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Original Investigation

Activity budget, pattern and rhythm of maned sloths (*Bradypus torquatus*): Responses to variations in ambient temperature

Gastón Andrés Fernandez Giné[a,*], Camila Righetto Cassano[a], Sabrina Souza de Almeida[b], Deborah Faria[a]

[a] *Universidade Estadual de Santa Cruz (UESC), Departamento de Ciências Biológicas, Laboratório de Ecologia Aplicada à Conservação, Rodovia Ilhéus Itabuna, Km 16, CEP 45650-000, Ilhéus, Bahia, Brazil*
[b] *Universidade Presbiteriana Mackenzie, Centro de Ciência Biológicas e da Saúde, Rua da Consolação, 930, CEP 01302-907, São Paulo, São Paulo, Brazil*

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ABSTRACT

Three-toed sloths (*Bradypus*) are heterothermic, and ambient temperature may have a direct effect on their activity levels. Our goal was to describe the time budget, pattern and rhythm of activity of the maned sloth, *Bradypus torquatus* (Xenarthra: Bradypodidae), and to evaluate the effect of ambient temperature on its activity. We hypothesized that (1) sloth activity increases with ambient temperature, fluctuating with the circadian temperature cycle, and (2) sloths are more active in the diurnal period during colder seasons than warm seasons due to constraints or avoidance of the colder times within a 24-h cycle. Nine radio-collared individuals were followed in forest remnants in southern Bahia, Brazil from March 2003 to April 2014. Behavior data of 8 sloths were collected during the diurnal period by direct visualization (608 h of record), and the activities of 4 sloths were recorded by an automated system during continuous hours (744 h of record). The maned sloths exhibited low activity levels, resting 77% of a 24-h period. In general, they were cathemeral, although they were twice as active in the diurnal phase (active 32% of the time) compared with the nocturnal phase (15%). The ambient temperature had a significant positive effect on activity levels. The rhythm of activity was circadian and synchronized with the ambient temperature. No difference was detected in the diurnal activity between hotter and colder seasons, most likely reflecting the low fluctuations in climatic conditions of this tropical forest. The narrow relationship between the circadian activity pattern of maned sloths and the ambient temperature cycle highlights their poor thermoregulatory ability. The lower activity levels exhibited during colder times may represent a behavioral adaptation that reduces heat loss, enhances body temperature control and optimizes energetic benefits, a key feature for a species relying on a low energetic diet.

Introduction

Knowledge of the factors and mechanisms controlling the time that an animal spends in different activities (i.e., activity budget) and the temporal distribution and periodicity of its activities during a 24-h cycle (i.e., activity pattern and rhythm, respectively) provides a basis for understanding the ecology of a given species (Kronfeld-Schor and Dayan, 2003). Most mammals concentrate their activities in diurnal, nocturnal or crepuscular periods and only few species, known as cathemeral, are regularly active in all these phases of a 24-h cycle (Halle, 2006). Cathemeral species have received particular attention given their rarity and flexibility in allocating activities over the 24-h daily cycle. Although most mammals have their activity rhythm synchronized with photoperiodic changes, the activity of cathemeral species may not obey any strong constraints linked to a specific phase of a 24-h cycle and be primarily dictated by factors such as ambient temperature, metabolic needs, food availability, competition and predation risk (Halle, 2006; Donati and Borgognini-tarli, 2006; Ensing et al., 2014).

Three-toed sloths *Bradypus* (Xenarthra: Bradypodidae) are cathemeral (Chiarello, 2008) and heterothermic animals, with a low and labile body temperature (27.7–36.8 °C; Kredel, 1928; Goffart, 1971; McNab, 1978). They are among the most lethargic mammals in the world (Eisenberg, 1978). *Bradypus* are poor regulators of body temperature due mainly to low metabolism and low percentage of body muscle mass, which in turn are adaptations to folivorous and arboreal habits (McNab, 1978). Given the low energy intake (due to

* Corresponding author.
E-mail address: gastongine10@gmail.com (G.A.F. Giné).

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folivory) and the limited body size to allow an arboreal life, sloths have little ability to increase body heat in cold conditions, even when performing locomotor or feeding activities (Kredel, 1928; McNab, 1978; Montgomery and Sunquist, 1978). As body temperature of sloths oscillates with ambient temperature, metabolic constraints on activity levels are expected (Britton and Kline, 1939) as well as behavioral changes to avoid heat loss and overheating (Montgomery and Sunquist, 1978; Urbani and Bosque, 2007).

Indeed laboratorial studies on the widespread *B. variegatus* have indicated that sloth body temperature varies as a function of sunlight exposition and ambient temperature, suggesting that increasing body temperature is the best stimulator of sloth activity (Britton and Kline, 1939). However, there is a scarcity of information on how sloth activity varies with thermal factors in the field. Montgomery and Sunquist (1978) conducted the only known field study that simultaneously recorded sloth activity and ambient temperature throughout a 24-h cycle. *Bradypus variegatus* exhibited thermoregulatory behavior as it moved along the vertical forest strata to regulate sunlight exposition. Nevertheless, no association between activity levels and ambient temperature was found by these authors. In fact, free-ranging three-toed sloths (*B. variegatus*) may be predominantly diurnal (Sunquist and Montgomery, 1973; Urbani and Bosque, 2007) or nocturnal (Queiroz, 1995; Castro-Vásquez et al., 2010), concentrating their activities in warmer or colder periods of the 24-h cycle. However, Urbani and Bosque (2007) suspected that the ambient temperature would be a stronger proximate factor influencing sloth activity patterns in colder regions, where the mean daily temperature is close to or less than the lower limit of thermoneutrality of this species (18–24 °C; McNab, 1978; Gilmore et al., 2000). According to these authors, the avoidance or constraints of colder nocturnal periods may explain the high degree of diurnality in sloths from colder regions.

The maned sloth, *Bradypus torquatus*, is a threatened species endemic to the northern portion of the Atlantic forest of eastern Brazil (IUCN, 2014) and has also been considered cathemeral (Chiarello, 1998). Individuals of this species are predominantly diurnal in the colder regions of a montane Atlantic forest in Espírito Santo state and apparently nocturnal in warmer lowland sites in Rio de Janeiro (Pinder, 1985; Chiarello, 1998). However, the environmental influence on the behavior of this species and other sloth species is far from being fully understood. Except for Montgomery and Sunquist's research, previous studies on free-ranging sloth activity lack nocturnal data and do not include ambient temperature records. Furthermore, the current knowledge on maned sloth activity comes mainly from the study of few radio-collared individuals in the montane region of Espírito Santo (Chiarello, 2008). Individuals from this region are larger than those from lowland forests (Lara-Ruiz and Chiarello, 2005) and belong to a population genetically distinct from those in southern and northern portions of the species range (Lara-Ruiz et al., 2008). Therefore, further studies on maned sloth activities are needed to increase our understanding on individual and population variations.

Here, we aimed to describe the daily budget, patterns and rhythm of activity of the maned sloth in the lowland Atlantic forest in southern Bahia, a highly relevant region for the conservation of this species (Lara-Ruiz et al., 2008), and evaluate inter-individual variations in activity parameters. Considering the low capacity for thermoregulation of this genus and its potential thermal constraints, we tested the following hypotheses: (1) ambient temperature is a proximate factor determining activity patterns of maned sloths, with activity fluctuating directly with the oscillation of environmental temperature throughout a 24-h cycle; and (2) to avoid lower temperatures, we expect an increase in diurnal sloth activity levels within a 24-h cycle during colder seasons compared with warmer seasons.

Material and methods

Study area

We conducted this study in Atlantic forest remnants localized in two federally protected areas in southern Bahia in northeastern Brazil (39°15′ to 39°00′W, 15°18′ to 15°04′S; Fig. 1): the Una Biological Reserve (Rebio-Una) and Una Wildlife Refuge (REVIS-Una). The vegetation is classified as tropical lowland rainforest (Oliveira-Filho and Fontes, 2000), characterized by a canopy height between 25 and 30 m with abundant epiphytes and woody lianas. Forests cover approximately 67% of the landscape, while shaded cocoa plantations and open areas cover 6% and 27%, respectively (Faria et al., 2007).

The study area is situated 0.7–7.5 km from the Atlantic coast in poor sandy soils located between 0 and 80 m above sea level. The local annual average temperature is 24–25 °C, and the monthly average temperature range is 17.1–26.1 °C from June to August and 20.8–30.3 °C from October to April (Mori et al., 1983). The photoperiod averages 11.25 h in June (winter) and 12.98 h in December (summer), with sunrise occurring from 0501 to 0601 h, and sunset, from 1714 to 1811 h throughout the year. The annual average rainfall is 2000 mm/year, with no typical dry season (Mori et al., 1983).

Radio-tracking and data record

We captured nine free-ranging maned sloths (Table 1) between March 2003 and July 2013. Individuals were physically immobilized, measured and weighted. Age classes and sex were determined following Lara-Ruiz and Chiarello (2005). Five sloths were fitted with an 80-g radiocollar (TW-3 tags; Biotrack Ltd., Wareham, UK), and four individuals were fitted with a 40-g radiocollar with a built-in mortality-motion sensor (LB-81 tags; MS6A sensors; Telonics Inc., Mesa, Arizona). These sensors emit 30 BPM pulse when the radiocollar is totally static, indicating animal inactivity, or 60 BPM pulse when the radiocollar is submitted to slight vibration, indicating animal activity. Once tagged, we released the animals on the same tree where they were captured except one animal (BT123), which was translocated to a forest remnant within the REVIS-Una after being captured on a cattle ranch. All of the procedures regarding the capture, handling, tagging and transport of the animals were conducted under the legal approval and consent of the Brazilian Federal Authority and followed the guidelines of the American Society of Mammalogists (Sikes et al., 2011).

We recorded activity using two different sampling methods (Table 1). First we recorded the sloth's behavior through direct observation of eight individuals in 69 diurnal time series of 8–11 h each, between 0600 and 1700 h, totaling 608 h of behavioral data from March 2003 to January 2014. In these diurnal series, we continuously observed the animals with binoculars (8 × 40 mm) and recorded the first visible behavior performed at each 10-min interval following the scan sampling method (Altmann, 1974). We categorized the animal's behavior as resting (no vertical or horizontal displacement of the body and absence of feeding or auto-grooming), traveling (any vertical or horizontal displacement, whether moving, walking or climbing), feeding (any feeding activity, whether biting, chewing, browsing, handling or swallowing food), or other activities (any activity not included in the above categories).

Secondarily, we recorded the activity signals of four individuals fitted with mortality-motion sensors during nine time series of 72 h and two time series of 48 h, totaling 744 h of records during 31 diel cycles (Table 1). These series started and ended at 0800 h and were performed between November 2013 and April 2014. The activity signals of the individuals were simultaneously