

Effects of Ectoparasitism on Behavioral Thermoregulation in the Tropical lizards *Anolis cybotes* (Squamata: Dactyloidae) and *Anolis armouri* (Squamata: Dactyloidae)

Authors: Conover, Asa E., Cook, Ellee G., Boronow, Katherine E., and Muñoz, Martha M.

Source: *Breviora*, 545(1) : 1-13

Published By: Museum of Comparative Zoology, Harvard University

URL: <https://doi.org/10.3099/brvo-545-00-1-13.1>

The BioOne Digital Library (<https://bioone.org/>) provides worldwide distribution for more than 580 journals and eBooks from BioOne's community of over 150 nonprofit societies, research institutions, and university presses in the biological, ecological, and environmental sciences. The BioOne Digital Library encompasses the flagship aggregation BioOne Complete (<https://bioone.org/subscribe>), the BioOne Complete Archive (<https://bioone.org/archive>), and the BioOne eBooks program offerings ESA eBook Collection (<https://bioone.org/esa-ebooks>) and CSIRO Publishing BioSelect Collection (<https://bioone.org/csiro-ebooks>).

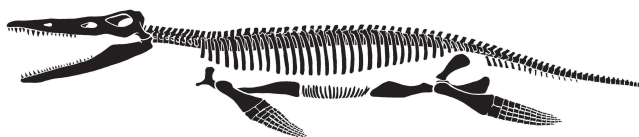
Your use of this PDF, the BioOne Digital Library, and all posted and associated content indicates your acceptance of BioOne's Terms of Use, available at www.bioone.org/terms-of-use.

Usage of BioOne Digital Library content is strictly limited to personal, educational, and non-commercial use. Commercial inquiries or rights and permissions requests should be directed to the individual publisher as copyright holder.

BioOne is an innovative nonprofit that sees sustainable scholarly publishing as an inherently collaborative enterprise connecting authors, nonprofit publishers, academic institutions, research libraries, and research funders in the common goal of maximizing access to critical research.

B R E V I O R A

Museum of Comparative Zoology



US ISSN 0006-9698

CAMBRIDGE, MASS.

3 JUNE 2015

NUMBER 545

EFFECTS OF ECTOPARASITISM ON BEHAVIORAL THERMOREGULATION IN THE TROPICAL LIZARDS *ANOLIS CYBOTES* (SQUAMATA: DACTYLOIDAE) AND *ANOLIS ARMOURI* (SQUAMATA: DACTYLOIDAE)

ASA E. CONOVER,^{1,2} ELLEE G. COOK,³ KATHERINE E. BORONOW,^{4,5} AND MARTHA M. MUÑOZ⁶

ABSTRACT. A febrile response, or a raised body temperature in response to infection, has been widely documented in various species of reptiles in laboratory trials. However, whether and how behavioral fever is achieved in nature remains almost entirely unknown. Here, we examine whether two species of lizard in the cybotoid clade of Hispaniolan trunk-ground anoles (*Anolis cybotes* and *Anolis armouri*) change their basking behavior in response to infestation by the chigger mite, *Eutrombicula alfreddugesi*. We examined body temperature and basking behavior in wild populations of *A. cybotes* and *A. armouri* from four localities that spanned a 2,000-m elevational transect in the Sierra de Baoruco, Dominican Republic. Although basking rate increased with elevation, we found that it did not correlate with mite load. Body temperature was also unrelated to parasite load. Thus, we found that *E. alfreddugesi* infestation did not induce behavioral fever in these anoles. We found a strong altitudinal pattern in chigger infestations: Infestations levels were highest in lizards from mid-elevation and dropped dramatically at low and high elevation (particularly in the latter). We discuss possible mechanisms for this altitudinal pattern in chigger infestation and discuss the relationship between infection and behavioral thermoregulation in lizards.

KEY WORDS: behavioral fever; parasitism; lizard; chigger mites; behavioral thermoregulation; anole

¹Stuyvesant High School, New York, New York, 10282, U.S.A.

²Department of Biological Sciences, University of Southern California, Los Angeles, California 90089, U.S.A.; e-mail: aeconove@usc.edu

³Division of Biological Sciences, University of Missouri, Columbia, Columbia, Missouri 65211, U.S.A.; e-mail: egcrg7@mail.missouri.edu

⁴Department of Organismic and Evolutionary Biology, Harvard University, Cambridge, Massachusetts 02138, U.S.A.; e-mail: kboronow@fas.harvard.edu

⁵Museum of Comparative Zoology, Harvard University, Cambridge, Massachusetts 02138, U.S.A.

⁶Ecology, Evolution, and Genetics, Australian National University, Acton, Australian Capital Territory, Australia 0200; e-mail: martha.munoz@anu.edu.au.

INTRODUCTION

Many lizards respond to pathogen infection through a febrile response, or a marked increase in body temperature, which is proposed to enhance the inflammatory reaction (Vaughn *et al.*, 1974; Bernheim and Kluger, 1976; Bernheim *et al.*, 1978). Unlike endothermic animals such as birds and mammals, ectotherms rely heavily on thermoregulation to induce heightened body temperatures (Huey, 1982; Angilletta, 2009). Laboratory studies on lizards (Bernheim and

Kluger, 1976; Muchlinski *et al.*, 1989; Ortega *et al.*, 1991; Ramos *et al.*, 1993; Scholnick *et al.*, 2010), crocodylians (Lang, 1987; Merchant *et al.*, 2007), turtles (Monagas and Gatten, 1983; Amoral *et al.*, 2002), and snakes (Burns *et al.*, 1996) have found that individuals injected with bacteria exhibit elevated set-point body temperatures, meaning that they attain warmer temperatures than uninfected individuals when placed in a temperature gradient and allowed to choose where to sit.

The laboratory studies discussed above suggest that behavioral thermoregulation mechanistically underlies fever, but this remains unconfirmed in wild populations of naturally infected lizards. In a semi-natural experiment, Muchlinski *et al.* (1989) found that, when injected with *Aeromonas* bacteria, free-ranging chuckwalla (*Sauromalus obesus*) exhibit heightened body temperatures, supporting the hypothesis that shifts in basking behavior are important for inducing fever. Malvin and Kluger (1979) found that iguanas do not increase their internal heat production to raise their core temperature during infection, further supporting the idea that extrinsic behavioral shifts are critical to achieving fever in lizards.

Here we tested whether infestations by chigger mites induced behavioral fever in anoles from the Dominican Republic. Ectoparasites such as chigger mites are known to affect lizard metabolism negatively (Booth *et al.*, 1993) and induce immune responses by skin inflammation (Goldberg and Bursey, 1991). Previous studies in lizards have found that ectoparasite infestation is associated with reduced body condition (Dunlap and Mathies, 1993; Klukowski and Nelson, 2001; Cook *et al.*, 2013), and reduced sprint speed (Main and Bull, 2000). In a previous study of *Anolis brevirostris*, an anole from the Caribbean island of Hispaniola, Cook *et al.* (2013) found that individuals with greater

infestations of the chigger *Eutrombicula alfreddugesi* exhibited poorer body condition, had duller colored dewlaps (extensible throat fans), and displayed less frequently than individuals with lower parasite loads. Fence lizards with malaria also exhibit shifts in coloration (Ressel and Schall, 1989) and reduced body condition (Dunlap and Mathies, 1993), suggesting that ectoparasites have negative effects on their lizard hosts, either through the effects of the parasites themselves or through pathogens transmitted by the chiggers. Given the negative effects of chiggers, it is possible that lizards respond to infestation by these parasites through behavioral fever; by increasing their core temperature through increased basking, lizards may combat pathogens transmitted by the chiggers or cause the mites to drop off. The relationship between basking behavior and parasite infestation may further vary with altitude: In a study of three Hispaniolan anoles (*Anolis coelestinus*, *Anolis cybotes*, and *Anolis olssoni*), Zippel *et al.* (1996) found that chigger infestation levels increased dramatically with elevation. Given that basking frequency also tends to increase with elevation in some anoles from Hispaniola (Hertz and Huey, 1981; Muñoz *et al.*, 2014), the use of behavioral fever may be expected also to vary across altitude.

The goal of this study was to assess whether chigger infestations induce behavioral fever in wild populations of two species of *Anolis* lizards (*Anolis armouri* and *A. cybotes*) from the Dominican Republic, Hispaniola, arrayed across a 2,000-m elevational gradient. Specifically, we tested three hypotheses: (1) chigger infestation reduces lizard body condition; (2) lizards with greater parasite loads also have higher core body temperatures (i.e., exhibit a fever) and bask more than less infested lizards; (3) behavioral fever should be most pronounced at high elevation, where chigger infestations and basking rates are highest.

TABLE 1. SUMMARY DATA ARE GIVEN FOR EACH POPULATION FOR STUDY SITES IN THE SOUTHWESTERN REGION OF THE DOMINICAN REPUBLIC.

	Los Patos	Guayuyal	Polo	Zapoten
Coordinates	17° 57' 36''N, 71° 11' 24''W	18° 3' 36''N, 71° 8' 24''W	18° 10' 12''N, 71° 15' 0''W	18° 18' 0''N, 71° 42' 0''W
Elevation (m)	13	727	1,236	2,020
Mean annual temperature (°C) ^a	26.0	22.4	23.5	13.9
Sample size	18	18	20	22
Prevalence ^b	100	100	100	78.3
Infestation intensity ^c	29.4 ± 4.3	99.4 ± 18.4	108.4 ± 19.1	15.2 ± 4.4
Infestation range ^d	4–78	18–354	12–274	0–75
Observation time (min) ^e	58.2	57.7	59.1	57.2
Basking rate ^f	14.6 ± 1.0	44.4 ± 1.9	70.1 ± 2.1	90.3 ± 1.0
Body temperature (°C) ^g	30.9 ± 0.3	27.8 ± 1.7	26.7 ± 2.5	28.2 ± 2.3

^aMean annual temperature was extracted from the WorldClim database (Hijmans *et al.*, 2005).

^bPercentage of individuals with at least one mite.

^cMean number of mites per individual (± 1 SEM).

^dRange of infestation intensities for a population.

^eMean behavioral observation time.

^fPercentage of time lizards were observed basking (± 1 SEM).

^gTemperature ± 1 SEM.

METHODS AND MATERIALS

We conducted our study on the two cybotoid anoles, *A. cybotes* and *A. armouri*, in June and July 2012 in the Dominican Republic. The term “cybotoid” refers to the clade of anoles containing the widespread species *A. cybotes* and its relatives from the Caribbean island of Hispaniola (Glor *et al.*, 2003). Though *A. armouri* shares many overlapping morphological features with *A. cybotes* (Schwartz, 1989), this high-elevation specialist is considered a separate species (Glor *et al.*, 2003; Wollenberg *et al.*, 2013). Within the adaptive radiation of Caribbean anoles, the cybotoids all belong to the same “ecomorph” or habitat specialist category, meaning that they overlap substantially in behavioral, ecological, and morphological characteristics (Losos, 2009). Specifically, the cybotoids are “trunk-ground” anoles; as such, they perch close to the ground, especially on tree trunks, have stocky builds with long hindlimbs, and

forage actively on the ground (Schwartz, 1989; Glor *et al.*, 2003; Losos, 2009).

We worked at four different localities ranging between 13 and 2,020 m in the Sierra de Baoruco in the southwestern region of the Dominican Republic (Table 1; Fig. 2). Study sites were located at Los Patos (13 m above sea level [masl]; 17° 57' 36''N, 71° 11' 24''W), Guayuyal (727 masl; 18° 3' 36''N, 71° 8' 24''W), Polo (1,236 masl; 18° 10' 12''N, 71° 15' 0''W), and Zapoten (2,020 masl, 18° 18' 0''N, 71° 42' 0''W). *Anolis cybotes* is found at the three low-elevation sites (Los Patos, Guayuyal, and Polo), where it occupies mesic, semi-disturbed habitats, especially near agricultural sites (plantain, coconut, and coffee plantations). The high-elevation specialist *A. armouri* is found in Zapoten. At this montane locality the habitat is composed of monodominant pine forest and open fields with rocky outcrops.

Eutrombiculid mites are known to parasitize anoles from low- to mid-elevation (~ 520 masl) on Hispaniola (Zippel *et al.*, 1996). These

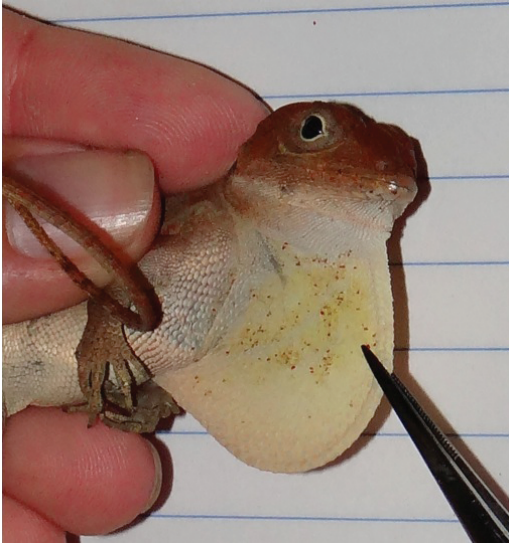


Figure 1. A male *Anolis cybotes* infested with *Eutrombicula alfreddugesi* mites on its dewlap (throat fan).

small, orange-colored mites are most commonly found in densely vegetated areas with high humidity and moderate ambient temperature (Clopton and Gold, 1993; Bulté *et al.*, 2009). The larvae attach to anoles through direct contact and typically cluster in skin folds, especially behind the front and back limb joints and on the dewlap, an extensible throat fan used extensively in *Anolis* communication (Fig. 1). Mites can cause lesions, blood loss, and skin inflammation in lizards (Goldberg and Bursey, 1991; Goldberg and Holshuh, 1992) and can transmit pathogens. In Asia, chigger mites are known to transmit scrub typhus (Traub and Wisseman, 1974), and, more generally, mites might be vectors for bloodborne parasites known as haemogregarines, which are known to reduce burst speed in lizards (Oppliger *et al.*, 1996; Garrido and Pérez-Mellado, 2014).

Following Rand (1962), we found focal lizards through slow, random sweeps through the habitat over the course of 2–3 days per site

during all weather conditions except rain. All observations were made on undisturbed, naturally behaving adult male animals following the methods of Johnson *et al.* (2010). We performed behavioral observations either by watching lizards with binoculars and manually transcribing observations or with video recordings (Sony HDR-XR500V camera, set in standard definition), which we subsequently scored. Observations lasted from 30 to 60 min ($\bar{X} = 57$ min) per lizard.

During each behavioral observation period we recorded the amount of time the lizard spent under different basking conditions. We recorded each lizard's basking status, which refers to how it was exploiting weather conditions, following Muñoz *et al.* (2014). During each observation period we recorded the weather conditions as sunny, partly sunny, or overcast. Under sunny or partly sunny conditions lizards could be scored as perching in the sun, in the partial sun, or in the full shade. Under overcast conditions lizards could only be in the shade (i.e., there was no basking choice), and these observations were discarded from further analysis. At the end of the observation, the relative amount of time each lizard spent basking was calculated as the total time spent either in the full or partial sun divided by the length of the total observation.

At the conclusion of each observation we attempted to catch the lizard to obtain information on body temperature, body condition, and parasite infestation. We noosed lizards using a dental floss noose tied to the end of a 10–12-foot (3–3.7 m) telescopic panfish pole (Cabela's Incorporated, Sidney, Nebraska). Immediately after capture, we measured the core temperature of the lizard by inserting a thermocouple (type T, copper-constantan; Omega Engineering) approximately 1 cm into the lizard's cloaca. The thermocouple was attached to a handheld

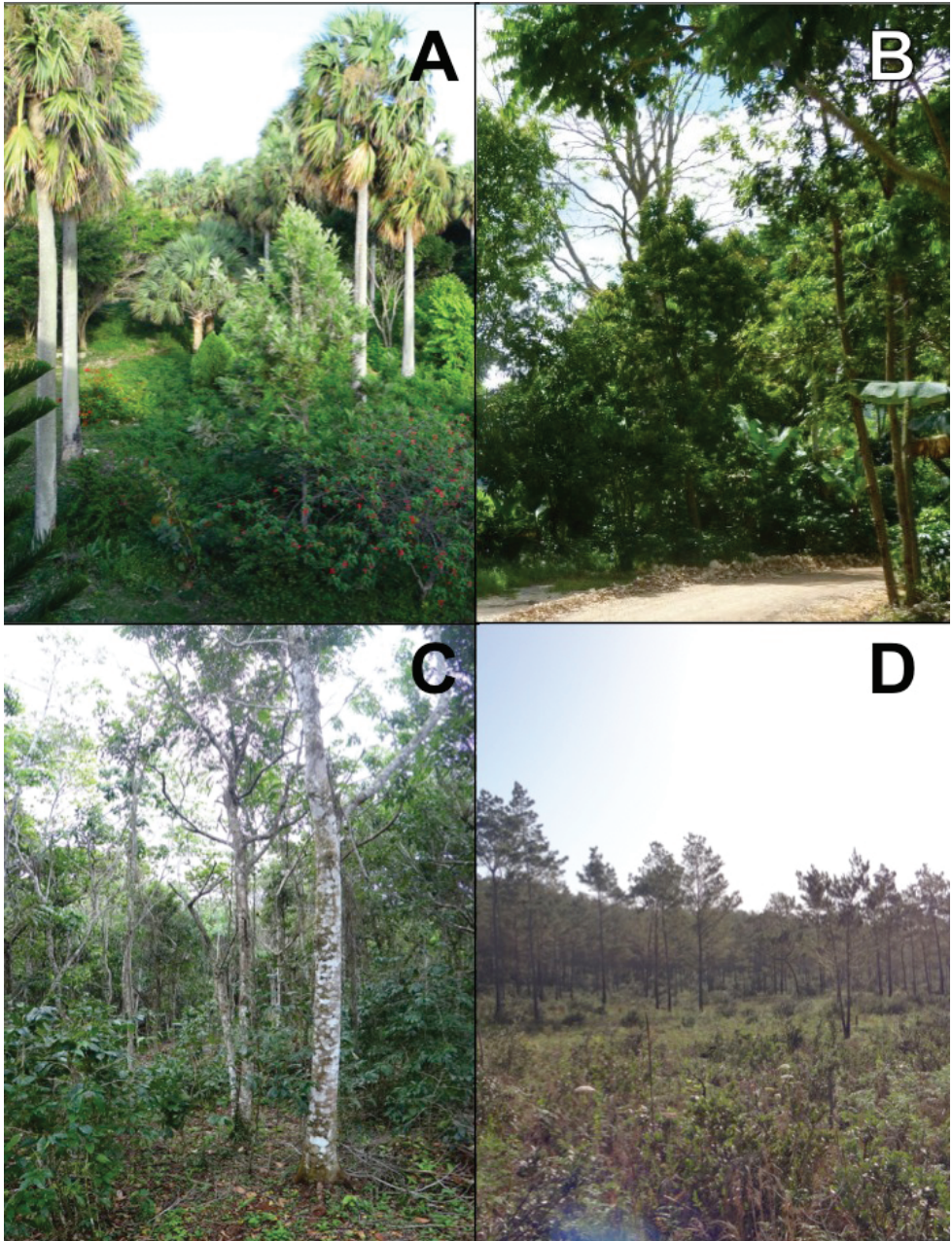


Figure 2. Images showing the four localities where this study was conducted: A, Los Patos (13 m elevation); B, Guayuyal (727 m); C, Polo (1,236 m); and D, Zapoten (2,020 m).

reader (model HH603A; Omega Engineering), which gave temperature measurements to the nearest 0.1°C.

For each lizard captured we also measured body mass to the nearest 0.1 g, using a spring scale, and body size as snout-vent length (SVL), the distance from the tip of the snout to the anterior edge of the cloaca, using digital calipers (Mitutoyo), which gave length measurements to the nearest 0.01 mm. We then counted the total number of ectoparasites on each anole using a handheld loupe. We sampled individuals only once and released them at the site of capture within 48 hours.

For each population, we calculated prevalence, which refers to the proportion of individuals in a population that had at least one mite. Following Margolis *et al.* (1982), we measured infestation intensity as the number of mites per lizard. We estimated body condition as the residuals of body mass regressed against SVL (Schulte-Hostedde *et al.*, 2005). Before statistical analyses, we log-transformed all continuous variables and arcsine square root-transformed the proportional variable (basking rate). Given that infestation intensity correlated strongly with body size (Pearson's $r = 0.441$, d.f. = 76, $p < 0.001$), we used the residuals of infestation intensity regressed against SVL as our measure of parasite load in our examinations of correlation with body temperature and basking rate. We assessed the Pearson correlation between variables, and used the Bonferroni correction to correct for multiple tests. None of the relationships were changed when we compared body temperature and basking rate to infestation intensity, rather than parasite load. We compared body temperature among populations using the Mann-Whitney U test.

RESULTS

Prevalence was extremely high across localities: 73 of the 78 lizards examined were

infested with *E. alfreddugesi* mites, and 100% of lizards from the three lower elevation sites were infested (Table 1). Prevalence was slightly lower in Zapoten, where 21.7% of lizards captured had no parasites, and most individuals had fewer than 20 mites (Fig. 3). On average lizards harbored 61.7 mites, and infestation intensity ranged from 0 to 354 mites (Table 1). Despite high numbers of ectoparasites, we found no significant relationships between infestation intensity and lizard body condition (Table 2).

Basking behavior differed among localities (Table 1): The proportion of time lizards spent basking increased with elevation from 14.6% in Los Patos (13 m) to 90.1% in Zapoten (2,020 m). Mean body temperature ranged from 26.7°C (Polo) to 30.9°C (Los Patos) (Table 1) and was significantly higher in Los Patos relative to the other populations (Mann-Whitney U test; all $p < 0.01$). However, basking rate and parasite load were not strongly correlated (Table 2). Similarly, we found no significant relationships between body temperature and parasite load (Table 2).

DISCUSSION

Behavioral fever is one way that ectothermic animals might be able to respond to parasite infestation. However, we found that basking frequency and body temperature were not correlated with parasite load (Table 2), indicating that *A. cybotes* and *A. armouri* did not exhibit a febrile response to chigger infestation. One possible explanation is that anoles do not exhibit behavioral fevers. Muchlinski *et al.* (1995) found that *Anolis equestris* injected with bacteria did not exhibit elevated core temperatures compared with uninfected individuals. In another study, *Anolis carolinensis* that were injected with bacterial lipopolysaccharide exhibited a hypothermic response (i.e., cooler,

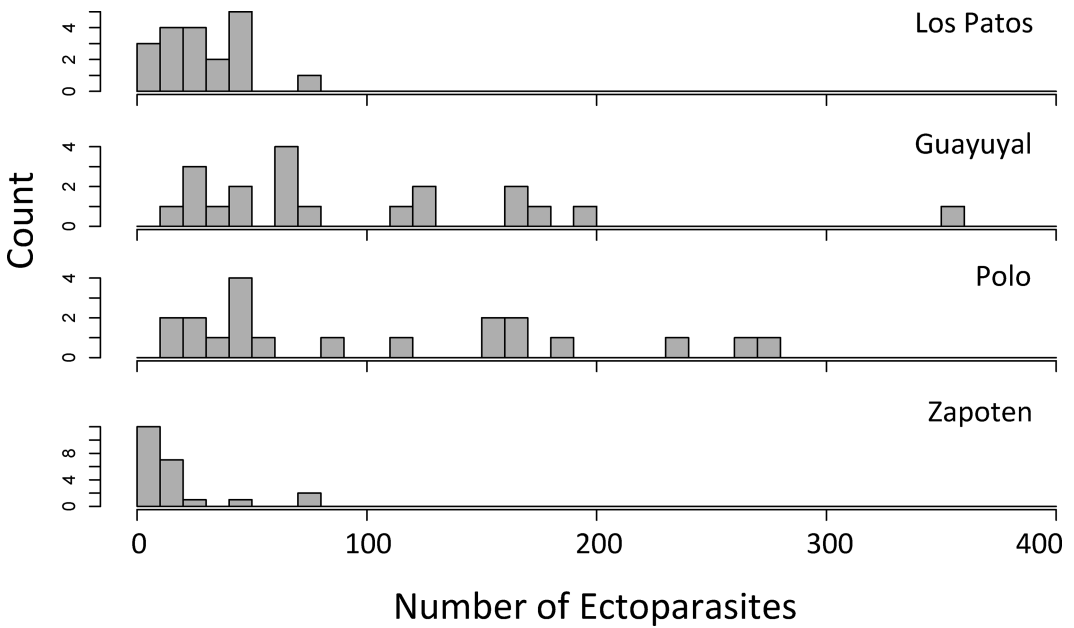


Figure 3. Histogram showing infestation intensity frequency in each of the populations sampled.

TABLE 2. RESULTS FOR CORRELATION TESTS EXAMINING RELATIONSHIPS BETWEEN (A) BODY CONDITION, (B) BASKING RATE, AND (C) BODY TEMPERATURE AND PARASITE LOAD. PEARSON'S r AND P VALUES ARE GIVEN FOR EACH TEST, AND SAMPLE SIZE IS GIVEN IN PARENTHESES.

	r	P
A. Body condition ~ infestation intensity ^a		
Los Patos (18)	-0.161	0.525
Guayuyal (18)	0.326	0.187
Polo (20)	0.231	0.328
Zapoten (22)	-0.319	0.148
B. Basking rate ~ parasite load ^b		
Los Patos	0.262	0.293
Guayuyal	-0.399	0.101
Polo	-0.129	0.599
Zapoten	0.033	0.896
C. Body temperature ~ parasite load		
Los Patos	-0.080	0.753
Guayuyal	-0.489	0.040
Polo	-0.219	0.353
Zapoten	0.036	0.875

^aResiduals of body mass/SVL and the number of ectoparasites (infestation intensity). SVL refers to the body size of the lizard, measured as the distance from the tip of the snout to the cloaca (snout-vent length).

^b(Time spent basking)/(total observation length) and parasite load (residuals of infestation intensity ~ SVL).

rather than warmer, body temperatures) when placed in a temperature gradient and allowed to choose where to sit (Merchant *et al.*, 2008). Looking more broadly, whereas many studies have observed a febrile response to infection in lizards (e.g., Bernheim and Kluger, 1976; Muchlinski *et al.*, 1989; Ortega *et al.*, 1991; Ramos *et al.*, 1993), others have failed to detect a pattern (Laburn *et al.*, 1981; Mitchell *et al.*, 1990) or have found that individuals can vary in whether or not fever is induced (Bernheim and Kluger, 1976).

Behavioral fever might not be prevalent in lizards because the costs associated with fever are too high to induce them in nature. Almost all studies examining febrile responses in lizards were conducted using laboratory heat gradients, where all other ecological variables besides infection are held constant. Given that extra time spent thermoregulating imposes a cost to other activities, such as foraging, predator avoidance, and reproduction (e.g., Huey, 1974; Grant and Dunham, 1988; Adolph and Porter, 1993), it is possible that selection does not favor fevers in nature. It is also possible that the chigger mites can withstand more heat than *A. cybotes* and *A. armouri*. Tropical lizards such as anoles tend to exhibit low body temperatures and heat tolerances relative to other lizard species (discussed in Sunday *et al.*, 2010; Araújo *et al.*, 2013); it is possible that a febrile response is not effective for lizards with low heat tolerances, such as these species (critical thermal maximum: $\sim 38\text{--}40^\circ\text{C}$; Muñoz *et al.*, 2014), although it may be possible and advantageous in more heat tolerant species.

It is also possible that mite infestations do not negatively affect lizards enough to induce fever in *A. cybotes* and *A. armouri*. Although some studies have found negative correlations between chigger infestation and lizard body condition (Dunlap and Mathies, 1993;

Klukowski and Nelson, 2001; Cook *et al.*, 2013), we did not observe any correlation between body condition and chigger infestation (Table 2). Similarly, other studies have found no effect of *E. alfreddugesi* infestation on lizard health (García-De La Peña *et al.*, 2004, 2010; Schlaepfer, 2006; Rocha *et al.*, 2008), and others have found positive correlations (Amo *et al.*, 2005), suggesting that the health effects of mite infestation may vary among taxa. This variable response in host health is not limited to chiggers: Even when infected with malaria, some anole species exhibit negative effects, whereas others do not (Schall, 1992; Schall and Pearson, 2000). These findings underscore that a more comprehensive understanding of how ectoparasites (and the pathogens they may transmit) affect lizard health is necessary for determining whether behavioral fever should occur.

More broadly, it is still not fully understood how ectoparasite infestation should affect lizard body condition. For example, the detrimental effects of ectoparasites can be inferred from both negative correlations between body condition and mite loads (Dunlap and Mathies, 1993; Klukowski and Nelson, 2001; Cook *et al.*, 2013) and from positive correlations (e.g., Amo *et al.*, 2005). In the former, the reduced body condition of infested lizards can suggest that the ectoparasites reduce health and immunity, as evident in the reduced body condition, and in the latter it is thought that parasites reduce survival and so only the individuals with best body condition can survive (Amo *et al.*, 2005). Furthermore, even when negative correlations between body condition and parasite load are detected, they may not be driven by the parasites inducing lizards to lose mass. Klukowski and Nelson (2001) found that body condition was reduced in infested lizards because high mite loads appeared to prevent lizards from gaining

mass. In short, a deeper understanding of how ectoparasites and their associated bloodborne pathogens influence host health will vastly improve our predictions for how behavioral fever should occur, if at all.

Although basking rate was uncorrelated with parasite load, the use of sun and shade varied considerably across elevation. Whereas lizards near sea level spent only a small fraction of their time perching in the sun, those found at high elevation (Zapoten) were almost invariably observed basking (Table 1), a result that aligns with findings from previous studies on these species (Hertz and Huey, 1981; Muñoz *et al.*, 2014). Prevalence was also considerably lower at Zapoten, and most lizards harbored fewer than 20 parasites (Fig. 3). If increased basking frequency were associated with warmer core temperatures in Zapoten, then it could be possible that fever in *A. armouri* reduced ectoparasite levels. However, this is unlikely because mean body temperature was significantly lower in Zapoten ($\bar{X} = 28.2^\circ\text{C}$) than in Los Patos ($\bar{X} = 30.9^\circ\text{C}$), suggesting that even though they bask continually, lizards in high-elevation populations might not always be able to attain body temperatures comparable to their low-elevation counterparts, let alone behaviorally induce a fever.

The markedly low levels of infestation intensity observed in *A. armouri* from Zapoten appear to conflict with previous findings on *A. cybotes* by Zippel *et al.* (1996), who found that intensity increased with elevation. Both their study and ours were conducted in the Sierra de Baoruco mountain chain in the western Dominican Republic. However, Zippel and colleagues did not sample *A. cybotes* lizards above 520 m, and our transect extended to 2,020 m. Consistent with Zippel *et al.* (1996), we found that mite infestation increased from sea level to mid-elevation, as intensities were particularly high in the mid-elevation populations at Guayuyal (727 m) and Polo (1,236 m), where up to 354 and 274

ectoparasites were observed on a single lizard, respectively (Table 1; Fig. 3). The infestation levels in Guayuyal and Polo are among the highest recorded for mites on other species of lizards (Amo *et al.*, 2005; Rocha *et al.*, 2008; García-De La Peña *et al.*, 2010; Delfino *et al.*, 2011; Ramírez-Morales *et al.*, 2012; Cook *et al.*, 2013, but see García-De La Peña, 2011), as well as for lizards with other types of ectoparasites such as ticks (e.g., *Ixodes ricinus* [Acari: Ixodidae]: Amore *et al.*, 2007; Gryczyńska-Sięmiątkowska *et al.*, 2007; Stuart-Fox *et al.*, 2009; Gomes *et al.*, 2013).

Why do intensities drop so dramatically in Zapoten? Habitat preference by *E. alfreddugesi* may explain particularly low infestation levels observed at high elevation. Previous work has shown that chigger mites tend to prefer mesic habitats with low-incident sunlight and moderate temperatures (Clopton and Gold, 1993; Schlaepfer and Gavin, 2001) and that parasite intensity is typically higher in forest interiors than in forest edges (Bulté *et al.*, 2009; Rubio and Simonetti, 2009). At elevations above approximately 1,800 m in Hispaniola, anoles tend to cluster in forest clearings and rocky outcrops, presumably to access open basking sites in this colder environment, where temperatures can reach near freezing throughout the year (Hertz and Huey, 1981; Muñoz *et al.*, 2014). Even contiguous forest tends to be more open than at low elevation because the pine forest lacks the closed canopy characteristic of the broadleaf forest at lower elevations (Fig. 2) (Martin *et al.*, 2011). Thus, open habitat and cold temperatures may prevent *E. alfreddugesi* from reaching densities comparable to those observed at lower elevations.

Although behavioral fever is likely a key response to infection in lizards, we still know little of how it occurs in nature. In the case of *A. cybotes* and *A. armouri*, we did not find evidence that lizards respond to ectoparasite infestation through behavioral fever. It is not fully known how these (and other)

ectoparasites influence their lizard hosts and what pathogens they transmit (Amo *et al.*, 2005; Garrido and Pérez-Mellado, 2014). A more detailed understanding of how ectoparasites and bloodborne pathogens influence lizard health and how pathogen and host temperature tolerances differ will lead to more detailed hypotheses about the conditions under which we expect lizards to exhibit behavioral fever.

ACKNOWLEDGMENTS

We thank I. Shields for assistance in the field, the Ministerio de Medio Ambiente y Recursos Naturales and the Museo Nacional de Historia Natural for granting our research permit requests, and J. Gastel, J. Losos, and M. Johnson for helpful comments on this manuscript. We thank two anonymous reviewers, who greatly improved this manuscript. This study was conducted in accordance with the Institutional Animal Care and Use Committee at Harvard University under protocol 26-11. This project was completed by Conover in partial fulfillment for the Intel Science Talent Search through Stuyvesant High School. Support for this work came from a David Rockefeller Center for Latin American Studies Research Grant; a Ken Miyata Award from the Museum of Comparative Zoology; a Sigma Xi Grant-In-Aid Award to M.M.M.; and a Beckman Scholar Award from the Arnold and Mabel Beckman Foundation, Sigma Xi Grant-In-Aid, and Explorer's Club Youth Activity Fund Grant to E.G.C. This material is based on work supported by National Science Foundation Graduate Research Fellowships to K.E.B. and M.M.M.

LITERATURE CITED

- ADOLPH, S. C., AND W. P. PORTER. 1993. Temperature, activity, and lizard life histories. *American Naturalist* **142**: 273–295.
- AMO, L., P. LÓPEZ, AND J. MARTÍN. 2005. Prevalence and intensity of haemogregarine blood parasites and their mite vectors in the common wall lizard, *Podarcis muralis*. *Parasitology Research* **96**: 378–381.
- AMORAL, J. P., G. A. MARVIN, AND V. H. HUTCHINSON. 2002. The influence of bacterial lipopolysaccharide on the thermoregulation of the box turtle *Terrapene carolina*. *Physiological and Biochemical Zoology* **75**: 273–282.
- AMORE, G., L. TOMASSONE, E. GREGO, C. RAGAGLI, L. BERTOLOTTI, P. NEBBIA, S. ROSATI, AND A. MANNELLI. 2007. *Borrelia lusitaniae* in immature *Ixodes ricinus* (Acari: Ixodidae) feeding on common wall lizards in Tuscany, Central Italy. *Journal of Medical Entomology* **44**: 303–307.
- ANGILLETTA, M. J., JR. 2009. *Thermal Adaptation: A Theoretical and Empirical Synthesis*. Oxford, U.K., Oxford University Press.
- ARAÚJO, M. B., F. FERRI-YÁÑEZ, F. BOZINOVIC, P. A. MARQUET, F. VALLADARES, F., AND S. L. CHOWN. 2013. Heat freezes niche evolution. *Ecology Letters* **16**: 1206–1219.
- BERNHEIM, H. A., P. T. BODEL, P. W. ASKENASE, AND E. ATKINS. 1978. Effects of fever on host defence mechanisms after infection in the lizard *Dipsosaurus dorsalis*. *British Journal of Experimental Pathology* **59**: 76–84.
- BERNHEIM, H. A., AND M. J. KLUGER. 1976. Fever and antipyresis in the lizard *Dipsosaurus dorsalis*. *American Journal of Physiology* **231**: 198–203.
- BOOTH, D. T., D. H. CLAYTON, AND B. A. BLOCK. 1993. Experimental demonstration of the energetic cost of parasitism in free-ranging hosts. *Proceedings of the Royal Society of London B Biological Sciences* **253**: 125–129.
- BULTÉ, G., A. C. PLUMMER, A. THIBAudeau, AND G. BLOUIN-DEMERS. 2009. Infection of Yarrow's spiny lizard (*Sceloporus jarrovi*) by chiggers and malaria in the Chiricahua Mountains, Arizona. *Southwestern Naturalist* **54**: 204–207.
- BURNS, G., A. RAMOS, AND A. MUCHLINSKI. 1996. Fever response in North American snakes. *Journal of Herpetology* **30**: 133–139.
- CLOPTON, R., AND R. GOLD. 1993. Distribution and seasonal and diurnal activity patterns of *Eutrombicula alfreddugesi* (Acari: Trombiculidae) in a forest edge ecosystem. *Journal of Medical Entomology* **30**: 47–53.
- COOK, E. G., T. G. MURPHY, AND M. A. JOHNSON. 2013. Colorful displays signal male quality in a tropical anole lizard. *Naturwissenschaften* **100**: 993–996.
- DELFINO, M. M. S., S. C. RIBEIRO, I. R. FURTADO, L. A. ANJOS, AND W. O. ALMEIDA. 2011. Pterygosomatidae and Trombiculidae mites infesting *Tropidurus hispidus* (Spix, 1825) (Tropiduridae) lizards in

- northeastern Brazil. *Brazilian Journal of Biology* **71**: 549–555.
- DUNLAP, K. D., AND T. MATHIES. 1993. Effects of nymphal ticks and their interaction with malaria on the physiology of male fence lizards. *Copeia* **1993**: 1045–1048.
- GARCÍA-DE LA PEÑA, C. 2011. *Eutrombicula alfreddugesi* (Acari: Trombiculidae): New host records from four species of lizards in the Sierra de Jimulco, Coahuila, Mexico. *Southwestern Naturalist* **56**: 131–133.
- GARCÍA-DE LA PEÑA, C., A. CONTRERAS-BALDERAS, G. CASTAÑEDA, AND D. LAZCANO. 2004. Infestación y distribución corporal de la nigua *Eutrombicula alfreddugesi* (Acari: Trombiculidae) en el lacertilio de las rocas *Sceloporus couchii* (Sauria: Phrynosomatidae). *Acta Zoologica Mexicana* **20**: 159–165.
- GARCÍA-DE LA PEÑA, C., H. GADSDEN, AND A. SALAS-WESPHAL. 2010. Carga ectoparasitaria en la lagartija espinosa de Yarrow (*Sceloporus jarrovi*) en el canon de las piedras encimadas, Durango, México. *Interciencia* **35**: 772–776.
- GARRIDO, M., AND V. PÉREZ-MELLADO. 2014. Sprint speed is related to blood parasites, but not to ectoparasites, in an insular population of lacertid lizard. *Canadian Journal of Zoology* **92**: 67–72.
- GLOR, R. E., J. J. KOLBE, R. POWELL, A. LARSON, AND J. B. LOSOS. 2003. Phylogenetic analysis of ecological and morphological diversification in Hispaniolan trunk-ground anoles (*Anolis cybotes* group). *Evolution* **57**: 2383–2397.
- GOLDBERG, S. R., AND C. R. BURSEY. 1991. Integumental lesions caused by ectoparasites in a wild population of the side-blotched lizard (*Uta stansburiana*). *Journal of Wildlife Diseases* **27**: 68–73.
- GOLDBERG, S. G., AND H. J. HOLSHUH. 1992. Ectoparasite induced lesions in mite pockets of the Yarrow's spiny lizard, *Sceloporus jarrovi* (Phrynosomatidae). *Journal of Wildlife Diseases* **28**: 537–541.
- GOMES, V., A. ŽAGAR, AND M. A. CARRETERO. 2013. A case of massive infestation of a male green lizard *Lacerta viridis/bilineata* castor bean tick *Ixodes ricinus* (Linnaeus, 1758). *Natura Sloveniae* **15**: 57–61.
- GRANT, B. W., AND A. E. DUNHAM. 1988. Thermally imposed time constraints on the activity of the desert lizard *Sceloporus merriami*. *Ecology* **69**: 167–176.
- GRYCZYŃSKA-SIEMIĄTKOWSKA, A., A. SIEDLECKA, J. STAŃCZAK, AND M. BARKOWSKA. 2007. Infestation of sand lizards (*Lacerta agilis*) resident in the Northeastern Poland by *Ixodes ricinus* (L.) ticks and their infection with *Borrelia burgdorferi* sensu lato. *Acta Parasitologica* **52**: 165–170.
- HERTZ, P. E., AND R. B. HUEY. 1981. Compensation for altitudinal changes in the thermal environment by some *Anolis* lizards on Hispaniola. *Ecology* **62**: 515–521.
- HJIMANS, R. J., S. E. CAMERON, J. L. PARRA, P. G. JONES, AND A. JARVIS. 2005. Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology* **25**: 1965–1978.
- HUEY, R. B. 1974. Behavioral thermoregulation in lizards: importance of associated costs. *Science* **184**: 1001–1003.
- HUEY, R. B. 1982. Temperature, physiology, and the ecology of reptiles, pp. 25–92. In C. Gans, and F. H. Pough, eds., *Biology of the Reptilia*. Volume 12. New York, Academic Press.
- JOHNSON, M. A., L. J. REVELL, AND J. B. LOSOS. 2010. Behavioral convergence and adaptive radiation: effects of habitat use on territorial behavior in *Anolis* lizards. *Evolution* **64**: 1151–1159.
- KLUKOWSKI, M., AND C. E. NELSON. 2001. Ectoparasite loads in free-ranging Northern Fence Lizards, *Sceloporus undulatus hyacinthinus*: effects of testosterone and sex. *Behavioral Ecology and Sociobiology* **49**: 289–295.
- LABURN, H., D. MITCHELL, E. KENEDI, AND G. N. LOUW. 1981. Pyrogens fail to produce fever in cordylid lizards. *American Journal of Physiology* **241**: R198–R202.
- LANG, J. 1987. Crocodylian thermal selection, pp. 301–337. In G. Webb, C. Manolis, and P. Whitehead, eds., *Wildlife Management: Crocodiles and Alligators*. Sydney, Australia, Surrey Beatty and Sons.
- LOSOS, J. B. 2009. *Lizards in an Evolutionary Tree: Ecology and Adaptive Radiation of Anoles*. Berkeley, California, University of California Press.
- MAIN, A. R., AND C. M. BULL. 2000. The impact of tick parasites on the behaviour of the lizard *Tiliqua rugosa*. *Oecologia* **122**: 574–581.
- MALVIN, M. D., AND M. K. KLUGER. 1979. Oxygen uptake in green iguana (*Iguana iguana*) injected with bacteria. *Journal of Thermal Biology* **4**: 147–148.
- MARGOLIS, L., G. W. ESCH, J. C. HOLMES, A. M. KURIS, AND G. A. SCHAD. 1982. The use of ecological terms in parasitology (report of an *ad hoc* committee of The American Society of Parasitologists). *Journal of Parasitology* **68**: 131–133.
- MARTIN, P. H., T. J. FAHEY, AND R. E. SHERMAN. 2011. Vegetation zonation in a neotropical montane forest: environment, disturbance and ecotones. *Biotropica* **43**: 533–543.

- MERCHANT, M., L. FLEURY, R. RUTHERFORD, AND M. PAULISSEN. 2008. Effects of bacterial lipopolysaccharide on thermoregulation in green anole lizards (*Anolis carolinensis*). *Veterinary Immunology and Immunopathology* **125**: 176–181.
- MERCHANT, M., S. WILLIAMS, P. L. TROSCLAIR, III, R. M. ELSEY, AND K. MILLS. 2007. Febrile response to infection in the American alligator (*Alligator mississippiensis*). *Comparative Biochemistry and Physiology—Part A* **148**: 921–925.
- MITCHELL, D., H. P. LABURN, M. MATTER, AND E. MCCLAINE. 1990. Fever in Namib and other ectotherms, pp. 179–192. In M. K. Seely, ed., *Namib Ecology: 25 Years of Namib Research* Pretoria, South Africa, Transvaal Museum Monograph. No. 7.
- MONAGAS, W. R., AND R. E. GATTEN JR. 1983. Behavioural fever in the turtles *Terrapene carolina* and *Chrysemys picta*. *Journal of Thermal Biology* **8**: 285–288.
- MUCHLINSKI, A. E., A. ESTANY, AND M. T. DON. 1995. The response of *Anolis equestris* and *Oplurus cyclurus* (Reptilia, Iguanidae) to bacterial endotoxin. *Journal of Thermal Biology* **20**: 315–320.
- MUCHLINSKI, A. E., R. J. STOUTENBURGH, AND J. M. HOGAN. 1989. Fever response in laboratory-maintained and free-ranging chuckwallas (*Sauromalus obesus*). *American Journal of Physiology* **257**: R150–R155.
- MUÑOZ, M. M., M. A. STIMOLA, A. C. ALGAR, A. CONOVER, A. RODRIGUEZ, M. A. LANDESTOY, G. S. BAKKEN, AND J. B. LOSOS. 2014. Evolutionary stasis and lability in thermal physiology in a group of tropical lizards. *Proceedings of the Royal Society of London B Biological Sciences* **281**: doi 10.1098/rspb.2013.2433.
- OPPLIGER, A., M. I. CÉLÉRIER, AND J. CLOBERT. 1996. Physiological and behaviour changes in the common lizard, *Lacerta vivipara*, parasitized by blood parasites. *Functional Ecology* **11**: 652–655.
- ORTEGA, C. E., D. S. STRANC, M. P. CASAL, G. M. HALMAN, AND A. E. MUCHLINSKI. 1991. A positive fever response in *Agama agama* and *Sceloporus orcutti* (Reptilia: Agamidae and Iguanidae). *Journal of Comparative Physiology B Biochemical Systemic and Environmental Physiology* **161**: 377–381.
- RAMÍREZ-MORALES, R., T. LISLEVAND, R. RETANA-SALAZAR, T. SOLHØY, AND S. ROTH. 2012. Ectoparasite loads of the Central American whiptail lizard *Ameiva festiva* (Squamata: Teiidae). *Journal of Herpetology* **22**: 151–155.
- RAMOS, A. B., M. T. DON, AND A. E. MUCHLINSKI. 1993. The effect of bacteria infection on mean selected body temperature in the common agama, *Agama agama*: A dose-response study. *Comparative Biochemistry and Physiology. Comparative Physiology* **105**: 479–484.
- RAND, A. S. 1962. Notes on Hispaniolan herpetology 5. The natural history of three sympatric species of *Anolis*. *Breviora* **154**: 1–15.
- RESSEL, S., AND J. J. SCHALL. 1989. Parasites and showy males: malarial infection and color variation in fence lizards. *Oecologia* **78**: 158–164.
- ROCHA, C. F. D., M. CUNHA-BARROS, V. A. MENEZES, A. F. FONTES, D. VRCIBRADIC, AND M. VAN SLUYS. 2008. Patterns of infestation by the trombiculid mite *Eutrombicula alfreddugesi* in four sympatric lizard species (Genus *Tropidurus*) in northeastern Brazil. *Parasite* **15**: 131–136.
- RUBIO, A. V., AND J. A. SIMONETTI. 2009. Ectoparasitism by *Eutrombicula alfreddugesi* larvae (Acari: Trombiculidae) on *Liolaemus tenuis* lizard in a Chilean fragmented temperate forest. *Journal of Parasitology* **95**: 244–245.
- SCHALL, J. J. 1992. Parasite-mediated competition in *Anolis* lizards. *Oecologia* **92**: 64–68.
- SCHALL, J. J., AND A. R. PEARSON. 2000. Body condition of a Puerto Rican anole, *Anolis gundlachi*: Effect of a malaria parasite and weather variation. *Journal of Herpetology* **34**: 489–491.
- SCHLAEFFER, M. A. 2006. Growth rates and body condition in *Norops polylepis* (Polychrotidae) vary with respect to sex but not mite load. *Biotropica* **38**: 414–418.
- SCHLAEFFER, M., AND T. A. GAVIN. 2001. Edge effects on lizards and frogs in tropical forest fragments. *Conservation Biology* **15**: 1079–1090.
- SCHOLNICK, D. A., R. V. MANIVANH, O. D. SAVENKOVA, T. G. BATES, AND S. L. McALEXANDER. 2010. Impact of malarial infection on metabolism and thermoregulation in the fence lizard *Sceloporus occidentalis* from Oregon. *Journal of Herpetology* **44**: 634–640.
- SCHULTE-HOSTEDDE, A. I., B. ZINNER, J. S. MILLAR, AND G. J. HICKLING. 2005. Restitution of mass-size residuals: validating body condition indices. *Ecology* **86**: 155–163.
- SCHWARTZ, A. 1989. A review of the cybotoid anoles (Reptilia: Sauria: Iguanidae) from Hispaniola. *Milwaukee Public Museum Contributions in Biology and Geology* **78**: 1–32.
- STUART-FOX, D., R. GODINHO, J. G. DE BELLOCQ, N. R. IRWIN, J. C. BRITO, A. MOUSSALLI, P. SIROKY, A. F. HUGALL, AND S. J. E. BAIRD. 2009. Variation in phenotype, parasite load and male competitive ability across a cryptic hybrid zone. *PLoS One* **4**: e5677.
- SUNDAY, J. M., A. E. BATES, AND N. K. DULVY. 2010. Global analysis of thermal tolerance and latitude in ectotherms. *Proceedings of the Royal Society of London B Biological Sciences* **278**: 1823–1830.

- TRAUB, R., AND C. L. WISSEMAN. 1974. The ecology of chigger-borne rickettsiosis (scrub typhus). *Journal of Medical Entomology* **11**: 237–303.
- VAUGHN, L. K., H. A. BERNHEIM, AND M. J. KLUGER. 1974. Fever in the lizard *Dipsosaurus dorsalis*. *Nature* **252**: 473–474.
- WOLLENBERG, K. C., I. J. WANG, R. E. GLOR, AND J. B. LOSOS. 2013. Determinism in the diversification of Hispaniolan trunk-ground anoles (*Anolis cybotes* species complex). *Evolution* **67**: 3175–3190.
- ZIPPEL, K. C., R. POWELL, J. S. PARMERLEE, JR., S. MONKS, A. LATHROP, AND D. D. SMITH. 1996. The distribution of larval *Eutrombicula alfreddugesi* (Acari: Trombiculidae) infesting *Anolis* lizards (Lacertilia: Polychrotidae) from different habitats on Hispaniola. *Caribbean Journal of Science* **32**: 43–49.