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THERMAL PHYSIOLOGY OF SCELOPORUS OLIVACEUS AND SCELOPORUS VARIABILIS IN SOUTH TEXAS

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THERMAL PHYSIOLOGY OF *SCELOPORUS OLIVACEUS* AND *SCELOPORUS VARIABILIS* IN SOUTH TEXAS

Graduate Thesis

By

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ABSTRACT

Thermal Physiology of *Sceloporus olivaceus* and
Sceloporus variabilis in South Texas
April 2024

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Graduate Thesis Chair: Dr. Charles Watson

This study explores the thermal physiology of two sympatric lizard species, *Sceloporus olivaceus* (Texas spiny lizard) and *Sceloporus variabilis* (rose-bellied lizard), in South Texas. I document the metabolic rate and its temperature sensitivity, thermal limits, and performance at different temperatures to better understand the impact of rising temperatures and urbanization on these ectotherms, whose body temperature and, consequently, metabolic rate, activity level, and reproductive success depend on their thermal environment. I hypothesize that *S. olivaceus* will exhibit greater thermal resilience owing to its broader latitudinal range, variable habitat usage within Texas, and presumed more versatile thermoregulatory strategies. *Scelorporus olivaceus's* higher voluntary thermal maximum and thermal stability across temperatures indicate a greater tolerance to elevated temperatures and a potential competitive advantage in warmer habitats that result from urbanization and climate change. *Sceloporus variabilis* appears to be less adapted to extremely warm temperatures, which may be why we do not see them on campus while they are common in adjacent forested habitats. Understanding these species' thermal ecology is crucial for predicting their adaptability and guiding conservation efforts in rapidly changing environments.

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I. INTRODUCTION

Understanding the thermal physiology of ectotherms is crucial because their body temperature is closely dependent on the environment, influencing everything from their activity level and metabolism to their geographic range and vulnerability to climate change (Huey & Kingsolver, 1989; Deutsch et al., 2008). Temperature directly impacts growth (Angilletta et al., 2002), metabolic rate (Deutsch et al., 2008), sprint performance (Huey & Stevenson, 1979), and ultimately, reproductive success (Sinervo & Huey, 1990). Despite understanding the general effects of temperature on physiology, detailed data on individual species from understudied regions like South Texas is lacking, making predictions of their response to climate change and urbanization difficult. Moreover, phenotypic plasticity within these lizard species provides a mechanism for short-term acclimatization to changing temperatures. This adaptability is essential for managing physiological stresses imposed by temperature fluctuations, which can significantly affect their survival and ecological roles (Huey & Kingsolver, 1989). Lizards must carefully regulate body temperature and face challenges in environments with wide or extreme temperature variations (Cowles & Bogert, 1944). Furthermore, these challenges become particularly complex in environments subject to fluctuations or extremes in temperature (Cowles & Bogert, 1944). Additionally, the capacity for phenotypic plasticity within these lizard species offers a potentially crucial mechanism for short-term acclimatization to changing temperatures. Understanding species-specific thermoregulatory challenges is crucial for predicting ecological resilience, potential range shifts, and potential disruptions in ecological roles performed by lizards within the South Texas communities. Gaining a deeper understanding of these lizards' species specific thermal physiology is vital, offering potentially valuable insights into their ecology and ability to persist under varying environmental conditions, especially with the potential for rapid climate change (Huey & Kingsolver, 1989; Deutsch et al., 2008).

Lizards actively manage their body temperatures by utilizing microclimates created by shaded refugia and exposed basking sites (Stark et al., 2024). Climate change models forecast significant changes in temperature for South Texas, pointing to a future that could dramatically affect local ecosystems (Stamm et al., 2015). Specifically, projections for the Boerne, Texas weather station, from now until 2050, predict an increase in mean annual air temperature, moving from an average of 18.7°C to 19.7°C. This marked rise in temperature is expected to significantly impact regional climate dynamics (Stamm et al., 2015). These models also project an increase in mean annual precipitation, from a historic level of 892 millimeters to 974 millimeters by 2050. This increase may not alleviate the effects of higher temperatures. The combination of elevated temperatures and increased precipitation may result in complex changes for South Texas, particularly affecting water availability, ecosystem dynamics, and species vulnerability. For lizards, these climatic shifts may be of particular concern. The predicted warmer conditions, even with more rainfall, could exacerbate water scarcity due to higher evaporation rates and increased vegetation water use, posing direct challenges to lizard survival by limiting resource access and inducing physiological stress, which could ultimately impact their reproductive success (Fitch, 1970; Adolph & Porter, 1993).

The influence of climate change on species interactions and ranges is profound, leading to reorganized food webs and geographic distributions, as documented by Balle et al. (2021) and Socolar et al. (2023). As temperatures rise and habitats are altered, traditional interspecies dynamics may shift, with some species becoming more dominant and others being pushed towards vulnerability or even local extinction (Sinervo et al., 2010). For instance, species with narrow thermal tolerances may find their ranges contracting or becoming fragmented, leading to reduced genetic diversity and increased competition for dwindling resources (Sinervo et al., 2010). Conversely, species with broader thermal tolerances may expand their ranges, potentially encroaching on the habitats of less adaptable species and altering the composition of local ecosystems (Huey et al., 2009). This reshuffling of species distributions and interactions could ripple through ecosystems, affecting food webs and biodiversity (Tekwa et al., 2022). Predicting these shifts requires a nuanced understanding of each species' thermal biology, reproductive strategies, and ecological roles, underscoring the importance of targeted research in regions like South Texas, where the effects of climate change are poised to alter the ecological landscape (Huey et al., 2009; Sinervo et al., 2010).

In light of 2023 being the warmest year on record, with temperatures reaching 1.18°C (2.12°F) above the 20th-century average, there is a signal of a profound shift in the thermal landscape in which organisms operate. This unprecedented warmth, as reported by the NOAA National Centers for Environmental Information on January 17, 2024, surpasses the previous record set in 2016 by 0.15°C (0.27°F). The last decade (2014–2023) has seen the warmest 10 years in the 174-year global record, underscoring the accelerating impact of climate change. Additionally, the compounding effects of urbanization often lead to increased temperatures, creating 'heat islands' that elevate local temperatures, adding an additional layer of stress for local wildlife (Clark & Johnson, 2024). Some species may benefit from these altered conditions, finding new niches or expanded ranges, while others may face greater challenges to survival (Gainsbury et al., 2022).

Ectotherms depend on external heat sources for body temperature regulation, making them sensitive to thermal environment changes. (Tatu et al., 2024). Against this backdrop, the study of ectothermic organisms, such as lizards, becomes particularly relevant.

This study focuses on two sympatric lizards, *Sceloporus olivaceus* (Texas spiny lizard) and *Sceloporus variabilis* (rose-bellied lizard), chosen for several reasons. Their proximity to Texas A&M University-San Antonio (TAMUSA) provides a unique opportunity for detailed study, while the relative lack of data on their thermal physiology and their widespread use (particularly *S. olivaceus*) within the *Sceloporus* genus for broader ecological research add to the significance of using these species for investigation. Comparing these species deepens our understanding of how different populations of related species might respond to the challenges posed by climate change, especially in regions experiencing a marked increase in urbanization and temperature. As climate change continues to make South Texas's weather hotter and less hospitable, it is hypothesized that *S. olivaceus* and *S. variabilis* will display distinct physiological and behavioral adaptations to these environmental stresses (Kearney et al., 2009). Specifically, *S. olivaceus*, with its broader habitat range within Texas and presumably more veried thermoregulatory strategies, is anticipated to demonstrate a greater capacity for thermal tolerance, showing enhanced resilience to higher temperatures (Logan et al., 2013). Conversely, *S. variabilis*, due to its smaller size and potentially more specialized habitat requirements, may have a narrower thermal tolerance range, making it more susceptible to extreme temperature fluctuations (Clusella-Trullas et al., 2011). Such differential resilience could influence their survival and reproductive success, habitat utilization, interspecies interactions, and distribution within the changing landscape of South Texas. The complexity of responses to climate change, influenced by climatic factors on physiological parameters, underscores the necessity of incorporating mechanistic insights into species distribution models, particularly under climate change scenarios (Buckley et al., 2010). This approach could illuminate expected distribution shifts for *S. olivaceus* and *S. variabilis* in South Texas, providing a nuanced understanding of their future in a warming world (Huey et al., 2009; Sinervo et al., 2010).

Based on the observation that *S. olivaceus* remains common on the TAMUSA campus, which is significantly warmer than adjacent scrubland due to the prevalence of concrete and other heat-conductive surfaces while *S. variabilis* is absent. I predict *S. olivaceus* will exhibit a thermal preference for higher temperatures and have a more stable metabolism at higher temperatures than *S. variabilis*. The extreme heat and limited precipitation characteristic of South Texas's harsh climate necessitate precise thermoregulation from both species.

To gain insight into how these species might respond to rising temperatures, this study investigates aspects of their thermal physiology, including thermoregulatory behavior, preferred body temperatures, sprint speeds at ecologically-relevant temperatures, and microhabitat utilization (Taylor et al., 2021). This study includes determining thermal preferences through choice trials alongside measurements of physiological limits (voluntary thermal maximum, critical thermal minimum, sprint speed, and metabolic rate).

Ontogenetic plasticity, or adaptations of metabolic rates and thermal preferences, may be integral to survivorship in a changing climate. Similarly, performance—encompassing a range of physical capabilities crucial for daily survival such as foraging, avoiding predators, and mating—relies heavily on the ectotherms' ability to navigate and adapt to thermal environments

(Deutsch et al., 2008). Metabolic rate, a measure of the chemical reactions in the body (predominantly cellular respiration) using oxygen consumption as a proxy, is directly influenced by temperature, affecting a lizard's digestion, activity, energy usage, and overall efficiency (Angilletta et al., 2000; Huey & Stevenson, 1979). In a warming climate, the potential to exceed metabolic and thermal performance limits could also significantly restrict activities essential for survival and reproduction. Understanding species-specific differences in metabolic rate and thermal sensitivity is crucial for predicting how these lizards might respond to rising temperatures. This knowledge will illuminate potential disparities in how *S. olivaceus* and *S. variabilis* might cope with climate change and urbanization, offering insights into the long-term resilience of these species within South Texas. Evidence suggests localized population extinctions within lizard species have occurred due to thermal stress (Sinervo et al., 2010). While desert-dwelling lizards demonstrate specific adaptations for harsh climates, the projected change for South Texas may outpace the potential for rapid evolutionary adjustment in *S. olivaceus* and *S. variabilis*. This underscores the need to identify specific microhabitats critical for species persistence. Studying these species thus offers valuable insights into adaptive capacities and generational plasticity (Wadgymar et al. 2018). This knowledge not only informs our understanding of resilience within this genus but also informs targeted habitat preservation, pinpointing specific microhabitats essential for protecting these lizards within their native region.

Investigating these species' thermal ecology helps illuminate patterns related to their habitat preferences, activity, and interspecies interactions. Through analysis of the thermal physiology of *S. olivaceus* and *S. variabilis*, I hope to further the knowledge of the mechanisms supporting their coexistence, exploring the potential role of subtle differences in their thermal tolerances in shaping niche differences within their South Texas environment (Sinervo & Losos, 1991; Vitt et al., 2003).

II. SPECIES OVERVIEW

Overview: *Sceloporus olivaceus* (Texas Spiny Lizard)

Habitat: *Sceloporus olivaceus* is widespread, inhabiting woodlands, grasslands, scrublands, and rocky areas within its semi-arid Texas range (Smith, 1939). Its keeled scales and typically brownish coloration offer camouflage on various substrates. It utilizes vertical structures (trees, rocks, and human-made ones) for basking and predator surveillance (Smith, 1939). To balance thermoregulation with foraging and predator avoidance. *S. olivaceus* needs open and sheltered areas. Mapping of sun-shade ratios and observations of refuge use would provide insights into their microhabitat specialization and how these choices might shift in response to changing climate conditions (Pinzón-Barrera et al., 2024; Laspiur et al., 2024). Despite its larger size, a comparison of *S. olivaceus* with the smaller *S. variabilis* could reveal how body size interacts with thermoregulatory needs, offering insights into their differential responses to climate change and potentially differentiating their ecological niches within South Texas. Studies such as those by Pinzón-Barrera et al. (2024) on *Anolis tolimensis* and Laspiur et al. (2024) on *Phymaturus* and *Liolaemus* lizards provide valuable frameworks for examining how size influences thermal tolerance and activity patterns, suggesting that similar mechanisms may be at play in *S. olivaceus* and *S. variabilis*.

Morphology

Sceloporus olivaceus is a medium-sized, spiny lizard. Adults typically have a snout-vent length (SVL) ranging from 76 to 114 mm and can reach a total length of 280 mm with a complete tail

(Smith, 1939; Conant & Collins, 1998). *Sceloporus olivaceus* in our study ranged from 44-92 mm SVL with masses between 4.0 – 30.9g (Figure 5).

Coloration:

- **Dorsal:** Generally olive green to brownish, often having darker crossbands. Males tend to be more colorful than females (Smith, 1939; Conant & Collins, 1998).
- **Ventral:** Yellowish to gray. Breeding males develop vivid blue throat patches and blue-green patches on the side of the belly (Smith, 1939; Conant & Collins, 1998).
- **Scales:** Large, keeled, mucronate, and imbricately arranged dorsal scales (Smith, 1939).

Figure 1. *Sceloporus olivaceus*. Photograph: I. Rockel Watson Integrative Ecology Lab, Texas A&M University-San Antonio.

Sexual Dimorphism

Sexual dimorphism is pronounced in S. *olivaceus*. Males are more colorful, with distinctive blue throat and belly patches during the breeding season. Females also tend to be larger than males (Smith, 1939; Conant & Collins, 1998).

Geographic Variation

Although some regional variation in color pattern exists, the overall morphology of *S. olivaceus* remains consistent throughout its range (Smith, 1939; Bartlett & Bartlett, 1999) (Fig. 1).

Range: *Sceloporus olivaceus* exhibits a more extensive geographic reach within Texas than *S. variabilis*, including a greater extension to the north (Figure 2). This broader range reflects the species' adaptability to diverse environments across Texas. Investigating the limits of their range, particularly where species ranges overlap, is essential for understanding the factors that limit distributions and how species respond to different environmental conditions. The contrasting distribution of *S. variabilis*, with its more limited presence, highlights the potential influence of environmental factors such as temperature and habitat availability on geographical limits (Figure2).

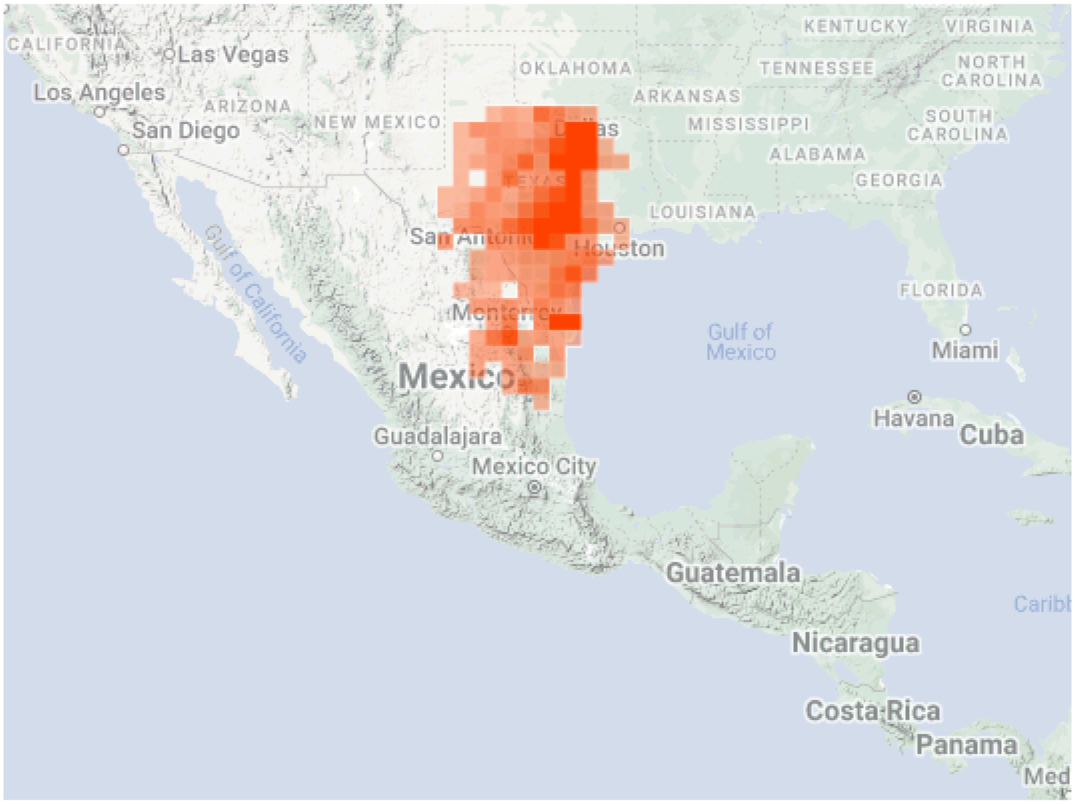

Figure 2. Distribution of *S. olivaceus* within Texas. Note the broader range North, East, and West compared to *S. variabilis* (see Fig. 1). (Source: inaturalist, 2024)

Diet: *S. olivaceus* has an insectivorous diet, characterized by its opportunistic feeding of a diverse selection of insects like beetles, crickets, and spiders. Exploring differences in diet between these species could provide additional insights into resource partitioning between these species within this South Texas ecosystem.

Conservation: *Sceloporus olivaceus*, listed by the IUCN as of Least Concern status, has an expansive range. Nonetheless, it requires proactive monitoring similar to that of *S. variabilis* to address potential negative impacts of habitat fragmentation and climate change (Trumbo et al., 2021). As a larger-bodied ectotherm, it encounters challenges related to resource access and adapting to varied thermal environments. These challenges highlight the need for nuanced conservation strategies that account for both the spatial range and the quality of habitats, emphasizing their suitability in changing climates. A holistic approach integrating habitat quality with range size is essential for a comprehensive view of the species' resilience. Conservation efforts should prioritize habitat preservation and restoration (Trumbo et al., 2021), enhancing connectivity between fragmented areas to support gene flow and population stability (Parsons et al., 2019). A detailed understanding of *S. olivaceus's* thermal biology is crucial for predicting its adaptability to warming climates and for implementing targeted conservation actions to protect these reptilian communities.

Sceloporus variabilis **(Rose-bellied Lizard)**

Habitat: *S. variabilis* inhabits diverse open habitats such as grasslands, woodlands, and human-altered landscapes within South Texas. Its mottled coloration serves as camouflage, blending into these varied environments effectively. This species uses a mix of sunlit and shaded areas for thermoregulation, essential for maintaining optimal body temperature critical for metabolic processes and predator evasion. Like *S. olivaceus*, *S. variabilis* relies on microhabitats that offer shelter from extreme temperatures, underscoring the importance of microhabitat availability in their survival and reproductive strategies (Smith, 1939). The smaller size of *S. variabilis* compared to the larger *S. olivaceus* may influence its thermoregulatory and habitat needs, potentially reducing competition by utilizing niches less favorable to its larger counterpart. Comparative studies could illuminate how these size differences affect ecological roles and responses to environmental changes.

Morphology

S. variabilis is a relatively small spiny lizard within the genus *Sceloporus*. Adults typically reach a snout-vent length (SVL) of 54 mm, with a maximum total length of approximately 140 mm when tails are intact (Smith, 1939; Wiegmann, 1834). A visual representation of the lizard's size and form, as described, is provided in Figure 3. This figure shows a representative individual, highlighting the key morphological features detailed below:

- **Coloration:**
    - **Dorsal:** It has a tan or olive base color and with a double series of dark brown spots along the back. Two lighter yellowish dorsolateral stripes are present on each side (Smith, 1939).
    - **Ventral:** Dirty white or yellowish (Smith, 1939).
    - **Males:** Distinctive large pink blotches on each side of the belly, bordered with dark blue. They also have a black axillary mark on the armpit region (Smith, 1939).
- **Scales:** Keeled, pointed, and spiny dorsal scales.

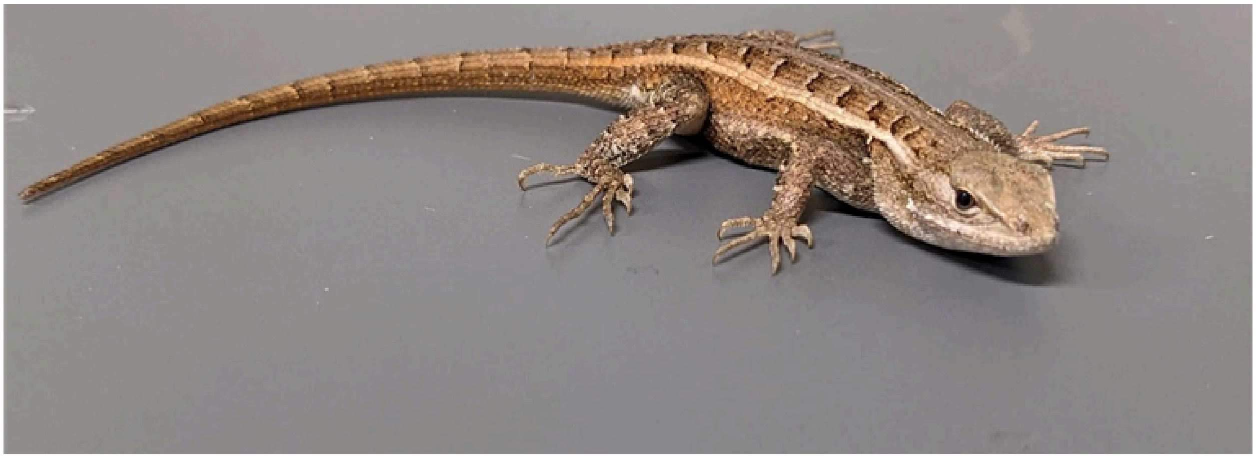

Figure 3. *Sceloporus variabilis*. Photograph: I. Rockel Watson Integrative Ecology Lab, Texas A&M University-San Antonio.

Sexual Dimorphism

Aside from the vibrant male coloration on the belly and the axillary mark, sexual dimorphism is subtle. Males tend to be darker on the sides below their dorsolateral stripes (Smith, 1939).

Geographic Variation

Several subspecies of *S. variabilis* exist, which may exhibit slight variations in color pattern and scalation (Sites & Dixon, 1982).

Range: The Rose-bellied Lizard (*S. variabilis)* range extends into Southern Texas. with range limits that can fluctuate with ecological factors. The species goes far into eastern Mexico, covering states along the Gulf Coastal Plain. *S. variabilis* ranges southward into portions of Central America, specifically countries including Guatemala, Honduras, and El Salvador. The species' northernmost limits within Texas are likely influenced by ecological factors (Sexton et al., 2009), suggesting a potential for distribution shifts in response to climatic changes.

The distribution of *S. variabilis* across Texas, predominantly along the Gulf Coastal Plain with potential variations at its northern boundary, is emphasized by its adaptability to diverse ecosystems within the state and suggests that environmental factors such as temperature and habitat availability could influence its geographical limits (Figure 4).

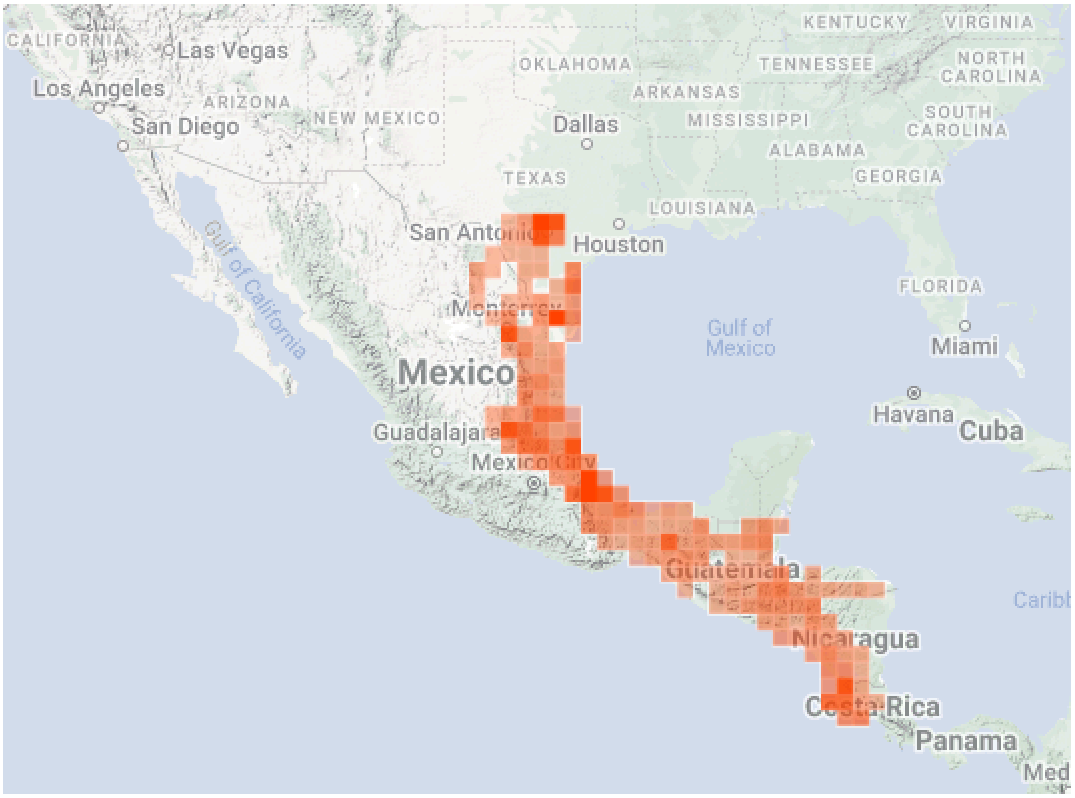

Figure 4. Range of *S. variabilis* within Texas. Note the strong association with the Gulf Coastal Plain and the potential for fluctuation along the northernmost edge. (Source: inaturalist, 2024)

Diet: *S. variabilis* has a primarily insectivorous diet, feeding on smaller insects like beetles, crickets, and spiders.

Conservation: Despite the IUCN Least Concern status of *Sceloporus variabilis*, monitoring is essential to detect any climate or habitat-induced declines. Its smaller size and specialized habitat needs may limit its thermal tolerance range, increasing vulnerability to temperature fluctuations and habitat changes due to climate change and human activities. Effective conservation strategies for *S. variabilis* are vital, focusing on preserving habitat quality and suitability in changing climates. An approach that integrates habitat quality with geographical distribution will offer insights into the species' resilience and capacity to adapt. Conservation should focus on preserving and enhancing habitats, ensuring connectivity to support genetic diversity and population stability (Mackenzie et al., 2022). Understanding the thermal biology of *S. variabilis* is crucial for developing adaptive management strategies to anticipate and mitigate the impacts of global warming, ensuring the protection of this and similar reptilian species.

Ontogenetic Considerations

My comparison of the two species does not overlook the importance of size on thermal ecology, as body size and development stage influence thermoregulation and physiological limits (Claunch et al., 2021). The similarity in size between juvenile *S. olivaceus* and adult *S. variabilis* introduces an avenue to explore how these factors intersect. It allows us to investigate whether similar-sized lizards of different species and life stages demonstrate equivalent responses to environmental temperatures and pressures that may drive selection for differing growth rates within those species. This thesis will investigate the thermal ecology of *S. olivaceus* and *S. variabilis* in South Texas. Specifically, it will determine their preferred body temperatures, assess their physiological performance capabilities across thermal gradients, and evaluate metabolic variations within fluctuating environments. Additionally, this study will compare thermal strategies and limits between juvenile *S. olivaceus* and adult *S. variabilis*, revealing how size and developmental stage interact to influence their responses to changes in climate. Together, these data will help to inform predictions of these lizards' resilience, ecological responses, and long-term population stability.

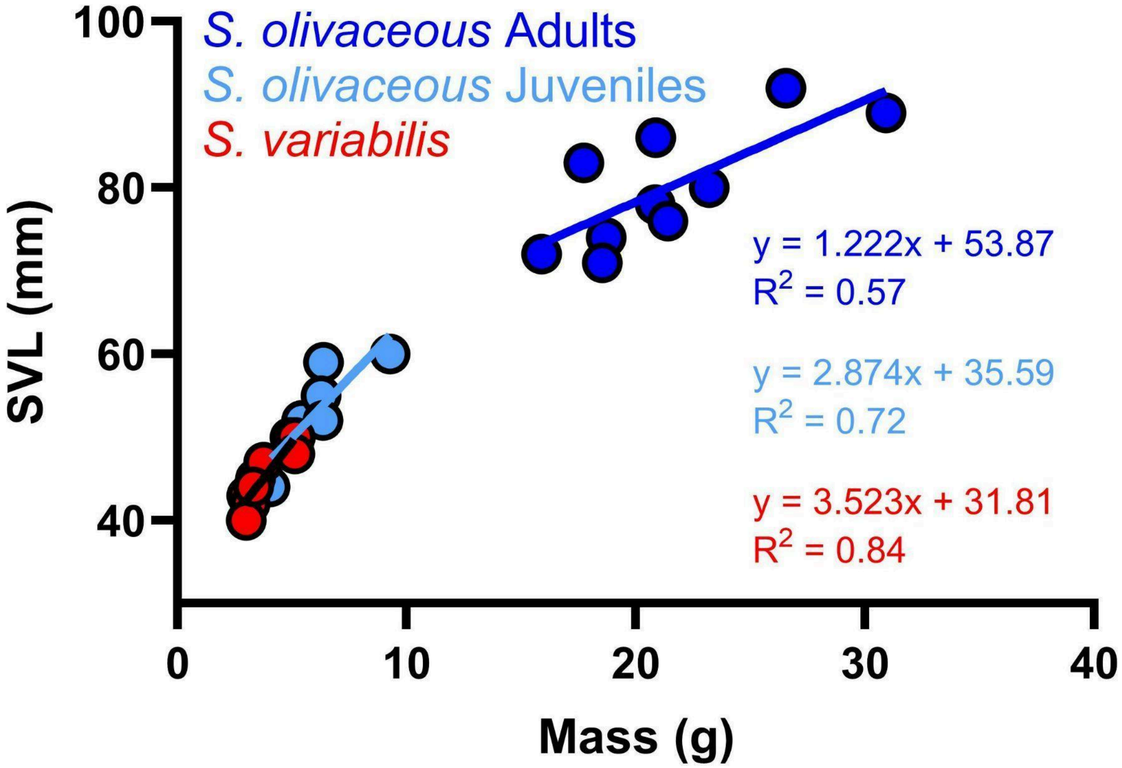

Figure 5. Mass and Snout-to-Vent Length (SVL) relationships for *S. olivaceus* adults and juveniles and *S. variabilis* used in this study.

The relationship between body mass and snout-to-vent length (SVL) for *Sceloporus olivaceus* and *Sceloporus variabilis* indicates a positive allometric growth among these sympatric lizard species (Figure 5). In the present study, *S. olivaceus* adults, exhibit a distinct linear relationship from *S. olivaceus* juveniles and *S. variabilis* adults. For *S. olivaceus* adults, the regression line indicates a lower slope (y = 1.222x + 53.87) with an R^2 value of 0.57, which reflects a consistent but moderate increase in SVL relative to mass. In contrast, *S. olivaceus* juveniles show a steeper slope (y = 2.874x + 35.59) with an R^2 value of 0.72, denoting a more pronounced increase in SVL for a given body mass, which may be attributable to the rapid growth phase during their juvenile period. *Sceloporus variabilis*, demonstrated the steepest slope (y = 3.523x + 31.81) with an R^2 value of 0.84, suggests a substantial increase in mass ass their in SVL increases, highlighting potentially different growth dynamics or ecological adaptations within this species. The R^2 values signify a strong correlation between body mass and SVL for *S. variabilis*, and relatively robust for *S. olivaceus*, suggesting a strong linear relationship of mass and body size within groups. These data show that the juvenile *S. olivaceus* is morphologically similar to the adult *S. variabilis*.

III. RESEARCH DESIGN

Lizard Collection from the Field

I collected *S. olivaceus* and *S. variabilis* from the land adjoining Texas A&M University-San Antonio. *Sceloporus olivaceus* and *S. variabilis* were targeted due to their abundance within the study area, offering appropriate sample sizes for statistical analyses.

I captured lizards using a catch pole (Fitzgerald, 2012), reducing risk compared to hand capture (Beaupre et al., 2004). To construct the catch pole, a modified Tenkara-style fishing rod and lightweight braided fishing line were used to create a flexible lasso. Lizards were gently secured upon capture to prevent escape and facilitate safe data collection. To ensure the welfare of the animals, specimens to be transported from the field to Texas A&M University-San Antonio were held in white cloth bags composed of a thin fabric that allowed free movement of air. Specimens were not held for more than 6 hours before being returned to the lab.

Upon capture, the following data were recorded for each lizard:

- **Identification:** Species and sex (for adults, determined by visual inspection of sexual dimorphism).
- **Date and Time:** To examine potential correlations between time of day, lizard activity, and temperature.
- **Environmental Conditions:** Ambient air temperature, perch/substrate temperature, humidity, wind speed, light conditions, and weather. These variables directly affect lizard thermoregulation (see Cowles & Bogert, 1944).
- **Location:** GPS coordinates (latitude/longitude) for spatial analysis of microhabitat utilization patterns.

- **Body Temperature:** Cloacal temperature taken immediately upon capture (e.g., using a K-type thermocouple thermometer). This captures core body temperature influenced by microhabitat choice prior to any handling-induced stress (Marcellini, 1976).
- **Morphology:** After capture, mass (g) and snout-to-vent length (SVL) were obtained in the lab. These measures are used to determine relationships between body size and thermal response within each species.

Ethical Considerations, Sampling Limitations, and Permitting

In conducting this study, we followed established ethical guidelines for the treatment of lizards and other reptiles, as outlined by Beaupre et al. (2004). Our methods were designed to minimize animal stress and harm, focusing on ethical capture, handling, and research processes. These protocols were approved under Texas A&M University-San Antonio's IACUC #IACUC2022-0715 and collection of animals was authorized under Texas Parks and Wildlife Department Scientific Permit #SPR-0422-058.

Acclimation and Husbandry:

In the acclimation and husbandry phase, up to 10 animals from each species were acclimated to laboratory conditions at a time. They were housed under a controlled 12/12 light-dark cycle, with ambient temperatures maintained between 25-27°C to approximate their natural habitats. A basking spot, simulating natural sunlight, was provided, reaching temperatures of approximately 40°C to meet their thermoregulatory needs. The lizards were fed a diet of appropriately sized crickets twice weekly. Before starting experimental procedures, a thorough health assessment was done for each lizard. Any specimens exhibiting signs of stress, illness, or weakness were excluded from participation in the trials.

Thermal Preference

Lizards actively select preferred temperatures (T_{pref}) within their physiological tolerance limits that optimize various functions. We constructed a thermal choice chamber (120 cm x 60 cm plastic tote) with an approximately 2.5 cm layer of sand substrate to attempt to best mimic the lizards' natural substrate loosely following the methods of Diaz & Cabezas-Diaz (2004). A 9 m heat cable was arranged in a serpentine pattern beneath the sand. Coil spacing was tighter at the warmer end, gradually increasing toward the cooler end to allow heat dissipation and create a thermal gradient of 21°C – 57°C. Gradient temperatures were verified using an infrared heat gun prior to and following each trial session, along with thermal imaging for gradient mapping.

Lizards were moved directly from housing to the chamber's midpoint without acclimation. After 30 minutes of free exploration, the following temperatures were recorded in sequence to minimize disturbance: (1) dorsal surface (broadest part of the back) using an infrared heat gun,

(2) substrate directly beneath the lizard's ventral surface using an infrared heat gun, and (3) cloacal using a handheld digital thermocouple. The chamber was thoroughly cleaned of any lizard waste using a garden trowel and allowed time to air out between trials to mitigate potential scent bias (Parker et al., 2021). Temperature data was analyzed using a one-way ANOVA ($\alpha = 0.05$) to determine if significant differences in thermal preference exist among *S. olivaceus* adults, *S. olivacous* Juveniles, and *S. variablis*.

Measurement of Voluntary Thermal Maximum (VT_{max}) and Critical Thermal Minimum (CT_{min})

While the measurement of Voluntary Thermal Maximum (VTmax) and Critical Thermal Minimum (CTmin) occurred last in our series of experiments, we discuss these findings after thermal preference data for narrative coherence. Voluntary Thermal Maximum (VT_{max}) and Critical Thermal Minimum (CT_{min}) were assessed for five individuals of each species. VT_{max} determination involved placing the lizards in a transparent glass container partially submerged in a water bath, initially set at 35°C. The water bath temperature was incrementally increased by 1°C every five minutes until signs of heat stress, such as gaping, rapid movement, and deep breathing, became evident. Upon reaching VT_{max}, lizards were carefully removed, and their cloacal temperature was promptly measured with a thermometer fitted with a K-type thermocouple probe. Subsequently, lizards were cooled under running water to safely reduce their body temperature, employing VT_{max} as a humane and informative alternative to the Critical Thermal Maximum (CTmax) measurement, which has been associated with a higher risk of mortality due to the onset of muscle spasms (Telemeco & Gangloff, 2021).

Similarly, CT_{min} was measured by placing lizards in individual clear containers (Falcon tubes) within a refrigerated chamber and gradually lowering their body temperature. The tubes were rolled completely over every degree. The failure to right themselves when flipped onto their backs marked their CT_{min}, at which point we recorded their cloacal temperature before ensuring their return to a comfortable environment for recovery. These procedures allowed us to dissect the nuanced physiological and performance parameters across different temperatures, shedding light on each species' thermal tolerance limits and their adaptive responses to environmental fluctuations. Notably, our findings underscore the importance of considering seasonal variations and the dynamic nature of these thermal tolerance thresholds (Clusella-Trullas & Chown, 2014), providing pivotal insights into how *S. olivaceus* and *S. variabilis* might navigate the challenges posed by climate change and other environmental stressors.

These data were analyzed using a one-way ANOVA ($\alpha = 0.05$).

Sprint Speed Across a Thermal Gradient

These lizards rely on burst locomotion to escape predators and capture prey (Miles, 2004). The ability of cold-blooded animals to move quickly depends a lot on the temperature, which is why it is essential to understand how changes in temperature affect their speed (Huey & Stevenson, 1979; Marsh & Bennett, 1986). I examine sprint speed in this study within a controlled thermal gradient while standardizing other environmental factors. Following the methods of Watson and Formanowicz (2012), lizards were individually acclimated for 25 minutes to one of the experimental temperatures (15°C, 20°C, 25°C, 30°C, 35°C) within a temperature-controlled enclosure. Sprint responses were recorded across these ecologically- relevant temperatures in ascending order to assess potential performance trends associated with thermoregulatory behavior. A standardized stimulus (e.g., gentle tail brush) was used to initiate each sprint trial to minimize bias further.

Lizards were placed in an environmental chamber at 15°C for 25 minutes so that body temperature matched the chamber temperature; this was confirmed by cloacal temperature measurement upon chamber removal. Maximum sprint speed at this starting temperature was determined by releasing individuals onto a 1m track constructed of acrylic with a replaceable rubber floor with 10-cm increments marked. Trials were recorded from above using a high-speed camera set to 60 fps for subsequent analysis. Lizards received mild tactile stimulation (e.g., a gentle tail/hindlimb tap) to encourage running if needed. After three trials, the lizards were returned to the environmental chamber, and the temperature was increased by 5°C. This procedure was repeated for 20°C, 25°C, 30°C, and 35°C.

Video analysis was conducted using GoPro 9 Black action camera (www.gopro.com). The fastest 10 cm segment was identified for each trial, and the corresponding start and end frames were marked. Burst sprint speed was calculated based on frame rate and expressed in m/s. These speeds are representative of those employed during ecologically vital predator escape and prey capture events. Potential sprint differences could relate to the physiological effects of body size in *S. olivaceus*, influencing how temperature directly alters muscle performance.

While informative, it is important to acknowledge the potential for order effects (e.g., fatigue or learning) to influence lizard responses (Hare et al., 2001). Consecutive runs at each temperature might cause fatigue, introducing bias toward performance decline compared to fresh lizards earlier in the temperature trials. Order effects were of concern in sprint speed trials for several reasons. Firstly, repeated sprints within a single temperature exposure could induce exhaustion, decreasing maximum performance as trials progress. Secondly, potential learning effects might occur; initially startled, a lizard could become desensitized to the 'tap' stimulus with repetition, limiting its true 'burst' response later. These combined biases could mask the true relationship between temperature and sprint capacity. To minimize the likelihood of fatigue bias, I only used the fastest recorded speed for each lizard at each temperature for comparison. I used a 2-way Repeated Measures ANOVA to determine if there are significant differences between mean sprint speed among *Sceloporus olivaceus* adults, Juveniles, and *Sceloporus variabilis* adults.

Measurement of Oxygen Consumption Rates & Thermal Sensitivity (Q_{10})

The metabolic rate is significantly influenced by temperature, highlighting the importance of understanding how differences in temperature broadly affect chemical reactions within the bodies of *S. olivaceus* and *S. variabilis* (Brown & Au, 2009). This is because a high degree of thermal sensitivity to high or low temperatures would drastically affect the biology of these lizards in changing environments (Brown & Au, 2009). The energetic cost of thermoregulation varies with temperature, and data on resting metabolic rate will offer insights into how *S. olivaceus* and *S. variabilis* may need to adjust their energy budgets accordingly. We measured oxygen consumption as a proxy for metabolic rate after 3-5 days of recovery for up to 10 specimens of each species by placing the lizards individually into glass containers within a large environmental chamber with room air pumped through their containers during acclimation to the experimental temperature. At the onset of the trial, the containers were sealed, and the $\%O_2$ inside the container was measured through the glass using fiber optic sensor technology (Presens OXY-4 ST Multi-Channel O2 Meter, https://www.presens.de/). The $\%O_2$ was measured constantly until it had been reduced by a minimum of 0.5%; the time it took to reach that value was then recorded. These values were used to calculate that animal's VO_2 at that temperature. The container then had room air circulated once again through the container, and the temperature was increased by 5°C. These methods were repeated for 15°C, 20°C, 25°C, and 30°C°. These temperatures would all be experienced by these two species in nature.

Temperature sensitivity between temperature intervals can be determined using the temperature coefficient (Q_{10}). Q_{10} values were calculated across adjacent temperature intervals using the following derivative of van't Hoff equation:

$$Q_{10} = \left(\frac{R_2}{R_1}\right)^{\frac{10°C}{(T_2 - T_1)}}$$

In this equation, R is the rate [of oxygen consumption] and T is the Temperature at measurement. Since I measured these rates at 5-degree intervals, the exponent is 2, resulting in the Temperature Coefficient (Q_{10}) being the fraction of the rate at the higher temperature (R_2) divided by the rate at the lower temperature (R_1) squared.

IV. RESULTS

Thermal tolerance benchmarks were established for *S. olivaceus* and *S. variabilis* to ascertain interspecific differences in temperature regulation capabilities. The Voluntary Thermal Maximum (VT_{max}) for *S. olivaceus* adults was significantly higher than that for *S. variabilis*, with values averaging 39°C and 36°C respectively (Figure 6).

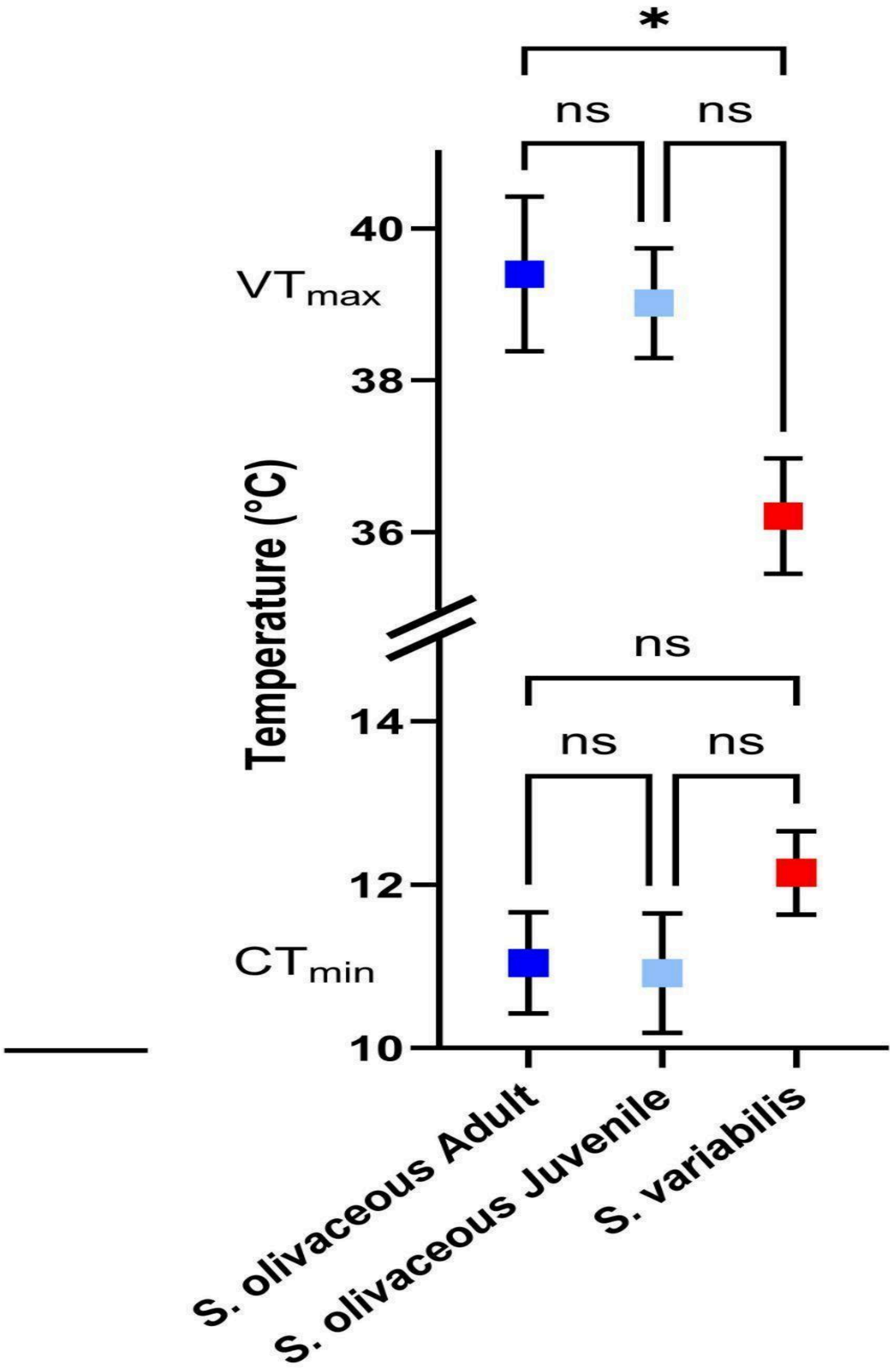

Figure 6. Voluntary Thermal Maximum (VT_{max}) and Critical Thermal Minimum (CT_{min}) for *Sceloporus olivaceus* and *Sceloporus variabilis* [±SEM]

Neither of these values were significantly different than *S. olivaceus* juveniles. This difference was statistically significant ($F_{(2, 18)} = 4.466$, P=0.0266). The implication of this finding suggests a divergence between the species in terms of their upper thermal activity thresholds, with *S. olivaceus* capable of sustaining activity at higher temperatures.

Conversely, when examining the Critical Thermal Minimum (CT_{min}), both species showed no significant difference in their tolerance to lower temperatures ($F_{(2, 19)} = 1.345$, P=0.2843). The mean CT_{min} was approximately 11°C for all. This result suggests that both species possess a comparable lower thermal physiological threshold.

The analysis of the thermal range, defined as the difference between the VT_{max} and CT_{min} values, indicated that adults of *Sceloporus olivaceus* have a broader thermal range than *Sceloporus variabilis* ($F_{(2, 18)} = 4.023$, P=0.0360, Dunnett post hoc P=0.0385).

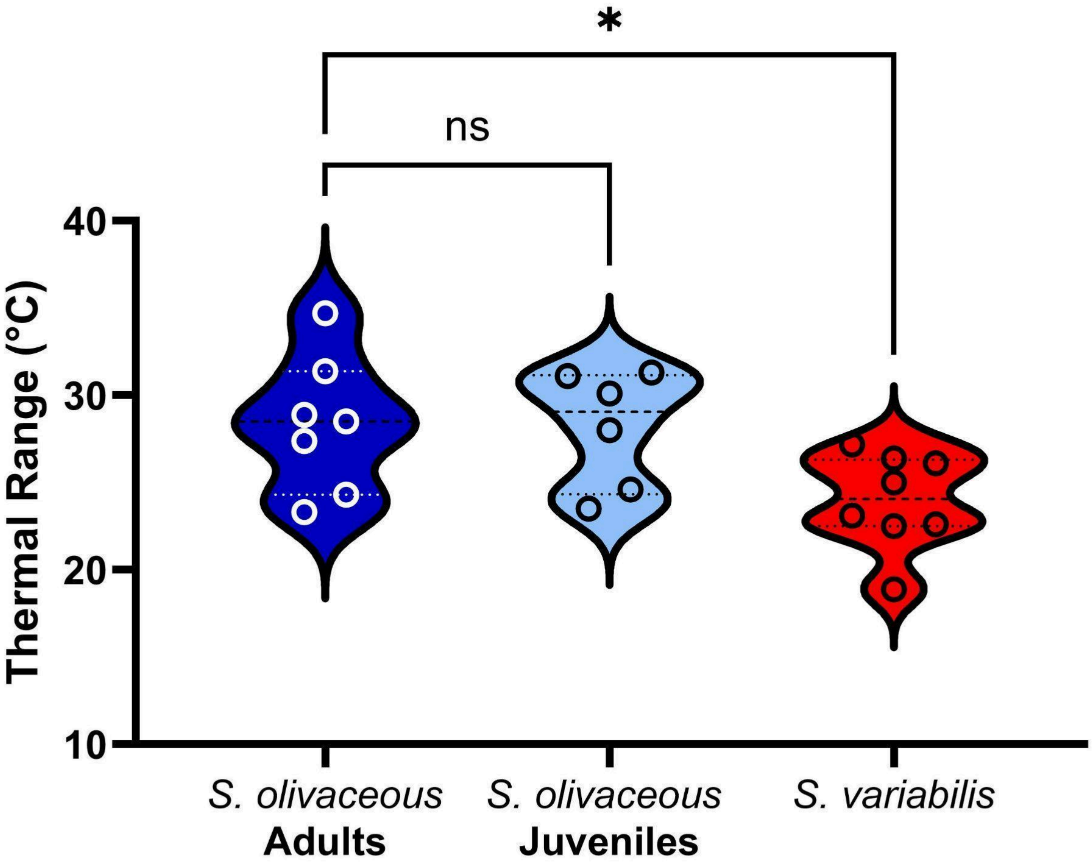

Figure 7. Thermal Range values for *Sceloporus olivaceus* Adults (A) and Juveniles (J) and adult *Sceloporus variabilis.* Significant differences as determined by an ANOVA and post-hoc Dunnett's multiple comparisons test is denoted by an asterisk (*)

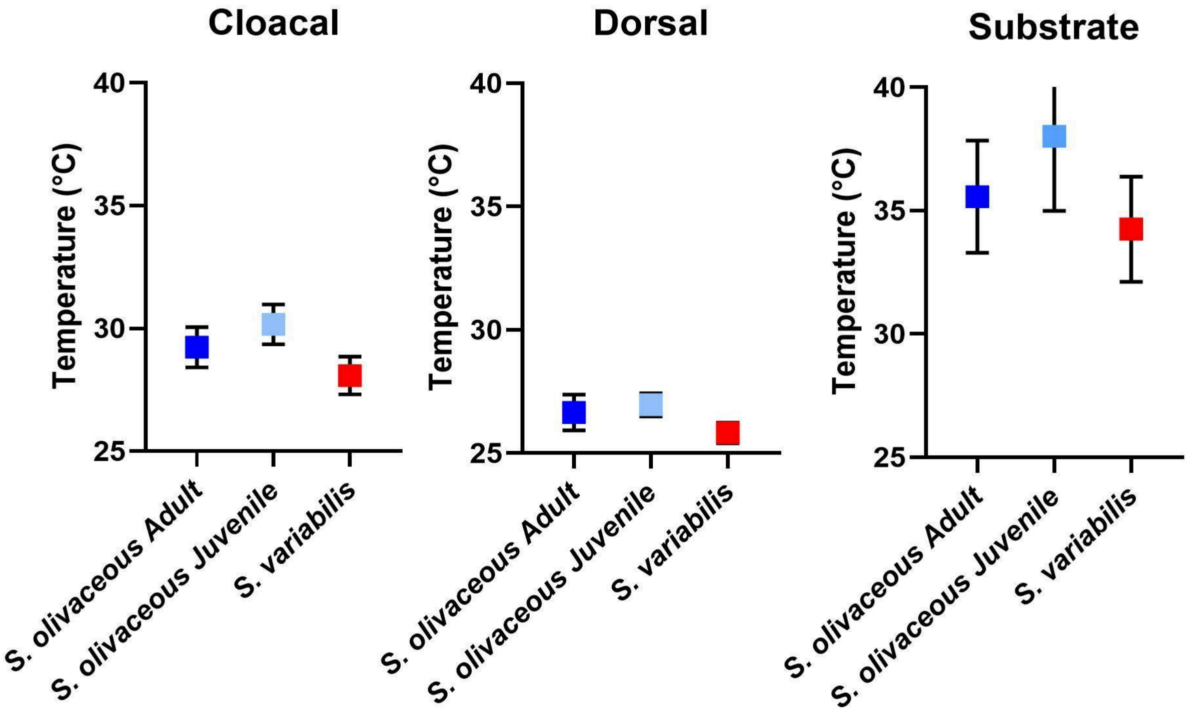

Figure 8. Values for Cloacal Temperature, Dorsal Surface Temperature, and Substrate Temperature for *S. olivaceus* and *S. variabilis* as determined from thermal choice trials [± SEM].

Thermal preference tests showed species-specific temperature choices in *S. olivaceus* and *S. variabilis*. The mean cloacal temperature selected by *S. olivaceus* was approximately 29°C, while *S. variabilis* selected a slightly cooler mean cloacal temperature of approximately 28°C (Figure 8). Similarly, the mean dorsal surface temperature for *S. olivaceus* was approximately 27°C, compared to approximately 25°C for *S. variabilis* (Figure 8). For substrate temperature, which influences the thermoregulatory behavior of these ectothermic organisms, *S. olivaceus* selected a mean temperature of approximately 37°C, and *S. variabilis* displayed a preference for a mean temperature of approximately 35°C (Figure 8).

Statistical analysis indicates that the differences in mean cloacal and dorsal surface temperatures between the two species are not statistically significant ($F_{(2,6)}=0.1671$, $P=0.8499$).

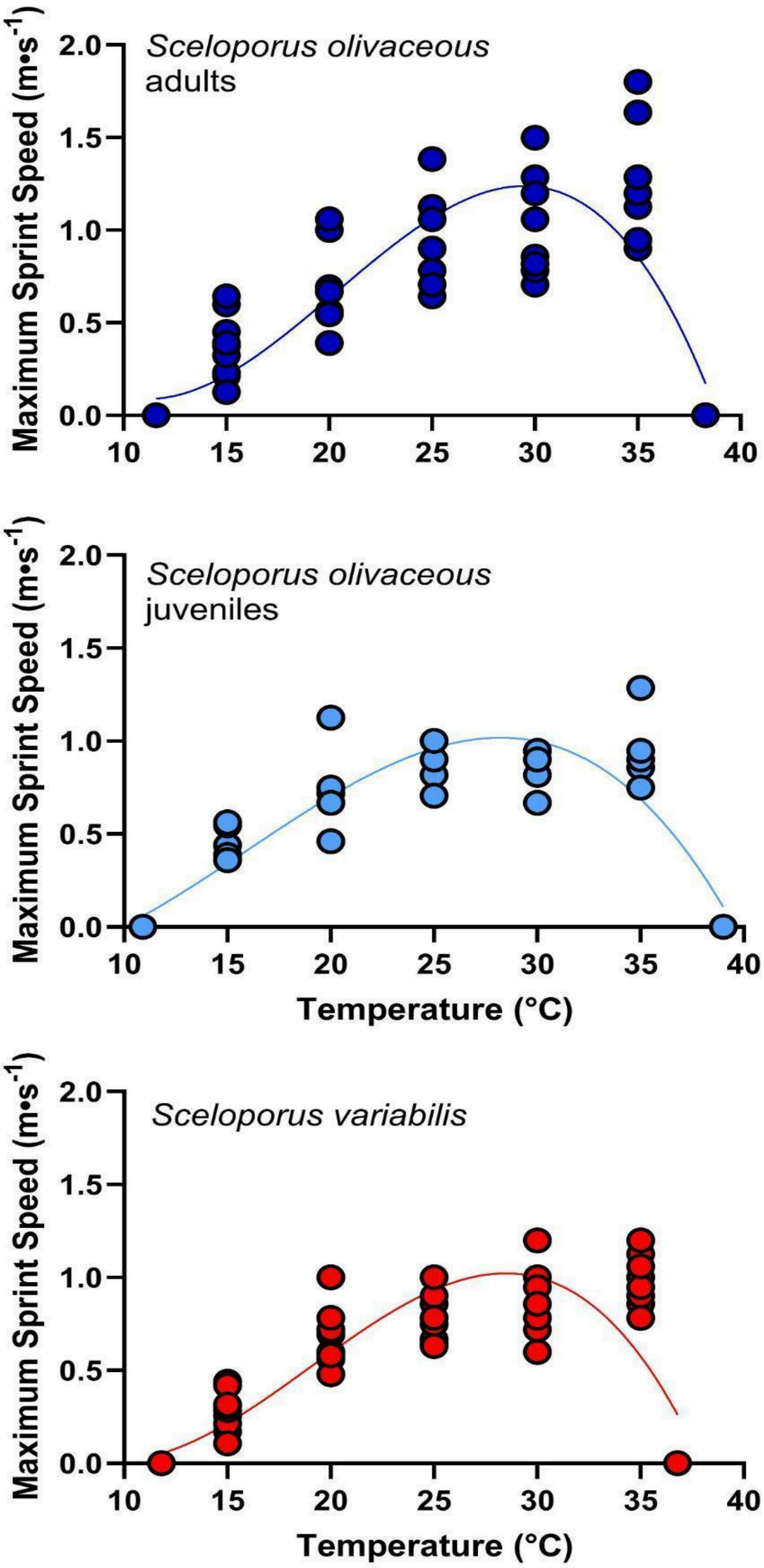

Figure 9. Maximum Sprint Speed of *S. olivaceus* and *S. variabilis* at ecologically relevant temperatures.

My investigation into the thermal performance of *S. olivaceus* and *S. variabilis* uncovered distinct patterns in maximum sprint speed across a range of temperatures. *S. olivaceus* exhibited an increase in sprint speed with rising temperatures from 15°C, achieving an optimal performance peak between 30-35°C. Beyond this range, a notable decline in speed was observed, delineating a clear upper thermal threshold for the species.

S. variabilis, while following a similar increasing trend, reached its peak sprint speed at a similar temperature window of 30-35°C. Notably, *S. variabilis* experienced a precipitous decline in performance post-peak, starting at temperatures nearing 36°C, marking its critical thermal limit. Figure 7 showcases the Maximum Sprint Speed of *S. olivaceus* and *S. variabilis* at ecologically relevant temperatures, visually capturing the performance trends across the temperature spectrum for both species.

The performance curves for both species are similar, with *S. olivaceus* displaying a slightly higher thermal optimum than *S. variabilis*. There was no significant differences in sprint speed at any temperature analysis for any group (Mixed-effects models: Specimen $F_{(1.022,\ 10.79)} = 1.904$, $P=0.1959$; Species $F_{(2,\ 12)} = 0.2596$, $P=0.7756$).

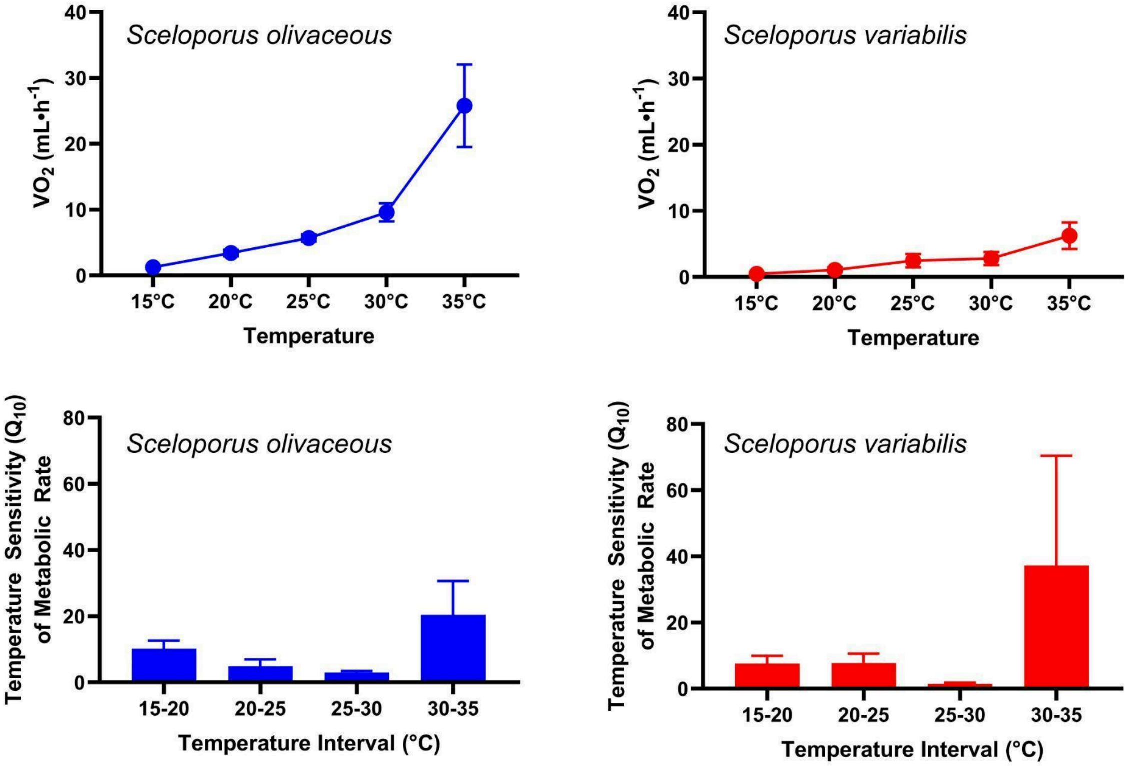

Figure 10. Metabolic rate (mL O_2/hour, ±SEM) and temperature sensitivity (Q10, ±SEM) of *Sceloporus olivaceus* and *Sceloporus variabilis* at ecologically relevant temperatures.

I assessed adult metabolic rates of *S. olivaceus* and *S. variabilis* metabolic rates at various ecologically relevant temperatures to understand their metabolic response to different temperatures. Oxygen consumption rates (VO_2) and temperature sensitivity of metabolism (Q_{10}) were the primary metrics used for this assessment.

Oxygen Consumption Rates (VO_2): As expected with any ectotherm, the oxygen consumption rate of *S. olivaceus* increased with temperature. The VO_2 at 15°C began at approximately 5 ml·h-1, climbed to about 10 ml·h-1 at 25°C, and then showed a significant increase to just over 30 ml·h-1 at 35°C, indicating an escalation in metabolic rate with temperature. In contrast, *S. variabilis* exhibited a lower VO*2* across all temperatures, starting near 1 ml·h-1 at 15°C and reaching around 6 ml·h-1 at 35°C. The disparity in metabolic rates between the species was most pronounced at the upper temperature of 35°C (Figure 10).

Temperature Sensitivity of Metabolism (Q_{10}): For *S. olivaceus*, Q10 values depicted moderate temperature sensitivity between 15°C-20°C and 25°C-30°C, remaining below 10. However, a significant rise in Q_{10} was noted in the 30°C-35°C interval, signaling a heightened metabolic response to temperature increase. *S. variabilis* maintained low Q_{10} values from 15°C to 30°C, followed by a sharp rise in the 30°C-35°C bracket. The variability of this response was high, as indicated by the extensive error bars, suggesting a pronounced sensitivity and metabolic instability at this temperature range.

The metabolic rates (mL O2/hour, ±SEM) and the temperature sensitivity (Q10, ±SEM) of *Sceloporus olivaceus* and *Sceloporus variabilis* across ecologically relevant temperatures highlight the physiological differences between the two species (Figure 10). This data complements the metabolic differences and temperature sensitivities discussed, providing a depiction of the physiological variances observed between the species at different temperatures.

Data scatter around the mean VO_2 values for both species indicates individual variability within the species, though the mean trends were clear and distinct. The error bars, indicative of the standard error of the mean (SEM), revealed the data's variability but also affirmed the overall consistency within each species' temperature preference.

V. DISCUSSION

The thermal physiology study of *Sceloporus olivaceus* and *Sceloporus variabilis* lizards in South Texas describes important aspects of these species biology in the face of changing temperatures resulting from climate change and urbanization on ectothermic organisms. By measuring and comparing the thermal preferences, physiological limits, and sprint speeds of these species, this research contributes significantly to our understanding of their adaptability to rising temperatures and altered habitats. The differential thermal tolerances identified between *S. olivaceus* and *S. variabilis* highlight the potential for niche partitioning and the reshaping of community dynamics under environmental stressors. This study not only advances our knowledge of lizard thermal ecology but also emphasizes the need for conservation strategies that account for species-specific thermal biology in the face of climate change. Integrating such physiological insights with habitat management could aid in mitigating the adverse effects of global warming and urban development on these and similar ectothermic species.

My investigation into the thermal ecology of *Sceloporus olivaceus* and *Sceloporus variabilis* enhances understanding of ectotherm physiological ecology. By quantifying thermal preferences and limits, I have provided insights into adaptive strategies within thermal biology. This study underlines thermal tolerance's role in shaping ecological resilience and capacities of these species, aligning with the findings of Sinervo et al. (2010) and Marsh & Bennett (1986). It highlights thermal ecology's crucial role in species persistence under climate pressure, particularly around VT_{max} and survival strategies in changing climates.

The distinction in thermal tolerances between *S. olivaceus* and *S. variabilis* suggests physiological and behavioral adaptations that could influence survival and reproductive success in a changing climate. The higher VT_{max} of *S. olivaceus* may confer an advantage in exploiting a range of microhabitats, potentially broadening geographic distribution, and enhancing resilience to temperature extremes. Conversely, the lower VT_{max} of *S. variabilis* suggests a constrained thermal niche, limiting adaptability to warming climates and elevating extinction risk.

Our findings on thermal tolerance further emphasize this point. While both species share similar lower temperature tolerances, *S. olivaceus* has adapted to be more tolerant of higher temperatures. These thermal traits could have significant implications for their behavior, distribution, and survival, particularly in the face of environmental temperature fluctuations.

The relationship between temperature and locomotor efficiency observed in our sprint performance analysis illuminates the balance between thermal adaptation and ecological fitness. The ability of these lizards to maintain optimal performance across a thermal gradient reflects physiological flexibility and ecological versatility in navigating their habitats' thermal mosaic. This aspect is crucial for understanding predator-prey interactions, competition, and the conservation of biodiversity in thermally heterogeneous environments.

The observed differences in metabolic rate and temperature sensitivity offer insights into the thermal ecology of these lizard species. *S. olivaceus* demonstrated a higher metabolic rate at increased temperatures and a marked rise in temperature sensitivity at 35°C. *S. variabilis*, while presenting a lower metabolic rate overall, showed a pronounced threshold effect in metabolic sensitivity at the highest temperature range, which may explain its inability to persist in urbanized environments. These findings deepen our understanding of how these sympatric species physiologically adapt to their thermal environments.

Differences in T_{pref} help illuminate how *S. olivaceus* and *S. variabilis* might partition overlapping habitats. These results suggest that *S. olivaceus* has a propensity for selecting warmer temperatures across various body and environmental parameters, which may affect its thermoregulatory strategies and habitat preferences. The consistency of this preference across the three measured parameters suggests a physiological adaptation that may offer a competitive advantage in warmer environments, potentially affecting the species' distribution and ecological interactions. Meanwhile, *S. variabilis* exhibits a preference for cooler temperatures, which could have implications for its survival and behavior in habitats with lower temperature profiles.

The implications of these findings extend to the ecological niche occupation and potential competitive interactions between these sympatric species. The observed temperature preferences may influence each species' physiological performance and behavior, affecting their foraging, reproduction, and survival strategies. The warmer temperatures selected by *S. olivaceus* may represent a greater capacity for activity during periods of higher ambient temperatures, potentially allowing for expanded daily activity periods and greater access to resources. Conversely, the lower thermal range exhibited by *S. variabilis* might reflect a more conservative thermoregulatory strategy, possibly reducing the risk of overheating and desiccation, which could be advantageous in environments where thermal stress is a significant factor.

The differential temperature preferences observed may also relate to microhabitat selection and interspecific competition. If *S. olivaceus* and *S. variabilis* occupy overlapping geographic ranges, the distinct thermal preferences could reduce direct competition by partitioning the thermal landscape over time, allowing each species to exploit different thermal niches across different times of day or seasons. This temporal partitioning could be particularly relevant in the context of climate change, where shifts in temperature regimes may alter the availability and quality of suitable habitats not only spatially but also temporally. Other factors, like prey species preferences or behavioral differences, may also influence their coexistence, but are beyond the scope of this study.

The specific thermal preferences identified in this study have implications for conservation management. Understanding the thermal biology of these species can inform habitat preservation efforts, particularly as it relates to maintaining the thermal integrity of their environments. As global temperatures continue to fluctuate, the thermal traits of these lizards will play a critical role in their ability to adapt and persist in their native habitats. This research highlights the necessity for continued monitoring of thermal preference behaviors in ectothermic species and the need to consider these behaviors in ecological and conservation planning.

The adaptive strategies of *S. olivaceus* and *S. variabilis* are linked to their ecological roles within the ecosystem. Differential thermal preferences and capabilities underscore the complexity of their environmental interactions, highlighting the need for conservation that considers thermal ecology's nuances.

Specifically, *S. olivaceus*'s higher voluntary thermal maximum suggests a competitive advantage in warmer climates, which could lead to range expansions and altered interspecific interactions. Conversely, the findings raise concerns for *S. variabilis*, whose narrower thermal tolerance may limit its adaptability, posing a risk for localized population declines or extinctions as temperatures continue to rise.

These findings underscore the species-specific thermal adaptations and their potential ecological implications. The higher optimum temperature range of *S. olivaceus* may indicate evolutionary adaptations to warmer climates or specialized microhabitats, suggesting this species has evolved mechanisms to thrive in such conditions. Conversely, the more pronounced temperature sensitivity of *S. variabilis*, particularly the sudden decrease in sprint speed at its upper thermal limit, may imply that this species has evolved to thrive within a narrower and potentially less variable thermal niche. This specialization could result from selection pressures that favor stability in environmental conditions, allowing the species to operate within its optimal physiological temperature range consistently.

The sharp decrease in performance at higher temperatures for both species emphasizes the critical role of the thermal environment in defining the boundaries of their physiological capabilities, which in turn may determine their geographic and ecological distribution. In summary, our data reveal that *S. olivaceus* and *S. variabilis* not only have distinct thermal windows for maximum sprint speed but also that these windows have significant implications for their behavior, predator avoidance, foraging efficacy, and overall fitness within their respective ecological contexts. The observed interspecific differences accentuate the importance of temperature as an environmental variable influencing the life history traits and survival strategies of these ectothermic species, highlighting the necessity for further research into the effects of climate variability on their ecological dynamics and conservation.

Integration with Existing Research

Our findings complement existing research on thermal tolerances and ecological resilience in lizards. The higher VT_{max} for *S. olivaceus* compared to *S. variabilis* and the corresponding disappearance of *S. variabilis* from warmer, urbanized environments support predictions in Sinervo et al. (2010) regarding thermal stress-induced extinctions in lizards. This emphasizes thermal tolerance's role in species persistence with increased temperatures(Sun et al., 2022). Our sprint performance analysis across thermal gradients reiterates the link between temperature and locomotor efficiency in lizards, documented by Marsh and Bennett (1986).

These findings contribute to a broader understanding of the ecological implications of thermal physiology, suggesting potential niche partitioning that could influence future distribution patterns under changing climates. The adaptability of *S. olivaceus* to warmer climates or specialized microhabitats suggests evolutionary mechanisms for thriving in such conditions and is paralleled by the broad latitudinal range of this species (Nowakowski et al., 2018). In contrast, the temperature sensitivity of *S. variabilis* implies a narrower, less variable thermal niche, resulting from selection pressures favoring stability in environmental conditions. This phenomenon reflects the varying thermal tolerances of lizards that allow some species to adapt while others may face increased risks of extinction under similar conditions (Brusch et al., 2015).

The metabolic rate sensitivities to temperature could differently impact their energy budgets, influencing activity levels and resource requirements in a warming landscape. This promotes niche partitioning by reducing direct competition and leads to different prey specializations, with implications for survival and behavior in habitats with lower temperature profiles (Watson & Burggren, 2016).

Ecological Implications

The observed differences in upper thermal tolerances and thermal range between *S. olivaceus* and *S. variabilis* suggest potential niche partitioning, which could influence future distribution patterns under changing climates. The higher thermal tolerance of *S. olivaceus*, with a VT_{max} of approximately 39°C, may allow for broader dispersal and greater flexibility, as suggested by Huey and Stevenson (1979). This could lead to changes in foraging patterns or utilization of prey species that thrive in warmer conditions. In contrast, *S. variabilis's* preference for cooler temperatures and its lower VT_{max} of approximately 36°C could limit its range, indicating vulnerability to habitat loss and climatic extremes. Metabolic rate sensitivities to temperature could further impact their energy budgets differently, influencing activity levels and resource requirements in a warming landscape.

The differing thermal preferences could promote niche partitioning by reducing direct competition. For example, *S. olivaceus* might be more active during the hottest parts of the day when *S. variabilis* is forced to seek shade. This temporal separation scenario could lead to different prey specializations. Furthermore, *S. olivaceus* might utilize more exposed basking sites, while *S. variabilis* relies on shaded refugia like dense vegetation or burrows, leading to spatial segregation, a phenomenon also observed between native and invasive Anolis lizards as a result of asymmetric competition (Culbertson & Herrmann, 2019).

Climate Change Context

The observed higher thermal tolerance of *Sceloporus olivaceus* compared to *S. variabilis* underscores a potential shift in competitive dynamics under the projected climate change scenarios for South Texas. The capacity of *S. olivaceus* to endure higher temperatures may enable it to exploit a broader range of microhabitats and resources, potentially at the expense of less thermally tolerant species. As such, the thermal resilience of *S. olivaceus* could act as a double-edged sword, where its survival advantage may lead to a restructuring of the local lizard community, altering species interactions, competition, and predation dynamics.

Conversely, the thermal vulnerability of *S. variabilis* brings to light its sensitivity to warming temperatures, signaling a pressing need for targeted conservation interventions. This sensitivity not only highlights the potential for *S. variabilis* to serve as an indicator species for ecosystem health but also emphasizes the urgency of mitigating climate change impacts through the preservation of cooler microhabitats (Sinervo et al., 2010). These microhabitats are crucial for the survival of *S. variabilis* and likely other thermally sensitive species. As such, conservation efforts should prioritize the identification and protection of these critical areas, incorporating climate adaptation strategies into management plans to enhance ecosystem resilience.

Our findings on the thermal preferences and physiological performances of these species provide a valuable baseline for predictive modeling of climate change's impact on lizard populations in South Texas. By integrating thermal preference and tolerance data with habitat and climate models, we can begin to forecast potential range shifts, changes in species interactions, and alterations in biodiversity patterns (Taylor et al., 2021). This proactive approach is essential for developing adaptive conservation strategies that not only address current threats but also anticipate future challenges.

Furthermore, the urban heat island effect, exacerbated by climate change, presents an additional layer of complexity for lizard conservation in South Texas. As urban areas expand and temperatures rise, the creation of thermal refugia and the maintenance of green spaces become pivotal for the survival of urban lizard populations (Kearney et al., 2009; Battles and Kolbe, 2019). Conservation planning in urban contexts must therefore consider the thermal ecology of species like *S. olivaceus* and *S. variabilis*, leveraging urban design to mitigate heat stress and promote biodiversity.

Our study emphasizes the critical role of thermal ecology in understanding species' responses to climate change and highlights the need for conservation strategies that are informed by ecological research. As we continue to witness unprecedented changes in global climate patterns, the insights gained from our research underscore the importance of integrating thermal biology with conservation planning to safeguard the future of lizard populations in South Texas and beyond (Sinervo and Losos, 1991).

Urbanization and Heat Island Effect

Urbanization and its resultant 'heat island effect' significantly alter local climates, intensifying climate change impacts. Urban areas, with their dense infrastructure and limited green spaces, become thermal hotspots, markedly increasing temperatures relative to less urbanized areas. This rise in temperature not only reshapes the urban thermal landscape but also places unique physiological strains on ectothermic species like lizards. Kearney et al. (2009) provided foundational insights into how ectotherms' thermal physiology is vulnerable to these urban-induced changes. Similarly, Battles and Kolbe (2019) observed that the altered thermal habitats in urban areas, characterized by open canopies and higher temperatures, significantly differ from natural habitats, underlining the urban thermal dynamics' complexity on species such as Anolis lizards.

Urban heat islands elevate surface temperatures, enhancing thermal stress on wildlife (Ackley et al., 2015). Ectotherms, which rely on environmental temperatures for body temperature regulation, may find themselves pushed beyond their optimal thermal operating zones due to elevated urban temperatures. Battles and Kolbe (2019) highlighted this issue, showing that urban areas tend to have higher operative temperatures and less cover, complicating ectotherms' temperature regulation and potentially affecting their survival and dispersal. Kearney et al. (2009) emphasized the importance of behavioral thermoregulation strategies, like selecting specific microhabitats, to counteract the thermal stress induced by urban environments.

Studies typically show that as urbanization intensifies, reptile species richness and population sizes decline (Ackley et al., 2009; Banville and Bateman, 2012; Sullivan et al., 2017). Yet, some species, particularly those introduced through the pet trade, exhibit traits that allow them to flourish in urban areas (Rodda and Tyrrell, 2008). Additionally, certain native reptiles, notably some snake species, are also found to thrive in urban settings (Moreno-Rueda and Pizarro, 2007; Barrett and Guyer, 2008), indicating a complex relationship between reptiles and urban environments characterized by both challenges and opportunities for resilience and adaptation (French et al., 2018). These observations affirm that urban environments play a crucial role in reptile ecology and conservation. The capacity of certain species to navigate and exploit urban landscapes suggests that conservation efforts need to account for the unique urban challenges and opportunities. Accordingly, conservation strategies must be carefully crafted to address these threats and the potential for adaptation among urban-dwelling reptiles.

Considering this, species like *Sceloporus olivaceus* and *Sceloporus variabilis*, which inhabit both urban and non-urban areas, may exhibit varied responses to urban heat islands. Gainsbury et al. (2022) shed light on the adaptability of both native and non-native reptiles to urbanized environments, pointing to the necessary ecological flexibility to survive the modified thermal landscapes created by urbanization. Battles and Kolbe (2019) further reveal that urban settings, with their unique thermal characteristics, provide different levels of habitat suitability for ectothermic species, underscoring the need for urban planning that considers the thermal ecology of local wildlife.

The effects of urbanization and the heat island phenomenon highlight the essential need for urban planning and the development of green infrastructure that incorporates the thermal ecology of the wildlife residing within. Kearney et al. (2009) advocate for the inclusion of vegetated areas and green roofs to counteract heat island effects, thus aiding the persistence of ectothermic organisms. Battles and Kolbe (2019) support this view, illustrating how urban thermal conditions influence the persistence and spread of ectotherms like *Anolis* lizards in urban areas.

The ongoing urban expansion and the accompanying heat island effect provide critical insights into the future of ectothermic organisms in changing environments. The study of adaptive strategies of species like *Sceloporus olivaceus* and *Sceloporus variabilis* against urban heat stress enhances our understanding of their ecological resilience (Kearney et al., 2009; Battles & Kolbe, 2019), while Gainsbury et al. (2022) highlight the wider effects of habitat changes on biodiversity and ecosystem health. These studies collectively narrate the intricate relationship between urbanization, thermal ecology, and ectotherms' adaptability.

Future Research Directions

The investigation into the thermal ecology of lizards, particularly in the context of South Texas, sets the stage for several promising avenues of research that extend beyond our current understanding of lizard adaptations to temperature variations. Building on the work conducted thus far, the following areas represent directions for future research:

Impact of Urban Heat Islands on Thermal Ecology: As urbanization accelerates, especially in regions like South Texas, the emergence of urban heat islands presents a critical area of study. Future research should aim to understand how these altered thermal landscapes impact community structure, including lizard populations. This includes assessing changes in thermoregulatory behavior, habitat selection, and overall survival in urban settings compared to more natural environments. Such studies could offer valuable insights into the resilience of lizard species to anthropogenic climate modifications and inform urban planning to mitigate adverse effects on local wildlife.

Role of Phenotypic Plasticity in Thermal Tolerance: The capacity for phenotypic plasticity within lizard species offers a potentially crucial mechanism for short-term acclimatization to changing temperatures. Investigating this plasticity—how it manifests, its limits, and its ecological implications—could reveal strategies lizards use to navigate the thermal challenges presented by both natural and human-induced changes. Experimental approaches that manipulate environmental temperatures and observe physiological and behavioral responses will be particularly valuable in teasing apart the complexities of thermal adaptation.

Influence of Microclimatic Variation on Habitat Use: Microclimatic variations within lizard habitats play a significant role in species' survival and distribution (Huey & Stevenson, 1979). Future studies should focus on identifying how these small-scale climate variations, influenced by factors such as vegetation density, substrate types, and water sources, affect lizard behavior and physiology. While these factors offer insights into microhabitat selection, a more comprehensive analysis of microhabitat use through direct field observations would be valuable for future research. Understanding these dynamics can aid in identifying critical microhabitats that provide thermal refuge and are essential for the development of effective habitat management and conservation strategies.

Comparative Studies Across Different Ecological Contexts: Expanding research to include comparative studies of lizard populations across various ecological contexts can elucidate broader patterns of thermal ecology. By comparing species from diverse climatic zones—arid deserts, lush tropics, and temperate regions—researchers can uncover the range of thermal adaptation strategies employed by lizards. Such comparisons are invaluable for understanding the ecological and evolutionary pressures shaping these strategies and their implications for species' future viability under global climate change.

Interactions with Other Environmental Stressors: The interplay between thermal stress and other environmental stressors—such as habitat loss, the presence of invasive species, and pollution—warrants thorough investigation. These stressors can exacerbate the challenges faced by lizard populations, leading to compounded effects on survival and reproductive success (Sinervo et al., 2010). Research in this area should aim to disentangle these complex interactions to provide a comprehensive picture of the threats to lizard biodiversity and inform integrated conservation efforts that address multiple stressors simultaneously.

Together, these future research directions underscore the need for a multifaceted approach to understanding lizard thermal ecology. By integrating studies on urban impacts, phenotypic plasticity, microclimatic variation, comparative ecology, and stressor interactions, we can gain a more comprehensive understanding of how lizards will fare in a rapidly changing world. This knowledge is crucial for developing conservation strategies that ensure the persistence of lizard populations in the face of global climate change and other anthropogenic challenges.

VI. CONCLUSION

This thesis contributes to thermal ecology by investigating the thermal adaptations of *Sceloporus olivaceus* and *Sceloporus variabilis*. It connects physiological research with ecological theory, highlighting the relationships between temperature, performance, and metabolic rate. Understanding the thermal dimensions of wildlife biology is crucial for predicting species responses to climate change and for conserving biodiversity in changing environments.

This research underscores the role of thermal tolerance in ecological resilience and adaptive capacity, aligning with previous studies. It emphasizes thermal ecology's importance in species persistence amid climate change, focusing on VT_{max} and survival strategies in new thermal conditions. The differences in thermal tolerance between *S. olivaceus* and *S. variabilis* suggest physiological and behavioral adaptations that could affect survival and reproductive success in a warmer climate. The higher VT_{max} of *S. olivaceus* indicates an advantage in exploiting diverse microhabitats, while the constrained thermal niche of *S. variabilis* shows limited adaptability to warming climates.

Our analysis of sprint performance across thermal gradients highlights the connection between temperature and performance in ectotherms. This link is critical for understanding the dynamics of predator-prey interactions, competition, and biodiversity conservation in varied thermal environments. The adaptive strategies of *S. olivaceus* and *S. variabilis* are tied to their ecosystem roles, reflecting the complexity of their environmental interactions and the need for conservation efforts that address thermal ecology's nuances.

Future research should further explore thermal adaptation's ecological consequences to enhance our understanding of species responses to climate change and inform conservation strategies. As climate change progresses, integrating ecological research with conservation planning is essential for protecting ecosystem diversity and stability.

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VIII. VITA

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TEACHING EXPERIENCE

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