Thermal Ecology of *Urosaurus ornatus* (Ornate Tree Lizard), in the Northern Chihuahuan Desert on Indio Mountains Research Station, Texas

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By

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Abstract

The main goal of this study was to determine the thermal ecology of the small tree lizard *Urosaurus ornatus* in a Chihuahuan Desert landscape. The study site was located at Indio Mountains Research Station (IMRS), Hudspeth County, Texas. We obtained body temperature (Tb) data on 385 lizards collected from April 2007 to June 2014 during the active period using a cloacal thermometer. Additionally, we recorded air temperature (Ta) and substrate temperature (Ts) of lizard microhabitats at the time of capture, and the operative temperature of lizard models left in the sun and shade from May to September 2014. My results showed that the mean Tb for all adult lizards was 33.6 ± 2.8°C, with a range of 24.0 to 40.2°C. This average Tb was similar but lower than those found in other populations in Southwestern United States. The results indicated that *U. ornatus* at IMRS displays mostly a thigmothermic behavior. Thermoregulatory behavior of these individuals showed that *U. ornatus* is a thermoconformer on IMRS. There was no statistical difference in mean Tb between males and females or between non-gravid females. However, there was a significant difference between lizards found in the sun and lizards found in the shade. It is expected that rising global temperatures will influence this region and therefore will have an impact on the population of *U. ornatus* too; possibly affecting aspects such as time for feeding, reproducing, and of course thermoregulating. Thus, it is important for us to understand the thermoregulatory needs of ectothermic organisms as they are dependent on the direct environmental temperatures for survival, especially since many recognize that rapid global warming has already been activated by human misuse of natural resources.

Table of Contents

List of Tables

Lists of Figures

Introduction

Thermal ecology is the study of the independent and interactive biotic and abiotic components of naturally heated environments (http://encyclopedia2.thefreedictionary.com/thermal+ecology; 27 July 2013). It is universally critical to understand thermal relationships associated with any species, including the small Ornate Tree Lizard, *Urosaurus ornatus* because temperature plays a major role in the distribution, seasonal activities, and diversity patterns shown within reptiles. Vitt and Caldwell (2009) describe temperature as "the master limiting factor in the distributional and diversity patterns of amphibians and reptiles," because they are ectothermic and use external heat sources to regulate their body temperatures. When looking at the broader scale, Vitt and Caldwell (2009) pointed out that there are no reptiles and amphibians in cold regions, like Antarctica, while the greatest diversity lies within the tropics and warm temperate regions. On a smaller scale, Vitt and Caldwell (2009) asserted that even "in a single habitat, the spatial occurrence and temporal activity pattern of each amphibian or reptilian species is related one way or another to temperature." Pough (1973) mentioned that when asking a biological question about reptiles, it is almost impossible not to include indirect or direct thermoregulatory capacities. He gave examples of how temperature is related in different ways to the following three different biological disciplines: "ecologists found that niches are defined in part by thermal relationships; ethologists discovered that reptiles behave differently at different body temperatures; and zoogeographers must consider radiant energy patterns available in postulated routes of migration." Based on the way reptiles obtain body heat, they can be classified four ways (Huey and Slatkin, 1976; Zug et al, 2001): 1) heliothermic - obtaining most of their heat through solar radiation; 2) thigmothermic - obtaining most through substrate; 3) thermoregulation - actively regulating their body temperature; or 4) by being a thermoconformer - where body temperature fluctuates with the ambient temperature.

Urosaurus ornatus is a member of the New World lizard family, Phrynosomatidae (Spiny Lizards), which according to the Center for North American Herpetology (CNAH; www.cnah.org) contains nine genera and 47 species in North America. *Urosaurus* is comprised of seven species ranging from southwestern U. S. to northern Mexico (Haase 2009; Wilson and Johnson 2010). Distribution of *U. ornatus* is restricted to southwestern U.S. and northern Mexico (Fig. 1; Haase 2009). Even though there has been 10 recognized subspecies (geographic variants) of *U. ornatus* (Wikipedia, the free encyclopedia, 27 July 2014), subspecies as a formal taxonomic category is losing favor and considered to be a non-taxon by many modern phylogenetically grounded taxonomists (e.g., Fitzpatrick 2010; Johnson *et. al.* 2010: Padial and de la Riva 2010; Porras *et al.* 2013; Reiserer *et al.* 2013), so no subspecies designation will be followed herein. Consistent geographic variation in morphological characters is considered to represent geographic pattern classes (Grismer 2002), not formal taxonomic units.

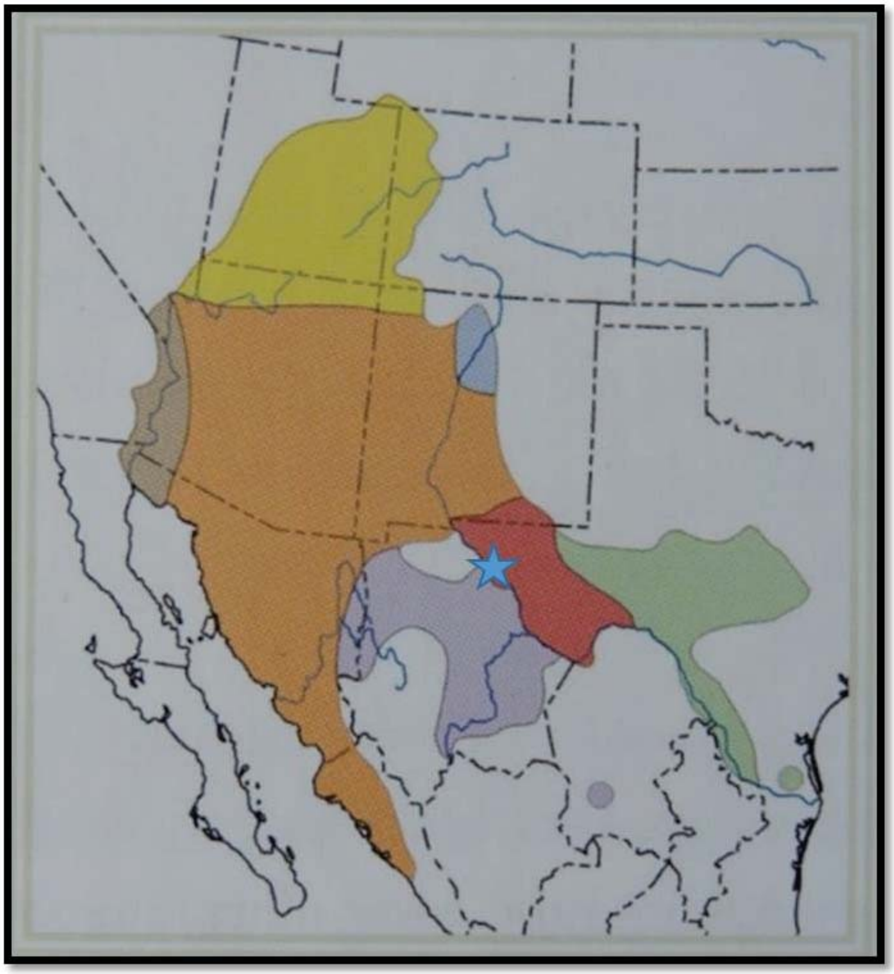

Figure 1. The distribution of *Urosaurus ornatus* in southwestern United States and northern Mexico (from Haase 2009); modified by J. S. Alva. The location of Indio Mountains Research Station, Hudspeth County, Texas is marked by the star. The different colors represent the subspecies (geographic variants) that Haase (2009) recognized.

Description: Most descriptive information below is based on Haase (2009) or from others cited in the text. *Urosaurus ornatus* is a small, thin lizard with a snout to vent length (SVL) of up to 60 mm. Vitt *et al.* (1981) reported SVL to range from 50 - 60 mm, with an average of 51.2 + .29 mm for females and 52.5 + .42 mm for males. Smith and Ballinger (1995) after measuring 490 *U. ornatus* found that in southeastern Arizona and southwestern New Mexico, males were significantly larger than females in SVL and body mass. *Urosaurus ornatus* possess a throat fold and two longitudinal folds along the sides of the body. Their dorsal surface has granular scales with two separated rows of enlarged mid-dorsal scales. Their legs and tail have noticeable keeled scales and males have two enlarged post-anal scales. Their dorsal coloration is gray, tan, or brown, with black or brown irregular blotches, crossbars, or striations that are often edged with lighter gray (Fig. 2A). Many males and females have light stripes from the sides of their heads going backward along each side of their bodies. The base of the tail is normally a rusty red-brown color. *Urosaurus ornatus* may appear dark when first emerging during the day, throughout courtship or territorial displays, or during cool ambient daytime temperatures. Males have two bluish (blue, metallic blue, blue-green) ventral patches, and a blue, blue-green, yellow, orange, or a combination of any of those colors on their throats (Fig. 2C), which according to Thompson and Moore (1991) and Hover (1985) signals their hierarchical status in a population. Females lack ventral belly coloration, but their throat can range from colorless to yellow or orange (Fig. 2B). Juveniles are similar to females in coloration, but have different body proportions, including relatively larger heads.

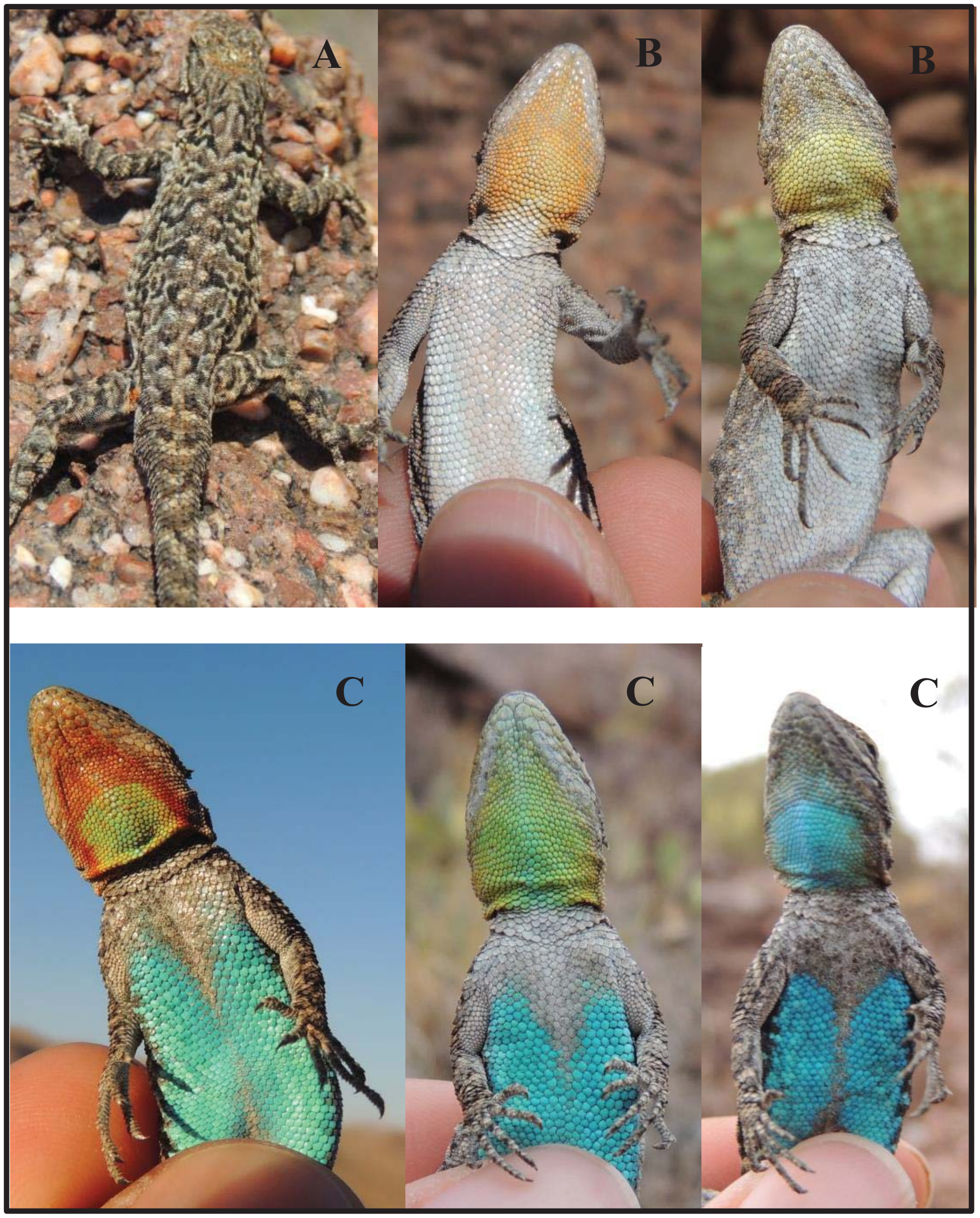

Figure 2. *Urosaurus ornatus* from Indio Mountains Research Station, Hudspeth County, Texas, during April and May 2013. (A) Dorsal view of a male, and throat and ventral color variations of two females (B) and three males (C).

Habitat: Ornate Tree Lizards are normally found in arid or semi-arid regions, and usually associated with trees (Baltosser and Best 1990; Thompson and Moore 1991) or rocks within habitats that include rocky slopes, canyons, cliffs, savannas, and riparian woodlands; reported elevation is from sea level to about 2440 m. Populations occupying trees have been found on mesquite, alder, cottonwood, oak, pine, and junipers, where they forage and bask, but in areas around human habitation, they also use rocks, stumps, fences, building walls, or other surface objects for those purposes (Haase 2009). *Urosaurus ornatus* are primarily arboreal in the Sonoran Desert because they are usually restricted to riparian habitats or - tree covered mountain ranges (Vitt *et al.* 1981). However, despite their common name they are most often found on rocks in southwestern Texas and throughout New Mexico (Dunham 1980; Degenhardt *et al.* 1996; Gehlbach 1965; Zucker 1989). Couvillon (2011) reported that *U. ornatus* occurs ubiquitously in Hudspeth County, Texas, on Indio Mountains Research Station (IMRS) where rocks are prevalent, and apparently do not discriminate between rock types. They are also found on fences and buildings located around IMRS Headquarters.

Diet and Predation: The diet of *U. ornatus* consists of varied insects, like ants, beetles, true bugs, beetle larvae, and other small arthropods, including scorpions (Haase 2009; Vitt *et al.* 1981). In central Arizona, Vitt *et al.* (1981) observed *U. ornatus* actively feeding during early morning hours, even though their body temperatures were at their lowest during those times. They are sit-and-wait predators, feeding mostly on insects, which are themselves most active during morning hours. *Urosaurus ornatus* have been shown to be preyed upon by small carnivorous mammals, raptorial birds, larger lizards, and some snakes (Haase 2009; Dunham 1981). The ground-foraging bat, *Antrozous pallidus*, was found to prey on *U. ornatus* on IMRS by Lenhart *et al*. (2010). *Urosaurus ornatus* were also reported to weigh less and grow slower during dry years than wet years because of the adverse relationship of dry weather to prey abundance (Ballinger 1977; Dunham 1981).

Reproduction: Much has been reported about reproduction in *U. ornatus*, which was reviewed extensively by Degenhardt *et al.* (1996), the source for most information referred to below; other material is referenced separately in the text. Females become mature between an age of nine to 12 months at a minimum SVL of 41 mm and produce up to six clutches per year; more commonly two or three per year. Availability of food and water resources is critical to reproduction cycles; Gehlbach (1965) found that the oviposition of *U. ornatus* seems to be correlated with the onset of summer rainfall; therefore dry years should have a negative effect on number of clutches and possibly clutch size (five to 16 eggs). Males become sexually mature at about the same time and size (40 mm SVL) as females. Males are territorial and actively fight to defend their space for exclusive mating opportunities with female residents (M'Closkey *et al.* 1987); females are relatively sedentary within their home ranges (Deslippe *et al.* 1990). Hatchlings may appear from July through August.

Thermal Ecology*:* Although thermal ecology of *U. ornatus* has previously been studied within desert environments, few such investigations transpired in the northern Chihuahuan Desert of Trans-Pecos, Texas, as implied by the absence of such investigation in the literature. Still, a few studies have been undertaken by others in the southwestern U.S.; a summary of those papers is given below.

Urosaurus ornatus can be active on warm days all year, even during cooler winter months on sunny days with ambient temperatures above 15°C (Haase 2009). In areas prone to subfreezing winter temperatures, they go into winter dormancy (brumate) from late fall through early spring, sometimes aggregating in large groups in prime refuges. They may also go into summer dormancy (aestivate) during times of drought or very warm temperatures to minimize water loss and retain fat reserves (Haase 2009). In Arizona, Vitt *et al*. (1981) found *U. ornatus* to actively thermoregulate by basking in the sun during early mornings to elevate their body temperatures, then moving back and forth from sun to shade to maintain a relatively constant body temperature (behavioral homeothermy); they also entered fissures in large mesquite trees or retreated under loose bark to avoid high temperatures. Vitt and Caldwell (2009) explained that within a relatively narrow range, reptiles and amphibians behaviorally regulate their body temperatures by taking advantage of the sun and warm surfaces to increase temperatures, and by using shade, retreats, water, and cool surfaces to decrease temperatures. Smith and Ballinger (1994b) compared thermal ecology between sympatric *Sceloporus virgatus* and *U. ornatus* from the Chiricahua Mountains of southeastern Arizona, and found that at similar ambient temperatures, *S. virgatus* body temperatures were significantly lower than *U. ornatus*. Smith and Ballinger (1995) compared ecology of *U. ornatus* in a desert environment at 1350 m elevation in southwestern New Mexico and at a low elevation (1700 m) montane site in southeastern Arizona; he found that elevation (desert and low-montane locations) and reproductive conditions (gravid and non-gravid females) to have no influence on the mean body temperature of *U. ornatus*. On the other hand, the month (Mar., June, July, and Aug. had the highest mean body temperatures) and the gender (females had a significantly lower Tb than males) had a significant effect on the mean Tb of the *U. ornatus*. Bogert (1949) found that species of different genera living side by side in the same environment were able to maintain significantly different body temperatures by behaviorally thermoregulating. That study also compared species of *Cnemidophorus* (= *Aspidoscelis*; Reeder *et al.* 2002) and S*celoporus* in different environments in Arizona and Florida, and found that lizards in the same genus, but living in different habitats or climatic regions, tend to have similar body temperatures, suggesting that they have genetically controlled preference for specific body temperatures. However, Pough (1973) believed that genetic controlled temperature preference could also be affected by environmental conditions. Congdon *et al.* (1982), in part, looked at body, substrate, and air temperatures associated with *U. ornatus* and *U. graciosus* in Arizona. They found body temperatures of both species to be low in the early morning and increase as the ambient and substrate temperatures increased. However, the afternoon body temperatures of *U. graciosus* significantly increased from their morning temperatures, but afternoon temperatures of *U. ornatus* did not significantly increase from its morning body temperatures. Vitt *et al*. (1981) investigated *U. ornatus* thermal activity in riparian habitats in central Arizona and correlated it to time of day, habitat temperatures, and body temperatures. Zucker (1987) did not focus solely on body temperatures of *U. ornatus*, but did determine them to time, air temperature, and light intensity when lizards emerged in the morning and when they moved from sun to shade. Lowe and Vance (1955) included some aspects of temperature tolerance, like the incipient upper lethal temperature and resistance time for *U. ornatus* near Tucson, Arizona.

The major goal of the study presented herein was to examine the thermal ecology of *U. ornatus* on IMRS, within a northern Chihuahuan Desert landscape located in Trans-Pecos, Texas. Relevant questions asked during the study included: 1). What was the normal range of temperatures for *U. ornatus* during its activity period? 2). Was thermal biology of *Urosaurus ornatus* on IMRS similar to those reported from other locations? 3). Was *U. ornatus* a thigmothermic or heliothermic lizard species? 4). Were *U. ornatus* thermoconformers or thermoregulators? 5). Did males and females differ in mean body temperature? 6). Did gravid and non-gravid females differ in their body temperatures? 7). Did the mean body temperatures of lizards found in the sun differ from those found in the shade? 8). Was there differences in body temperature patterns among seasons? 9). Were there similarities in patterns between mean operative temperatures (Te) and mean body temperatures (Tb) of active *U. ornatus*? The hypotheses related to all but number 1 of the above questions are: 1). Normal range of temperatures allowing lizard activity was determined after evaluating all temperature measurements during this study. 2). The thermal behavior of *U. ornatus* on IMRS will be similar to other locations. 3). *Urosaurus ornatus* will be thigmothermic because the Chihuahuan desert has one of the highest daily fluctuating environmental temperatures when compared to other deserts. 4). *U. ornatus* will be thermoregulators because *U. ornatus* is known to maintain its body temperatures by sun-shade shuttling (Congdon *et al*. 1982). Also, during this study individual *U. ornatus* were seen actively regulating on a regular basis, which is a common behavior for thermoregulators. On the other hand, thermoconformers usually stay put and their body temperature fluctuates with the changing ambient temperatures (Huey and Slatkin 1976). 5). There should be no significant difference in mean body temperatures between males and females because in a study done by Huey and Pianka (2007), in which they looked at 56 different species, 11,371 individuals, of lizards from deserts of Africa, Australia, and North America found both sexes to have similar body temperatures, ambient temperatures, and times of daily activity. Mean body temperatures of males and females of 80.4% of the species differed by less than 1°C, and in only eight out of the 56 species did the mean Tb of males and females differ significantly. 6). There will be a significant difference in body temperatures between gravid and non-gravid female *U. ornatus* because gravid females may alter their thermoregulatory behavior (Beuchat 1980). 7). There will be a significant difference in body temperatures between lizards found in the sun and those in the shade because it is assumed that lizards found basking in the sun would have a much higher mean Tb than those that are cooling in the shade. 8). There will be differences in body temperature patterns among seasons because that situation was observed in similar studies of other populations of *U. ornatus* in the southwestern United States (Smith and Ballinger 1994b, 1995). 9.) There will be similarities in patterns between mean operative temperatures and mean body temperatures of active *U. ornatus* because, when used correctly Te models can be a powerful instrument for assimilating thermal environments experienced by animals (Dzialowski 2005).

Temperature plays a critical role in the everyday lives of ectotherms, because it influences the distribution, seasonal activity behaviors, and diversity patterns in reptiles everywhere. Climate change is already having an effect on biodiversity and it is projected to become a larger threat in the future (www.globalissues.org/article/172/climate-change-affects-biodiversity). Although climate change has occurred throughout the history of earth, rapid changes can affect the ability for organisms to adapt. It is expected that rising global temperatures will also influence this region and therefore will have an impact on the population of *U. ornatus* too; possibly affecting aspects such as time for feeding, reproducing, and of course thermoregulating. Therefore, it is important for us to understand the thermoregulatory needs of ectothermic organisms as they are dependent on direct environmental temperatures for survival, especially since many recognize that rapid global warming has already been activated by human misuse of natural resources.

Materials and Methods

Study Site*:* Body temperature data was obtained from *U. ornatus* captured on Indio Mountains Research Stattion (IMRS), situated in southeastern Hudspeth County, Texas (Fig. 3), from April 2007-July 2012 by Vicente Mata-Silva, and from August 2012-June 2014 by me during activity periods of March through November. Study site information was mostly taken from Johnson (2000) and Worthington *et al*. (2014); other sources are mentioned in the text. IMRS is north and east of the Rio Grande near Culberson County border. The Headquarters (HQ) complex is centered on (30.776667°N, 105.015833°W; WGS84), 1230 m elevation, and located ca. 40 km southwest of Van Horn (Fig. 3). The IMRS at present contains about 40,000 acres of mostly pristine Chihuahuan Desert scrub and is managed by the University of Texas at El Paso (UTEP). It encompasses most of the Indio Mountains, which is the lower southern spur of the Eagle Mountains located to the north. IMRS is characterized by mountainous outcrops, alluvial fans and rocky slopes, both leading to numerous arroyos and bajadas supporting a variety of vegetation communities which vary with elevation and slope. The station lands contain a perennial water source, Squaw Spring, which flows a few hundred meters along Squaw Creek. Vegetation is typical of Chihuahuan Desert scrubland, with Creosote-Lechuguilla-Ocotillo-Yucca associations, and Tabosa-Black Grama desert grassland. Elevation ranges from 900 m near the Rio Grande, to almost 1600 m on several peaks. The eastern slopes of the Indio Mountains are primarily Cretaceous limestone with complex over thrusting and sharp ridges. The western slopes contain gently tilted Permian conglomerates, sandstones, and shales. The southcentral portion of the property also exhibits traces of Tertiary volcanism, complete with basalts, pumice, and ashfall layers. Salts and gypsum occur there as well, and clay and gravel beds are found in portions of the property nearest the Rio Grande. Animal life is typical of the northern Chihuahuan Desert scrubland and associated desert grassland fauna. Desert invertebrates, like insects and spiders, are abundant, 25 mammal species have been recorded, 141 species of an expected list of around 200 birds have been observed (Wiseman 2014), 38 species of reptiles (snakes, lizards, and turtles) have been recorded, and five amphibian species have been found on the property. IMRS was described by Escamilla (2012) as having the following six vegetation classes that were derived from cluster analysis and ordination: 1) *Agave Bouteloua* complex; 2) *Bouteloua* grassland; 3) *Agave Bouteloua Viguiera* complex; 4) Arroyo Riparian; 5) *Larrea* Acacia Complex; and Tanks (artificial ponds with earthen dams).

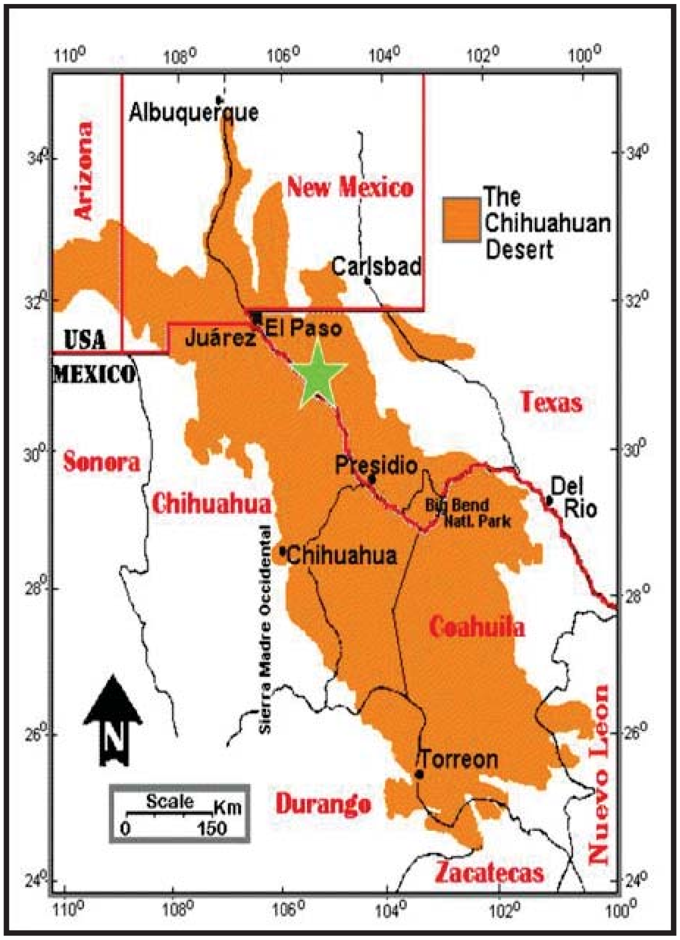

Figure 3. Map of Chihuahuan Desert (Schmidt 1979); modified by V. Mata-Silva. Location of IMRS is depicted by the star.

Data Procurement: Body size was determined in the field by measuring snout to vent length (SVL) and tail length (TL) to the nearest mm using a flexible ruler, and weight to the nearest 0.1 g using a hand-held spring scale (Fig. 4). Body temperatures (T_b), ambient temperature (Ta), at the level above ground where lizards resided, and substrate (T_s) temperatures were taken using a cloacal quick-read thermometer. The bulb of the thermometer was kept in the shade for all three measurements. Special care was taken to ensure that body temperatures were not overly influenced by handling. Lizards that could not be measured within 30 seconds after capture were let go and allowed to be re-acclimated to its surrounding for at least 30 minutes before another capture was attempted. Body temperatures were taken primarily from lizards actively basking or foraging, but those captured in rock crevices or tree fissures were processed as well. The temporal focus of twice daily lizard collecting during warm months was from 0800 to 1200 h and from 1700 to 2000 h. Searches were also made during colder months when temperatures reached >15º C. Lizards were captured mostly with a fishing rod with a noose made out of a thick white thread positioned at the end, but on a few occasions they were captured by hand. After a lizard was located and captured by hand or noose, the following was quickly recorded: Tb, Ta, and Ts, in that order; sex; SVL, TL, and weight; morphological color patterns; lizard behaviors (basking, foraging, and reproduction); date and time; location coordinates and elevation; microhabitat (localized biotic and abiotic features); weather conditions; and any other information perceived to be relevant. Each lizard was captured and measured only one time. At the beginning of the study a few lizards got away before I was able to take SVL and/or Mb measurements. Furthermore, operative temperatures (Te) were acquired through the use of calibrated HOBO® Temp/Temp External data loggers – H08-031-08 and lizard models, placed in microhabitats used by *U. ornatus*. Lizard models were made out of silicon plastic tubing, which were previously painted with brown color to match the animal's absorptivity. Data logger probes were embedded into the models, and sealed with a cork and rubber glue. Six models were used, three were located on rocky substrate, and exposed to the sun, and three were located always in shade inside rock crevices. Te was recorded during the warm months, from May to September, in 2013.

Data Analyses: Data of all adult lizards was statistically analyzed with Minitab or SPSS software. Tb and Ts data was normalized by removing outliers because we could not find a transformation that would produce a normal distribution. We used non-parametric test for the data sets that did not have a normal distribution. Analysis of covariance (ANCOVA) was used to determine if there were significant differences in body temperatures between adult males and females, between gravid and non-gravid females, and between lizards under different ambient conditions, considering the variables Ts as a covariant, because it had a stronger influence on the body temperature than Ta. Female lizards with an SVL of 42 mm or greater and males with an SVL of 41 mm or greater will be considered to be adults (Degenhardt *et al*. 1996). Pearson's correlation test was used to determine correlation between Tb and Ts, and Tb and Ta. Lizard populations were considered to be thermoregulators if the value of the slope of a lineal regression of Tb with Ts or Ta is zero or close to zero, or thermoconformers if the slope value was one or close to one (Huey and Slatkin 1976). Lizards were considered heliothermic if correlation between Tb and Ta was higher when compared to the correlation of Tb and Ts (Zug *et al*., 2001). However, they were considered thigmothermic if the opposite results were indicated.

Results

Urosaurus ornatus is primarily a saxicolous species on IMRS, since in most cases individuals were found on stone outcrops composed of a variety of rock types (i.e., conglomerate, sandstone, limestone and occasionally volcanic rock) located throughout the area. On a few occasions they were active on plants (e.g., Ocotillo, Honey Mesquite, Lechuguilla), on wooden fence posts, or on rock or stucco walls of IMRS Headquarters buildings. Tree Lizards were found at elevations ranging from 1002 to 1397 m. The mean elevation was 1246 m and most lizards were found at elevations between 1200 and 1300 m. Tree Lizards were captured in14 different types of weather conditions, with the highest number of lizards (220) found during calm and sunny days, sunny and breezy days (80), partly cloudy and calm days (38), and sunny and windy days (32). The other weather condition types, in descending order were: partly cloudy and breezy, cloudy and calm, cloudy and breezy, sunny and light breeze, partly cloudy and light breeze, partly cloudy and windy, cloudy and windy, cloudy and light breeze, dark and calm, and dusk and calm. Most of the lizards (304) were found basking in the sun, the second most (112 lizards) were resting in the shade, and on 10 occasions lizards were actively trying to catch prey, defecating, or exhibiting push-up behavior.

A total of 426 *U. ornatus* of all age classes were processed from April 2007 to June 2014 by Vicente Mata-Silva and myself. Of those, 390 (91.5%) were adults, 34 (8.0%) were juveniles, and two (0.5%) were hatchlings. The SVL range of 426 *U. ornatus* was 26 to 55 mm with a mean of 45.8 ± 4.5 mm, and the Mb range was 0.1 to 5.8 g with a mean of 2.9 ± 0.9 g. Adult *U. ornatus* had a mean SVL of 47.0 ± 2.9 mm with a range of 40.0 to 55.0 mm (N = 384), and a mean Mb of 3.1 ± 0.8 g with a range of 1.0 to 5.8 g (N = 382) (Fig. 4). The mean Mb without the outliers is 3.0 ± 0.7 g with a range of 1.0 to 5.0 g (N = 374). The two hatchlings observed on 24 August 2013 had a mean SVL of 26.5 ± 0.7 mm and a mean Mb of 0.5 ± 0.1 g. The 34 juveniles had a mean SVL of 36.1 ± 3.2 mm (range 30 to 40 mm) and a mean Mb of 1.4 g (range 0.1 to 2.8 g). The three smallest juveniles (SVL = 30 mm) were observed on 25 August 2012, 7 September 2012, and 21 September 2013. Of the 373 quantifiable adults, 237 were males and 135 were females. Males had both significantly larger mean SVL (47.5 ± 3.0 mm (N = 240) vs. 46.1 ± 2.8 (N = 141); $U_{1,\,380}$ = 11,932.0; z = -4.83; P < 0.00001) (Fig. 4) and higher Mb than females (3.2 ± 0.70 (N = 234) vs. 2.7 ± 0.75 (N=137); $U_{1,\,370}$ = 9,646.5; z = -6.42; P < 0.00001) (Fig.5). Of the 135 females 42 were gravid and 94 were not. Gravid females had both significantly longer mean SVL (48.2 ± 3.0 mm (N = 42) vs. 45.2 ± 2.3 (N = 94); $U_{1,\,135}$ = 920.0; z = -5.0; P = 0.000001)(Figure 6) and heavier Mb than non-gravid females (3.5 ± 0.88 (N = 42) vs. 2.5 ± 0.54 (N=93); $U_{1,\,134}$ = 562.5; z = -6.62; P < 0.0001) (Figure 7).

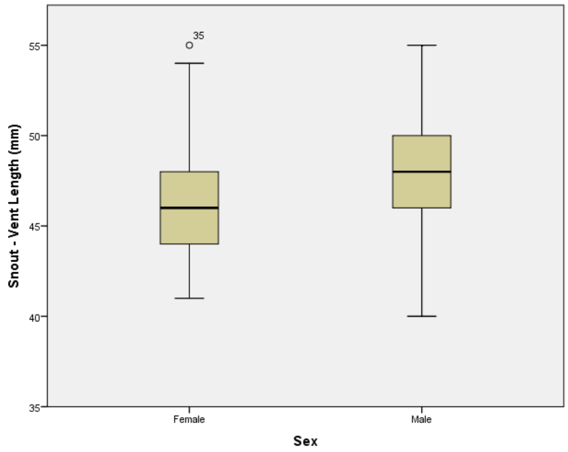

Figure 4. Boxplots of female and male adult *U. ornatus* mean snout – vent length (SVL) on IMRS during its activity period of March through November from 2007 through 2014.

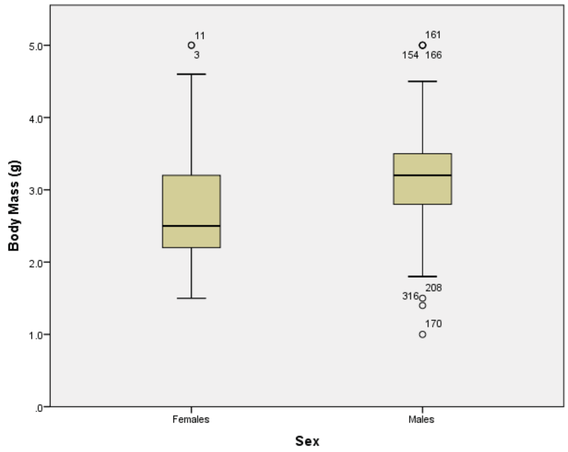

Figure 5. Boxplots of female and male adult *U. ornatus* mean body mass (Mb) at the time of this study on IMRS during its activity period of March through November from 2007 through 2014.

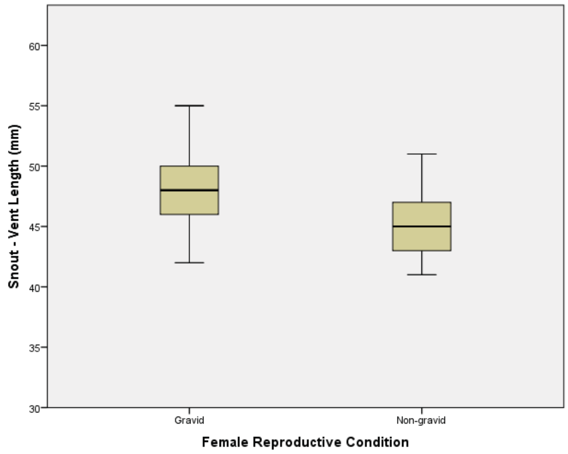

Figure 6. Boxplots of gravid and non-gravid female *U. ornatus* snout – vent length (SVL, mm) in IMRS during its activity period from 2007 through 2014.

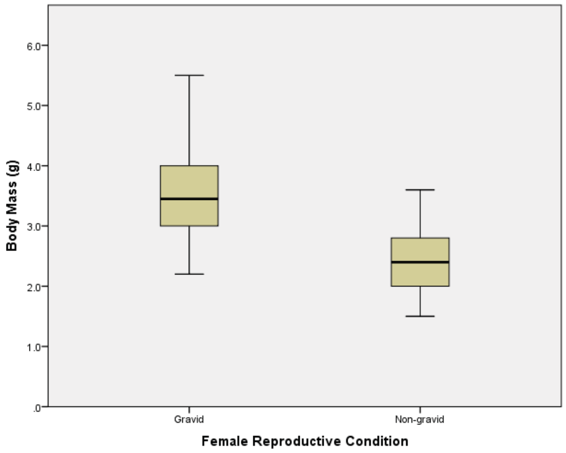

Figure 7. Boxplots of gravid and non-gravid female *U. ornatus* body mass (Mb, g) in IMRS during its activity period from 2007 through 2014.

Thermal Ecology:

Body temperatures**:** Tb of 385 *U. ornatus* ranged from 24.0 to 40.2°C with a mean of 33.6 ± 2.8°C. The most number of individuals (63) were found with a body temperature of 34°C and the next highest number of individuals, respectively, is 35 at 35°C and 34 at 36°C (Figure 8).

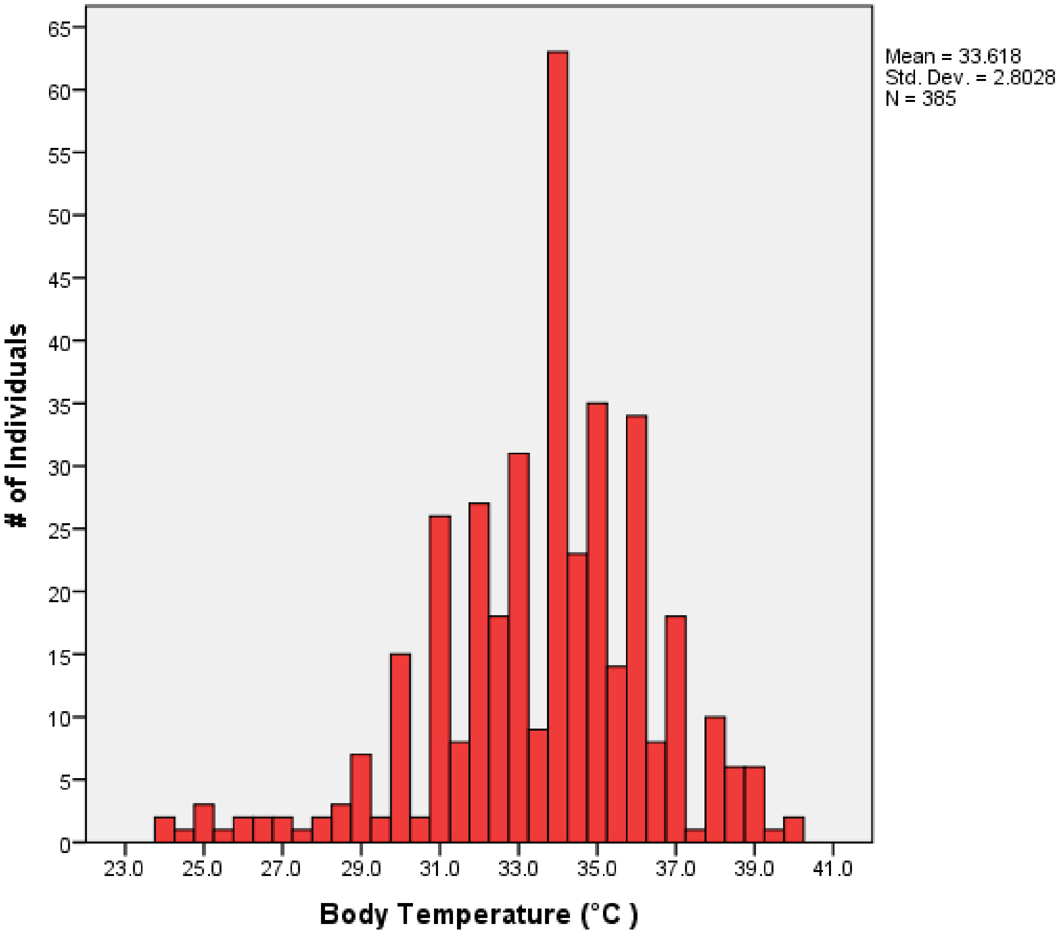

Figure 8. Distribution of body temperatures (Tb) at the time of capture of 385 active *Urosaurus ornatus* on IMRS during the study period from 2007 through 2014.

Ambient temperatures**:** Mean ambient temperature (Ta) for 385 lizards was 29.2 ± 3.9°C, range 16.0 to 38.2°C. Most lizards were found in ambient temperature between 26°C and 33°C, with the highest number (42) found at 28°C and the next highest (32) at 27°C (Figure 9).

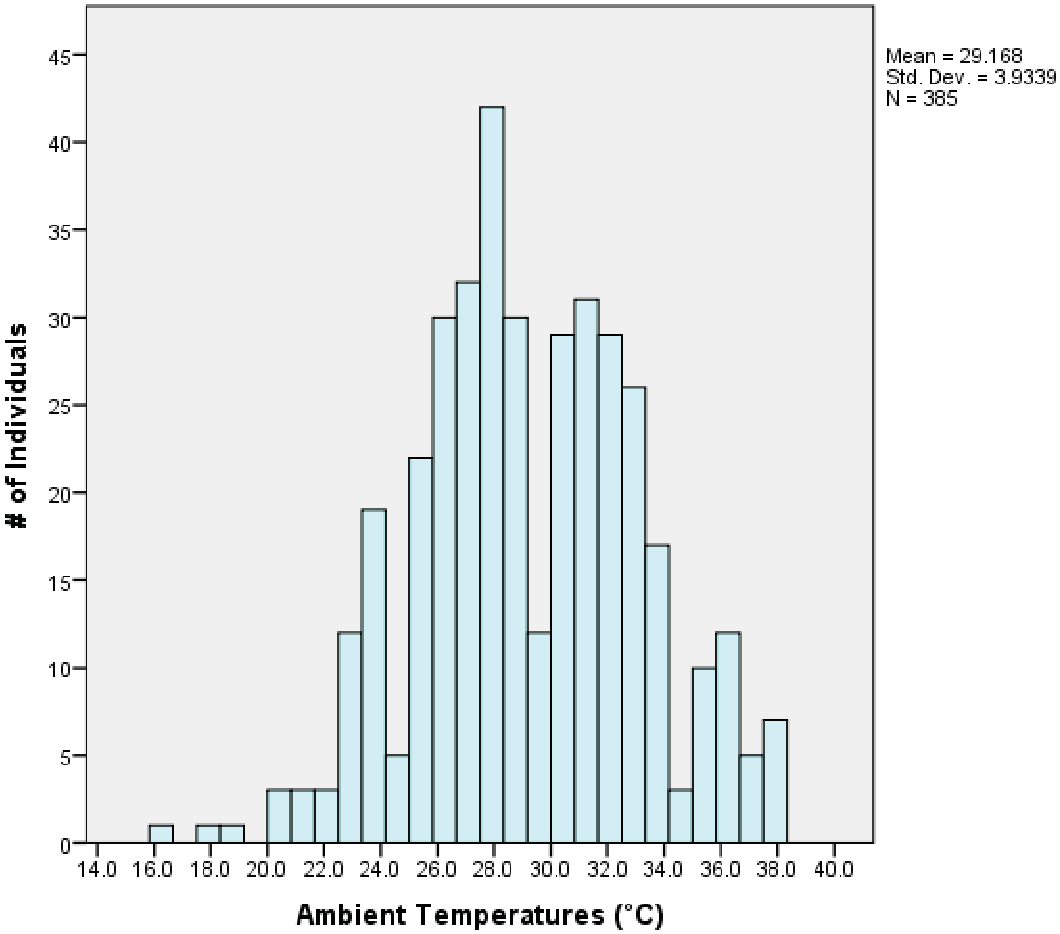

Figure 9. Distributions of ambient air temperatures at the time of capture of 385 active *U. ornatus* on IMRS during the study periods of 2007 through 2014.

***Substrate Temperatures*:** Mean Ts for 385 lizards was 30.8 ± 3.7°C, range 18.0 to 41.9. The highest number of lizards were found on substrates with temperatures between 28.0 and 34°C (Figure 10); the three highest numbers were at temperatures of 32°C (46), 33°C (43), and 28°C (40).

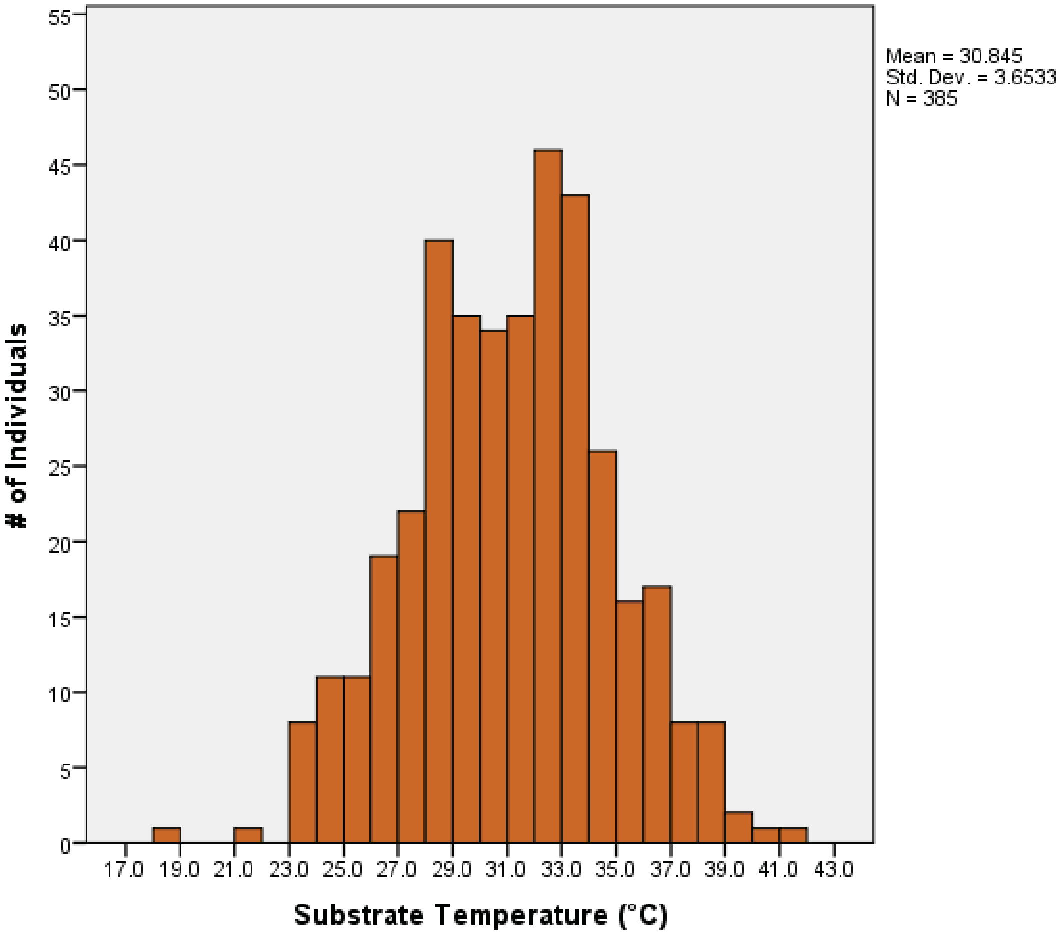

Figure 10. Distributions of substrate temperatures at capture time of 385 active *Urosaurus ornatus* on IMRS during the activity periods of 2007 through 2014.

***Relationships between Tb and Ta, and Tb and Ts*:** Active lizards found in the early morning and near dusk when ambient and substrate temperatures were at their lowest, had mean body temperatures that exceeded air and substrate temperatures. As the air and substrate temperatures increased and decreased there was a corresponding increase and decrease in the lizard's body temperatures (Tables 1 and 2). Table 1 shows that most lizards were found between average Ta of 26.3 and 32.3°C and with average Tb's ranging from 32.8 to 35.1°C. Table 2 indicates that most lizards were found between average Ts of 28.3 to 33.2°C with average Tb's of 32.4 to 35.1°C.

Table 1. Mean body temperatures (Tb), range of body temperatures, and number of active lizards at specific ambient temperatures (Ta) for *U. ornatus* on IMRS during activity periods of 2007 through 2014.

Mean Ta (° C)	*Mean Tb (° C)*	*Tb Range (° C)*	*N*
16	26.5	26.5	1
18.3	30.2	28.0-32.4	2
20.1	27.7	24.8-33.0	3
21.2	31.4	31-32.3	3
22.2	30.3	2.0-34.0	4
23.2	29.9	24.0-34.5	15
24.1	30.9	24.5-36.6	20
25.3	32.7	29.0-36.2	23
26.3	**32.8**	**28.5-37.0**	**37**
27.3	**32.9**	**29.0-36.0**	**38**
28.1	**33.4**	**29.8-38.4**	**37**
29.2	**33.4**	**26.0-38.0**	**33**
30.2	**33.5**	**24.0-36.9**	**30**
31.3	**34.7**	**29.0-39.0**	**40**
32.3	**35.1**	**31.8-38.0**	**31**
33.3	35.8	33.8-39.0	24
34.2	34.6	31.2-36.8	10
35.4	37.8	36.0-40.2	10
36.4	36.4	30.0-39.0	13
37.2	36.4	34.0-39.8	7
38.1	38.0	36.0-38.2	4

Table 2. Mean body temperatures (Tb), range of body temperatures, and number of active lizards at specific substrate temperatures (Ts) for *U. ornatus* on IMRS during the activity periods of 2007 through 2014.

Mean Ts (° C)	*Mean Tb (° C)*	*Tb Range (° C)*	*N*
18.0	26.5	26.5	1
21.0	25.4	25.4	1
23.1	28.4	24.0-33.0	8
24.2	29.8	24.5-34.5	11
25.3	30.1	25.0-36.6	11
26.2	31.8	26.0-35.0	19
27.2	32.5	29.4-36.5	22
28.3	**32.4**	**28.5-36.0**	**40**
29.2	**32.5**	**24.0-38.4**	**35**
30.2	**33.4**	**29.0-37.0**	**34**
31.3	**33.8**	**29.0-37.0**	**35**
32.2	**34.3**	**31.0-39.0**	**46**
33.2	**35.1**	**31.0-39.0**	**43**
34.1	35.5	33.0-38.0	26
35.1	35.7	33.0-39.0	16
36.2	35.5	30.0-40.2	17
37.3	37.2	35.5-39.8	8
38.1	38.2	36.5-39.5	8
39.2	36.0	36.0	2
40.0	38.5	38.5	1
41.9	39.0	39.0	1

***Parametric and Non-Parametric Tests*:** All the data below includes 373 adult lizards captured during the activity periods of March through November during the years 2007 through 2014. The data was not normally distributed and transformations failed, thus outliers were removed in order to normalize the data. However, this only worked for Tb and Ts (Shapiro-Wilk test, $p > 0.05$) data. A visual inspection of all three temperatures, Tb, Ta, and Ts, histograms, normal Q-Q plots, and box plots depicted that the data was approximately normally distributed. However, the Shapiro-Wilk test for Ta indicated the data was not normally distributed ($p < 0.05$). Whenever assumptions of analysis were violated non-parametric test were used.

***Thigmothermic vs Heliothermic*:** A Pearson product-moment correlation was run to determine the relationship between body (Tb) and substrate (Ts) temperatures for *U. ornatus*. There was a strong, positive correlation, which was statistically significant, between Tb and Ts ($r = 0.643$, $n = 373$, $p < .0001$). A Spearman's rank-order correlation was run to determine the relationship between body (Tb), and the ambient (Ta) temperatures for *U. ornatus*, which also had a strong positive correlation that was statistically significant ($r = 0.579$, $n = 373$, $p < .0001$). The stronger of the two correlations was Tb and Ts, suggesting *U. ornatu*s displays a thigmothermic behavior at IMRS (Zug *et al.*, 2001). Figure 11 shows the scatterplots of Tb and Ts, and Tb and Ta with lines of best fit.

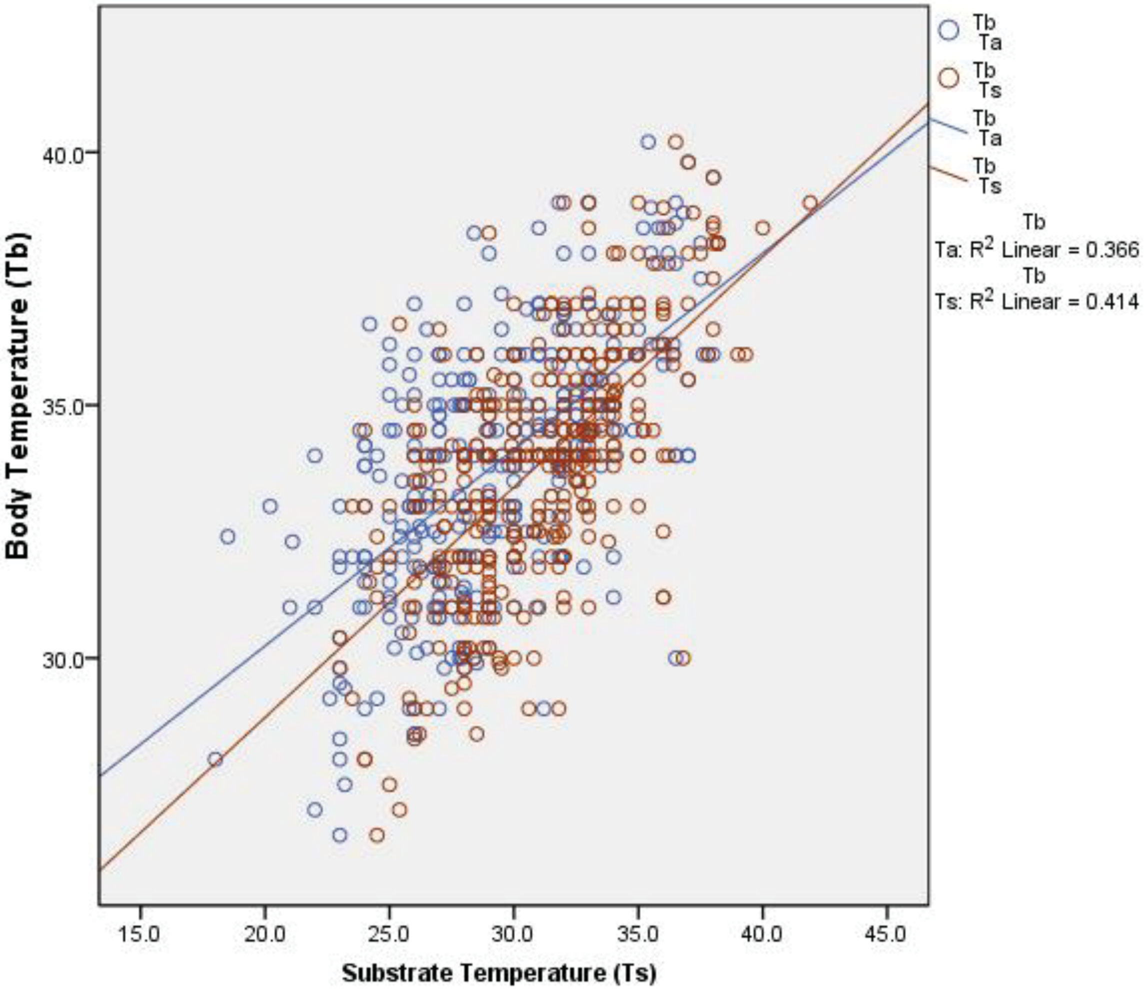

Figure 11. Scatter plots of Tb and Ta (blue circles), and Tb and Ts (brown circles) with lines of best fit: Tb and Ta (blue line: R^2 Linear = 0.383), Tb and Ts (brown line: R^2 Linear = 0.469).

Thermoconformers vs Thermoregulators: As just mentioned, there was a positive relationship between Tb and Ts and it is stronger than the relationship between Tb and Ta. There still exists a lot of variation around the regression line however the r^2 value is 0.414. The linear regression equation is Tb = 19.72 + 0.46 * Ts (Figure 12). There is a significant relationship between Tb and Ts ($p < 0.05$). Based on the slope value of 0.46, which is closer to zero than 1, this suggests that *U. ornatus* tend to behave as thermoregulators at IMRS (Huey and Slatkin, 1976).

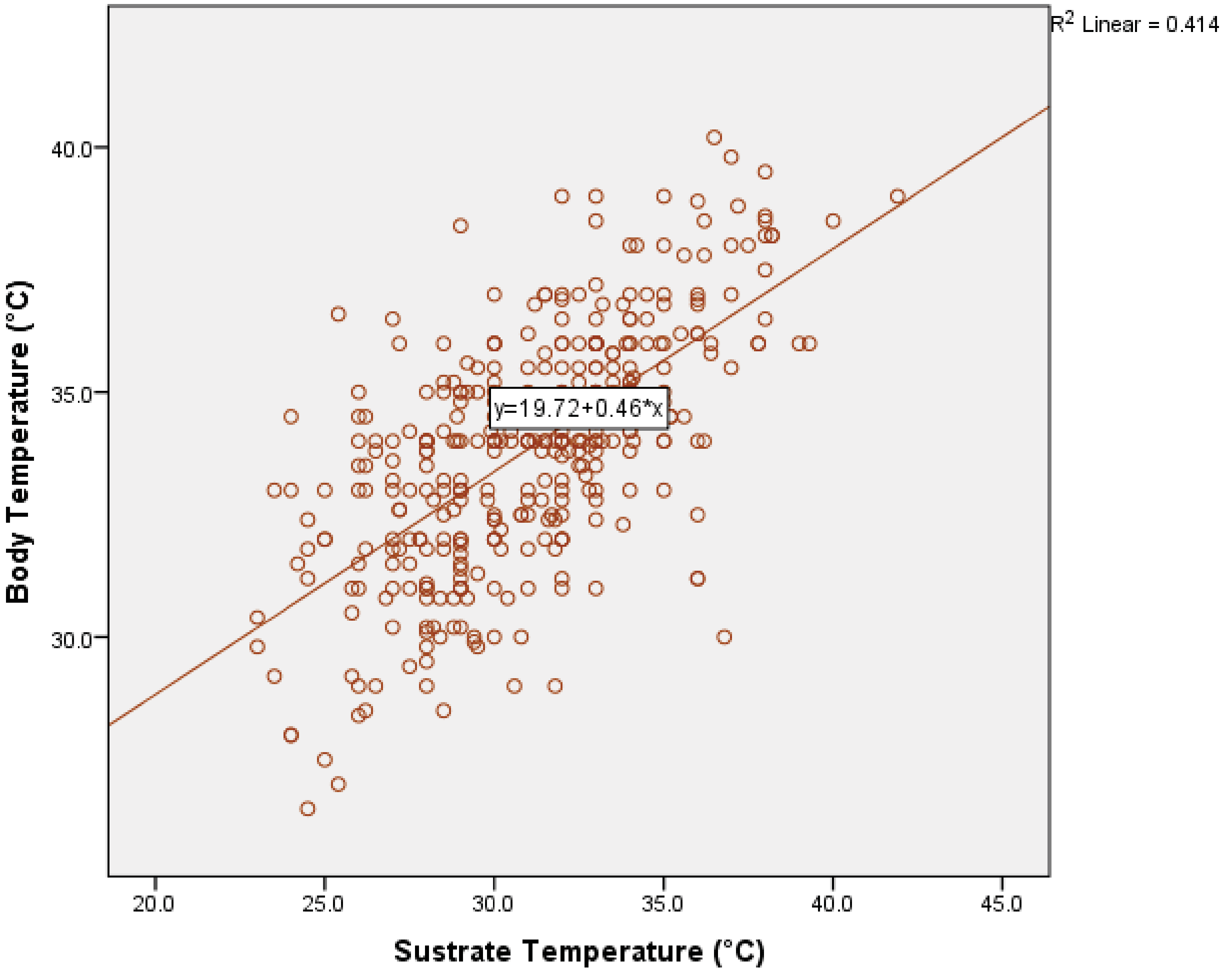

Figure 12. Scatter plot of Tb and Ts with line of best fit. R^2 Linear = 0.414.

Males vs Females: Of the 373 adults, 237 were males and 135 were females. As indicated before, males had both significantly larger mean SVL and heavier weight than females. There was only a 0.1 degree difference between mean male and female body temperatures, and an ANCOVA controlling for Ts found mean body temperatures to have no statistical difference (P = 0.337). Mean Tb for 135 females was 33.9°C, range 26.5-39.0°C and for 237 males was 33.8°C, range 27.0-40.2°C (Fig. 13).

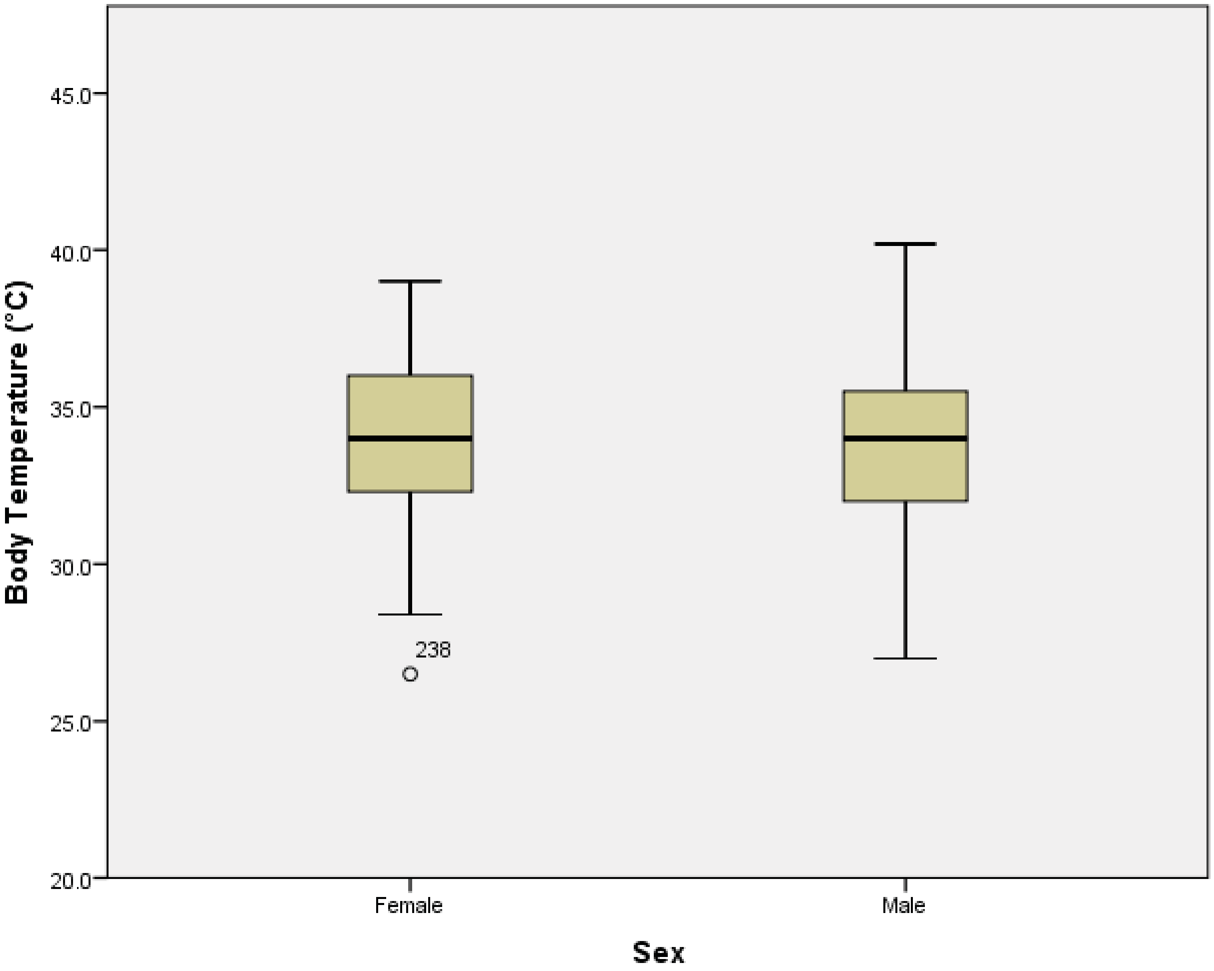

Figure 13. Boxplots, of 237 male and 135 female *U. ornatus* body temperature (Tb, °C) in IMRS during its activity period from 2007 – 2014. The box bounds the IQR divided by the median and whiskers extend to minimum and maximum values of the dataset. Open circles are outliers that extend past ± 1.5 × IQR.

Gravid and Non-Gravid Females: Of the 135 females, 42 were gravid and 94 were non-gravid females. As indicated before, mean Tb for 42 gravid females (33.5 ± 2.5°C) was slightly lower than the mean Tb for 94 non-gravid females (34.1 ± 2.6°C) (Figure 14). In order to assess if there are significant differences in body temperatures between gravid females and non-gravid females an analyses of covariance (ANCOVA) was conducted and found to have no statistically significant differences ($p > 0.05$).

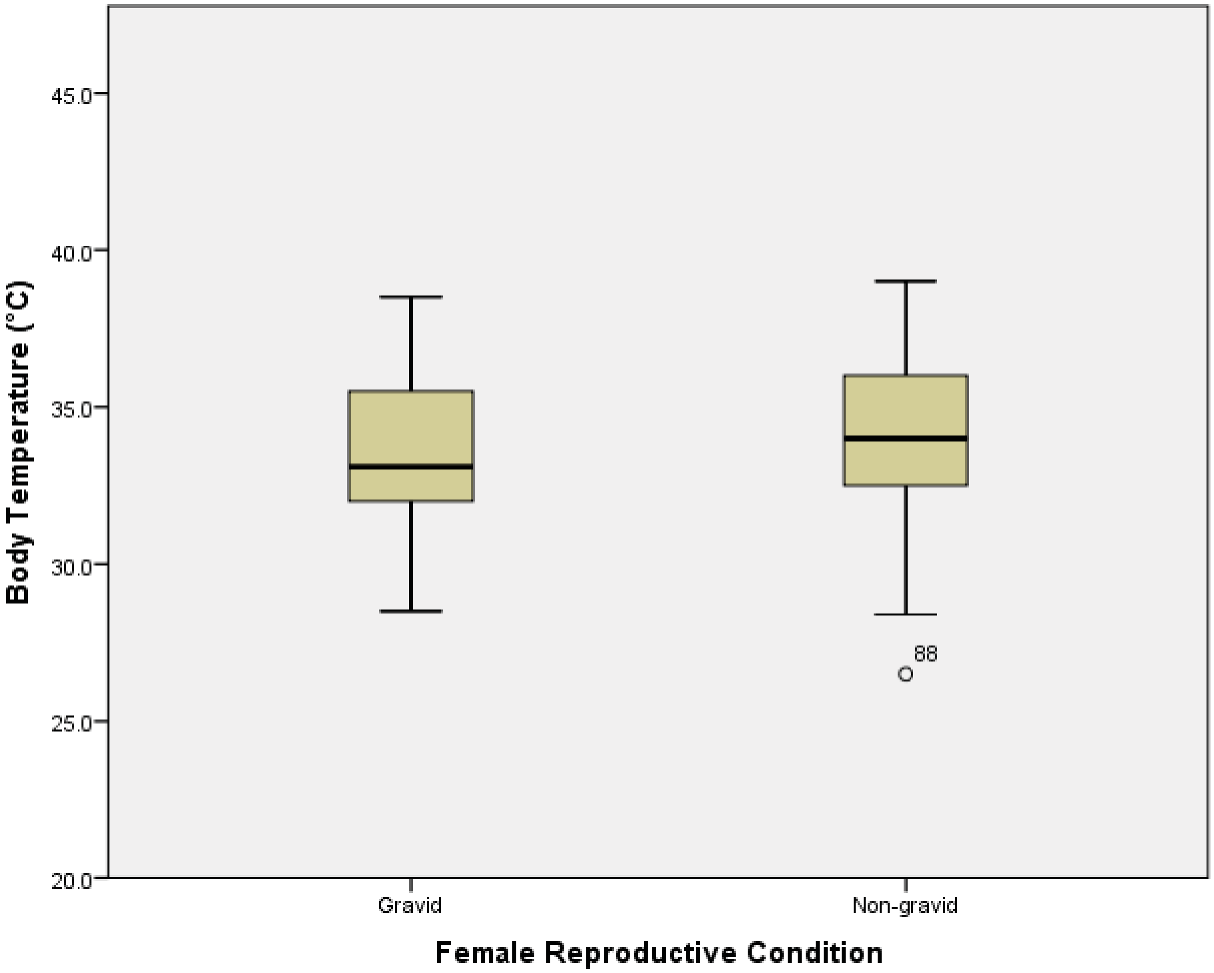

Figure 14. Boxplots showing body temperatures (Tb) of 42 gravid and 94 non-gravid female *U. ornatus* on IMRS during the activity periods of 2007 through 2014. The box bounds the IQR divided by the median and whiskers extend to minimum and maximum values of the dataset. Open circles are outliers that extend past ± 1.5 × IQR.

***Sun vs. Shade*:** The mean Tb of 269 lizards found in the sun (33.8 ± 2.4°C) was very similar to the mean Tb of 104 lizards found in the shade (34.0 ± 2.7°C); however, the mean Tb of the lizards in the sun was slightly higher (Fig. 15). An ANCOVA controlling for Ts found there was a statistical difference.

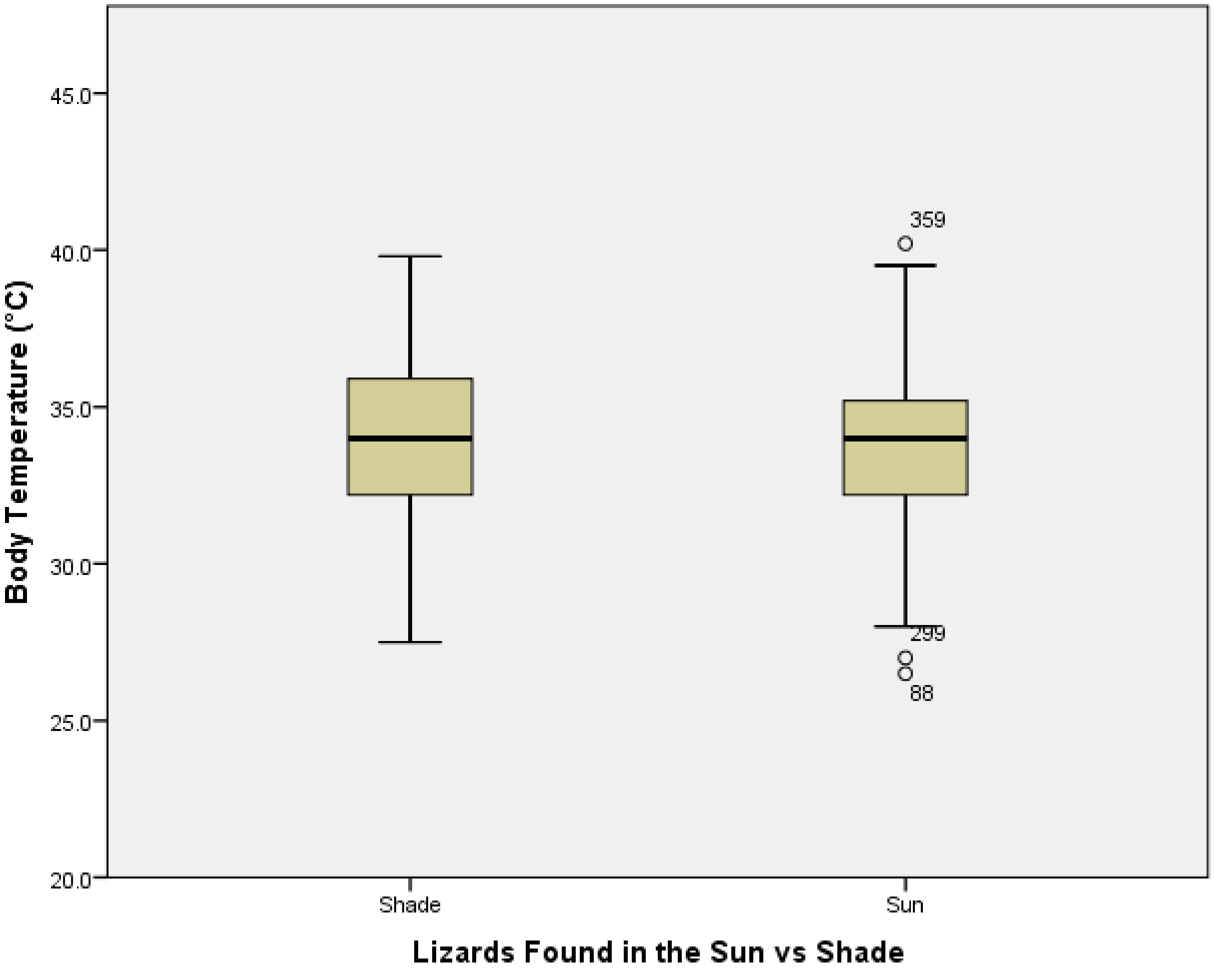

Figure 15. Boxplots of Tb (°C) for 269 lizards found in the sun and 104 found in the shade during the activity periods of 2007 through 2014. The box bounds the IQR divided by the median and whiskers extend to minimum and maximum values of the dataset. Open circles are outliers that extend past ± 1.5 × IQR.

***Monthly Body Temperatures*:** Figure 16 shows the mean Tb, Ta, and Ts of *U. ornatus* during each month of its active period. The lizards with the highest mean Tb were found in the month of June (35.0 ± 2.2°C, N = 74); following next were the months of August (34.8 ± 2.0°C, N = 11), September (34.4 ± 2.8°C, N=18), and May (33.9 ± 2.1°C, N = 122). On the other hand, the lizards with the lowest mean Tb were found in the months of November (30.1 ± 2.5°C, N = 8), March (32.6 ± 2.1°C, N = 21) and July (33.4 ± 2.5°C, N = 62). Mean Tb for lizards found in April was 33.6 ± 2.6°C (N = 48), and for lizards found in October was 33.6 ± 1.2°C (N = 9). However, in order to assess if there are significant differences in body temperatures between months an Analyses of Covariance (ANCOVA) was conducted. The ANCOVA for mean Tb of each month during *U. ornatus'* activity period controlling for Ts was found to have statistically significant differences ($p < 0.05$). A Tukey post-hoc test revealed significant differences between March and June ($p < 0.05$), November and June ($p < 0.05$), and July and June ($p < 0.05$). There were no significant differences between any other months.

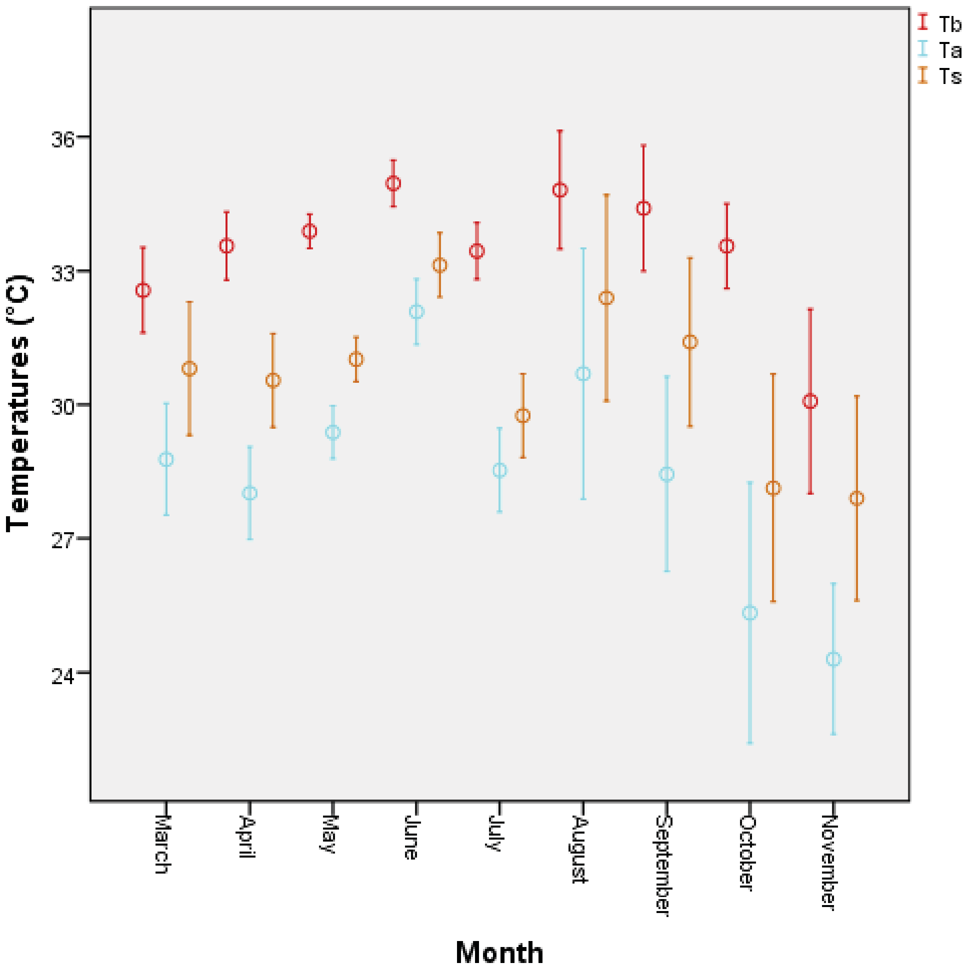

Figure 16. Boxplots of mean Tb, Ta, and Ts for each month during the activity period of *U. ornatus* on IMRS during the years 2007 through 2014. Means ± 2 standard error are shown.

***Operative Temperatures*:** Figures 17 through 20 are the mean Tb's of *U. ornatus* from 2007 through 2014, and Te's (sun and shade) from 2013, for each 30 minute intervals for each month from May through September. In May mean Tb's of active *U. ornatus* from nine to ten in the morning fell between sun and shade mean Te's. Once it started to warm up the mean Tb of lizards followed the Te of the shade models. From 1330 to 1530 in the afternoon, when temperatures were at their highest, no lizards were found (Figure 17). This pattern was also seen in the month of June and July, but the gap was wider from about 1200 to 1800 with the exception of one lizard at 3:30 pm (Figures 18 and 19).

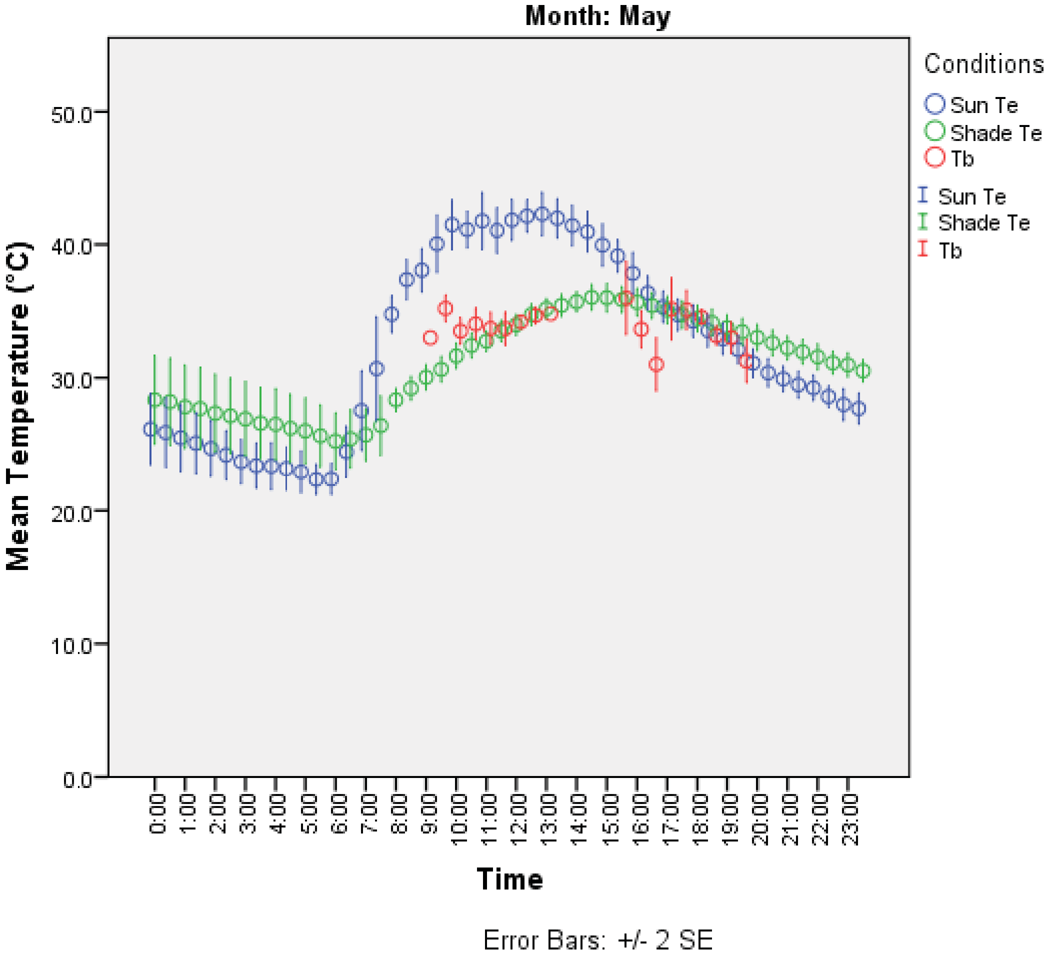

Figure 17. Mean body temperatures (Tb) (red), and sun (blue) and shade (green) optimal temperatures (Te's), with standard error bars for each 30 minute intervals in May. Mean Tb's were from the years 2007 through 2014, and Te's were only from the year 2013. Means ± 2 standard error are shown.

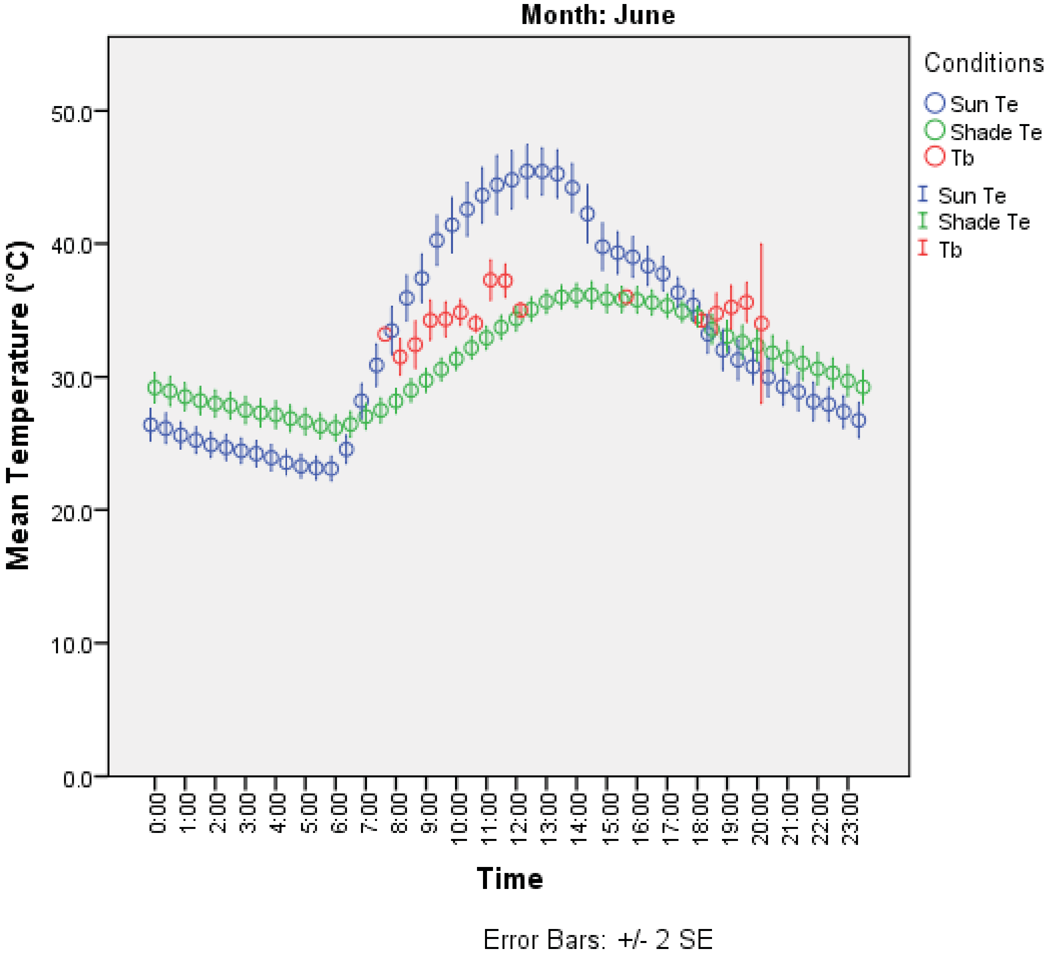

Figure 18. Mean body temperatures (Tb) (red), and sun (blue) and shade (green) optimal temperatures (Te's), with standard error bars for each 30 minute intervals in June. Mean Tb's were from the years 2007 through 2014, and Te's were only from the year 2013. Means ± 2 standard error are shown.

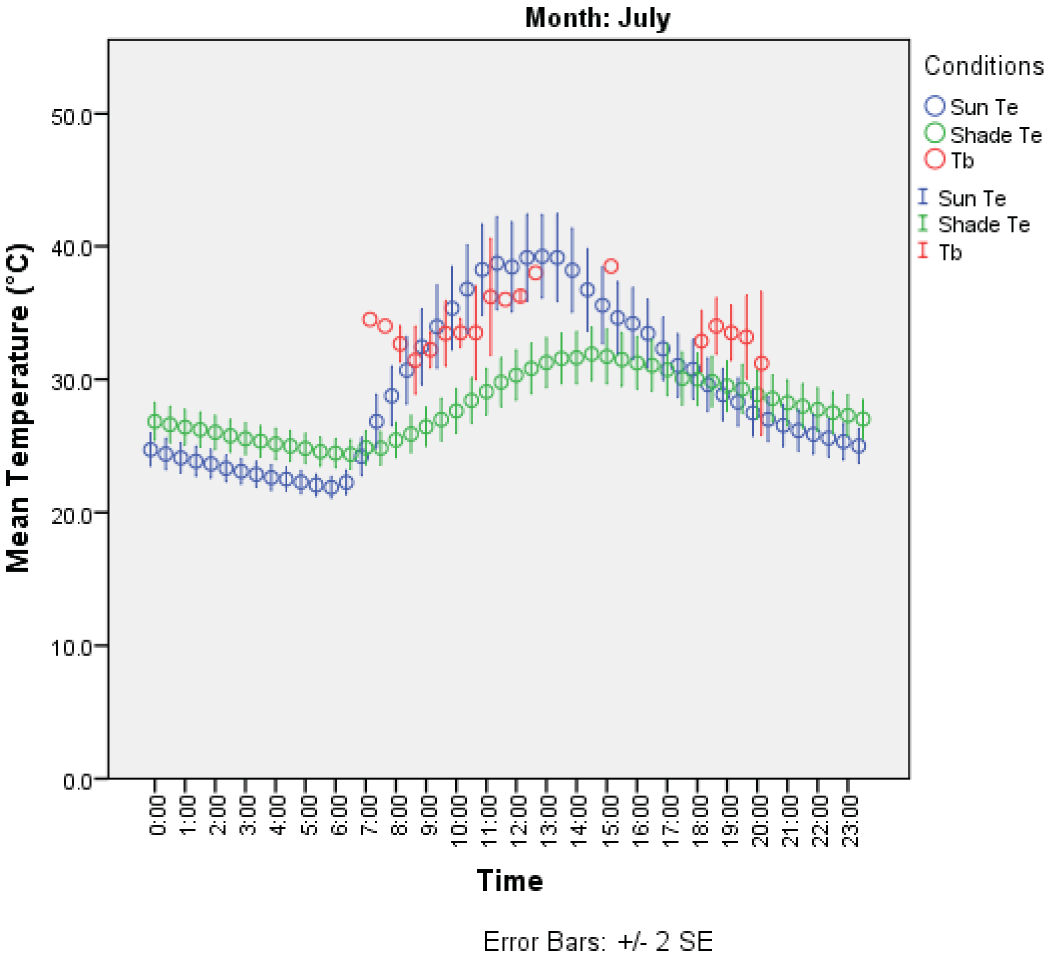

Figure 19 Mean body temperatures (Tb) (red), and sun (blue) and shade (green) optimal temperatures (Te's), with standard error bars for each 30 minute intervals in July. Mean Tb's were from the years 2007 through 2014, and Te's were only from the year 2013. Means ± 2 standard error are shown.

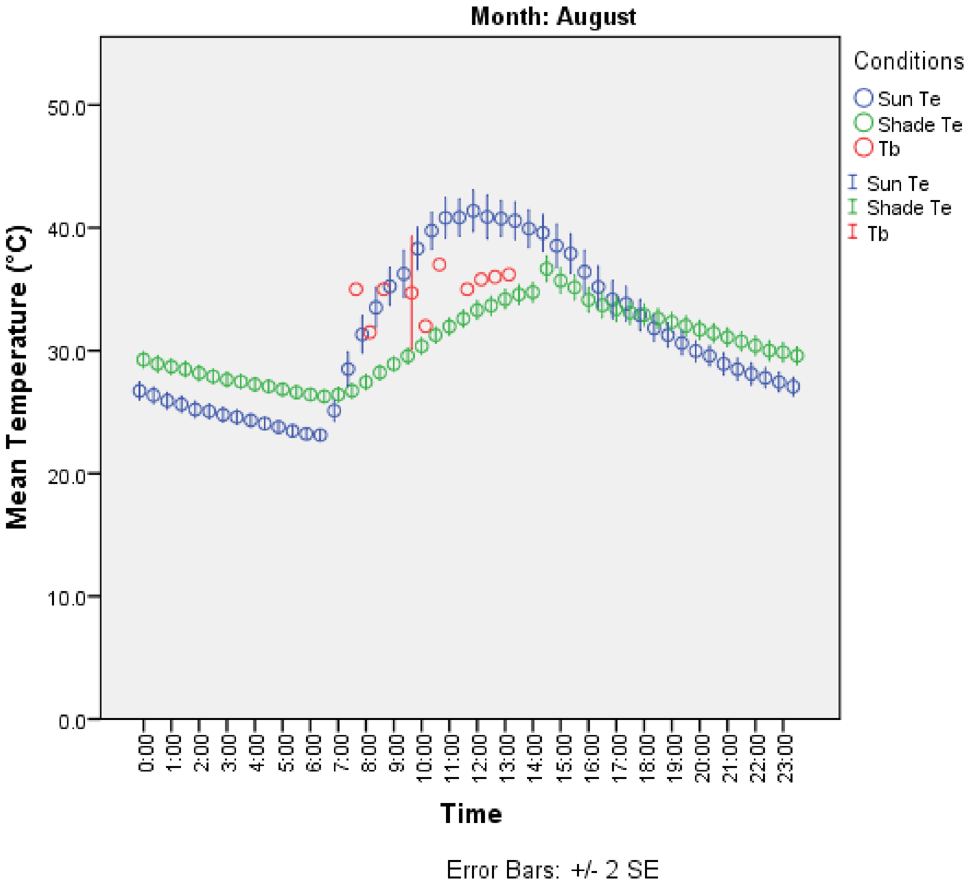

Figure 20. Mean body temperatures (Tb) (red), and sun (blue) and shade (green) optimal temperatures (Te's), with standard error bars for each 30 minute intervals in August. Mean Tb's were from the years 2007 through 2014, and Te's were only from the year 2013. Means ± 2 standard error are shown.

Discussion

In this study adult *U. ornatus* individuals had a mean Tb of 33.6 ± 2.8°C, with a range of 24.0 to 40.2°C. This average was lower but comparable to those found in other *U. ornatus* populations in the Southwestern United States; in central Arizona Vitt *et al*. (1981) reported a mean Tb of 34.6-37.2°C (N = 160) and Congdon *et al*. (1982) reported a mean Tb of approximately 36.0°C (N = 160) in a similar study site. Smith and Ballinger (1995) found the mean Tb to be 34.8°C (N = 429) in southwestern New Mexico and 35.0°C (N = 57) in southeastern Arizona. This variation could possibly be due to a difference in habitats as none of the previous studies were done in the Chihuahuan Desert.

Ambient and substrate temperatures were at their lowest in the early mornings and near dusk. Active lizards found during those times also experienced the lowest body temperature, although they far exceeded the air and substrate temperature. As the air and substrate temperatures increased or decreased there was a corresponding change in the lizard's body temperatures. These observations were similar to former studies of *U. ornatus* populations in the Southwestern United States (Congdon *et al*. 1982; Smith and Ballinger 1995).

To determine if *U. ornatus* was thigmothermic or heliothermic a correlation between Tb and Ts, and Tb and Ta had to be compared. If the ambient temperature influenced the body temperature more than the substrate temperature then the lizard is considered heliothermic and if the opposite occurs than the lizard is considered thigmothermic (Zug *et al*. 2001). Since the data between Tb and Ts was normally distributed a Pearson's Moment Correlation was performed (r = .643, n = 373, p < .0001). A Spearman's Correlation was done for Tb and Ta since Ta was non-normally distributed (r = 0.579, n = 373, p < .0001). The correlation between Tb and Ts was the strongest suggesting *U. ornatus* tends to be a thigmothermic species on IMRS. This could possibly be explained by the ambient temperatures fluctuating more quickly than the substrate temperatures allowing the lizards to better thermoregulate. Since the Chihuahuan Desert has one of the highest daily fluctuating environmental temperatures compared to other warm deserts these lizards could possibly prefer the radiant heat from the substrate since its temperature changing rate is more constant.

Since *U. ornatus* actively regulate their body temperature by sun-shade shuttling (Congdon *et al*. 1982), I hypothesized that they would be thermoregulators as opposed to thermoconformers. Thermoconformers do not actively move, so their body temperatures will fluctuate with the changing ambient temperatures (Huey and Slatkin 1976). The value of the slope between Tb and Ts of a linear regression should help answer this question. If the value of the slope is closer to zero than it is to one then they would be considered to be thermoregulators; if the value of the slope is closer to one then they would be considered to be thermoconformers (Huey and Slatkin 1976). The Tb and Ts linear regression had a slope value of 0.46, supporting the hypothesis that *U. ornatus* tend to be thermoregulators. During this study *U. ornatus* were observed actively moving from the sun to the shade and vice versa on a regular basis, which is a common behavior of thermoregulators.

The next question asked was if males and females differed in mean Tb. The hypothesis stated that there would be no statistical difference in mean Tb between males and females. Huey and Pianka (2007) looked at 56 different species, 11,371 individuals, of lizards from deserts of Africa, Australia, and North America. They found males and females, within the same species, have similar body temperatures and are active at similar ambient temperatures and time of day. Mean body temperatures of males and females of 80.4% of the species differed by less than 1°C, and in only eight out of the 56 species did the mean Tb of males and females differ significantly. To determine if there was a statistical difference between mean Tb of males and females an ANCOVA controlling for Ts was performed. The mean Tb of males (33.8°C) was almost identical to the mean Tb of females (33.9°C), and the ANCOVA controlling for Ts showed that the mean Tb of the males and females did not differ significantly from each other, supporting the hypothesis. Patterson and Davies (1978) found differences in preferred body temperatures (PBT) of males and females of *Lacerta vivipara* in south England; males had a higher PBT than females. Smith and Ballinger (1995) found female *U. ornatus* had a significantly lower Tb's than males (34.5 ± 0.2°C, N = 282 vs. 35.1 ± 0.2°C, N= 208) but still varied less than 1°C as those results found by Huey and Pianka (2007). Smith and Ballinger (1995) mentioned that other species in the Chiricahua Mountains had males with higher body temperatures than the females (e.g., *Sceloporus jarrovi*, Smith and Ballinger 1994a; *S. scalaris,* Smith et al. 1993), but in a different study no differences were found between *S. virgatus* (Smith and Ballinger 1994b). They did not have an explanation for the sexual differences in mean body temperatures of U. ornatus in the Chiricahua Mountains but suggested it could be a reflection of physiological or behavior differences between the sexes.

Differences in mean body temperatures of gravid and non-gravid *U. ornatus* females was analyzed, as well. The hypothesis stated there would be a significant difference because gravid females may alter their thermoregulatory behavior since many phases of embryonic development are sensitive to temperature (Beuchat 1980). Other studies have shown that gravid females might require more energy for the development of the embryo (Yue *et al.* 2012). In my study the mean Tb for 42 gravid females (33.5 ± 2.5°C) was slightly lower than the mean Tb for 94 non-gravid females (34.1 ± 2.6°C), but an ANCOVA controlling for Ts determined that it was not statistically different. In a similar study Smith and Ballinger (1995) also failed to find any differences in Tb's between gravid (34.2 ± 0.7°C, N= 14) and non-gravid (34.8 ± 0.2, N = 46) females. However, *U. ornatus* is oviparous and studies of ovoviviparous lizards found the mean body temperatures of gravid females to be significantly lower than non-gravid lizards (Beuchat, 1980; Patterson and Davies, 1978; Garrick, 1974). Smith and Ballinger (1995) proposed one of three hypothesis for the similarities found between reproductive stages: 1) The preferred body temperatures of *U. ornatus* is the appropriate temperature for the development of the eggs. 2). Body temperatures selected for egg development do not need to change due to the oviparity of this species. 3) Body temperatures are not changed because it could reduce survival of the gravid females.

Another question I attempted to answer was determining if there was a statistically significant difference between the mean body temperatures of lizards found in the sun from those found in the shade. It was hypothesized that there would be a significant difference because it is assumed that the lizards found basking in the sun would have a much higher mean Tb than those that are cooling in the shade. The mean Tb of 269 lizards found in the sun (33.8 ± 2.4°C) was very similar to the mean Tb of 104 lizards found in the shade (34.0 ± 2.7°C); however, the mean Tb of the lizards in the sun was slightly higher. An ANCOVA controlling for Ts found there was a statistical difference, supporting my hypothesis. These results likely could be explained by the thermoregulatory behavior of these individuals, with some individuals basking to increase their body temperatures and some found in the shade to reduce their body temperature. Because the study site is exposed to high amounts of solar radiation, lizards were observed shuttling from the sun to shaded microhabitats very likely to obtain optimal body temperatures.

To determine if there are temporal differences in mean body temperature during their active periods we analyzed monthly mean Tb. The hypothesis stated that there would be differences in body temperature patterns among months as this was found in similar studies of other populations of *U. ornatus* in the southwestern United States (Smith and Ballinger 1994b, 1995). To determine if there was a significant effect on Tb of *U. ornatus* by the month we did an ANCOVA controlling for Ts. This test showed that the monthly environmental temperatures had a significant effect on the Tb of *U. ornatus*. A Tukey post-hoc test revealed a significant differences between March and June ($p < 0.05$), November and June ($p < 0.05$), and July and June ($p < 0.05$). There were no other significant differences between the other months. March and November are the extremes of the active period of *U. ornatus* which could explain the significantly lower mean Tb during these months. July mean Tb of *U. ornatus* was expected to be similar to May, June and August. The significance difference of July from the other warm months could be explained because data was collected during a two week period of intense rain which correlated with lower temperatures.

Finally, we wanted to determine similarities in patterns between mean Te and mean Tb of active *U. ornatus*. The hypothesis stated that there would be similarities between these two variables because when Te models are used correctly they have shown to be a powerful instrument for assimilating the thermal environment experienced by an animal (Dzialowski 2005). Active *U. ornatus* mean Tb fell within the temperature range of the Te models (Figures 15-18). Since the models were permanently placed in either the sun or the shade and lizards are actively shuttling between sun and shade, it is expected that the mean Tb of the lizards would fall between the range of the Te from both sun and shade. May, June, and July (Figure 17-19) all had a period of time, in the middle of the day, when I did not have any lizard Tb's. This gap could be explained by two reasons. On many occasions I would leave in the early mornings to look for *U. ornatus* and would stay until the lizards would retreated to areas protected from the sun to avoid the heat. However, there were others days in which I would get tired or hungry before the lizards would and I would go back to the station to rest and/or eat before I stopped seeing them.

Temperature plays a critical role in the everyday lives of ectotherms everywhere, because it influences the distribution, seasonal activity behavior, and diversity patterns of these animals. In fact, it was described by Vitt and Caldwell (2009) as "the master limiting factor" for ectotherms because they have to actively regulate their body temperatures. For example, there is little to no reptiles in extreme ecosystems, such as Antarctica. In other ecosystems, like the tropics and temperate regions, lies the greatest diversity reptiles. Climate change is already having an effect on biodiversity and it is projected to become a larger threat in the future (www.globalissues.org/article/172/climate-change-affects-biodiversity). There is little variation in mean Tb of active *U. ornatus,* so even small changes in global temperatures could affect the distribution, abundance, and behavior this lizard. In this study most lizards were observed in the morning and late afternoon during the warm months. Although climate change has occurred throughout the history of earth, rapid changes can affect the ability for organisms to adapt. It is expected that rising global temperatures will also influence this region and therefore will have an impact on the population of *U. ornatus* too; possibly affecting aspects such as time for feeding, reproducing, and of course thermoregulating. Thus, it is important for us to understand the thermoregulatory needs of ectothermic organisms as they are dependent on the direct environmental temperatures for survival, especially since many recognize that rapid global warming has already been activated by human misuse of natural resources.

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Curriculum Vitae

Julia Sandoval was born on January 12, 1983 in Houston, Texas but she only lived there for a short period of time and has resided in El Paso, TX for most of her life. She is the second child of Beatriz Martinez and Bart Sandoval. She is only one minute older than her identical twin and has a brother that is 13 years older. She is a mother of two precious children, Starla D Alva and Desmond Jayce Alva. She has completed a Bachelor's of Science Degree in Biology in 2012 at the University of Texas at El Paso. She works as a Graduate Teaching Assistant and has continued to attend the University of Texas at El Paso in pursuit of a Ph.D. in Biology.