Vulnerability to climate change of *Anolis allisoni* in the mangrove habitats of Banco Chinchorro Islands, Mexico

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ABSTRACT

As niche specialist species, lizards from tropical environments are characterized by a low tolerance and high physiological sensitivity to temperature changes. The extent of vulnerability to thermal changes depends on the lizard's physiological plasticity to adjust the environmental changes. Herein we studied the thermal biology of *Anolis allisoni*, an endemic arboreal lizard from the tropical islands of the Banco Chinchorro Biosphere Reserve, Mexico, carried out during April and May 2012 and April 2014. We report field body (T_b) and preferred body temperatures in the laboratory (T_{pref}), operative temperatures (T_e) and restriction of hours of activity. *Anolis allisoni* showed high and identical T_b and T_{pref} (33 °C), not significantly different than the mean T_e (32.15 °C). The effectiveness of thermoregulation (E= −0.30) and the analysis of hours of restriction suggested that the high temperatures of T_e (40–62.5 °C) registered at midday (from 12:00 to 15:00) of *A. allisoni* habitat are hostile and force lizards to take refuge during a period of 3 h of their daily time of activity. The scarcity of opportunities to find alternative refuges for thermoregulation in Banco Chinchorro point out the vulnerability of *A. allisoni* and the risk of local extinction when considering future predictions of increase in global environmental temperatures.

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1. Introduction

Climate change has profoundly affected terrestrial organisms (Walther et al., 2002; Parmesan, 2006), and it is predicted that the rise in environmental temperature due to global warming in the coming decades will impact tropical species more harshly (Root et al., 2003; Angilletta, 2009; Deutsch et al., 2008). However, the direct biological consequences depend not only on the rate of climate warming but also on the physiological sensitivity to warming and on the behavioural and physiological capabilities of organisms to buffer the environmental changes (Huey and Slatkin 1976; Huey et al., 2003; Deutsch et al., 2008; Tewksbury et al. 2008). In the long term, avoidance of local extinctions will depend on the possibilities of adaptation to new thermal niche conditions (Logan et al., 2014).

Ectotherms (e.g. insects, amphibians, reptiles) constitute the vast majority of the biodiversity at tropical latitudes. However, many tropical ectotherms are thermal specialists and therefore vulnerable to even slight increases in regional temperature, which can adversely impact individual fitness and population viability. For instance, tropical and endemic lizards of tropical islands are adapted to less variable climatic conditions (Tewksbury et al., 2008) where body temperatures (T_b) are close to their critical thermal maximum (Huey et al., 2012). Therefore, lizards of tropical regions are characterized by low tolerance to high T_b, limited acclimation ability, and reduced dispersal capabilities (Janzen, 1967; Van Berkum, 1986; Addo-Bediako et al., 2000; Deutsch et al., 2008) making them vulnerable to thermally stressful changes.

Recent evidence is controversial about the possible paths of adaptive evolution of tropical lizards to global warming. Given enough time, species may shift geographically to milder thermal environments or could adjust to local conditions by behavioural and physiological plasticity, or may adapt by natural selection to changed environments, whereas a short-term behavioural change may be to retreat to a refuge during the hottest hours of the day. The shortening of the daily activity period, which in turn reduces feeding opportunities, social and reproductive behaviours,

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undermine body condition, growth and reproduction, increasing the risk of local extinction (Sinervo et al., 2010).

In a global warming scenario, lizards will have at least three main responses: dispersal, behavioural and physiological plasticity, and adaptation (Sinervo et al., 2010). For example, if environmental temperatures increase, sympatric species which occur in open habitats may invade the forest, competing and driving the forest lizard populations to extinction (Huey et al., 2009), or they could adapt to the changing environment by natural selection instead of shifting their geographic range and competing with novel sympatric species (Logan et al., 2013).

The genus *Anolis* (anoles) consists of about 400 species of small, arboreal, insectivorous lizards (Roughgarden, 1995). It is among the largest genera of vertebrates, occurring throughout the subtropical and tropical Western hemisphere, in the southern United States, Mexico, Central and South America, and about 150 species occur on the Caribbean Islands (Williams, 1969; Losos and Schneider, 2009). *Anolis allisoni*, endemic to Caribbean Islands, is the only anole occurring solely in mangrove forest habitats (Rand, 1964, 1967). *Anolis allisoni* can also be found in the upper trunks and crowns of trees in sympatry with species geographically widespread in open habitats such as *A. sagrei* and *Aspidocelis maslini*.

We hypothesize that the specialist character and the restricted distribution of *A. allisoni* make it vulnerable to rapid environmental changes. Herein, we estimate how a predicted increment of 3.2–4 °C (IPCC, 2013) in mean ambient temperature could affect the time of activity of the insular *A. allisoni* from the Banco Chinchorro Islands in Mexico. We integrate data on lizard field and preferred body temperature, quality of thermal microenvironment, and efficiency of thermoregulation (*sensu* Hertz et al., 1993), and we describe the main cooling or heat sources that these lizards use for thermoregulation.

2. Materials and methods

2.1. Study area and materials

Field work was carried out in Cayo Centro, the largest island of Banco Chinchorro atoll, Quintana Roo, Mexico (18°34′N–87°19′W) in April and May 2012, and April 2014. *Anolis allisoni* (N=34) were caught when active on the trunks of palm trees or on the branches of trees where the leaves provide small patches of sun and shade (i.e. performing any behaviour related to feeding or breeding activities) from 9:00 to 19:00 h, by hand or noose. Individuals were kept in captivity no more than 48 h, and were all released at the precise spot of capture using a GPS device (Garmin, eTrex 20).

2.2. Data collection

Body temperature (T_b, sensu Pough and Gans, 1982) was measured in the field in active lizards using a catheter probe TES TP-K01 (1.62 mm diameter) introduced approximately 1 cm inside the cloaca. Individuals were handled by the head to avoid heat transfer and temperature was recorded within 20 s of capture. Time of day at capture was also recorded.

The micro-environmental temperatures were recorded at capture sites in order to determine heat sources used by lizards. We measured substratum temperature (T_s), air temperature at 1 cm (T_a) and air temperature at 1 m above the ground (T_{air}). Temperatures were registered using thermocouples for substrate (TES TP-K03) and air (TES TP-K02), each instrument connected to a TES 1302 thermometer (TES Electrical Electronic Corp., Taipei, Taiwan, ± 0.03 °C).

The operative temperatures (T_e, *sensu* Hertz et al., 1993) were measured in the field using 12 plastic cylinder (PVC) physical

models, 15 cm length × 5 cm diameter, sealed at the ends, distributed at a variety of microsites on vertical substrates (trees and heights above the ground) where *A. allisoni* typically perch (Rand, 1964; Schoener and Schoener, 1971; Jenssen et al., 1984). The physical models were connected to three data loggers (HOBO U12, 4 External Channel Logger) each with four thermistors, and the micro-environmental temperatures were recorded every 15 min from 9:00 to 19:00 during captures (8 days in April and May 2012 and during 7 days in April 2014). The mean of the temperatures recorded from each model every day of capture were used to obtain the mean T_e.

2.3. Laboratory experiments

Thermoregulation experiments were conducted 1–2 days after capture. Lizards were placed individually in open-top terraria (100 × 45 × 20 cm) with a thermal gradient produced by a lamp over the end of the terraria making a substratum gradient from 25° to 50 °C. Temperatures were register using ultra-thin (1 mm) catheter thermocouples fixed in the abdomen with adhesive tape. The temperature of each lizard was obtained every 1 min for 2 h by connecting the thermocouple to a TC-08 Data Acquisition Module Omega® (8-Channel USB Thermocouple).

Experiments were performed to estimate the mean and range of the T_{pref} for each individual. The set-point range (T_{set}), considered as the temperatures within the interquartile range of the observations, was also noted because of neurophysiological evidence that ectotherms regulate between upper and lower set-point temperatures rather than around a single T_b (Barber and Crawford, 1977; Firth and Turner, 1982). The interquartile range represents the natural settings comprising the hypothalamic thermostat in lizards and fishes (Hertz et al., 1993).

In order to measure the average extent to which *A. allisoni* experienced T_b outside the set-point range, the sum of the absolute values of the deviations of T_b from T_{set} of each individual was calculated (individual deviation=d_b). The values obtained for each lizard were used to estimate the mean and range of T_{pref}, T_{set}, and d_b. In addition, the index of the mean thermal quality of a habitat from an organism's perspective (d_e) was calculated as the deviation of T_e in relation to the mean T_{set} for the species. The existence of active selection of the microhabitats and the effectiveness of the thermoregulation was obtained as E=1–(Mean d_b/ Mean d_e) which integrates the average degree to which *A. allisoni* experienced T_b outside the set-point range (d_b) and the quality of thermal environment to achieve T_{pref} (d_e). Thermoregulation can be considered as effective when E is close to 1, whereas that of a thermoconformer when E is close to 0, or as that of a moderately effective thermoregulator when E is close to 0.50 (Hertz et al., 1993; Bauwens et al., 1996; Medina et al., 2009; Ibargüengoytía et al., 2010; Medina et al., 2011). Negative values of E can occur when animals actively avoid microhabitats within the set-point range for example: when predators are abundant, food is rare at such sites or when the thermal conditions are restrictive (Huey and Slatkin, 1976; Hertz et al., 1993; Gutiérrez et al., 2010).

2.4. Restriction and activity time

We estimated the restriction in hours of activity (h_r), which is considered to be the additional time a lizard would remain in its thermal refugia due to temperatures exceeding their thermal preferences (Sinervo et al., 2010). Hours of restriction were estimated as the amount of time during which the temperature of at least one of the physical models exceeded the upper bound of T_{pref}=40.51 °C (T_{ei} > upper bound T_{pref}), because we considered as threshold for activity restriction (Kubisch et al., 2016). The activity hours were estimated as the period during which at least one