at the same time, side by side, in the environment under three types of microhabitats: vegetation (*Blutaparon portulacoides, Alternanthera maritima, Canavalia rosea, Ipomea pescaprae*; no English common names for any), wood (72 × 15 × 1.5 cm), and plastic (27 × 26 × 6 cm).

To know if each microhabitat type was adequate for lizard thermoregulation, we calculated the mean T_b in each microhabitat and we tested if it was inside the set point range (T_{set}). To obtain the set-point range (T_{set}), the central 50% of body temperatures of lizards, we recorded the preferred body temperatures of eight *L. lutzae* individuals in the laboratory (Huey 1982; Hertz et al. 1993). We estimated preferred body temperatures in a thermal gradient measuring 90 × 15 × 38 cm (length

× width × height) provided with an incandescent lamp (150 W) at one end. We recorded body temperatures of lizards every minute for 3–4 h by an Eltek Squirrel data logger using ultra-thin (1 mm) thermocouples attached to the cloaca or chest of a lizard with surgical tape. We used One-way Analysis of Variance (ANOVA) to test for differences in T_b among microhabitats.

We used a Chi-Square Test to evaluate the use of the different microhabitats in each season of the year, and also to compare the relative frequency of use of each the microhabitat type by hour of the day. We calculated the relative frequency by dividing the number of individuals captured in a given microhabitat by the total number of individuals captured in all microhabitats in that time interval. We used General Linear Models with a Poisson distribution (GLMs) to test the effect of temperature and the microhabitat type on the number of individuals. We used the number of individuals in each category of microhabitat (vegetation, plastic, wood) as the response variable and operative temperature as explanatory variables. We performed all analyses in the software RStudio, version 1.2.5019 (R Core Team 2019). For all tests, α = 0.05.

Results

We recorded 410 individual *Liolaemus lutzae* in seven types of microhabitats (i.e., bare sand, vegetation, footwear, styrofoam, canvas, wood, and plastic), with 230 records in the rainy season and 180 in the dry season. In the rainy season, natural vegetation was the microhabitat most often used by *L. lutzae* (30.3%), followed by plastic (29.4%), whereas the least used was styrofoam (1.3%). In the dry season, the structural element most frequently used by lizards to shelter was plastic (30.4%) followed by vegetation (29.4%), while footwear was the least used (2.1%; Fig. 3). The use of different microhabitats did not differ significantly between seasons ($X^2 < 0.001$, df = 6, $P = 0.997$).

In the rainy season, the peak of vegetation used as a shelter occurred around 1200, with another increase around 1500 (Fig. 4). Plastic marine debris were more frequently used by lizards at the end of the day (1700), with lower use in the warmer period of the day (1100–1200), while the frequency of wood use was, in general, constant throughout the day, with a slight increase by 1100 (Fig. 4). Microhabitat use, however, did not differ significantly by time of day ($X^2 = 14.95$, df = 18, $P = 0.665$).

In the dry season, microhabitat use differed significantly by time of day ($X^2 = 31.32$, df = 18, $P = 0.026$). Lizards used the vegetation more frequently between 0900–1400, with few active individuals at 0800 and 1500 and no active individuals after 1600 (Fig. 4). Plastic marine debris were more frequently used by
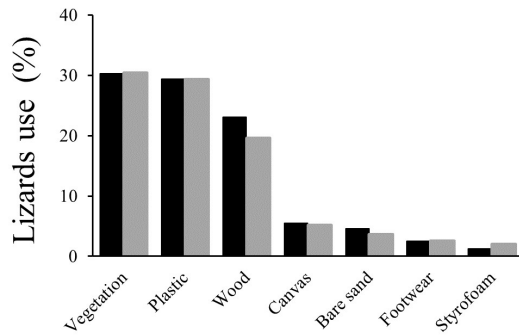
Figure 3. Microhabitat used by Lutz's Tree Iguana (*Liolaemus lutzae*) during the day in the rainy (black bars) and dry (gray bars) seasons in the Restinga of Praia Grande, Arraial do Cabo, Rio de Janeiro, Brazil.

lizards in the early morning (0800) and late afternoon (after 1500). Wood marine debris also had relatively more uniform use during the day, with a peak time in the late afternoon (1700; Fig. 4).

The number individuals were positively related to the T_e (GLM Poisson, $P < 0.001$; Table 1). The lizard models placed in the vegetation (only during the rainy season) recorded the highest variation in temperature and reached the highest recorded average of 40.8° ± 10.6° C standard deviation (range, 29.8°–59.9° C; n = 10). The frequency of use of vegetation by lizards increased throughout the day, with peaks at 1200 and 1500 (Fig. 5). The lizard model established under plastic marine debris recorded an average temperature of 36.8° ± 2.8° C (range, 30.1°–40.9° C; n = 10). Contrary to what occurred with vegetation, the frequency of use of plastic as a microhabitat by lizards during their period of activity was higher at the beginning and at the end of the day (Fig. 5). The lizard models established under wood recorded an average temperature of 35.1° ± 4.9° C (range, 25.9°–40.0° C; n = 10). The frequency of wood marine debris used by the lizards was the lowest among the three evaluated, with a peak of use of this microhabitat at 1100 (Fig. 5).

There were significant differences in the mean T_b of the lizards under the three microhabitats most used in the rainy season of 2012 ($F_{2-179} = 9.89$, $P < 0.001$). The T_b of the lizards under vegetation increased between 0800–0900, then remained relatively constant throughout the day until about 1300, when a gradual reduction occurred (Fig. 6). In the case of lizards using plastic marine debris, their T_b fluctuated throughout the day (Fig. 6), with a peak around 1100 and another around 1400, decreasing after 1500. The mean T_b of the lizards under wood marine debris increased gradually until reaching a peak at 1200 (35.3° C), decreasing from that time until 1600 (Fig. 6). In general, the average T_b of the lizards using the vegetation as microhabitat (33.5° ± 2.2° C; range, 28.4°–38.2° C; n = 70) remained
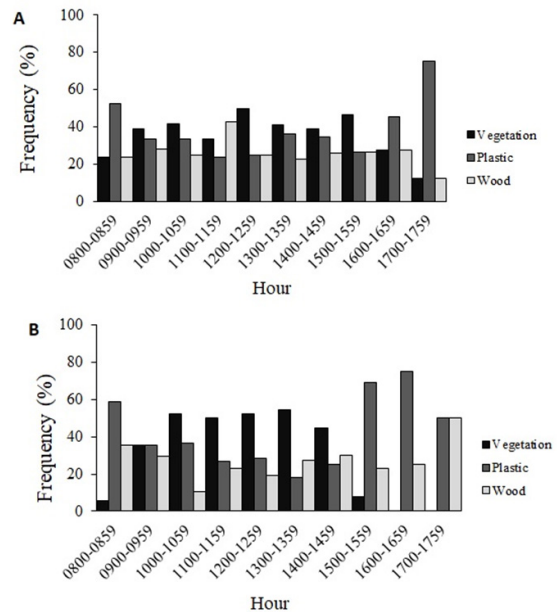

Figure 4. Three microhabitats most used (vegetation, plastic, and wood) by Lutz's Tree Iguana (*Liolaemus lutzae*) throughout the day during the (A) rainy and (B) dry seasons in the Restinga of Praia Grande, Arraial do Cabo, Rio de Janeiro, Brazil.

within the T_{set} range almost throughout the day. The T_b of active lizards under plastic marine debris (31.3° ± 3.7° C; range, 24°–40.2° C; n = 65) remained within the T_{set} between 1100–1400, decreasing abruptly after this time (Fig. 6). The T_b of active individuals under wood marine debris (32.3° ± 2.5° C; range, 27°–39.8° C; n = 47) remained within the range of T_{set} from 1000–1600.

DISCUSSION

Our data indicates that the microhabitats most frequently used as shelter and to thermoregulate during *L. lutzae* activity in the Praia Grande Restinga were vegetation, wood, and plastic. The sandy halophilic vegetation of the beach habitat constitutes the natural microhabitat of *Liolaemus lutzae*, where the lizard performs its daily activities, such as thermoregulation,

TABLE 1. Results of a Poisson Generalized Linear Model (GLM) of the number of individual Lutz's Tree Iguana (*Liolaemus lutzae*) from Praia Grande, Arraial do Cabo, Rio de Janeiro, Brazil, as a function of microhabitat type and of the operative temperature. The abbreviation SD = standard deviation.

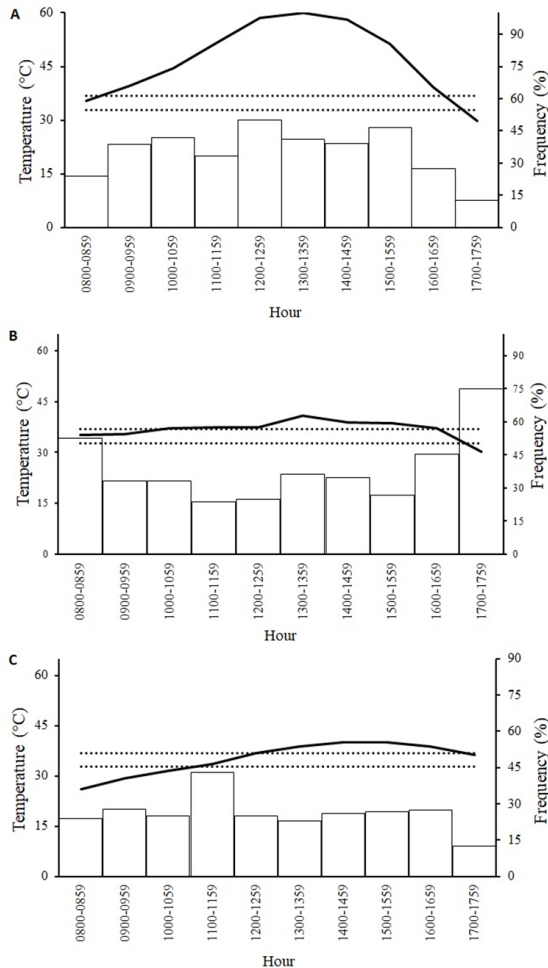| Variables	Estimate	SD	t	P-value
Intercept	0.5267	0.4252	1.239	0.215
Plastic	0.2406	0.1858	1.295	0.195
Vegetation	-0.0573	0.2411	-0.237	0.812
Operative temperature	0.0311	0.0112	2.770	< 0.001

FIGURE 5. Relative frequency of the three most used microhabitats: (A) vegetation; (B) plastic; and (C) wood by Lutz's Tree Iguana (*Liolaemus lutzae*) throughout the day in the rainy season of 2012 in the Restinga of Praia Grande, Arraial do Cabo, Rio de Janeiro, Brazil. Temperatures of the models (T_e) in 2012 rainy season (continuous black line). Set point (T_{set}): minimum range (32.8° C) and maximum (36.8° C) as shown by horizontal dotted lines.

FIGURE 6. Median body temperatures (°C) of individual Lutz's Tree Iguana (*Liolaemus lutzae*) throughout the day in the rainy season under the three most used microhabitats: (A) vegetation; (B) plastic; and (C) wood in the Restinga of Praia Grande, Arraial do Cabo, Rio de Janeiro, Brazil. Set point range (T_{set}): minimum (32.8° C) and maximum (36.8° C; black horizontal lines). Horizontal lines inside boxes are the medians, the boxes are the quartiles, the black dots are the data points, and the vertical lines are the range of values.

foraging, search for mates, and to hide from predators (e.g., Rocha 1988, 1993, 1996). In addition, some plant species of the habitat such as *Blutaparon* (= *Phylloxerus*) *portulacoides*, *Althernantera maritima*, *Ipomoea imperati* (= *littoralis*) and *Ipomoea pes-caprae* constitute part of the omnivorous diet of this lizard (Rocha 1996, 2000). Thus, it would be expected a greater frequency of use of vegetation by the lizard during its activity period compared to that of other microhabitats. On the other hand, the use of plastic in a proportion similar to that of vegetation and wood by *L. lutzae* probably reflects the relatively high availability of these types of marine debris in the environment (Oigman-Pszczol and Creed 2007; Silva et al. 2018). The frequency
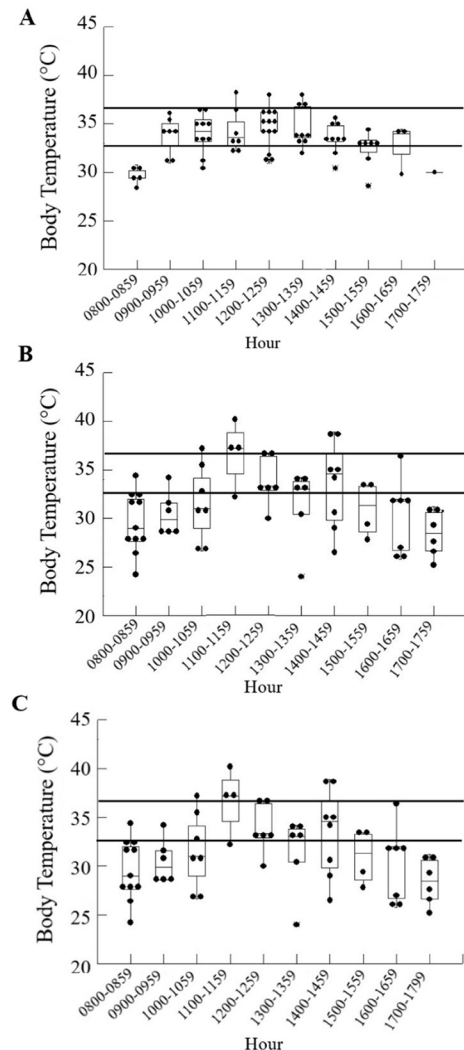
of use of bare sand by the lizards during activity was lower than that of other microhabitats, likely because it is an exposed environment, offering low protection against visually oriented predators (Rocha 1993) and reaching high temperatures (more than 50° C) on sunny days (Rocha 1988). Exposure to these temperatures, even for a relatively short period of time, could cause overheating, because elevated temperatures are known to be lethal to lizards (Bogert et al. 1959). The bare sand would function mainly as a matrix that the lizards use

to move among the potentially more thermally suitable microhabitats (Hertz et al. 1993).

The microhabitats most frequently used by *L. lutzae* varied throughout the day and between seasons. In the rainy season, we found lizards active among vegetation all day, with peak between 1000 and 1500, while in the dry season the vegetation was most frequently used between 0900 and 1400, with no active individuals being found after 1500. The frequency of vegetation used throughout the day coincided with the period of unimodal activity of this population, with a peak in activity between 0900 and 1400 in the rainy season and between 1100 and 1300 in the dry season (Maia-Carneiro et al. 2012). In fact, the vegetation covering the bare sand of the beach habitat constitutes an appropriate thermoregulation site for the lizards because the plant parts promote filtered incident light reaching the ground level, which reduces the light rate incident on the sand and prevents heating of the ground surface.

The frequency of plastic debris use was higher at the beginning and at end of the day. This probably results from the fact that *L. lutzae* individuals shortly after emerging from their nocturnal refuges take refuge under this marine debris, and because refuges retain heat, they would facilitate a faster increase in the body temperature of the lizards, mitigating the effect of the wind and potential exposure to predators. In fact, we did not find lizards outside refuges at night, and early in the morning lizards were often found under plastic and wood debris. During the dry season, when air temperature is lower, the trend of marine debris use at the beginning and end of the day was intensified, with individuals being found after 1500 under the marine debris. Possibly, this longer time under the marine debris in the dry season ensures that the lizards maintained their proper body temperatures for a longer time. For example, the thermal models established under wood, remained at constant temperatures after sunset, indicating that lizards could maintain their body temperature near T_{set} (32.8°–36.8° C) longer under these materials.

During the rainy season, the frequency of vegetation use by lizards remained high, even at the hottest times of the day, when temperatures climbed above the T_{set} range. Temperatures under wood and plastic were closer to T_{set}. We expected that microhabitats with lower temperatures would be more widely used in the hottest times of the day or in the period when microhabitats stayed close to or within the T_{set} recorded for the species because high ambient temperatures are potentially lethal to lizards. The adjustment of body temperatures of lizards can be obtained behaviorally by changing position in relation to heat sources and/or alternation between different microhabitats in a short period of time (Cowles and Bogert 1944; Hertz et al. 1993).

When we analyzed the average T_b of individuals under each microhabitat, we observed that the average T_b of individuals under wood and plastic debris oscillated more throughout the day than that of individuals found under vegetation. The mean T_b of individuals under vegetation remained, in general, within the T_{set} range at the peak time of lizard activity, however, indicating that *L. lutzae* manages to maintain its body temperature relatively stable within a range suitable for carrying out its activities. Thus, our data are consistent with the idea that lizards alternate between remaining under vegetation and under different types of marine debris to maximize their efficiency in thermoregulation.

Marine debris is currently one of the most important threats to biodiversity and is a cause for particular concern due to its abundance, durability, and persistence in the marine environment (Gall and Thompson 2015). Beaches are one of the most affected marine environments by plastic debris (Li et al. 2016). The effects of the marine debris and its potential to negatively impact biodiversity has not been widely evaluated (Gall and Thompson 2015). In our study, however, if we consider only the thermal ecology, the presence of marine debris seems to be favorable to lizards because *L. lutzae* use this debris to thermoregulate. There are negative effects of plastic pollution, which have been reported for several species around the world including seabirds, turtles, crustaceans, and fish (Derraik 2002; Gilman et al. 2009; Gilardi et al. 2010). The negative effects are mainly related to ingestion, entanglement, and intoxication (Li et al. 2016).

Despite the benefits related to thermoregulation for *L. lutzae*, plastic pollutants may have negative impacts to this species. In general, deposition of marine debris is undesirable because such debris is usually detrimental to vegetation and, consequently, to arthropods that live and feed on it. Vegetation provides protection against predators, and some plant species are part of the diet of adult *L. lutzae*, although juveniles consume predominantly arthropods (Rocha 1998). Harm to vegetation ultimately may harm *L. lutzae*. For example, Rocha and Bergallo (1992) registered a significant decline in the population of *L. lutzae* with the gradual reduction in beach vegetation over 10 y. Cabrera (2021) also registered a decrease in the abundance of the Shoulder Tree Iguana (*L. scapularis*) with the extraction of vegetation and consequent modification of the environment.

We conclude that natural vegetation was the microhabitat most frequently used by *L. lutzae* in the Restinga of Praia Grande, although anthropic material such as plastics and wood also were frequently used. The frequency of use of these microhabitats varied throughout the day and seasonally. Although not

expected, the marine debris appeared to be an important site for thermoregulation and were used throughout the period of activity of the species as thermoregulation sites. Data also reinforces the importance of vegetation for the species, indicating that even at high temperatures, the vegetation maintains the most suitable temperature spectrum, favoring the maintenance of the optimum temperature and the performance of the vital activities of the individuals of *L. lutzae*.

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