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# DIFFERING ECTOPARASITE LOADS, SEXUAL MODES, AND ABUNDANCES OF WHIPTAIL LIZARDS FROM NATIVE AND NON-NATIVE HABITATS

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*Abstract*.—**We investigated ectoparasite loads between two syntopic species of whiptail lizards (Teiidae) which differ in reproductive modes and occur in native and non-native riparian forests. Tiger Whiptails (*Aspidoscelis tigris*) reproduce sexually and Sonoran Spotted Whiptails (*A. sonorae*) are an all-female parthenogenic species. Both lizards carry ectoparasites and reside in riparian habitats. Our objectives were to compare ectoparasitic mite loads between whiptail species and compare mite loads on whiptails from three habitat types; native cottonwood (*Populus*) forests and mesquite (*Prosopis*) woodlands, and non-native saltcedar (*Tamarix*). We quantified mite loads during dry, hot, summer months and the wetter monsoon season. We captured whiptails from trap arrays and photographed their ventral side. We calculated mite infestation by dividing the number of scales with mites present by the total number of ventral scales. Sonoran Spotted Whiptails had higher mite loads than Tiger Whiptails, but the best predictors of mite load were the type of riparian habitat and seasonality. Whiptails from native vegetation forests had six times higher mite loads compared to non-native saltcedar sites. Mites were most abundant on whiptails during cooler early summer and during humid monsoon months. Although non-native habitats had a similar microclimate to native habitats, the ectoparasite loads on lizards were much lower, perhaps related to the low abundance of lizard hosts in the non-native habitat. Our results suggest that environmental factors such as habitat and climate may be better predictors of ectoparasitism than host reproductive mode when comparing sexual and unisexual species of lizards.**

*Key Words*.—arachnida; ectoparasite; monsoon season; parthenogenic; riparian; saltcedar; reptile

## INTRODUCTION

Host-parasite interactions of reptiles can be highly complex and may depend upon many factors such as environmental conditions, type of habitat or ecosystem, or genetic diversity of the host (Sobecka 2012). Mites in the family Arachnida are ectoparasites and can be found on lizard skin and scales and some species of lizards even harbor mites within skin pockets as a possible means to control damage (Arnold 1986; Bauer et al. 1993). Chigger mites (Trombiculidae), commonly found on lizards, have been found across North and South America (García-De la Peña 2011). Trombiculid mites are typically present in cool and shady areas with high humidity and dense vegetation (Rubio and Simonetti 2009). Abiotic factors may determine mite species distributions (Malenke et. al 2011); for example, in sub-montane scrub desert of Mexico, García-De la Peña (2011) found mites thriving in areas of dense vegetation, thick overstory with little sun, low to moderate temperatures, and with high relative humidity. Other researchers have found that lizards residing in more moist, cool habitats had higher Trombiculid mite loads compared to lizards in habitats with hotter, drier microclimates (Zippel et al., 1996; Schlaepfer and Gavin 2001, Rubio and Simonetti 2009). Klukowski (2004) saw a seasonal pattern showing additional associations that mites have with temperature and humidity. These seasonal patterns caused changes at the microclimate level (Klukowski 2004; Lumbad et al. 2011). Mites may prefer cool and shady spots with high humidity over sunny and dry microhabitats (Clopton and Gold 1993).

Other factors related to hosts could also explain host-parasite relationships. Some research has suggested that mite load could vary based on genetic diversity of the host. Unisexual or clonal species can have less genetic variation compared to bisexual species (Benton 1987) and may carry a higher proportion of mites than bisexual species. Moritz et al. (1991) showed that unisexual geckos harbored greater ectoparasites in a species complex compared to sexual counterparts. One principle explaining possible differences in unisexual and sexual species is the Red Queen Hypothesis, where unisexual species cannot maintain their competitive position against parasites compared to sexual species (Van Valen 1973). The Red Queen Hypothesis assumes that differences in parasitism are attributable to differences in susceptibility between unisexual and sexual species rather than some other factor determining patterns of parasitism (Anderson and May 1982). Other researchers have been critical of the suggestion that parthenogenic species (which are of hybrid origin) might be more susceptible to parasitism and results have been inconsistent when comparing mite load on unisexual and sexual species (Hanley et al.1995; Klukowski 2004).

In the American Southwest, several species of unisexual and sexual whiptails (Teiidae; Reeder et al. 2002) occupy grassland and riparian habitats (Mitchell 1979; Jones and Lovich 2009). We have observed mites on *Aspidoscelis tigris* (Tiger Whiptail), a sexual species, and the unisexual and parthenogenic *A. sonorae* (Sonoran Spotted Whiptail; Taylor and Caraveo 2003). These whiptails occur in native cottonwood (*Populus* spp.), willow (*Salix* spp.), and mesquite (*Prosopis* spp.) habitats and in non-native saltcedar (*Tamarix* spp.) habitat. Non-native *Tamarix* tends to be poor habitat quality for reptiles and supports lower abundances of lizards compared to areas with greater native tree cover (Bateman and Ostoja 2012; Mosher and Bateman 2016). Perhaps scale infestation varies across native and non-native habitats because prevalence of parasites can be an indicator of host health (McCoy et al. 2012) and degree of host stress (Esch et al. 1975).

We were interested in exploring the relationship between mites on whiptail lizards and predictive factors such as microclimate, habitat type, and reproductive mode. Our objectives were to compare the proportion of scales infested by mites between two whiptail species (*A. sonorae* and *A. tigris*) and compare infestation on whiptails from different riparian habitats (*Populus*, *Prosopis*, and *Tamarix*) during different seasons. We also compared the abundance of each whiptail species across the different riparian habitats. We hypothesize that environmental differences of habitats and type of whiptail (unisexual or bisexual) will affect mite loads. We predict a greater proportion of scales will be infested by mites on the unisexual *A. sonorae* and during humid seasonal conditions. We also predict that whiptails (bisexual and unisexual) from non-native habitats will have greater mite infestation. We think mite loads on whiptails may differ because of lizards occupying lower quality or marginal habitats; however, if host abundance might be a better predictor of mite infestation (i.e., lower mites in areas with fewer hosts), then we think mite infestation will be greater in the native habitats.

## Materials and Methods

***Study site***.—Our study site was located along the perennial and alluvial San Pedro River (12S 0524089, 3644361 to 0526018, 3635412) and perennial Gila River (12S 0514627, 3652137 to 515722, 3651749) in Pinal County, Arizona, USA. The San Pedro River supports a large gallery forest of Fremont Cottonwood (*Populus fremontii*) mixed with willow (*Salix* sp.) and mesquite (Stromberg and Tellman 2009). Study sites along the Gila River are dominated by monotypic stands of non-native *Tamarix*. Historically, the Gila River supported native vegetation of cottonwood and willow but has since been replaced with non-native trees (Haase 1972).

***Field data collection***.—We captured whiptail lizards from 18 trap arrays from July to September 2016 and from May to August 2017. Our trap array design included drift-fence arrays with pitfall traps (9 L buckets) and funnel traps patterned after other studies in riparian habitats (Bateman et al. 2008; Bateman and Ostoja 2012). We checked traps daily and identified lizards to species. We marked lizards with a unique toe clip (Waichman 1992). After processing, we released lizards at their point of capture. We categorized data collection into three seasons based on typical moisture regimes of the Sonoran Desert (Willingham 2011); Early (May), Summer (June), and Monsoon (August/September).

To quantify the proportion of scales infested by mites on lizards, we collected whiptails from trap arrays and photographed their ventral side in the field. Once whiptails were placed on their dorsal side, we took three to four photographs with an iPhone 6s Plus (1920-by-1080-pixel resolution; Apple Headquarters, Cupertino, California, USA). For consistency, all photographs were collected and scales counted by a single researcher. Most studies hold lizards in captivity or collect specimens to count mites (Cunha-Barros et al. 2003; de Carvalho et al. 2006; Lukefahr 2013; Zippel et al. 1996) and some studies count mites on lizards in the field (Rubio and Simonetti 2009). However, we used photography instead of euthanizing and collecting lizards in this project to avoid influencing the population for a concurrent species-habitat study. We chose the ventral surface of the lizard as a representative sample of mite infestation because ventral scales on whiptails are large and rectangular (compared to small granular dorsal scales).

From the photographs, we counted the total scales on the ventral side from the inguinal area to the axillary area. Next, we counted any scales that had mites around their edges (Fig. 1). When multiple photographs were taken, we counted scales three times and used the average. In cases when only one mite was present near a scale, we counted it as only one infested scale (Fig. 1). We quantified infestation as a proportion of ventral scales with mites around their edges, which likely reflected an underestimation of infestation (especially in cases with many mites crowded under a single scale; Fig. 1).

We measured microclimate in our study area by recording maximum daily temperature and relative humidity collected at 30 min intervals using data loggers (HOBO Pro v2, Onset Computer Corporation, Pocasset,

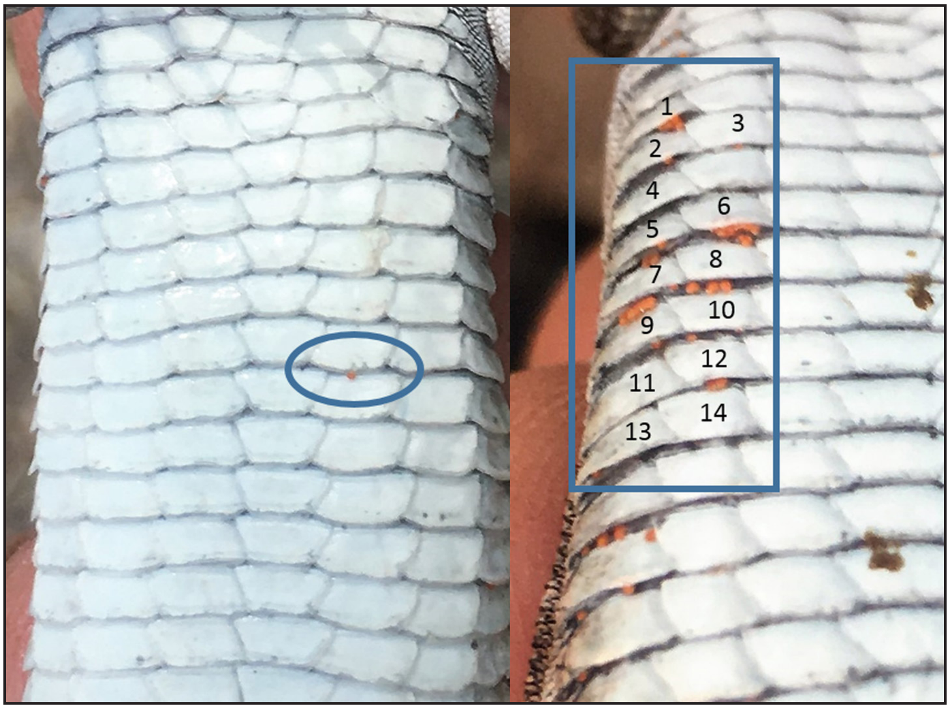

**Figure 1**. Ventral scales of whiptail lizards (e.g., *Aspidoscelis sonorae*). Left image shows a single mite (circled) on ventral belly scales, quantified as one infested scale. Right image shows a cluster of mites (for an example, inside box only) in contact with multiple scales, quantified as 14 infested scales. (Photographed by Lauren N. Jackson).

Massachusetts, USA). We deployed one to three loggers in each riparian forest type during 82 d in 2016 (between June and August) and during 74 d in 2017 (between May and July). We collected precipitation data from a NOAA weather station (number UCS00027530) located in San Manuel, Arizona.

***Data analyses***.—We calculated the percentage of infested scales for each individual by dividing the total number of scales by the number of scales with mites. We assessed mite infestation once per individual captured. The proportion of infested scales did not meet assumptions of normality; therefore, we transformed data based on Legendre and Legendre (2012), using Arcsine data transformation recommended for proportional data with many zeros or used non-parametric tests. Because of the interest in comparing ectoparasites on unisexual and sexual species, we compared infested scales between the two whiptail species. Data were non-normal, so we used a non-parametric Mann-Whitney Rank Sum Test on untransformed data to make comparisons between species.

We related the proportion of infested scales to several predictors including species of whiptail (*A. sonorae* or *A. tigris*), type of riparian habitat (*Populus*, *Prosopis*, or *Tamarix*), and season (Early, Summer, or Monsoon) using Generalized Linear Models in SPSS. We used Akaike Information Criterion for small samples (AICc) to select the most plausible models to explain scales infested by mites. AIC theory is based on a goodness-of-fit measure of candidate model i relative to the other models (Anderson 2007). We selected the most plausible models based the lowest Akaike weights (wi). We ranked models based on ΔAICi scores, where the ΔAICi is the difference in the AIC value between candidate model i, a ΔAICi value of zero indicates the best performing model, and models with ΔAICi < 2 are considered to be ecologically meaningful (Burnham and Anderson 2002).

We calculated relative lizard abundance (hereafter, abundance) as the number of unique individuals captured per 100-trap days. We compared lizard abundance between whiptail species and across the three habitat types using a two-way Analysis of Variance. We performed pairwise multiple comparisons using a Tukey Test. For all tests, α = 0.05.

## Results

***Proportion of infested scales***.—We captured 207 whiptail lizards (114 *A. sonorae* and 93 *A. tigris*) and about 75% of lizards possessed mites on ventral scales. Ventral scale number showed little variability; *A. sonorae* had a mean of 202.2 scales (± 0.84 SE) and *A. tigris* had a mean of 197.3 scales (± 0.88). *Aspidoscelis sonorae* had a mean of 11.3% (± 0.08) of scales infested with

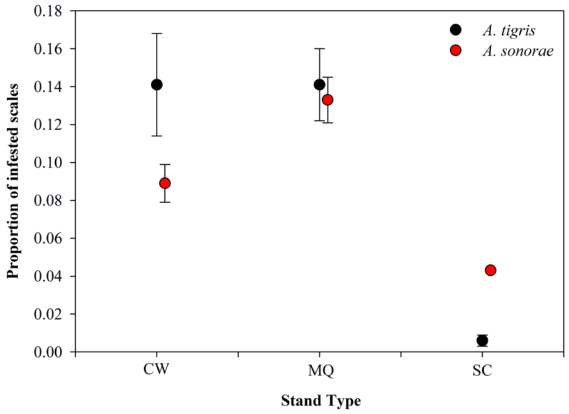

**Figure 2**. Mean (± 1 SE) of the proportion of scales infested by mites per lizard on two species of whiptail lizards (n = 114 parthenogenic *A. sonorae* and n = 93 sexual *A. tigris*). Lizards were captured in three riparian habitat types; CW = native gallery cottonwood forest (*Populus fremontii*), MQ = native mesquite (*Prosopis* spp.) woodland, and in SC = non-native saltcedar (*Tamarix* spp.).

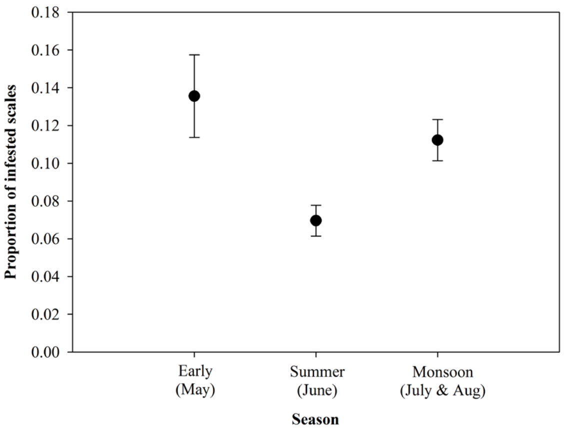

**Figure 3**. Mean (± 1 SE) of the proportion of scales infested by mites per lizard on two species of whiptail lizards (*A. sonorae* and *A. tigris*). Early season included 29 lizards captured during May and Summer seasons included 76 lizards captured in June and early July before monsoon rains commenced, and Monsoon season included 102 lizards captured during the rainy season in July and August.

mites and *A. tigris* had a mean of 8.4% (± 1.2) of scales infested with mites. We determined the parthenogenic species had significantly greater scales infested with mites compared to the sexual species ($U = 3700$, $P < 0.001$). We did consider other factors besides species that were better predictors of infestation.

We compared six models to determine which factors (species, habitat type, and season) were the best predictor of mites on lizards. The top performing model (Table 1) included two factors, habitat type (*Populus*, *Prosopis*, or *Tamarix*) and season (Early, Summer, or Monsoon). The second best model included only habitat type as the best predictor of proportion of scales infested by mites (Table 2) and lizards in non-native *Tamarix* had the lowest infestation (Fig. 2). The proportion of scales infested with mites also varied seasonally, with the lowest rate of infestation during the hot, dry summer (June; Table 2). We observed more infestation during the cooler part of the early summer (May; Table 2) and during the rainy, humid, monsoon season (Fig. 3).

**Table 1**. Ranking of six competing models of factors to predict the proportion of scales infested with mites in two species of whiptail lizards (family Teiidae). Top competing models have a ΔAICi < 2 and lower AICc scores are better. Variables in models include habitat Type (cottonwood, *Populus*; mesquite, *Prosopis*; or non-native saltcedar, *Tamarix* riparian forests), Season (early summer, May; pre-monsoon summer, June; or monsoon, July and August), and Species (unisexual *A. sonorae* and sexual *A. tigris*).

| Model | Variables | AICc | ΔAICi | weights |
|---|---|---|---|---|
| 1 | Type, Season | -181.768 | 0.000 | 0.499 |
| 2 | Type | -180.029 | 1.739 | 0.209 |
| 3 | Species, Type | -179.489 | 2.279 | 0.160 |
| 4 | Species, Type, Species×Type | -179.111 | 2.657 | 0.132 |
| 5 | Species | -103.318 | 78.450 | 0.000 |
| 6 | Season | -96.806 | 84.962 | 0.000 |
|  | Intercept (null model) | -91.779 | 89.989 | 0.000 |

***Lizard abundance***.—During a study to assess herpetofauna abundance and species-habitat relations, we captured 589 whiptail species during 2016 and 2017 over 643 trap nights. Whiptail abundance was greatest in native cottonwood forests for both species and only 13% of captures occurred in the non-native *Tamarix* stand (Fig. 4). Abundance data met the assumption of normality (Shapiro-Wilk, $P = 0.100$) and abundance varied by species and habitat type. *Aspidoscelis sonorae* had greater abundance than *A. tigris* ($F_{1,35} = 13.9$, $P < 0.001$). Whiptail abundance varied by habitat type ($F_{2,35} = 24.6$, $P < 0.001$) and, based on pairwise comparisons, abundance was greater in *Populus* than in *Prosopis* ($q = 6.83$, $P < 0.001$) and was greater in *Populus* than in *Tamarix* ($q = 9.65$, $P < 0.001$). Abundance was not

**Table 2**. Mean and standard error (sample size in parentheses) daily maximum temperature (° C) and monthly precipitation (cm) from the National Oceanic and Atmospheric Administration (NOAA) weather station in San Manuel, Pinal County, Arizona, USA (station number UCS00027530) for 2016 and 2017.

|  | Mean daily max Temp | Mean monthly precipitation |
|---|---|---|
| May | 29.9 ± 0.6 (62) | 0.7 ± 0.6 (2) |
| June | 37.5 ± 0.4 (60) | 2.3 ± 2.3 (2) |
| July | 35.8 ± 1.0 (61) | 6.2 ± 2.0 (2) |
| Aug | 33.2 ± 0.3 (62) | 7.8 ± 1.1 (2) |
| Sept | 31.3 ± 0.4 (60) | 3.2 ± 2.5 (2) |

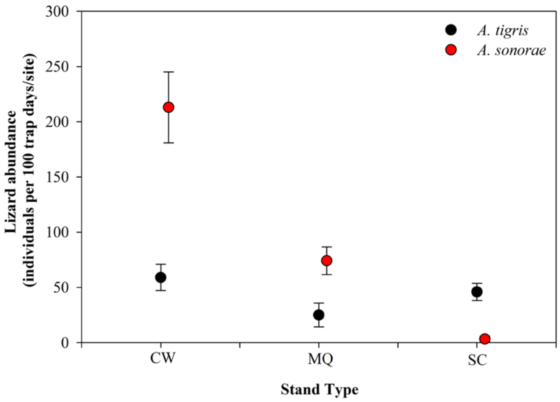

**Figure 4**. Mean (± 1 SE) of the abundance of two species of whiptail lizards (parthenogenic *A. sonorae* and sexual *A. tigris*). Lizards were captured in three riparian habitat types; CW = native gallery cottonwood forest (*Populus fremontii*), MQ = native mesquite (*Prosopis* spp.) woodland, and in SC = non-native saltcedar (*Tamarix* spp.).

significantly different in *Prosopis* and *Tamarix* ($q$ = 2.81, $P$ = 0.132).

***Microclimate***.—Sites were hottest in June during the pre-monsoon season (Tables 2 and 3) and humidity increased steadily and predictably with the arrival of monsoon season in July and August (Table 3). Microclimate was similar across the three riparian habitat types with one exception. Non-native *Tamarix* stands were 20% more humid and 4° C cooler during monsoon season compared to native stands (Table 3).

## Discussion

We evaluated whether the proportion of scales infested with mites differed in two species of whiptail lizards with the prediction that the parthenogenic species would have the highest mite load. Our prediction was met; however, more interesting was the relationship we observed between mite load and environmental conditions such as habitat type and seasonality. Although research has linked ectoparasites to moisture conditions within habitats, our study is among the first to compare ectoparasite load in native and non-native habitats.

Many researchers have investigated how endo- and ectoparasites have affected the fitness and health of unisexual species compared to bisexual species. In our study, parthenogenic lizards had higher proportions of infested scales than sexual *A. tigris*, which is consistent with some studies comparing parasite load in sexual and unisexual species, but not for others. For example, the clonal fish genus *Phxoinus* have sexual and asexual species. The asexual fish had higher endoparasite loads compared to the sexual fish suggesting a fitness or health advantage in the sexual species, but the advantages to this relationship were not identified (Mee and Rowe 2006). However, Hanley et al. (1995) observed that sexual species of geckos from the genus *Lepidodactylus* had higher mite loads than asexual species. Hanley et al. (1995), like other studies, was unable to explain the drivers of mite presence on some species and not others but did suggest that sexual species may be more susceptible to mites because of low genetic diversity compared to the asexual species, which has greater heterozygosity because of their hybrid origin. In our study, heterozygosity was likely similar in both species, as is often found in parthenogenic whiptails in the genus *Aspidoscelis* (Lutes et al. 2010). We suggest that dissimilarities in infested scales between whiptail species may not be related to differences in reproductive mode, but instead linked to whiptail abundance in native and non-native habitats. Over 40% of *A. tigris* from which we quantified mites were from non-native habitats, compared to < 1% of *A. sonorae* occurred there. Therefore, mite infestation may have been more related to host abundance or host habitat preference than to mite preference for specific species of whiptail.

By comparing sympatric species of parthenogenic and sexual whiptails, we were able to consider the relationship of ectoparasite load related to differences in habitat and microclimate. Studies show a positive relationship between mite prevalence and humidity

**Table 3**. Mean and standard error maximum daily temp (° C) and Mean daily humidity (%) by month in three riparian habitat types; CW = native gallery cottonwood forest (*Populus fremontii*), MQ = native mesquite (*Prosopis* spp.) woodland, and in SC = non-native saltcedar (*Tamarix* spp.). Sample sizes are in parentheses (number of days × number of loggers).

| Habitat | May | June | July | August |
|---|---|---|---|---|
| Temperature | | | | |
| CW | 37.8 ± 0.6 (26) | 40.6 ± 0.4 (121) | 40.0 ± 0.4 (105) | 36.5 ± 0.3 (93) |
| MQ | 37.6 ± 0.6 (28) | 41.3 ± 0.4 (115) | 40.1 ± 0.3 (155) | 37.5 ± 0.3 (93) |
| SC | 36.3 ± 0.5 (42) | 39.2 ± 0.3 (156) | 36.0 ± 0.3 (186) | 33.0 ± 0.3 (93) |
| Humidity | | | | |
| CW | 34.8 ± 1.0 (26) | 42.8 ± 1.4 (121) | 54.5 ± 1.4 (105) | 66.1 ± 3.3 (93) |
| MQ | 29.1 ± 5.5 (28) | 36.6 ± 3.4 (115) | 54.6 ± 4.4 (155) | 61.8 ± 6.4 (93) |
| SC | 33.2 ± 0.6 (42) | 41.8 ± 1.0 (156) | 66.5 ± 1.1 (186) | 72.9 ± 1.4 (93) |

created seasonally (Klukowski 2004; Lumbad et al. 2011; Malenke et. al 2011). For example, in Tennessee, USA, Eastern Fence Lizards (*Sceloporus undulatus*) had the greatest level of mite loads in June and July during the hot, humid summer (Klukowski 2004). Mite infestation on lizards decreased in August and September during cooler periods (Klukowski 2004). Lizards that reside in moist cool areas have a higher proportion of scales infested with mites (Rubio and Simonetti 2009). In our study, the increase in humidity coincides with the Sonoran Desert monsoon season, defined as short, high intensity storms occurring during the summer months (Willingham et al. 2011). During the summer, we found mite loads were greatest during the humid monsoon season in July and August compared to hotter or dryer periods. We observed the lowest number of infested scales across lizard species and habitat types during pre-monsoon June, which can be the hottest and driest part of the summer.

Habitat can be an important factor in creating the correct microclimate for the mites to survive (Espinoza-Carniglia et al. 2015; Zippel 1996). Rubio and Simonetti (2009) explored the ties between forest type and microclimate. Fragmented forest edges were sunnier with higher temperatures, lower humidity, and lizards with poorer body conditions compared to lizards that resided in continuous forest. They found lower chigger infestation on lizards from drier, hotter tropical habitats (Rubio and Simonetti 2009). During our research, we supported the relationship between humidity and mite abundance. However, we did not document high mite infestation on lizards during monsoon season from non-native *Tamarix* stands, even though these habitats were the most humid areas. Based on previous studies on reptiles in southwestern riparian areas, we expected abundance of lizards to be greatest in native riparian forest compared to non-native *Tamarix* stands (Bateman and Ostoja 2012; Mosher and Bateman 2016). We found whiptails in *Tamarix* stands had the lowest proportion of infested scales, although this habitat has often been considered lower quality. It seems this nonnative habitat is also lower quality for the host-seeking mite. Therefore, mite load may have been lowest in the non-native vegetation type because of the low abundance of hosts. Although we did not quantify mites in each habitat type, one potential reason for low infestation could be a lack of lizard hosts or lack of mites in non-native *Tamarix*. We suggest that mite infestation may not be related to the microclimate differences between native and non-native forests or related to reproductive modes of whiptails, but instead related to season fluctuations in humidity and temperature and related to abundance of whiptail hosts.

Overall, it is interesting how fluid mite load can be across seasons. Mite life cycles can be closely aligned with humid conditions (García-De la Peña 2011) and, in our study, mites may show similar preferences for whiptail lizard hosts. Some researchers suggest that parasites may not select for specific hosts, but perhaps parasites select for variables related to micohabitat (de Carvalho et al. 2006; Zippel et al. 1996). Parthenogenic species had slightly greater mite infestation on scales, but factors related to forest type with high host abundances and during humid conditions were better predictors for mite infestation rates.

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