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Daily Activity Patterns in *Leiolepis rubritaeniata* (Squamata: Leiolepididae)

GUNTHER KÖHLER[1], KATHARINA GEIß[1] AND PANUPONG THAMMACHOTI CHARUNROCHANA[2*]

[1]*Senckenberg Forschungsinstitut und Naturmuseum, Senckenberganlage 25, 60325 Frankfurt a.M., GERMANY*
[2]*Department of Biology, Faculty of Science, Chulalongkorn University; Bangkok 10330, THAILAND 10330*
[*]Corresponding author. Panupong Thammachoti Charunrochana (panupong.th@chula.ac.th)
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ABSTRACT. – Based on 220 hours of video footage recorded during the months of April through July 2020 we examined the daily activity pattern in the lizard species *Leiolepis rubritaeniata* at a site in northeastern Thailand. The lizards open their burrows mostly between 06:30 and 8:30 h. Then, for usually less than 30 minutes, the lizard typically remained in a position with only the head or the head and forebody outside the hole, observing its environment. Having left the burrow completely, it spread the ribs to stretch the lose skin fold along the sides of the body in order to increase surface area exposed to the sunlight to increase body temperature. After this thermoregulatory period the lizard started to move around to feed or to interact with conspecifics. During the rest of the active part of the day, the lizard showed active periods of foraging and moving across its home range as well as periods of inactivity when the animal was documented to sit motionless near its burrow opening or had disappeared into the burrow. Any disturbance prompted it to quickly retreat into the burrow. In the evening the lizards usually close their burrow with a plug of lose substrate and open it again on the next morning to resume activity.

KEYWORDS: ecology, ethology, Khorat Plateau, lizards, Southeast Asia, Thailand

INTRODUCTION

Butterfly lizards (genus *Leiolepis*, family Leiolepididae) occur widely across Southeast Asia with introduced populations in Florida (Grismer et al. 2014; Krysko and Enge 2005). They prefer open, sandy habitats where they dig burrows in which they retreat when they feel threatened and at night. As far as known, these heliophilic lizards are strictly diurnal and leave their burrows after sunrise and their activity ceases before nightfall (Hartmann et al. 2012; Lei et al. 2021). Currently ten species are recognized in the genus *Leiolepis*, among them *L. rubritaeniata* which is widely distributed on the Khorat Plateau in Thailand and adjacent regions of Laos and Cambodia as well as in south-central Vietnam (Hartmann et al. 2012). This is a bisexual species that like all butterfly lizards is known to exploit a broad diet range that includes any invertebrates and vertebrates they can subdue and swallow as well as a variety of vegetarian matters such as grass, leaves, flowers, and fruits. Very little is known about the natural history in most species of this genus and *L. rubritaeniata* is no exception (Weitkus 1999; Köhler and Thammachoti 2023).

Mertens (1961) described *L. rubritaeniata* as a subspecies of *L. belliana.* Later, *L. rubritaeniata* was recognized as a subspecies of *L. reevesii* (e.g., Peters 1971; Darevsky and Nguyen 2004). However, more recently, morphological and genetic evidence was published that established *L. rubritaeniata* as a distinct species (Teynié et al. 2004; Das 2010; Hartmann and Böhme 2010).

During the months of April through July 2020 we studied aspects of the natural history of *Leiolepis rubritaeniata* (see also Köhler and Thammachoti 2023). Here we report on the daily activity patterns of these lizards based on the analysis of about 220 hours of video footage. Typically, these lizards close the burrow with a plug of loose substrate every evening and open it the next morning as it resumes its daily activity. Thus, the objective of this contribution is to provide data on how the time span of lizard activity (i.e., from opening the burrow in the morning to closing it in the evening) of a complete day is devoted to which activity category by these lizards.

MATERIALS AND METHODS

The study site is near the village of Ban Sa At Na Di (16.16443°N, 104.11363°E, 140 m a.s.l.), Roi Et Province, Thailand, where we conducted field work during the months of April through July 2020. A map of the study site was published in Köhler and Thammachoti (2023). Coordinates and elevation were recorded using Garmin GPS receivers with built-in altimeters. All coordinates were recorded in decimal degrees, WGS 1984 datum. The area is dominated by rice paddy fields and the butterfly lizards are mostly confined to the dams between the individual rice fields (Fig. 1). The predominant ground substrate at the study site is loamy sand.

Each butterfly lizard was recognized individually based on their unique dorsal pattern. We used digital video cameras (Panasonic Camcorder H-VC-380) to

FIGURE 1. A. *Leiolepis rubritaeniata* female a few minutes after opening its hole, remaining motionless with its forebody outside the hole and observing its environment; B. adult male spreading the ribs to stretch the lose skin fold along the sides of the body in order to increase surface area exposed to the sunlight to increase body temperature ("basking"); C. Male feeding on an insect; D. female–female interaction; E. male resting near opening of its burrow; F. freshly closed burrow of *L. rubritaeniata*. Photos taken from video footage by G.K.

monitor the activities at the burrow entrance of butterfly lizards. The camera was placed on a tripod at about 3 m distance from the burrow entrance and was protected from the strong sun light by placing a folded T-Shirt on top of it. The camera was then connected to a power bank and set to record for three hours. Every three hours, the SD card of each camera was changed and video taping continued until dawn. Filming was done without observers because these lizards are very sensitive to the presence of humans and will disappear into their burrows when humans are nearby (<10 m distance). The camera mostly covered only the immediate surroundings of the lizards burrow entrance (about one square meter). In total we recorded 220

TABLE 1. List of recorded observations and their classification to activity categories.

Behavior	Definition	Activity
basking	Individual sits in front of its burrow spreading its ribs. Dorsum mostly directed towards sun and head points towards slope.	basking
resting	Individual sitting on slope or next to burrow, body completely outside of burrow. Pelvic region, belly and hind legs touching the ground. Forebody supported on forelegs and partially erect. Lizard observes surroundings.	resting
resting in burrow	Individual is sitting in burrow entrance. Only the forebody or the head are outside the burrow.	resting in burrow
retreat in burrow	Individual retreats completely into burrow, burrow entrance either closed or open.	retreat in burrow
eating	Individual eats plant material or insects	foraging
foraging	Walks slowly along slope with head lowered, occasionally pecking at ground and chewing.	foraging
hunting	Runs or jumps after flying insects.	foraging
digging	Digs with front legs in burrow entrance.	other
scratching	Scratches head or body with right or left hind leg.	other
grooming	Turns head backwards and starts chewing on old skin of tail or hip.	other
yawning	Opens mouth and yawns.	other
running	Individual runs quickly along the slope. Does not retreat into burrow nor are chewing movements discernible.	other
closing burrow	Closes burrow entrance with sand in the afternoon/evening.	other
opening burrow	Removes sand in front of burrow entrance in the morning.	other
capture	Individual was caught in a trap built in front of burrow entrance.	other
interaction	Individual interacts with other individuals, including head bobbing, push-ups, chasing the opponent, licking burrow entrance while other animal retreated into burrow, or fight between two males.	interaction
unknown	Unknown activity. Individual out of sight or no recordings available for this time period.	unknown

hours and 8 minutes of raw video footage, of which 102 hours and 43 minutes represented ten full days for which we videotaped a certain individual. The remaining footage was used for other aspects of our study on the ecology of butterfly lizards at this site (e.g., behavioral observations, prey caught by the lizards, aspects of reproduction; see also Köhler and Thammachoti 2023). For the present study, only video footage covering complete days was used (i.e., 102 hours and 43 minutes of footage). We selected the individuals for video surveillance based on availability of the lizards with burrows that were easy to reach preferred of those in more distant places, also for the safety of the cameras. Our study included six complete days of a single female (“#007”, SVL 88.0 mm) and four complete days of males: male #020 (SVL 121.0 mm) covered on two days, males #022 (SVL 121.0 mm) and #028 (SVL 121.0 mm) only for a single day each. These individual number correspond to the numbers of individual butterfly lizards reported by Köhler and Thammachoti (2023). Each lizard was caught one time to determine its sex, snout–vent length (SVL), tail length, and weight. The lizard was then released back into its original hole.

Rainfall was noted but not measured; we just noted whether the rain was little and less than one hour duration or substantial and more than one hour duration. Additionally, it was noted whether each day was cloudy or sunny.

For each recorded video, the following information was noted: date of recording; start and end time of recorded observation according to Thai time zone [hh:mm]; timeline as time [mm:ss] in which observation occurred within the video sequence; recorded observation; comments on individual video sequences, e.g., “observes environment” or “bird walks through footage”. The duration of each observation was calculated by subtracting the start time of an observation from its end time. The recorded behavioral acts were assigned to the following activity categories (Table 1): basking, resting, resting in burrow, retreat in burrow, foraging, other, interaction, and unknown.

Descriptive statistics (range, mean value and SD) were calculated using Microsoft Excel. The obtained data were analyzed using R version 4.2.1 (R Core Team 2022). To compute ratios of activity categories, only video footage that represented full days with lizards opening and closing their burrows were considered.

First, the single observations were summed up by individual and day to get the total amount of activity (in percentage) per day using the package “stats” version 4.2.1 (R Core Team 2022). The percentage of each activity category was calculated for each individual and day using the package “dplyr” version 1.0.9. (Wickham et al. 2022). The obtained data were visualized with stacked barplots using the packages “ggplot2” version 3.3.6. (Wickham 2016) and “extrafont” version 0.18. (Chang 2022).

To visualize the distribution of the activity categories over a daily course, a twelve hour period from 6 am to 6 pm was considered and divided into 30 minute intervals. Outside this twelve hour period, the burrows were closed and the lizards inactive due to the lack of day light. The single observations were summed up for each 30 minute interval by individual and day to obtain the total duration of each activity category (in percentage) using the package “stats” version 4.2.1 (R Core Team 2022). The total percentage of each activity category for every 30 minute interval was calculated using the package “dplyr” version 1.0.9. (Wickham et al. 2022). The obtained data were visualized with stacked barplots using the packages “ggplot2” version 3.3.6. (Wickham 2016) and “extrafont” version 0.18. (Chang 2022).

Furthermore, disturbances that caused the lizard to retreat into its burrow during the day were categorized as follows: caused by animals larger than the lizards (i.e., chicken or dogs coming near the burrow entrance); caused by humans (i.e., people approaching the burrow entrance); interaction with conspecifics (i.e., male or female butterfly lizards visiting the burrow). Since the area we videotaped was about one square meter, we could only identify the disturbing object when it was caught on video (i.e., closer than 1 m to the burrow entrance). In our analyses we differentiated between reappearance of the head (=head) and the complete emergence of the lizard from its burrow (= body) after a given disturbance. The analyzed data were visually checked for outliers and outliers were removed. A Shapiro-Wilk test was performed to check the data for normality using the package “RcmdrMisc” version 2.7-2 (Fox 2022). Since the data were not normally distributed, a Kruskal-Wallis rank sum test was performed using the package “stats” version 4.2.1 (R Core Team 2022). In case the data showed significant differences between the disturbance categories, a Dunn's Kruskal-Wallis test for multiple comparisons was performed using the packages “FSA” version 0.9.3 (Ogle et al. 2022) and “rcompanion” version 2.4.16 (Mangiafico 2022) to test which of the disturbances was responsible for the significant differences. The obtained data were visualized with boxplots using the packages “ggplot2” version 3.3.6 (Wickham 2016), “ggpubr” version 0.4.0 (Kassambara 2020), “patchwork” version 1.1.1 (Pedersen 2020) and “extrafont” version 0.18. (Chang 2022).

RESULTS

The lizards usually closed their burrow with a plug of lose substrate in the evening and opened it again on the next morning to resume activity. Of 11 butterfly lizards that we video documented the opening of its burrow, the time varied between 06:31 and 11:28 h (07:36±01:07 h, n = 29 events). Sunrise at the study site was approximately 05:48 h in April, 05:33 h in May, 05:32 h in June, and 05:40 h in July. After opening the burrow, the lizard typically remained in a position with only the head or the head and forebody outside the hole, observing its environment (Fig. 1A). After 3–114 min (19.05±23.77 min, n = 20), the lizard left the burrow completely and spread the ribs to stretch the lose skin fold along the sides of the body in order to increase surface area exposed to the sunlight to increase body temperature (“basking”; Fig. 1B). This thermoregulatory behavior lasted 7–88 min (36.73±20.16 min, n = 17), before the lizard started to move around to feed (Fig. 1C) or to interact with conspecifics (Fig.1D). The lizard’s behavior was not documented when the lizard moved out of the area captured by the video camera. During the rest of the active part of the day, the butterfly lizard showed active periods of foraging and moving across its home range as well as periods of inactivity when the animal was documented to sit motionless near its burrow opening (Fig. 1E) or had disappeared into the burrow. Any disturbance prompted it to quickly retreat into the burrow. Usually between 0.02–30 min (3.12±5.5 min, n = 123) after the lizard had retreated into the burrow due to a disturbance, the head of the animal reappeared in the burrow entrance and the lizard observed the surroundings. The very short values of 2-3 s were recorded several times and probably correspond to minor disturbances further away from the hole that let the lizard to stick out its head almost immediately after retreating. 0.12–14 min (4.23±3.92 min, n = 45) after the lizard stretched its head out of the burrow entrance it completely emerged from its burrow.

The Kruskal-Wallis rank sum test revealed significant differences among the disturbance

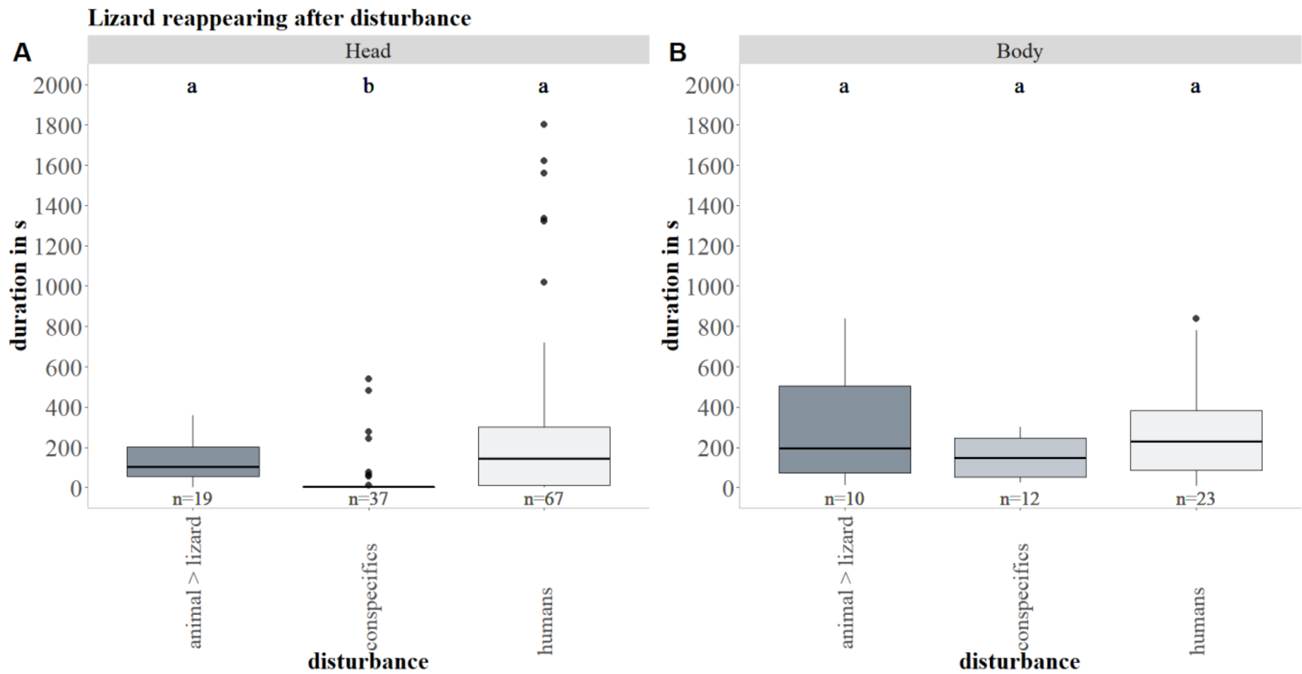

FIGURE 2. Boxplots of duration in s that the lizards needed to show their head (A) and whole body (B) outside their burrows, depending on different disturbances. Letters above boxplots indicate significant differences between the groups according to Dunn's Kruskal-Wallis test for multiple comparisons.

categories for the time span of disappearance and the reemerging of the lizards head (χ^2 = 28.019, df = 2, p = 8.238e-07) (Fig. 2A) but showed no significant differences among these categories for the time span until the lizard's body completely left the burrow (χ^2 = 1.739, df = 2, p = 0.4192) (Fig. 2B). The lizard showed its head in 0.03–6 min (2.15±1.82 min, n = 19) after animals larger than itself approached the burrow, in 0.02–30 min (4.67±6.83 min, n = 67) after humans approached, and in 0.02–9 min (0.82±2.08 min, n = 37) after conspecifics approached. The lizard left the burrow completely in 0.22–14 min (5.28±4.88 min, n = 10) after animals larger than itself approached the burrow, in 0.12–14 min (4.70±3.98 min, n = 23) after humans approached, and in 0.40–5 min (2.47±1.72 s, n = 12) after conspecifics approached.

Lizard activity usually ceased in the evening but varied from 11:53 and 18:28 h (16:36±01:52 h, n = 14), and the animal usually closed its burrow with a plug of substrate (Fig. 1F). In case of afternoon rain, the animal disappeared into its burrow and often closed it early and never came out again that day. Sunset at the study site was approximately 18:18 h in April, 18:26 h in May, 18:36 h in June, and 18:38 h in July. Figure 3 shows the daily activity patterns of three adult males and figure 4 for one adult female for which we had complete day recordings. They all show that thermoregulatory behavior for warming up was most pronounced after leaving the burrow in the morning with only short thermoregulatory periods in the course of the day. Most of the activity periods of the studied butterfly lizards constitutes a mosaic of foraging, resting, and retreat in burrow. Figure 5 shows the cumulative representation of each activity category for each full day of video surveillance. In most cases, the activity duration per days was approximately 9 to 11 hours (10.05±1.32 h), but in two of the documented days it was 7.65 and 7.78 h, respectively, due to unfavorable weather conditions (rain). The relative time (relative to the complete activity period of the particular day) the lizard spend was 2.34–20.05% (8.96±4.96%) for thermoregulating ("basking"), 1.51–15.41% (9.67±4.13%) for foraging, 0.68–28.71% (15.33±9.36%) for resting, 3.76–28.30% (16.62±7.28%) for resting inside the burrow entrance, and 6.99–38.29% (19.14±10.05%) for retreated into the burrow.

DISCUSSION

The study of the daily activity patterns of a given species yields essential information for the understanding of its ecology (Heatwole and Taylor 1987). Our study included six complete days of a single female and four complete days of males (one male covered on two days, the other ones only for a single day each). No difference in the daily activity pattern nor in the activity duration per day was found

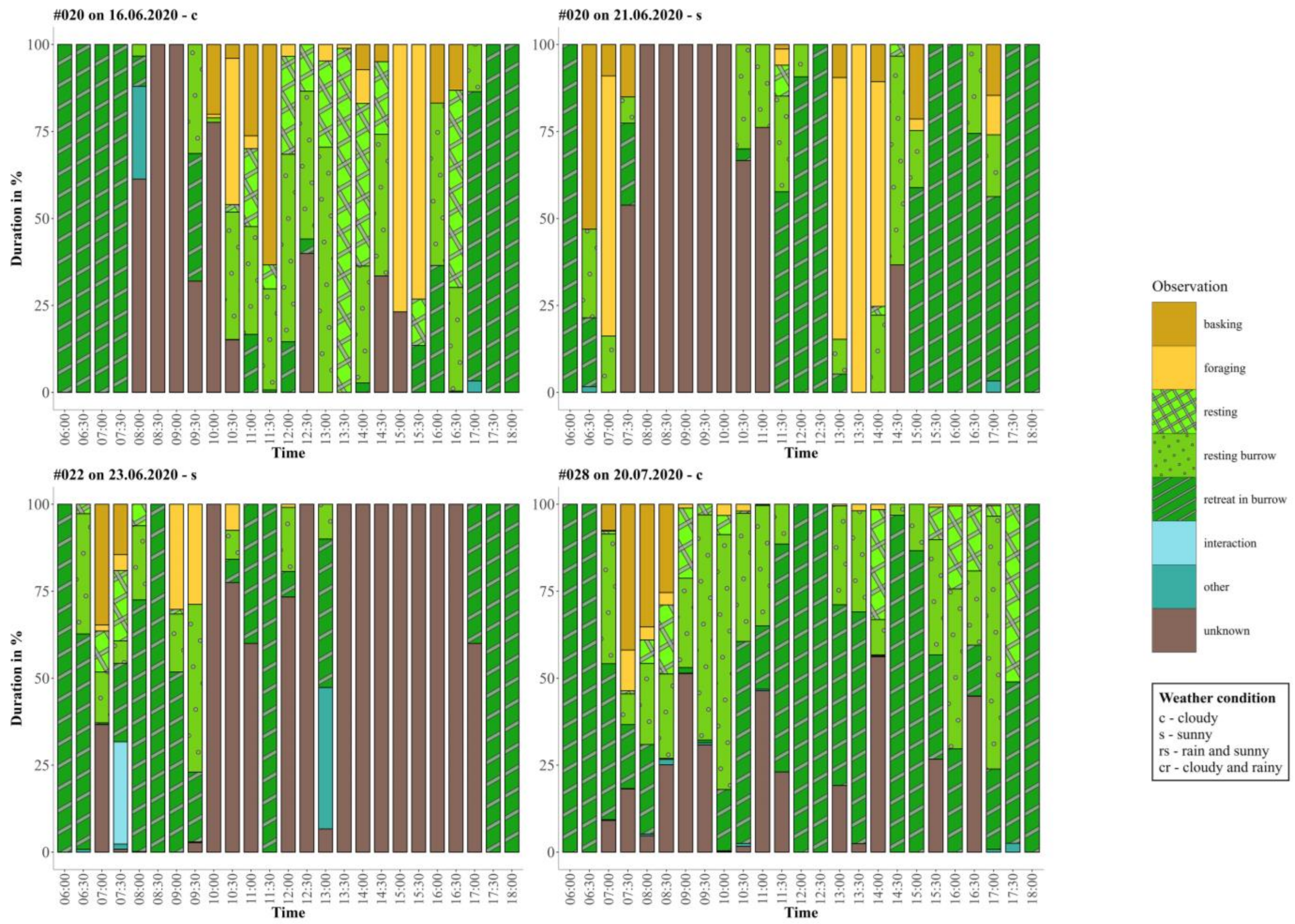

FIGURE 3. Daily activity pattern of male butterfly lizards #020, #022 and #028. Weather conditions indicated by bold letters of ordinate axis legend: s – sunny = hot sunny day, no rain; rs – rain and sunny = mostly sunny with rain shower(s) in the afternoon; c – cloudy = cloudy with short bright spells without rain showers; cr – cloudy and rainy = cloudy with short bright spells with rain shower in the afternoon.

between sexes, but given our small sample size this result might not be representative. During hot sunny days without rain the lizards generally spend less time basking ("warming up") as compared to more cloudy days or such with rainfall. Thermoregulation for increasing body temperature through spreading of the rips was mostly observed in the morning with only short thermoregulatory periods in the course of the day. On days with afternoon rain showers, the lizard disappeared into its burrow and closed it early not to come out again that day.

In the present study we recorded the daily activity pattern of individual lizards using video surveillance. Cunningham (2000) also documented the activity patterns of individual lizards (i.e., *Uromastyx aegyptius microlepis*) but observed the animals directly using binoculars. Other studies have reported the number of observed active individuals over the course of the day (e.g., Kirchhof et al. 2010; Pal, Swain and Rath 2010; Bouam et al. 2016). To gain a more complete picture of the daily and seasonal activity patterns of *Leiolepis rubritaeniata*, it is essential to increase the sample size, both in respect of more individuals and of more surveillance days per individual, and to study the variation of the activity pattern in the course of the year. Our overall observations seem similar to those of other diurnal lizards (Cunningham 2000; Radder, Saidapur and Shanbhag 2005; Bajru, Yadav and Yankanchi 2016): *L. rubritaeniata* takes intense basking periods shortly after leaving its burrow in the morning. After warming up, the lizards would start other activities such as foraging, resting, or retreating to their burrows. Animals larger than the lizard itself or humans approaching the lizard prompts it to retreat into its burrow. Surprisingly, when people approached the camera (e.g., to check its status), the lizard's head reappeared very quickly after disappearing to check its surroundings. Other agamid lizards, i.e., *Uromastyx aegyptius microlepis*, appear to be more sensitive to disturbance and often do not leave their burrows for

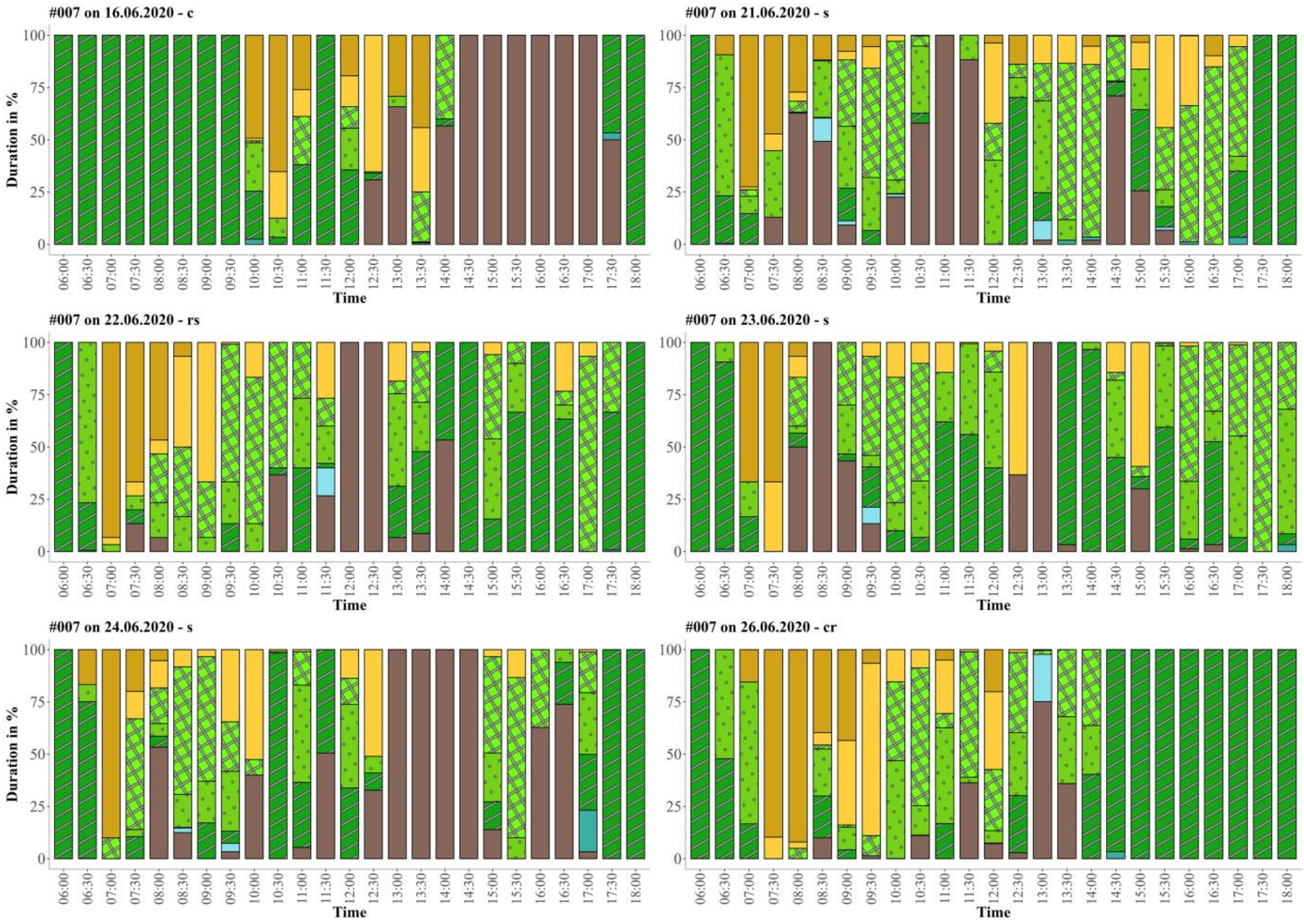

FIGURE 4. Daily activity pattern of butterfly lizards #007 (female). Legend see fig. 3

extended time periods after disturbance (Cunningham 2000). Hartmann et al. (2012) observed *L. rubritaeniata* in Cambodia also retreating into their burrows when disturbed. In contrast to our observed animals, their individuals reportedly always closed the entrances with substrate after any disturbance (Hartmann et al. 2012). Our *L. rubritaeniata* individuals only closed their burrows as a reaction to disturbance when this event was severe (e.g., when they were captured for taking measurements).

The distinct seasonality of the climate (e.g., air temperature, precipitation) at the study site may have a profound influence on the activity patterns of *L. rubritaeniata*. In areas with pronounced seasons, often a shift from a unimodal activity pattern in spring to a bimodal one in summer is observed (e.g., Pollo and Pérez-Mellado 1989; Rouag et al. 2007; Bouam et al. 2016). For several widely distributed species, it was demonstrated that depending on the local annual climatic regime, populations of the same species showed different activity patterns (Heatwole and Taylor 1987). However, for some species, despite distinct seasonality of the climate at the study site, no remarkable interseasonal differences in diel activity patterns were reported whereas these shifts were recorded for other sympatric species (e.g., Rouag, Berrahma and Luiselli 2006). At our study site rainfall is mostly restricted to the months of May through October with the total annual precipitation being 1145 mm in 2021 and 1347 mm in 2022. During the warmest months (March through August), the monthly mean temperature varied from 29.6 to 31.2°C whereas during the coolest months (December and January) these varied from 22.3 to 23.8°C. Although we do not have the data to demonstrate this assumption, our preliminary observations indicate that in *L. rubritaeniata* activity in general is reduced during the rainy season. This assumption is based on observations where the lizards closed their burrows earlier in the afternoon during prolonged rain or did not open them at all on rainy days. More information is needed to gain full insight into the daily activity patterns of *Leiolepis rubritaeniata* and its relation to daily changing weather conditions as well as seasonal change.

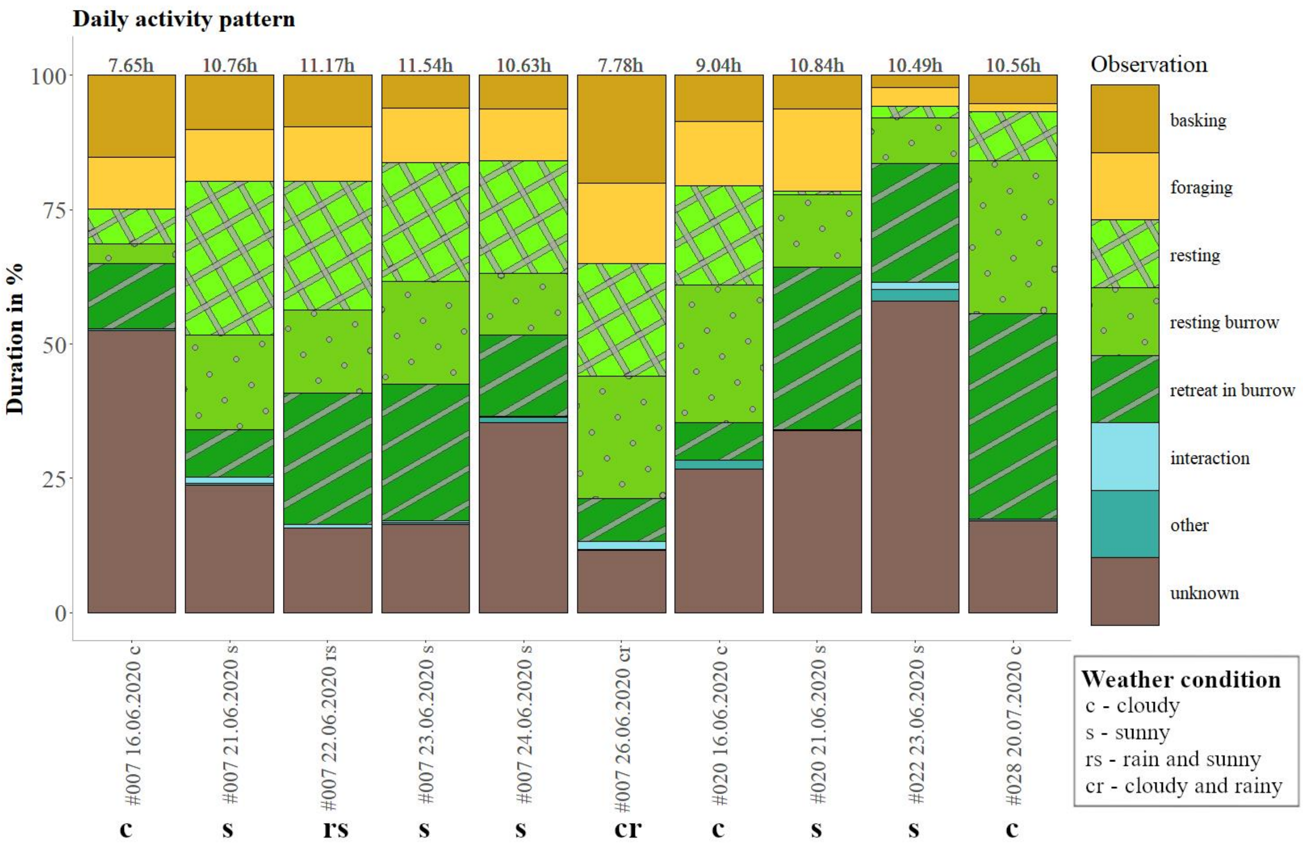

FIGURE 5. Cumulative representation in percentage of each activity category for each full day of video surveillance. Individuals included in analysis: female #007; males #020, #022, #028. Explanation for weather conditions see fig. 3.

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