Urban Heat Island Effect and Rodent Body Condition

by

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ABSTRACT

        The built environment increases radiant heat exchange in urban areas by several

degrees hotter compared to non-urban areas. Research has investigated how urbanization

and heat affect human health; but there is scant literature on the effects of urban heat on

wildlife. Animal body condition can be used to assess overall health. This parameter

estimates the storage of energy-rich fat, which is important for growth, survival, and

reproduction. The purpose of my research was to examine the Urban Heat Island effect

on wild rodents across urban field sites spanning three strata of land surface temperature.

Site level surface temperatures were measured using temperature data loggers and I

captured 116 adult pocket mice (*Chaetodipus* spp. and *Perognathus* spp.) and Merriam's

kangaroo rats (*Dipodomys merriami*) to measure their body condition using accurate and

noninvasive quantitative magnetic resonance. I used baited Sherman live traps from mid-

May to early September during 2019 and 2020 in mountainous urban parks and open

spaces over two summers. Rodents were captured at seven sites near the Phoenix

metropolitan area; an ideal area for examining the effect of extreme heat experienced by

urban wildlife. Results supported the prediction that rodent body condition was greatest

in the cooler temperature stratas compared to the hottest temperature strata. I related

rodent body condition to environmental predictors to dispute to environmental predictors

to dispute alternative hypotheses; such as vegetation cover and degree of urbanization.

Results based on measures of body fat and environmental predictors show pocket mice

have more fat where vegetation is higher, nighttime temperatures are lower, surface

temperatures are lower, and urbanization is greater. Kangaroo rats have more fat where

surface temperature is lower. My results contribute to understanding the negative effects

of extreme heat on body condition and generalized health experienced by urban wildlife

because of the built environment. This research shows a need to investigate further

impacts of urban heat on wildlife. Management suggestions for urban parks and open

spaces include increasing vegetation cover, reducing impervious surface, and building

with materials that reduce radiant heat.

DEDICATION

I dedicate this work to my great grandmother Trula aka Memaw, who has shown me

unconditional love and encouraged me to create more masterpieces.

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INTRODUCTION

Future climatic changes predicted for the southwest United States include increases in surface temperature, less annual precipitation, river flow and soil moisture declines, and more severe droughts (Garfin et al. 2013). Heat-related stress and mortality has been a focus in human studies globally (Sherwood and Huber 2010; Hondula et al. 2015) and within urban areas in Arizona (Golden et al. 2008; Harlan et al. 2014; Petitti et al. 2016). Human mortality occurs in cities that reach a median daily ambient temperature of 37.5 °C (Harlan et al. 2014). All ages and genders have an increased risk of death if the individual has a history of cardiac disease, stroke, and respiratory disease (Harlan et al. 2014). Humans from lower socioeconomic and ethnic minority groups are more likely to live in warmer neighborhoods and experience greater heat stress as a result of greater housing density, decreased vegetation, and less resources to mitigate the effects of extreme heat (Harlan et al. 2006). For non-human animals, the response to the thermal environment is a stress that requires spending energy to maintain body temperature by physiological or behavioral adjustments and if adjustments are not made then the individual can experience a decline in overall health and mortality (Collier et al. 2017). Studies have shown negative effects of heat on human health in cities (Petitti et al. 2016); however, no studies have focused on the health of non-human vertebrates to urban heat.

My study occurs across an urban heat gradient in Phoenix, Arizona, located in the Sonoran Desert ecosystem in the southwestern US. Phoenix and the surrounding cities have been altered from an agricultural land use to mostly residential suburbs with warmer temperatures (Chow et al. 2012). Due to continued urbanization, concerns for the region

include: water scarcity, declining biodiversity, poor air quality, and the urban heat island (UHI) effect (Archer and Predick 2008). Urban heat island effect occurs as cities grow and land cover is converted from soil and vegetation to concrete in roads and buildings with more impervious surfaces. The effect is from both emissions and heat radiating from the built environment. In the United States, the effect results in 0.5-4.0 °C higher daytime temperatures and 1.0-4.5 °C higher nighttime temperatures in urban areas (Hibbard et al. 2017). The arid Southwest is noted for increased susceptibility to climate change and climate variability (Archer and Predick 2008). These arid environments provide vast ecological services such as wildlife habitat, rangelands, biodiverse plants and animals, hydrologic processes, and outdoor recreation and aesthetics (Archer and Predick 2008). Desert-adapted wildlife in arid lands may be especially sensitive to a changing climate (Archer and Predick 2008) as a consequence of living near their physiological limits (for rodents, Walsberg 2000; for squamates, Sinervo et al. 2010).

Rodents play important roles as bioengineers, seed dispersers, and are prey for many animal taxa (Monadjem et al. 2015). The ability of desert-adapted rodents to tolerate and survive extreme heat makes them the ideal candidate for this study. Rodent abundance and survival has been linked to temperature extremes, surface temperature, vegetation cover and food availability, and their ability to persist in urban environments. Temperatures are shown to limit the range of rodent species due to metabolic rate requirements and their ability to tolerate heat (Munger et al. 1983; Walsberg 2000). Studies have found that surface temperature alters desert-adapted rodent abundance and as surface temperature increases, apparent survival decreases (Moses et al. 2012; Pianalto

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and Yool 2017). Vegetation coverage and food provided by plants has a positive relationship on rodent abundance, reproduction, and survival; these resources are especially important for desert-adapted species during dry seasonal periods (Chew and Butterworth 1964; Beatley 1969; Negy and Gruchacz 1994). Urbanization has a negative impact on rodent communities generally, with cities having lower species diversity and richness, and more non-native species (Cavia et al. 2009; Saari et al. 2016; Guevara and Ball 2018). Studying rodents in the Sonoran Desert, especially the Phoenix urban interface, is an opportune research area for evaluating incredibly diverse and well-adapted organisms that overlap urban areas (Guevara and Ball 2018).

The rodents of my study, pocket mice (*Chaetodipus* spp. and *Perognathus* spp.) and Merriam's kangaroo rats (*Dipodomys merriami*), live in dry, hot areas where the average maximum soil surface temperatures in June in Southern Arizona may exceed 60 °C (140 °F) as air temperatures reach 35 °C (95 °F) or greater. During the day the rodents live in burrows where temperatures are up to 60° less than soil and 10° less than air temperatures (Reynolds 1960). A study found banner-tailed kangaroo rats (*Dipodomys spectabilis*) thermal neutral zone (TNZ) is 20-30 °C and their upper lethal zone (ULT) is 40 °C during summer months (Kay 1975). Kangaroo rats are noted for not needing to drink water, and instead survive on water metabolized from seeds high in carbohydrates (producing approximately half a gram of water per gram of seed eaten). Pocket mice seldom drink and gain water primarily through seeds. Pocket mice conserve water by burrowing and even plug their burrow hole to prevent humidity losses (Lazaroff 1998).

Desert adapted rodents are known for their ability to conserve water by producing highly concentrated urine and dry feces (Lazaroff 1998; Tracy and Walberg 2001).

According to a well-known biological principle, Bergmann's Rule, animals, particularly endotherms, in warmer climates tend to be smaller than the same species in cooler climates (Yom-Tov 2003; Santini et al. 2018; Hantak et al. 2021). I could test the prediction that animals affected by the UHI would be smaller in size or mass compared to animals exposed to cooler temperatures. However, if urban areas are associated with more anthropogenic resources, the resource availability hypothesis would predict that animals in cities are larger compared to non-urban counterparts with fewer food sources. One study found the body size and diet diversity was greater among urban dwelling rodents compared to non-urban populations (Santini et al. 2018). Hantak et al. (2021) found the effect of urbanization across mammal species was larger body size; however, this study did not investigate the intra-urban variation of temperature as in my study. Both studies predicted that urban wildlife may have benefited from increased food availability, higher calorie diets, and less predation or competitors (Santini et al. 2018; Hantak et al. 2021). Additional findings from Hantak et al. (2021) was that animals in warmer climates that hibernated or underwent torpor, a way to buffer thermal stress, were more sensitive to warm temperatures with a stronger decrease in body size. Yom-Tov (2003) found that body size of carnivore mammals increased with urbanization but not with temperature. Dickman and Doncaster (1987) found that rodent abundance did not respond to degree of urbanization, but that vegetation cover or structure was a better predictor. Although studies have compared mammal body size and condition in urban and

non-urban areas, this work is novel because it explores how body condition varies in the urban matrix across different land surface temperatures.

Body condition can be used as one measure of overall animal health. Body condition is a parameter that estimates the storage of energy-rich molecules in the body, e.g. lipids (fat), which are important for growth, survival, and reproduction (Young 1976). I used a quantitative magnetic resonance (QMR) instrument to quantify rodent body condition. QMR has been used across animal studies (Nixon et al. 2010; Riley et al. 2016; Warner et al. 2016) to estimate body composition. To obtain body condition estimates through chemical carcass analysis the animal must be sacrificed by humane euthanasia. QMR offers a noninvasive and accurate measurement of body condition in rodents and other animals (Nixon et al. 2010). Studies compare QMR scans to chemical carcass analysis and indicate QMR as an accurate measure of body fat, lean mass, and water content of rodents (Nixon et al. 2010).

The purpose of my study is to evaluate the effect of Urban Heat Island on rodent health by quantifying how body condition varies across an urban heat gradient in Phoenix metropolitan area. My objectives are to evaluate: (1) the use of QMR as a method of wild rodent body condition; (2) how rodent body condition varies across three strata of urban heat; and (3) how rodent body condition relates to environmental predictors (i.e. land use, land cover, temperature, index of vegetation biomass, and degree of urbanization). I predict the proportion of body fat, lean mass, and water will be greater in animals from cooler summer temperatures compared to warmer temperatures. The application of this

study is to better understand extreme heat on urban wildlife and help decision makers make informed decisions to mitigate the UHI effect on body condition.

METHODS

Study Area

I selected wild rodent sampling sites (Appendix B) based on long-term climate data in the urban heat gradient in Phoenix, Arizona (Figure 1) across three stratas of summer surface temperature (47.0-49.0 °C, 50.0-52.0 °C, and 53.0-55.0 °C). Temperature strata were derived from 5-year average daily temperature in June from the long-term surface temperature LANDSAT imagery (D. Hondula unpublished data; Parastatidis et al. 2017). The long-term temperature data was manipulated to exclude buildings and impervious surfaces and include eligible landcover types to trap animals (compacted urban soil, inactive crops, undisturbed land, desert vegetarian, and riparian vegetation). This was to create 400 m circular plots to sample temperature strata with similar landcover types (data available from Central-Arizona Phoenix, Long-Term Ecological Research program; Li et al. 2015).

Field Data Collection

Rodent Sampling

I captured adult nocturnal rodents, pocket mice and Merriam's kangaroo rats. Research by Reynolds (1960) summarizes life history traits of pocket mice and kangaroo rats (Family Heteromyidae) which are nocturnal, burrowing animals, with fur-lined cheek

pouches for storage and transportation of seeds. These rodents are primarily granivorous (seed eating) but they also may eat some insects and a little vegetation. For Merriam's kangaroo rats, their caches (seed stores) consisted primarily of *Bouteloua* spp. (annual grama grasses) or *Plantago* spp. (perennial plantain herbaceous plants). Weights of rodents varied seasonality with the lowest weights occurring in winter and highest weights during the summer growing season. Merriam's kangaroo rats weights averaged 39.5-46.5 g for males and 36.5-43.8 g for females. They are known to be active throughout the year and are strictly nocturnal; their activity was noted to be greatest in the early evening and early morning hours (Reynolds 1960). Pocket mice captured, *Chaetodipus* and *Perognathus*, are combined and are presented in my study as pocket mice due to difficulty of field identification and based on their similar body sizes, metabolic rates, and genetics (Riddle 2007). Pocket mice can range from 11-39 g and some species are known to use torpor while other species remain active year-round (Lazaroff 1998).

To capture live rodents, I used baited Sherman live traps from mid-May to early September in mountainous urban parks and open spaces in 2019 (year 1) and 2020 (year 2). Ventilated, baited traps (brown rice, oats, and cereal) with cotton batting were open from sunset to sunrise three to five days (50-100 traps/night) in the 400 m trapping areas identified as the three strata of summer surface temperature. If more than one 400 m area was available then one with the highest evidence of rodent activity (recently dug holes and small mammal paths) was chosen or one area at random was chosen. Once captured, animals were given a temporary mark on the right inner thigh to prevent resampling;

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juvenile and pregnant or lactating rodents were released live on site. Animals included in analyses were transported within an air-conditioned vehicle to a climate-controlled building where the QMR machine was located. Animals were analyzed with quantitative magnetic resonance, weighed (year 1, Pesola spring scale, ± 0.01g; year 2, Sartorius Secura analytical balance scale, ± 0.001g), sexed, had physical traits measured; then were returned to the site of capture and released live in less than 24 hours.

Temperature Logger Deployment

Surface level temperature loggers (n = 76, Maxim Integrated Products iButtons) were placed during year two at sites to obtain site-specific surface temperature. Temperature measurements were recorded every 30 minutes from 2 June to 24 June 2020 (22 days). The start date of analyses is when all temperature loggers were placed and had a full 24-hour measurement period and the end date is the full 24-hour period before the first temperature logger was removed from the field. Temperature data were extracted (Appendix C) from retrieved and functioning loggers (n = 41). The variable used for analyses was average nighttime temperature (nighttemp) from 7 PM to 5 AM AZT based on sunrise and sunset periods; the period when animals in the study were most active (Walsberg 2000).

Laboratory

QMR Measurements

The QMR instrument (Appendix D) uses Hydrogen (Proton)-nuclear magnetic resonance principles with measurements based on the different responses of tissues to

disturbances using radio waves emitted by the machine. Disturbances cause the protons to excite and relax, producing different positions and intensities that are measured reflecting the chemical composition as fat, lean muscle, or water (Jones et al. 2009). Scans are performed by placing one animal into an acrylic cylinder (animal holder), with a second smaller cylindrical inset to limit animal movement, then placed inside the machine. Each scan takes approximately 3-5 minutes. Animals were scanned 6-12 times; the first six scans are used in analyses. The QMR output ($\pm$ 0.001 g) measures body fat (g), lean mass (g), and water content (g). The QMR outputs for each animal were averaged and divided by the animal's measured mass (g); the proportion is used in this study as the dependent variables (i.e. proportion of body fat, lean mass, and water content).

For my study, I used the EchoMRI™ Mobile Body Composition Analyzer for Birds and Bats, or other small animals up to 200 grams (http://www.echomri.com). I examined the output of QMR measurements to determine variability and establish protocols for animal and QMR use. Based on recommendations by Nixon et al. (2010), each sample was processed using 'Primary Accumulation 3,' which is an average of three scans per output. Prior to year 2 field data collection, I analyzed QMR outputs of the empty animal holder, test vials for the standard sample (two different types), and test vials with known fat samples. A known fat sample (canola oil) was used during year 1 and year 2 as a standard sample to evaluate the consistency of QMR output (fat, lean mass, and water content). The expected outputs of the standard sample are 100% fat and no lean mass or water content. The fat sample mass was chosen based on a study that

found a pocket mouse species (deer mouse, *Peromyscus maniculatus*) fat content (mean fat (g) ± the standard deviation) was 1.06 ± 0.50 (Schulte-Hostedde et. 2001). The standard sample in year 1 (1.02 g; 13 unique runs; 119 scans) was measured before animals were processed every 1-2 days. A protocol using the standard sample was established for year 2, the standard sample was measured at the beginning and end of the day and before each animal was processed in the QMR (0.80 g; 109 QMR unique runs; 833 scans). From year 1 data I evaluated if differences were present when individual rodents were scanned six or 12 times and lastly explored if a difference occurred between males and females QMR outputs (body condition).

Spatial Data

Several environmental predictor variables (Appendix E) were summarized from remotely sensed data at the site centers for year one (2019) and year two (2020). Temperature data were derived from 5-year average daily temperature in June from the long-term surface temperature LANDSAT imagery (D. Hondula unpublished data). To evaluate vegetation, cover and food available to rodents, I used Normalized Difference Vegetation Index (NDVI) values derived from the MODIS vegetation index, upscaled to 1 km x 1 km pixel size (averaged from 250 m x 250 m pixels) for 22 month during 2019 and 2020 (12 months for the Queen Creek Sossaman site that was only surveyed in 2019); values ranged from -0.2 to 1 (F. Albuquerque unpublished data). The proportion of urbanization (Appendix F) GIS layer was calculated as the proportion of urbanization (e.g., human structure and impervious surface land covers, Li et al. 2015), within a 1 km

radius buffer for each 10 x 10 m raster cell; values ranged from 0 (no development) to 1 (complete development) (J. Lewis unpublished data).

Data Analyses

To determine the consistency of QMR output, a paired t-test was used to compare the means of 6 QMR scans and 12 QMR scans. The mean and variation were calculated from the outputs of the empty animal holder inserted into the QMR machine, two different vials for holding the standard sample for year 2 QMR measurements and amounts of standard sample. Coefficient of variation (CV) was analyzed for each variable output from the QMR of the standard sample; fat content (g), lean mass (g), and water content (g). Year 1 and year 2 standard sample outputs were analyzed separately to assess the precision of the QMR outputs. To determine if body condition varied by sex, I compared fat for female and male rodents with a Levene's test to examine variance and then a two-sample t-test assuming equal variance.

Data analyses were completed separately for pocket mice and kangaroo rats with year 1 and year 2 data combined across each temperature range. Linear regressions were used to compare the proportion of body fat to nighttemp, NDVI, and urbanization using Microsoft Excel (2013). Abundance of kangaroo rats and pocket mice included only animals used in body condition analyses. Shapiro-Wilk test to examine normality of data and Levene's test to test for equal variances to analyze all data. If data were normally distributed, I used analysis of variance (ANOVA) to compare how body fat varied across urban surface temperatures; then a Tukey's honestly significant difference (HSD) post

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hoc test to determine where differences lie. When data were not normally distributed, I used a Kruskal-Wallis test to determine if there was a significant effect of the heat stratas and proportion of body fat; then post hoc pairwise comparisons using the Wilcoxon Rank Sum Test were used to examine where the differences lie. The tests on proportion of body fat, mass, and abundance in relation to heat strata were completed using R Statistical Program (R Core Team 2020).

To determine the independence of environmental variables, I used bivariate Pearson Correlation to determine if variables were associated with each other in SPSS version 26.0 (IBM Corp 2019). The sample unit of the ecological models was the number of trapping locations where the spatial data were independent at a 1 km scale and n=7. I evaluated general linear models (GLMs) using a Corrected Akaike's Information Criterion (AICc) to examine the response of rodents' body condition to urban heat and environmental predictors (R Core Team 2020; vegan, AICcmodavg, and MuMIn packages).

RESULTS

During the 2019 and 2020 trapping seasons (33 days of trapping), I processed 69 pocket mice (Appendix G) and 47 kangaroo rats (Appendix H) from the seven field sites spanning three strata of land surface temperature. Each season we set 25-75 traps/site/night resulting in over 1000 trap nights per year (Appendix I). Over both years of the study, pocket mice were processed from the coolest (n = 21), moderate (n = 23),

and hottest (n = 25) sites. Kangaroo rats were processed from the coolest (n = 12),

moderate (n = 22), and hottest (n = 13) sites.

Based on the coefficients of variance analyses of the known standard sample

(Appendix J), measurements for body fat were more consistent than measurements for

lean mass and water content. Therefore, I used the proportion of body fat for comparisons

across surface temperature strata and in ecological models. Mean CV values indicated the

standard sample from year 1 fat measurements (CV = 17.14%, SE = 0.05) and year 2 fat

measurements (CV = 28.09%, SE = 0.05) had the most consistent results. For year 1 (lean

mass, CV = 92.42%, SE = 0.03; water content, CV = 96.16%, SE = 0.14) and year 2 (lean

mass, CV = 150.34%, SE = 0.009; water content, CV = 145.31%, SE = 0.02) lean mass

and water content varied significantly.

The body fat from QMR outputs of the first 6 scans and of 12 scans (Appendix K)

was averaged from year 1. There was no significant difference between 6 scans (M =

0.51, SE = 0.06) and 12 scans (M = 0.55, SE = 0.06; t = 1.54, df = 11, P = 0.132). For all

analyses, males and females were combined per rodent genera and 6 scans were used.

There was no difference in proportion of body fat between sexes (Appendix L) for pocket

mice (males, M = 0.43, SE = 0.08; females, M = 0.45, SE = 0.13; t = 0.14, df = 22, P =

0.893) or for kangaroo rats (males, M = 0.83, SE = 0.13; females, M = 0.70, SE = 0.14; t

= -0.62, df = 11, P = 0.551).

Comparisons across land surface temperatures

For pocket mice, the proportion of body fat varied across the surface temperature strata (H = 14.11, df = 2, P = 0.0009). Pocket mice from the coolest strata had more fat than those from medium and hot strata (P = 0.003, P = 0.002, respectively). Pocket mice from the medium and hot strata did not differ (P = 1.00). For kangaroo rats, the proportion of body fat varied across the surface temperature strata (F= 10.45, df = 2, P = 0.0002). Kangaroo rats from the coolest strata had more fat than those from medium and hot strata (P = 0.002, P = 0.0002, respectively). Kangaroo rats from the medium and hot strata did not differ (P = 0.402). The trend showed for both rodent genera that those from the coolest strata had more fat than those from the hotter stratas (Figure 2).

For pocket mice, the body mass did not vary across the surface temperature strata (H= 4.387, df = 2, P = 0.112). For kangaroo rats, body mass varied across the surface temperature strata (F= 12.94, df = 2, P = 0.00003). Kangaroo rats from the coolest and medium strata had more fat than those from hot strata (P = 0.00003, P = 0.003, respectively). The trend showed for kangaroo rats that those from the cooler stratas had more fat than those from the hottest stratas (Figure 3).

Temperature logger data and spatial data were summarized from the study sites (Table 1). A linear regression showed nighttemps and proportion of fat were negatively associated (r-squared = 0.356, P = 0.031) with rodent proportion of body fat greatest in areas with the lowest night-time temperatures (Figure 4). A linear regression showed NDVI and proportion of fat were not correlated (r-squared = 0.002, P = 0.869, Appendix

M1) and urbanization and proportion of fat were not correlated (r-squared = 0.071, P = 0.379, Appendix M2).

Abundance data for all rodents (F_2 = 1.698, P = 0.237) did not vary across the surface temperature strata (Figure 5). For pocket mice (F= 1.113, df = 2 P = 0.375, Appendix N1) and kangaroo rats (F= 1.683, df = 2, P = 0.253, Appendix N2), abundance did not vary across the surface temperature stratas.

Relating body fat to environmental variables

The four environmental variables from seven sites were not correlated (Table 2); therefore, all were included in models. The top model for pocket mice to predict rodent fat was the global model with all predictor variables (Table 3). Pocket mice body fat was greatest in areas with more vegetation, lower nighttime temperatures, lower surface temperatures, and more urban land cover (Table 4). The top models for pocket mice and kangaroo rats carried 100% of the cumulative AICc model weight and outcompeted the null model.

DISCUSSION

This is among the first study to investigate how the UHI affects the body condition of vertebrate wildlife in cities. Using a non-invasive approach to quantify animal body condition, results supported my hypothesis that animals from hotter locations (both from long-term data sources and field-collected sources) had poorer body condition. This was somewhat unexpected because the focal species are desert-adapted rodents and have evolved to live in hot, arid environmental conditions. Models further

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corroborated the patterns by showing that body fat was related to areas with high vegetation, lower nighttime and surface temperatures, and greater urbanization for pocket mice. Models for kangaroo rats showed body fat was related to areas with lower surface temperatures. Aridland species may be increasingly at risk due to a changing climate and the UHI effect, especially those persisting near their physiological limits (Walsberg 2000). Implications of my study could indicate that other urban and aridland wildlife are vulnerable to increasing temperatures due to the rapid expansion of urban areas and climate change.

Rodents from cooler temperatures had more body fat than those from hotter temperatures. In this study, rodent body fat was negatively related to field collected nighttime temperatures. When fat is reduced, the chance of reproduction and survival is reduced for rodents (Moitra et al. 1998) and mammals generally (Young, 1976; Speakman 2008; Heldstab, 2017). Mice with no fat were found to have decreased reproductive success and experienced premature death (Moitra et al. 1998). In female rabbits, Rödel et al. (2016) found that higher fat reserves could boost reproduction by increased litter size and total offspring growth. Additionally, the study found decreased feeding effort during lactation. Similarly, Myers and Master (1983) found prairie deer mouse (*Peromyscus maniculatus bairdii*) mass was positively correlated with the number of young and average mass of young at birth. Studies on birds show similar patterns and are comparable because birds and mammals both have high metabolic demands from being endothermic. The survival of collared flycatcher (*Ficedula albicollis*) females with larger brood sizes is decreased in females with poor body condition (Cichon et al. 1998).

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Adult female great white-fronted geese (*Anser albifrons frontalis*) body condition was positively related to survival (Schmutz and Ely 1999). My research suggests that high environmental temperatures affect the body condition of rodents and could mean that heat affects a rodent's ability to survive and reproduce.

Environmental variables were also good predictors of body fat in this study. Pocket mice body fat was greater where vegetation was higher, which was not unexpected. Increases in desert rodent abundance and reproductive success after plant growth has been well documented in literature (Chew and Butterworth 1964; Van de Graaf and Balda 1973; Petryszyn 1982). Petryszyn (1982) found increased plant production resulted in six times more heteromyid rodent density in the Sonoran Desert, Arizona. One study monitored rodent abundance in semi-arid areas and found a strong positive correlation with NDVI (Chidodo et al. 2020). Moses et al. (2012) found that among the highest supported models included vegetation production to predict kangaroo rat apparent survival. The ability of rodents to survive and reproduce may be highly influenced by the availability of vegetation (Munger et al. 1983). These findings were also supported by my study, which indicated the importance of vegetation to pocket mice body condition.

The built environment, consisting of buildings and paved surfaces, can raise temperatures in cities from from 3.6 °C to 14.4 °C (2 to 8°F) (Golden et al. 2008). It is expected by 2030 that up to 60% of the world's population will live in urban areas (United Nations, 2002) and most of this population growth is expected to occur in arid areas (Baker et al. 2004). The increase in temperature due to the UHI effect and climate

change may affect arid-adapted mammals greater, as many live at their physiological limits and are at risk of hyperthermia and mortality (Speakman and Król 2010). My findings support these predictions, for both pocket mice and kangaroo rats, the proportion of body fat was greatest in areas where surface temperatures were lower. In addition, I found that rodents had a greater proportion of body fat where site level nighttime temperatures were lower. I found that kangaroo rat body mass was greater in the cooler temperature strata compared to the hottest temperature range. Pocket mice body mass did not show this same trend but this is not surprising because we had to combine species of pocket mice and the species have different adult body masses. My results corroborated a study that found a negative impact on apparent survival of banner-tailed kangaroo rats as daytime surface temperatures increase (Moses et al. 2012). Kangaroo rats are known for their behavioral and physiological adaptations that allow them to survive in harsh desert conditions (Moses et al. 2012), forecasting potentially worse implications for less arid-adapted organisms. My study and other research on small mammals indicate that the effect of increasing surface temperatures on rodents is negatively affecting their body condition.

Summer TNZ for banner-tailed kangaroo rats is 20-30 °C (Kay 1975), which exceeds the field-collected nighttime temperatures recorded in study sites. Other studies showed kangaroo rats' environmental conditions are harsher than previously believed with soil temperatures and burrow temperatures, exceeding 35 °C during the summer (Walsberg 2000; Tracy and Walsberg 2002). Moses et al. (2012) found temperatures in the Chihuahuan Desert, New Mexico taken 30 years previously reached a maximum land

surface temperature of 34 °C where measurements at the same site from 2006-2010 were 44-50 °C. High nocturnal surface temperatures may reduce foraging times if the temperatures exceed the TNZ of desert rodents (Kay 1975; Kay and Whitford 1978). High surface temperatures could desiccate plant and seed materials eaten by rodents and reduce desert rodent survival. It is possible that desert rodent populations could acclimate to higher temperatures by increasing heat tolerance and adjusting rates of water loss or could respond by an upward shift in their TNZ or ULT (Tracy and Walsberg 2001). However, rodents may not be able to expend additional energy to dig deeper burrows or reduce surface activity for foraging. Therefore, environmental conditions that drive body temperatures above ULT could result in rodent mortality (Speakman and Król 2010). To maintain water and food reserves, desert rodents may need to increase foraging activity which could increase the risk of predation (Moses et al. 2012). High surface temperatures could result in physiological stress, reduced time to forage, desiccation of food, and increased predation affecting the health and survival of desert rodents. Rodents' need for climate acclimation might be especially important for rodents living in cities that experience further temperature increases due to the UHI effect.

The Phoenix metropolitan area is growing at a faster rate than any other major city, increasing 11.2% in the last decade (US Census Bureau, 2020). Previous studies of wildlife focus on abundance or diversity in urban areas (Rodewald and Shustack 2008; Shochat et al. 2010; Banville and Bateman 2012), but this study focuses on wildlife health. Pocket mice body fat was greater in urban areas; kangaroo rat body condition was not impacted by urbanization. The relationship to urbanization may have been influenced

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by riparian forest when present. For instance, the Queen Creek Sossaman site contained one such corridor providing higher density food resources resulting in increased body condition for area pocket mice (Johnson and Jones 1977; Johnson and Haight 2020). Pocket mice from my study showed similar results to studies on animal abundance, primarily birds, had greater abundances (Faeth et al. 2011) or survival (Phillips et al. 2018) in urban areas. Phillips et al. (2018) found male white-crowned sparrows (*Zonotrichia leucophrys*) have higher survival. Disconfirming a widely accepted hypothesis based on 40 analyses, Saari et al. (2016) found overall abundance of terrestrial animals were similar across different levels of urbanization; Guevara and Ball (2018) reported similar findings for small mammals in the Phoenix area.

Previous research on animal body condition uses methods that require euthanasia; however, I used a method that allowed for the release of live animals back to their source of capture. In this research I used a relatively novel method, QMR, to study body condition. QMR has been used to assess many organisms (Taicher et al. 2003; McGuire and Guglielmo 2010; Nixon et al. 2010; Riley et al. 2016) but hasn't been previously used to assess the effect of heat on body condition. My finding suggests that the least variation of QMR values occurs in fat measurements compared to a known standard sample. These findings may suggest lean mass and water content is imprecise compared to fat measurements by QMR. As such, body fat ensured the most consistent results for evaluating body condition across the urban heat interface. Some studies found water content to be accurate with QMR analysis (Riley et al. 2016) while others did not (McGuire and Guglielmo 2010); however, in many studies water content was not

reported. Studies compared QMR measurements of fat mass and lean mass to standard methods of examining body composition and found QMR equally reliable (Jones et al. 2009; Nixon et al. 2010, Metzinger et al. 2014). A study using QMR and chemical extraction of live bats found that fat mass and lean mass were highly accurate and precise while body water was neither (McGuire and Guglielmo 2010). Further studies compared the use of QMR, DEXA (dual-energy X-ray absorptiometry), and chemical analysis. The researchers found fat and lean mass were highly correlated between the three methods in mice; also they found improved precision with QMR compared to the other methods (Taicher et al. 2003). A QMR study using snakes found fat mass, lean mass, and total water mass to be very accurate compared to carcass analysis (Riley et al. 2016). QMR fat measurements were consistently accurate and precise in my study.

The known standard sample resulted in more variance of lean mass and body water. When measuring the standard sample, I expect the QMR outputs to be zero for lean mass and body water, which was not my finding. QMR technology may be affected by temperature and is optimized at 37°C (McGuire and Guglielmo 2010). The fat sample was room temperature which potentially affected QMR measurements. Evaluation of QMR results compared to a standard sample or other forms of body composition analysis is further recommended for future studies due to variability in QMR instrument measurements. Although there were no significant differences in rodent abundance, I believe with a greater sample size then the trend could suggest abundance is higher in cooler areas. Limitations of this study included low sample size to pair animal metrics with environmental predictors. For future studies, increasing the number of sites of each

treatment area will increase the power to relate specific environmental variables to the rodent body condition. The results are robust however, because over 100 animals were included in the study and both the comparison across land surface temperature stratas and the ecological models point to temperature acting as a major predictor of animal fat.

Implications

Among the fastest areas to be urbanized are arid ecosystems (UNDP 2014). The southwest is predicted to become hotter and drier with climate change (Kunkel et al. 2013), which will potentially exaggerate the patterns found in this study. Climate change could have negative consequences for heteromyid rodent fitness because it may reduce their activity to forage during hot periods (Moses et al. 2012; Schweiger and Frey 2021). Climate change and the UHI effect could especially reduce survival during stressful periods, summer, due to increased heat stress, severe summer showers ruining food caches, desiccation of seeds, and increased snake predation resulting from longer active periods (Moses et al. 2012). Schweiger and Frey (2021) predict that climate change will reduce rodent activity during early summer periods, this period is when females gather resources for reproduction, and reduced activity during this period will reduce fitness and reproductive success. Climate change and urban heat may result in poorer body condition and increased mortality. As Johnson et al. (2019) found with urban spiders, extreme heat slowed the growth of spiderlings and increased mortality. My results contribute to understanding the effects of extreme heat on urban wildlife body condition and health. Heat can affect elements of lifespan (decreased survival) and reproductive success of urban wildlife. Due to the rapid expanse of arid urban areas and the southwest climate

change predictions, urban arid wildlife could be especially vulnerable in the future. This research brings attention to the need to mitigate the effects of extreme heat on urban wildlife and humans.

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TABLE 1. Long-term surface temperatures were derived from 5-year average daily temperature in June from the long-term surface temperature LANDSAT imagery (D. Hondula unpublished data). The proportion of urbanization was calculated as the proportion of urbanization (e.g., human structure and impervious surface land covers, Li et al. 2015); values ranged from 0 (no development) to 1 (complete development) (J. Lewis unpublished data). Average nighttime temperatures (standard error), in table as nighttemp, were recorded every 30 minutes for 22 days in June (2020) from 7 PM to 6 AM AZT based on sunrise and sunset periods using temperature loggers. Normalized Difference Vegetation Index (NDVI) values derived from the MODIS vegetation index (F. Albuquerque unpublished data).

location	surface temperature range (°C)	urbanization	urban (n)	logger nighttemp (°C)	logger (n)	NDVI	NDVI (n)	long-term surface temp (°C)
MDSP	47.0-49.0	0.022	2	22.46 (1.97)	6	0.255	22	48.17
QCS	47.0-49.0	0.147	1	24.90 (1.88)	6	0.242	12	48.17
CB	50.0-52.0	0.000	2	27.11 (1.85)	10	0.333	22	51.82
GWA	50.0-52.0	0.083	2	28.34 (2.15)	5	0.173	22	51.16
CB	53.0-55.0	0.000	2	25.55 (3.79)	2	0.282	22	53.01
CB Dyke	53.0-55.0	0.000	2	25.42 (2.78)	4	0.257	22	53.87
GWA	53.0-55.0	0.066	2	24.50 (1.87)	9	0.184	22	53.07

TABLE 2. Correlation of predictor (independent) variables for year one (2019) and year two (2020) at rodent trapping sites in Phoenix, Arizona. P value in parentheses (P > 0.05). The average nighttime temperatures (nighttemp) were recorded every 30 minutes for 22 days in June (2020) from 7 PM to 6 AM AZT based on sunrise and sunset periods. Urban (urbanization) was calculated as the proportion of urbanization (e.g., human structure and impervious surface land covers, Li et al. 2015); values ranged from 0 (no development) to 1 (complete development) (J. Lewis unpublished data). NDVI (Normalized Difference Vegetation Index) values derived from the MODIS vegetation index (F. Albuquerque unpublished data). ST (surface temperature) were derived from 5-year average daily temperature in June from the long-term surface temperature LANDSAT imagery (D. Hondula unpublished data).

	Urban	nighttemp	NDVI	ST
Urban	1			
nighttemp	0.039 (0.934)	1		
NDVI	-0.577 (0.175)	-0.046 (0.921)	1	
ST	-0.550 (0.201)	0.378 (0.403)	0.026 (0.956)	1

TABLE 3. General Linear Model (GLM) of environment variables (independent) to evaluate proportion body fat of pocket mice (*Chaetodipus* spp. and *Perognathus* spp.) at the site level using year one (2019) and year two (2020) data in Phoenix, Arizona. Top performing global model and null models reported, all other models did not outperform the null model. The "+" indicates a positive association while the "-" indicates a negative association to the environment variable(s).

Model	(Intercept)	k	logLik	AICc	delta	weight
(+) NDVI, (-) Nighttemp, (-) SurfaceTemp, (+) Urbanization	0.26	6	27.46	-126.91	0	1
Null	0.02	2	18.53	-29.06	97.85	0

TABLE 4. General Linear Model (GLM) of environment variables (independent) to evaluate proportion body fat of Merriam's kangaroo rats (*Dipodomys merriami*) at the site level using year one (2019) and year two (2020) data in Phoenix, Arizona. Top performing model and null models reported, all other models did not outperform the null model. The "+" indicates a positive association while the "-" indicates a negative association to the environment variable(s).

Model	(Intercept)	k	logLik	AICc	delta	weight
(-) SurfaceTemp	0.15	3	33.69	-53.38	0	1
Null	0.02	2	26.20	-45.61	7.97	0

FIGURE 1. Rodent capture sites year 1 and year 2 north and southeast of Phoenix, Arizona. Temperature stratas were derived from 5-year average daily temperature in June from the long-term surface temperature LANDSAT imagery (D. Hondula unpublished data). Phoenix (blue circle with black dot) in reference to the United States (whereig.com).
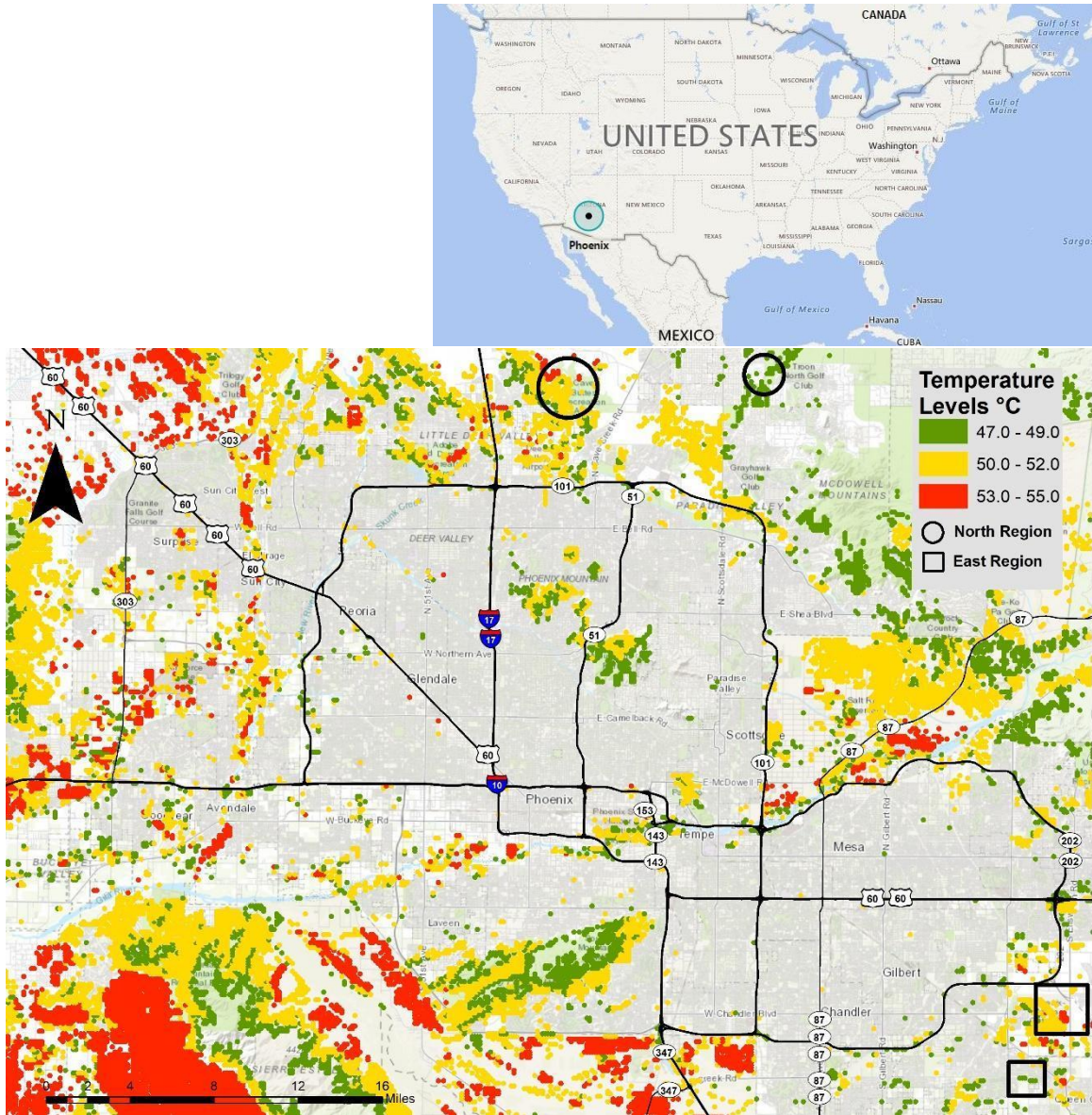
FIGURE 2. Measure of proportion of body fat (%) for A.) pocket mice (*Chaetodipus* spp. and *Perognathus* spp.) and B.) Merriam's kangaroo rats (*Dipodomys merriami*) captured from three strata of land surface temperature during 2019 and 2020 in Phoenix, Arizona. For A.) analysis of variance (ANOVA) and Tukey's honestly significant difference (HSD) post hoc test were used. For B.) Kruskal-Wallis test and post hoc pairwise comparisons using the Wilcoxon Rank Sum Test. Different letters above bar graph symbolize significant results of Tukey test or pairwise comparisons, solid bars are means, bars above and below are quartiles, and open circles are outliers.
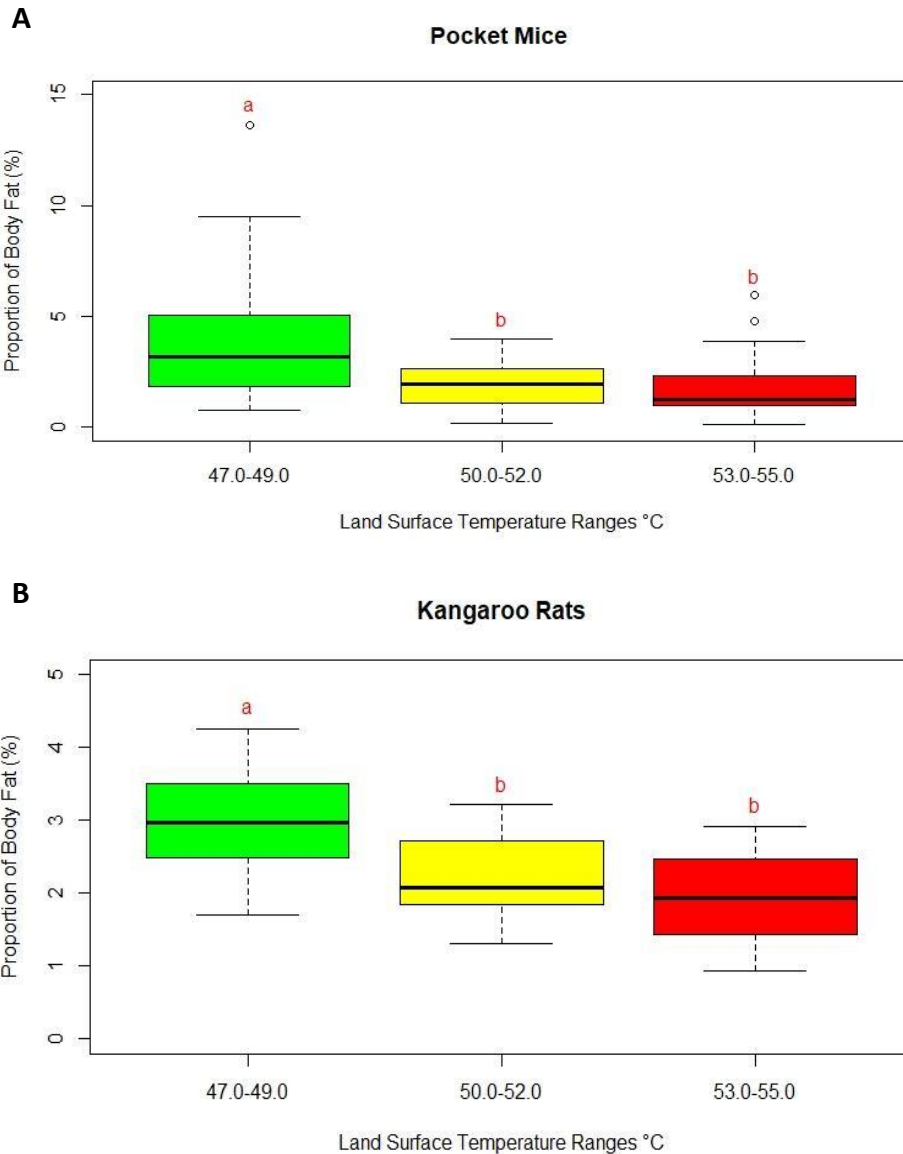
FIGURE 3. Measure of mass (g) for A.) pocket mice (*Chaetodipus* spp. and *Perognathus* spp.) and B.) Merriam's kangaroo rats (*Dipodomys merriami*) captured from three strata of land surface temperature during 2019 and 2020 in Phoenix, Arizona. For A.) analysis of variance (ANOVA) and Tukey's honestly significant difference (HSD) post hoc test were used. For B.) Kruskal-Wallis test and post hoc pairwise comparisons using the Wilcoxon Rank Sum Test. Different letters above bar graph symbolize significant results of Tukey test or pairwise comparisons, solid bars are means, bars above and below are quartiles, and open circles are outliers.
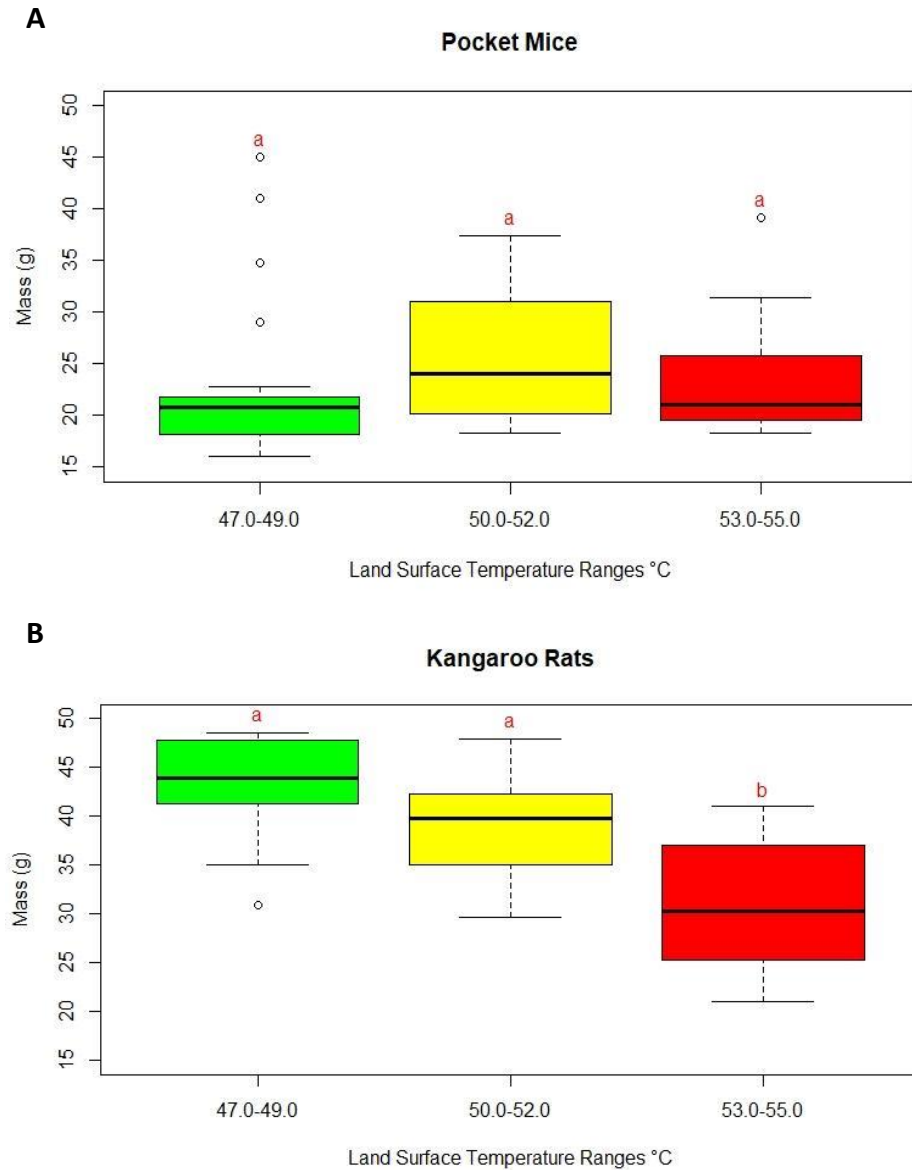
FIGURE 4. Mean proportion body fat for rodents (n=69 for *Chaetodipus* spp. and *Perognathus* spp., n=47 for *Dipodomys merriami*) captured during 2019, 2020 in greater Phoenix metro, Arizona with negative association (r-squared = 0.356, P = 0.031) to nighttime temperatures. Mean proportion body obtained through quantitative magnetic resonance. Nighttime temperatures (nighttemp) record every 30 minutes for 22 days in June (2020) from 7 PM to 6 AM AZT based on sunrise and sunset periods.
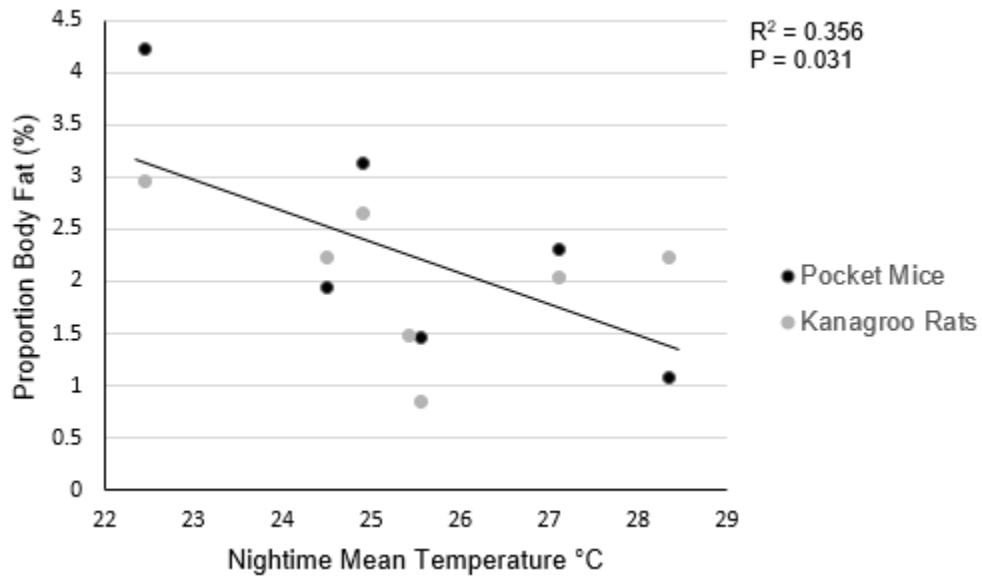
FIGURE 5. Measure of abundance for rodents used in laboratory measurements (pocket mice, *Chaetodipus* spp. and *Perognathus* spp.; kangaroo rats, *Dipodomys merriami*) captured from three strata of land surface temperature during 2019 and 2020 in Phoenix, Arizona. Analysis of variance (ANOVA) and Tukey's honestly significant difference (HSD) post hoc test were used. Different letters above bar graph symbolize significant results of Tukey test or pairwise comparisons, solid bars are means, bars above and below are quartiles, and open circles are outliers.

Rodent Abundance
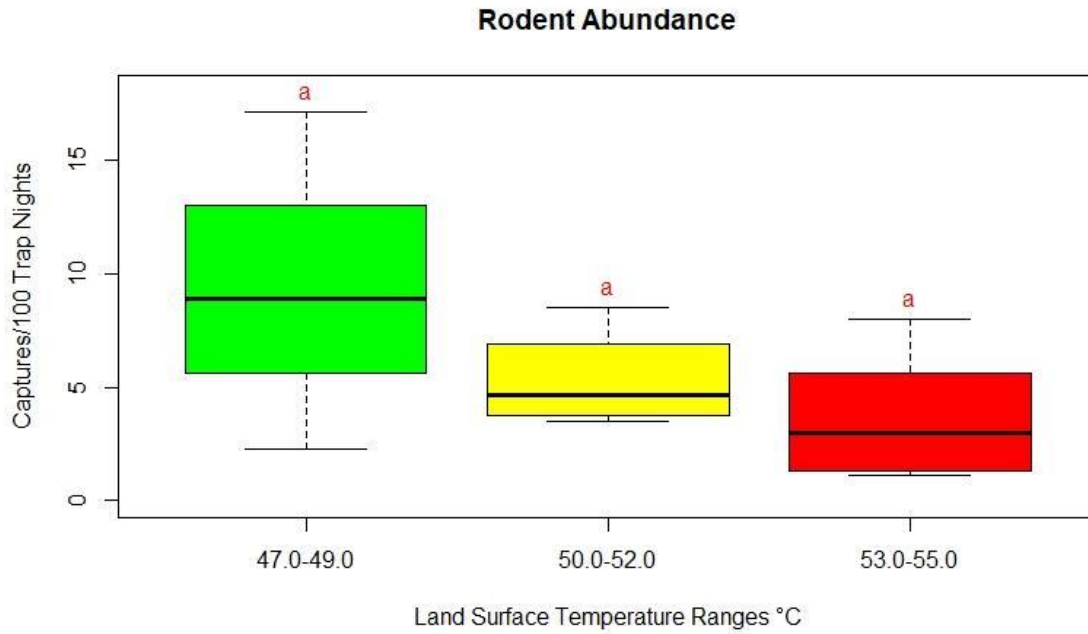
APPENDIX A

IACUC APPROVAL

Appendix A. Methods and animal use permits granted from ASU Institutional Animal Care and Use Committee (IACUC, Protocol #19-1719R).

Institutional Animal Care and Use Committee (IACUC)
Office of Research Integrity and Assurance
Arizona State University
660 South Mill Avenue, Suite 312
Tempe, Arizona 85287-6111
Phone: (480) 965-6788 FAX: (480) 965-7772

Animal Protocol Review

ASU Protocol Number:	19-1719R RFC 1
Protocol Title:	Physiology of Urban Lizards and their Response to the Urban Heat Gradient
Principal Investigator:	Marianne Moore
Date of Action:	7/10/2019

The animal protocol review was considered by the Committee and the following decisions were made:
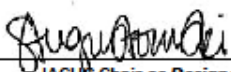
Request for changes was approved to add additional procedures and 768 wildlife mammals to the protocol.

If you have not already done so, documentation of Level III Training (i.e., procedure-specific training) will need to be provided to the IACUC office before participants can perform procedures independently. For more information on Level III requirements see https://researchintegrity.asu.edu/animals/training.

Total # of Animals:	1056	
Species:	Lizards	**Unalleviated Pain/Distress: No-288**
Species:	Wildlife Mammals	**Pain Category: C-768**

Protocol Approval Period:	5/1/2019 – 4/30/2022

Sponsor:	N/A
ASU Proposal/Award #:	N/A
Title:	N/A

Signature: _____ for C. Shalley   Date: 7/19/2019
IACUC Chair or *Designee*

Cc: IACUC Office
            IACUC Chair

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APPENDIX B

CAPTURE SITES

APPENDIX B. Site centers where animals were captured in year 1 and year 2 in Phoenix, Arizona. Coordinates in UTM (easting, northing), capture period of animals for year 1 (2019, 7/27-9/8) and year 2 (2020, 5/11-6/3), and treatment (temperature range of long-term data of summer surface temperatures, D. Hondula unpublished data).

| Site	Easting	Northing	Year	Treatment (°C)
MDSP	417574	3734644	2019	47.0-49.0
QCS	437364	3680647	2019	47.0-49.0
CBY	403684	3731942	2019	50.0-52.0
GWY	439459	3686429	2019	50.0-52.0
CBR	403116	3734068	2019	53.0-55.0
CBRD	401326	3734904	2019	53.0-55.0
GWR	440674	3685103	2019	53.0-55.0
MDSP	417590	3734760	2020	47.0-49.0
CBY	403834	3731917	2020	50.0-52.0
GWY	439525	3686384	2020	50.0-52.0
CBR	403163	3734230	2020	53.0-55.0
CBRD	401193	3734858	2020	53.0-55.0
GWR	440584	3685379	2020	53.0-55.0

APPENDIX C

SITE LEVEL TEMPERATURES

APPENDIX C. Temperature logger data at each site in Phoenix, Arizona. Temperatures were recorded every 30 minutes for 22 days in June (2020). Land surface temperature stratas were derived from 5-year average daily temperature in June from the long-term surface temperature LANDSAT imagery (D. Hondula unpublished data). Count (n) is the number of temperature loggers used in analyses, daymean is the daytime mean (0530-1830), daymax is the maximum temperature during the entire study period, elevenmean is the mean of temperatures at 1100, nightmean is the nighttime mean (1900-0600). Standard error is in parenthesis.

site	surface temperature range (°C)	count	daymean (°C)	daymax (°C)	elevenmean (°C)	nightmean (°C)
MDSP	47.0-49.0	6	47.39 (5.64)	75.63	58.17 (2.11)	22.46 (1.97)
QCS	47.0-49.0	6	38.24 (2.95)	56.65	42.07 (1.24)	24.90 (1.88)
CB	50.0-52.0	10	48.73 (4.24)	74.63	55.43 (1.80)	27.11 (1.85)
GWA	50.0-52.0	5	42.21 (3.41)	58.72	44.95 (1.69)	28.34 (2.15)
CB	53.0-55.0	2	44.69 (7.47)	65.95	46.70 (2.41)	25.55 (3.79)
CB Dyke	53.0-55.0	4	49.07 (6.08)	73.28	58.32 (2.29)	25.42 (2.78)
GWA	53.0-55.0	9	48.12 (3.63)	68.28	54.86 (1.58)	24.50 (1.87)

APPENDIX D

ECHOMRI™

APPENDIX D. Instrument used to obtain rodent body condition quantitative values. EchoMRI™ Mobile Body Composition Analyzer. Image obtained from echomri.com.
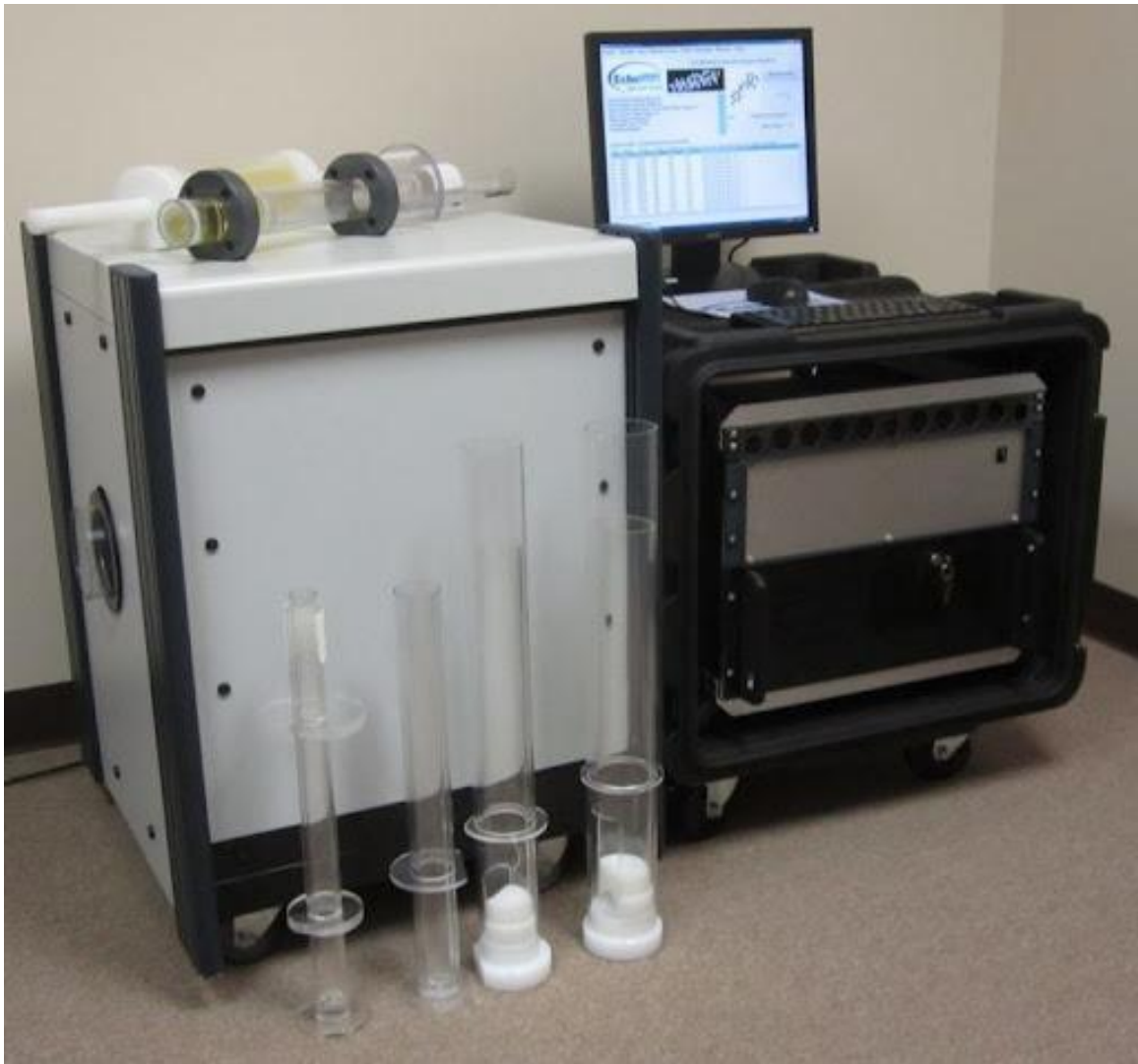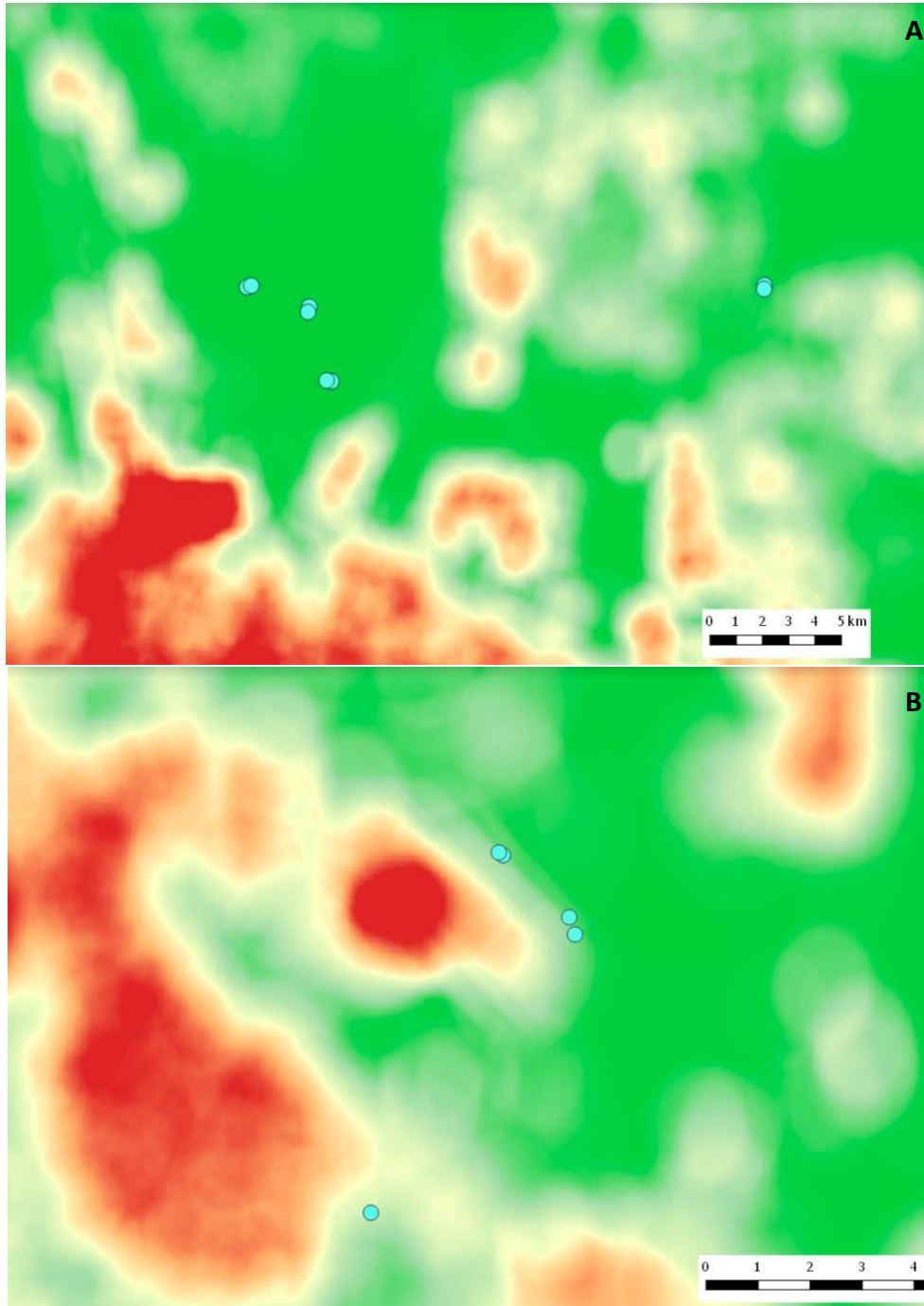
APPENDIX E

MULTIVARIATE ANALYSES VARIABLES

APPENDIX E. Dependent variables measured from individual animals in Phoenix, Arizona with predictor (independent) variables measured at each site, the description of the variable, and the data source of the variable.

Type	Variable Name	Description	Source of variable
dependent	proportion body fat	ratio of body fat (g) divided by animal mass (g)	quantitative magnetic resonance and scale
independent	nightemp	temperature recorded every 30 minutes from 6/2/2020-6/24/2020 (22 days) from sunset to sunrise at sites	temperature logger measurements deployed at sites during year two of study in June
independent	surface temp	5-year average daily surface temperatures (°C) in June	NASA LANDSAT Land Surface Temperature (D. Hondula unpublished data)
independent	NDVI (normalized difference vegetation index)	amount of green biomass from spectral imagery, upscaled to 1 km x 1 km for 22 month during 2019 and 2020 (12 months for the Queen Creek Sossaman)	NASA MODIS NDVI (F. Albuquerque unpublished data)
independent	urbanization	Measure of urbanization ((e.g., human structure and impervious surface land covers) within a 1 km radius buffer for each 10 x 10 m raster cell; values ranged from 0 (no development) to 1 (complete development)	(J. Lewis unpublished data)

APPENDIX F

URBANIZATION OF SITES

APPENDIX F. GIS layer of north sites (A) and east sites (B) with the proportion of urbanization (e.g., human structure and impervious surface land covers) within a 1 km radius buffer for each 10 x 10 m raster cell; values ranged from 0 (green, no development) to 1 (red, complete development) (J. Lewis unpublished data).

APPENDIX G

STUDY ORGANISM: POCKET MOUSE

APPENDIX G. *Chaetodipus* spp. (pocket mouse) after being released from trap during year 1 (2019) sitting on herbaceous plant in Phoenix, Arizona.

APPENDIX H

STUDY ORGANISM: MERRIAM'S KANGAROO RAT

APPENDIX H. *Dipodomys merriami* (Merriam's kangaroo rat) being released from Sherman live trap during year 2 (2020) in Phoenix, Arizona.

APPENDIX I

TRAP DATA

APPENDIX I. Sherman trap set dates, locations in Phoenix, Arizona, treatment (temperature range of long-term data of summer surface temperatures, D. Hondula unpublished data), traps per night, total traps set during time period, and total captures of animals processed using QMR.

Dates	Location	Treatment	Traps/ 1 Night	Total Traps	Total Captures	Captures/100 Trap Nights
7/25-7/28, 2019 8/1-8/5, 2019 8/9-8/12, 2019	Cave Buttes (CB) Recreation Area	53.0-55.0	50 8/9-8/12: 25	475	5	1.1
8/8-8/12, 2019	Cave Buttes (CB) Recreation Area	50.0-52.0	50	200	7	3.5
8/22-8/25, 2019	Gateway Airport (GWA)	50.0-52.0	50 x 2 days 25 x 1 day	125	5	4
8/23-8/26, 2019	Gateway Airport (GWA)	53.0-55.0	25 x 1 day 50 x 2 days	125	7	5.6
8/30-9/4, 2019	McDowell Sonoran Preserve (MDSP)	47.0-49.0	75	300, no traps 9/1	7	2.3
9/8-9/9, 2019	Queen Creek Rd/Sossaman Rd (QCS)	47.0-49.0	35	35	6	17.1
5/10-5/13, 2020	McDowell Sonoran Preserve (MDSP)	47.0-49.0	75	225	20	8.9
5/19-5/27, 2020	Gateway Airport (GWA)	53.0-55.0	75	225 no traps 5/21	18	8.0
5/23-5/27, 2020	Gateway Airport (GWA)	50.0-52.0	50 x 3 day 75 x 2 day	300	16	5.3
5/30-6/3, 2020	Cave Buttes (CB) Recreation Area	50.0-52.0	50	200	17	8.5
5/30-6/3, 2020	Cave Buttes (CB) Recreation Area	53.0-55.0	50	200	6	3
5/31-6/3, 2020	Cave Buttes (CB) Recreation Area Dyke	53.0-55.0	50	150	2	1.3

*Total captures are the number of animals processed using QMR.

APPENDIX J

KNOWN STANDARD SAMPLE

APPENDIX J. A known standard sample from year 1 (2019) and year 2 (2020) were measured using quantitative magnetic resonance (QMR) for mean outputs of body fat (g), lean mass (g), and total water (g) with standard deviation in parenthesis. Coefficient of variation (CV) is analyzed for each variable (fat, lean, and water values from QMR). For 2019, the standard sample (canola oil sample, 1.02 g, 13 unique runs, 119 scans) was measured every other day while the QMR was used in animal analyses. For 2020, the standard sample (canola oil sample, 0.80 g, 109 QMR unique runs, 833 scans) was measured at the beginning and the end of day and before each animal was processed in the QMR.

	Fat	Lean	TotalWater	CV Fat	CV Lean	CV TotalWater
Average (2019)	1.08 (0.70)	0.12 (0.16)	0.53 (0.56)	58.28	158.96	125.78
Range (2019)	0.65 (2.54)	0.39 (0.36)	1.56 (1.83)	162.92	142.20	232.53
Average (2020)	0.92 (0.33)	0.07 (0.09)	0.15 (0.22)	28.09	150.34	145.31
Range (2020)	2.05 (4.10)	0.46 (1.03)	1.92 (2.58)	157.28	318.97	438.71

APPENDIX K

6 SCANS VS 12 SCANS

APPENDIX K. Paired t-tests were used to compare the means of quantitative magnetic resonance (QMR) scans outputs (variable tested) of body fat (g), lean mass (g), and water content (g). The count (n), mean (variance) of 6 scans and 12 scans, t-statistic, and two-tailed P-values are presented.

| QMR output	12/6 (n)	12 scans	6 scans	t-stat	P value
Body Fat	37/37	0.55 (0.15)	0.51 (0.13)	1.54	0.13
Lean Mass	37/37	17.5 (20.6)	17.6 (21.3)	-0.59	0.56
Water Content	37/37	13.8 (21.0)	14.1 (22.7)	-0.98	0.33

APPENDIX L

FEMALE VS. MALE RODENT ANALYSIS

APPENDIX L. Two sample t-tests assuming equal variances for females (F) and males (M) captured in Phoenix, Arizona evaluating the quantitative magnetic resonance (QMR) output of body fat (g), lean mass (g), and water content (g). The outputs are separated by genera *Chaetodipus* (pocket mouse) and *Dipodomys* (kangaroo rat) with their count (n), mean (variance), t-statistic, and two-tailed P-value is presented for each sex.

QMR output	Genera	F/M (n)	Females	Males	t-stat	P value
Body Fat	*Chaetodipus*	10/14	0.45 (0.18)	0.43 (0.09)	0.14	0.89
Lean Mass	*Chaetodipus*	10/14	14.8 (9.6)	16.4 (10.2)	-0.62	0.22
Water Content	*Chaetodipus*	10/14	11.3 (9.3)	12.1 (8.5)	-1.26	0.51
Body Fat	*Dipodomys*	8/5	0.70 (0.16)	0.83 (0.09)	-1.12	0.55
Lean Mass	*Dipodomys*	8/5	19.6 (31.0)	22.7 (11.2)	-0.66	0.29
Water Content	*Dipodomys*	8/5	16.1 (28.6)	19.7 (11.2)	-1.37	0.20

APPENDIX M

RODENTS' BODY FAT FOR NDVI AND URBANIZATION

Appendix M. Mean proportion body fat for rodents (n=69 for *Chaetodipus* spp. and *Perognathus* spp., n=47 for *Dipodomys merriami*) captured during 2019, 2020 in greater Phoenix metro, Arizona with no association to 1.) urbanization (r-squared = 0.071, P = 0.379) or 2.) NDVI (r-squared = 0.002, P = 0.896). Mean proportion body obtained through quantitative magnetic resonance.The proportion of urbanization was calculated as the proportion of urbanization (e.g., human structure and impervious surface land covers, Li et al. 2015); values ranged from 0 (no development) to 1 (complete development) (J. Lewis unpublished data). Normalized Difference Vegetation Index (NDVI) values derived from the MODIS vegetation index (F. Albuquerque unpublished data).
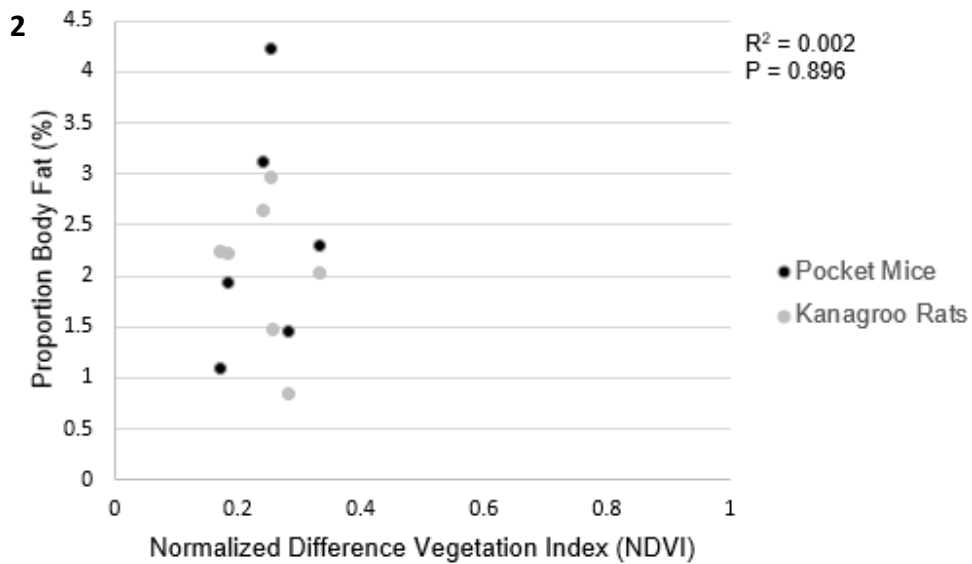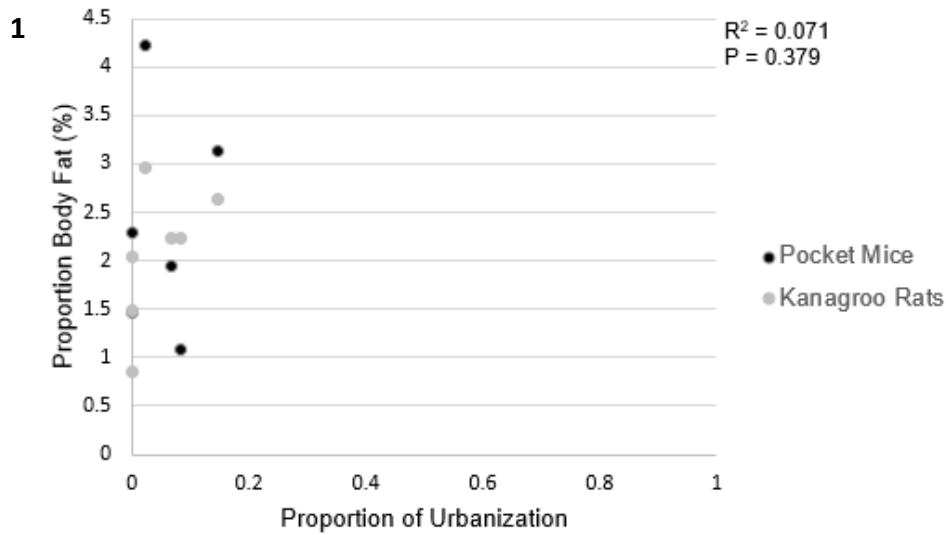
APPENDIX N.

POCKET MICE AND KANGAROO RATS ABUNDANCE AND TEMPERATURE

Appendix N. Measure of abundance for rodents used in laboratory measurements for 1.) pocket mice (*Chaetodipus* spp. and *Perognathus* spp.) and 2.) Merriam's kangaroo rats (*Dipodomys merriami*) captured from three strata of land surface temperature during 2019 and 2020 in Phoenix, Arizona. Analysis of variance (ANOVA) and Tukey's honestly significant difference (HSD) post hoc test were used. Different letters above bar graph symbolize significant results of Tukey test, solid bars are means, bars above and below are quartiles, and open circles are outliers.

1

2