

# Many-lined Sun Skinks (*Mabuya multifasciata*) Shift Their Thermal Preferences Downwards When Fasted

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**Abstract** We maintained adult many-lined sun skinks (*Mabuya multifasciata*; 12 females and 12 males) collected from Hainan (southern China) in September 2006 in two outdoor enclosures to examine the effect of feeding condition on selected body temperature ( $T_{sel}$ ). Skinks shifted their thermal preferences when fasted. Temporal variation in  $T_{sel}$  was not found within each sex  $\times$  feeding condition combination, and neither in fed nor in fasted skinks did the mean values for  $T_{sel}$  differ between sexes. Body temperatures selected by fed skinks fell within the range from 30.2 to 33.9 °C, and those selected by fasted skinks within the range from 25.1 to 31.8 °C. Body temperatures ( $31.8 \pm 0.3$  °C) selected by fed skinks were on average 4.0 °C higher than those ( $27.8 \pm 0.4$  °C) selected by fasted skinks. Fasted skinks had no difficulty in attaining higher body temperatures, but they voluntarily shift their thermal preferences downwards to save energy. This finding suggests an adaptive mechanism adopted by many-lined sun skinks to enhance their fitness during the periods when food availability is low.

**Keywords** Scincidae, feeding condition, selected body temperature, adaptive response, food deprivation

## 1. Introduction

Reptiles attempt to maintain relatively high and constant body temperatures when conditions allow them to do so, often because biochemical, physiological and behavioral activities are maximized at moderate to relatively high temperatures (Avery, 1982; Huey, 1982; Huey and Kingsolver, 1989; Angilletta *et al.*, 2002; Angilletta, 2009). The body temperature preferred by a reptile can be estimated by measuring its selected body temperature ( $T_{sel}$ ) in a laboratory thermal gradient. Temporal, spatial and/or inter-individual variation in  $T_{sel}$  has been found in many species of reptiles (e.g., Gatten, 1974; Ellner and Karasov, 1993; Christian and Bedford, 1995; Andrews, 1998; Xu and Ji, 2006; Yang *et al.*, 2008). One of the factors likely affecting  $T_{sel}$  is the feeding condition. Studies of croco-

dilians (Lang, 1979), turtles (Gatten, 1974; Hammond *et al.*, 1988), lizards (Sievert, 1989; Brown and Griffin, 2005) and snakes (Slip and Shine, 1988; Sievert and Andreadis, 1999; Sievert *et al.*, 2005) show that animals often shift their thermal preferences upwards after feeding. Postprandial thermophily has been also found in other ectothermic vertebrates including fishes (Javaid and Anderson, 1967), salamanders (Gvoždík, 2003) and anurans (Witters and Sievert, 2001). One commonly cited explanation for why postprandial thermophily is so widespread among ectothermic vertebrates is that high body temperatures not only increase their feeding rates, but also enhance their ability to assimilate ingested food (Wang *et al.*, 2003; McConnachie and Alexander, 2004; Sievert *et al.*, 2005). However, not all ectothermic vertebrates show postprandial thermophily after feeding (Hammerson, 1987; Morgan and Metcalfe, 2001; Wall and Shine, 2008).

To our knowledge, studies of lizards in this field have all been conducted on laboratory thermal gradients, primarily because it is difficult to collect data in the field. Nonetheless, the effects demonstrated in laboratory ex-

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periments often do not reflect in nature. Thus, extrapolation of laboratory results to field populations should be made with caution (Wall and Shine, 2008). Moreover, most studies of lizards have focused upon the possible shifts in thermal preferences after feeding.

The Many-Lined Sun Skink (*Mabuya multifasciata*) is a medium sized (up to 117 mm snout-vent length; Ji *et al.*, 2006), viviparous scincid lizard that has an exclusively tropical distribution covering southern China, southeast Asia, Indo-Australian Archipelago and New Guinea (Huang, 1999). The skink is typically found in open sunny spaces, forest edges, and riverbeds (Huang, 1999). We maintained adult skinks in outdoor enclosures to examine the effect of feeding condition on  $T_{sel}$ . We used *M. multifasciata* as a model animal for three reasons: (1) the skink can be easily collected and handled; (2) thermoregulation can occur in highly disturbed environments; and (3)  $T_{sel}$  is not a fixed (and thus, unchangeable) trait in the skink (Ji *et al.*, 2007; Lin *et al.*, 2008).

## 2. Materials and Methods

**2.1 Animal collection and maintenance** Twenty-four adults (12 females and 12 males; SVL > 100 mm) were collected in September 2006 from a population in Ledong (18°45'N, 109°10'E), Hainan, China. The collected skinks were transported to our laboratory in Hangzhou, where females and males were equally assigned into one of the two 2.6 m × 1.2 m × 0.8 m (length × width × height) outdoor enclosures inside which the microhabitats were built according to their habitats in nature. During daylight hours, the skinks could regulate body temperature by exploiting spatially and temporally variable heating sources created by natural sunlight and five 250 W light bulbs suspended above one end of each enclosure, at 25 cm intervals; and their overnight body temperatures followed outdoor ambient temperatures. Mealworms (larvae of *Tenebrio molitor*), house crickets (*Achetus domesticus*), field-captured grasshoppers and fresh water enriched with vitamin and minerals were provided daily, at 2200 hrs.

**2.2 Measurement of  $T_{sel}$**  We used a model of repeated-measures analysis (ANOVA) to examine the effect of feeding condition on  $T_{sel}$ . Skinks in the enclosures were measured for the first time one week after they were collected from the field. All skinks were fed prior to being measured. To avoid the possible influence of male dominance hierarchy or interactions among individuals on  $T_{sel}$ , we widthwise divided each enclosure into twelve 2.6 m × 0.1 m (length × width) lanes with wood blocks.

A 250 W light bulb suspended above one end of each lane created a thermal gradient ranging from the ambient temperatures (18–20 °C) to 55 °C (2 cm above the lane floor) for 14 h daily. We introduced one skink into each lane at 0700 hrs when the heating lights were switched on. Body (cloacal) temperatures were taken for each skink at 1400, 1600 and 1800 hrs with a UT325 digital thermometer (Shanghai Medical Instruments, China) and, at each time step, measurements were completed within 10 minutes. Efforts were made to avoid heat transfer between the hand and the lizard.

Following the  $T_{sel}$  measurement for fed skinks, we dismantled lanes, and removed food from the enclosures. We fasted skinks for 5 days to ensure post-absorptive conditions, and then measured them for  $T_{sel}$  following the procedures described above.

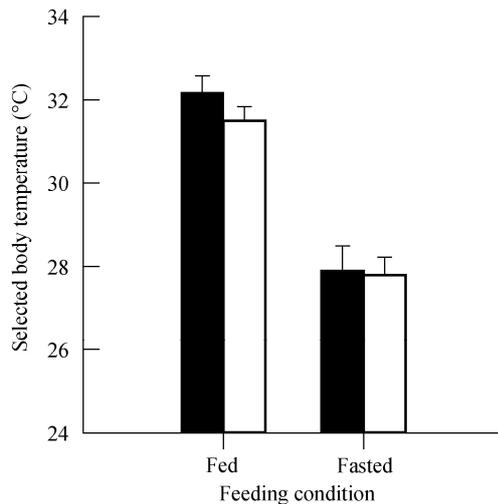
**2.3 Statistical analyses** Statistical analyses were performed with STATISTICA software (Version 6.0 for PC). All data were tested for normality (Kolmogorov-Smirnov test) and homogeneity of variances (F-max test). As data met assumptions for parametric tests (normality, homogeneity and additivity), there was no need for any transformation. Data were analyzed with repeated measures ANOVA. All values were presented as mean ± standard error (SE), and the significance level was set at  $P = 0.05$ .

## 3. Results

Temporal variation in  $T_{sel}$  was not found within each sex × feeding condition combination (all  $P > 0.072$ ), so we pooled data for the three time steps (1400, 1600 and 1800 hrs). The mean values for  $T_{sel}$  differ between fed and fasted skinks ( $F_{1, 22} = 150.58$ ,  $P < 0.0001$ ) but not between the sexes ( $F_{1, 22} = 0.49$ ,  $P = 0.489$ ), and the interaction between sex and treatment (fed versus fasted) was not a significant source of variation in  $T_{sel}$  ( $F_{1, 22} = 0.77$ ,  $P = 0.389$ ). Body temperatures selected by fed skinks fell within the range of 30.2–33.9°C, and those selected by fasted skinks within the range from 25.1–31.8°C. Body temperatures ( $31.8 \pm 0.3^\circ\text{C}$ ) selected by fed skinks were on average 4.0°C higher than those ( $27.8 \pm 0.4^\circ\text{C}$ ) selected by fasted skinks (Figure 1).

## 4. Discussion

Consistent with studies of other lizards, the results of this study show that Many-lined Sun Skinks shift their thermal preferences downwards when fasted. Lizards typically maintain body temperatures within their volun-



**Figure 1** Mean values (+SE) for body temperatures selected by fed and fasted skinks. Black bars represent females, and white bars represent males.

tary range when thermoregulation is not constrained by any biotic or abiotic factors, such that they express their behavioral and physiological performances at relatively high levels (Xu and Ji, 2006 and references therein). Higher-than-usual or lower-than-usual body temperatures have been recorded in many lizards with ‘unusual’ physiological conditions. For example, female lizards often shift thermal preferences downwards or upwards when pregnant, because the maximal reproductive benefits are achieved in individuals that shift thermal preferences towards the levels optimal for embryonic development (Braña, 1993; Daut and Andrews, 1993; Mathies and Andrews, 1997; Le Galliard *et al.*, 2003). Our experimental design, in which all  $T_{sel}$  measurements were carried out in outdoor enclosures mimicking natural habitats, allows us to discuss whether fasted skinks select lower body temperatures reflects an adaptive response of animals in nature to low food availability.

For Many-Lined Sun Skinks with free access to food, body temperatures selected by adult males and nonpregnant females fall within the range of 30–36 °C, and those selected by pregnant females within the range from about 28–31 °C (Ji *et al.*, 2007). It has been reported for the species that body temperatures with the range from 30–36 °C are optimal for locomotor performance, and that body temperatures lower than 30 °C are suboptimal for feeding performance (Lin *et al.*, 2008). Body temperatures near 29 °C are optimal for embryonic development in *M. multifasciata* (Ji *et al.*, 2007), and these temperatures allow pregnant females to produce high-quality offspring at relatively low energetic costs, but have no noticeably adverse influence on locomotor

performance (Lin *et al.*, 2008).

In the present study, body temperatures selected by fed and fasted skinks did not differ between the sexes. This result is not unexpected, because females used in this study were not pregnant in September when our study was conducted. Body temperatures selected by fed skinks fell within the range (30–36 °C) recoded in adults of *M. multifasciata* with free access to food, whereas those selected by fasted skinks were mostly below the lower limit (~30 °C) of body temperatures optimal for feeding and locomotor performances. It has been known that net energy gains achieved from feeding can be allocated to somatic tissue growth and production of offspring (Nagy, 1983), and that locomotor performance is of importance for avoiding predators and enhancing foraging success (Pough, 1989; Bauwens *et al.*, 1995; Miles *et al.*, 1995; Shine, 2003; Wang *et al.*, 2003). So, why did fasted skinks select body temperatures that do not allow them to express feeding and locomotor performances at high levels? The answer presumably lies in that fasted skinks shift their thermal preferences downwards to save energy. Within a certain range of temperatures, feeding rates cannot be increased without an increase in body temperature in lizards (Xu and Ji, 2006 and included references). Such a pattern of thermal dependence of feeding rates can be also found in *M. multifasciata* (Lin *et al.*, 2008). Assuming a positive correlation between foraging effort and food ingested, one may expect that to compensate for the negative consequences of starvation, skinks should forage longer and/or maintain body temperatures optimal for foraging activities. However, if keeping foraging activities at normal levels is costly when food availability is low or no food is available, skinks that select lower-than-usual body temperatures are more likely to save energy while simultaneously minimizing the risks of predation, due to the reduced energetic costs and activities at low body temperatures. In the present study, fasted skinks could have easily attained higher body temperatures, but they voluntarily shift their thermal preferences downwards. This finding suggests an adaptive mechanism adopted by many-lined sun skinks in nature that enables them to enhance their fitness during periods when food availability is low.

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