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The influence of urbanization on morphological traits in the Balsas Basin Whiptail lizard (*Aspidoscelis costatus costatus*)

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Abstract

Urbanization is the process of wildlands transformation for development of human settlements and the resulting ecosystem presents changes that could affect animal populations. *Aspidoscelis costatus costatus* is an endemic Mexican lizard (Family Teiidae); preliminary observations show possible effects of urbanization on this lizard. We collected 50 *A. costatus costatus* from an urban area in Ixtapan de la Sal, Estado de México, that were compared with 56 *A. costatus costatus* from wildlands close to Ixtapan de la Sal and Tonatico, Estado de México. Weight, snout-vent length and other eight morphometric traits, and three meristic traits were recorded for each specimen. We compared between habitat types (urban and wildlands), the differences in morphological variation (dispersion measures), and morphological shifts (central tendency measures) using univariate and multivariate statistical methods. Multivariate results show morphological shifts, but not significant differences in morphological variation. Therefore, there exist no influence of urbanization in the population canalization. In the univariate analyses, four characteristic show differences in dispersion measures using variance-ratio test for normal traits (axilla-groin length and hindlimb length) and Levene's test for non-normal traits (supraocular scales and femoral pores). Likewise, eight characteristics show differences in central tendency using ANCOVA with snout-vent length as covariate for morphometrics traits (limb measurements, head measurements and axilla-groin length) and Mann-Whitney *U* test for meristic traits (femoral pores). The differences in some morphometric traits could be explained by the flight requirements of the population in the urbanized habitat; in addition, the differences in femoral pores may be related with chemical pollution.

Keywords *Aspidoscelis costatus costatus* · Estado de México · Urbanization · Morphological variation · Morphological shifts · Human settlement

Introduction

The human population continues to alter ecosystems around the world (Horiuchi 1992; Vitousek et al. 1997) and wildlands are being urbanized in a process that gradually transforms them into urban lands with some degree of relatively permanent human presence (Marzluff et al. 2001). As a result of urbanization, the land is increasingly fragmented into areas with new climatic conditions, modified vegetation structures and human constructions (Bradley 1995; Koenig et al. 2002; McKinney 2002; Nowak et al. 2016). Those environmental conditions produce environmental stresses on animal populations that can induce rapid changes in some morphological characteristics (Hoffmann and Hercus 2000). In reptiles some of these changes are: the induction of fluctuating asymmetry (Lazić et al. 2013), reduction in body condition (Lazić et al. 2017), increase in wound occurrences (Koenig et al. 2002; Winchell et al. 2019), and modification of typically invariable diagnostic characteristics. That is, morphological characteristics that are unique and constant in the species, therefore are considered of importance for its taxonomy (Gómez-Benitez et al. 2016). Urbanization can also induce changes in morphometric and meristic traits of lizards; some studies have reported that urban lizards are larger and lighter (in mass) with larger limbs than wild lizards (Iglesias et al. 2012; Winchell et al. 2016).

Hoffmann and Parson (1997) and Hoffmann and Hercus (2000) established that when an animal population reaches a new environment, an increase in the phenotypic variation normally occurs, some studies report an increase in genetic variation

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of reptile species when they inhabit cities (Delaney et al. 2010; Lazić et al. 2015). Nevertheless, there have been cases in which urbanization did not generate any consequences on genetic variation (Rubin et al. 2001) or produce the opposite effect to those previously exposed (Noël et al. 2007).

In the last 5 years, the more widely studied group of lizards in urban habitats were species of the genus *Anolis* (Kolbe et al. 2015; Winchell et al. 2016; Chejanovski et al. 2017; Winchell et al. 2018). In México, among the few studies of lizards in urbanized habitats included diet and reproductive changes in the gecko *Gehyra mutilate* (Barragán-Ramírez et al. 2015) and extirpation of populations of *Aspidoscelis* in Central Mexico (Hernández-Gallegos et al. 2009). We provide the first study of morphological changes in teiid lizards in Mexican urban habitats. *Aspidoscelis costatus* comprises a diverse clade of lizards (Barley et al. 2019) that, according to Duellman and Zweifel (1962), invariably possess enlarged postantebrachial scales. However, Gómez-Benitez et al. (2016) recorded in an urbanized habitat, an individual of *Aspidoscelis costatus costatus* with slightly enlarged postantebrachial scales. This record and diverse field observations indicated the need to assess the additional effects of urbanization on *A. costatus costatus*. This species, commonly named Balsas Basin Whiptail lizard, is endemic to México and distributed at different elevations in the states of México, Guerrero, Morelos, Puebla, Tlaxcala, and Oaxaca (Maslin and Secoy 1986; Rodríguez-Romero et al. 2003; Gómez-Benitez et al. 2016; Méndez-de la Cruz et al. 2018; Barley et al. 2019). It is considered a species of least concern by the IUCN Red List (Frost et al. 2007), but it is under special protection by Mexican laws (SEMARNAT 2010), and ranked as 11 placing it as a species with a medium vulnerability according to EVS (Wilson et al. 2013). The objective of the present study was to evaluate the effect of urbanization on the morphology of *A. costatus costatus*, specifically, changes in morphological variation (dispersion) and morphological shifts (central tendency) compared to wild populations.

Material and methods

Study area

We collected individuals of *A. costatus costatus* in an urbanized population in the municipality of Ixtapan de la Sal, Estado de Mexico (18°50′34.5” N, 99°40′51.8” W) with an elevation of 1800 m. Ixtapan de la Sal is a small city with a population of 33,541 inhabitants (INEGI 2010). The climate is semi-warm subhumid with rainfall primarily in summer, the temperature ranges from 14 °C to 22 °C and a mean annual precipitation between 1000 and 1200 mm throughout the year (INEGI 2009). The urban footprint of this city is constantly growing and altering land previously occupied by agriculture, grasslands and wildlands (natural environment not build or cultivated). Degree of urbanization was determined using the settlement landscape criteria proposed by Marzluff et al. (2001): percent land covered by buildings, building density and residential human density. Ixtapan de la Sal is within the urban category with 52% of the area with buildings, and a density of 22 buildings per hectare, of which 16 are dwellings according to Gómez-Benitez (2017). *Aspidoscelis costatus costatus* were captured within private property in an urban habitat near an asphalt road. A wide variety of grasses and herbaceous annual and perennial plant species (i.e., *Tridax coronopifolia*, *Thunbergia alata* and *Phaseolus vulgaris*) were along sidewalks and driveways and in small limestone barrens; moreover, an introduced South American tree species (*Jacaranda sp.*) and introduced landscape ornamentals shrubs mainly of the family Cupressaceae were also found. Cats and dogs were potential domesticated predators on lizards at the study site, whereas *Bassariscus astutus* (Ring-Tailed Cat) was a potential natural predator.

Sampling and data collection

We collected *A. costatus costatus* by hand, turning rocks or employing a drift fence and transported them in blanket bags to the Laboratorio de Herpetología of the Facultad de Ciencias of the Universidad Autónoma del Estado de México. We recorded the weight of each individual, assessed snout-vent length (SVL), axilla-groin length (AGL), femur length (FemL), hindlimb length (HLL), forelimb length (FLL), longest finger length (FiL), head width (HW), head height (HH) and head length (HL), and three meristic measures [femoral pores (FP), supraocular scales (SO) and subdigital lamellae (SDL)]. To sex the individuals, we considered post-cloacal scales (Ashton, 2003). Processed animals from urban population were released where they were collected.

We also recorded both, morphometric and meristic features, in individuals of a wild *A. costatus costatus* population in Ixtapan de la Sal, Estado de México (18°50′31“ N, 99°39’5” W) with an elevation of 2076 m and Tonatico (18°45′17.1“ N, 99°37’20.1” W) with an elevation between 1500 and 1600 m. Specimens of the wild populations had been captured, and used for previous studies (Pérez-Almazán 2007; Granados-González et al. 2015; López-Moreno et al. 2016). Both populations fit in wildlands category according to Marzluff et al. (2001), in Ixtapan de la Sal *A. costatus costatus* population is located on the outskirts of the city within a tropical deciduous rainforest and coniferous forest and in Tonatico wild population is located near to a rural population in a tropical deciduous rainforest.

Data analysis

We conducted a principal component analysis (PCA), based in a correlation matrix, to determine the pattern of morphological variation, applying a size correction to morphometric traits (SVL was not used in the PCA; Villamil et al. 2017). We compared the principal components in PC1, PC2 and PC3 (due that principal components achieve an eigenvalue major than 1; PC1 = 4.12, PC2 = 1.40, PC3 = 1.18) with a variance-ratio test (to evaluate differences in dispersion measures, thereafter referred as morphological variation) and student's t test (to evaluate differences in central tendency measures, thereafter referred as morphological shifts) between urban and wild populations. PC1 was Box-Cox transformed to meet the assumptions of the parametric test using the following equation:

$$Y = \frac{X^{\lambda}-1}{\lambda}$$

Where:

X = The data to be transformed, we added a constant 7.7094 to all PCA scores in order to avoid zero or negative values.

λ = Parameter of the Box-Cox transformations family. The value used was 1.7851 calculated by maximizing the log likelihood function:

$$L(\lambda) = \frac{-n}{2} ln\sigma_{\lambda}^{2} + (\lambda-1)\sum_{i=1}^{n} lnx_i$$

Where:

σ_{λ}^{2} = variance of the transformed data.

We also assessed morphological variation in a univariate analysis comparing the standard deviation of the morphometric data using a variance-ratio test (Zar 1999). We evaluated variation in meristic traits with the Levene's test because these had a non-normal distribution.

The morphological shifts were determined by comparing the size corrected morphometric measurements with an ANCOVA using the degree of urbanization as a factor and SVL as a covariate between urban and wild populations. A Mann-Whitney *U* test was conducted for the meristic traits. All the hypothesis tests consider an $\alpha = 0.05$ of significance threshold. A multifactorial ANOVA to compare principal components, employing municipality, habitat type and sex as factors, was conducted in order to explain the effect of sex and geographic location in our results. The statistical analysis were conducted with the software Statgraphics Centurion XVI.II except the Box-Cox transformation which was conducted with PAST3.

Results

We compared 50 individuals from the urbanized population with 56 wild individuals collected in Ixtapan de la Sal ($n = 36$) and Tonatico ($n = 20$). The first three principal components for interpretation summarized 56% of the variation: PC1 = 34.4%, PC2 = 11.7%, PC3 = 9.9%. The comparison of the principal components shows a statistically significant difference between urban and wild lizards in the components 1 and 2 (PC1: df = 105; t = −11.3837; P < 0.0001; PC2: df = 105; t = −3.1875; *P* = 0.0019; PC3: df = 105; t = 1.1833; *P* = 0.2393). Loads in PC1 shows high importance of HH, FLL, HW, HLL, FemL and weight. In the second component, HL, FP and AGL have the highest loads (Fig. 1). The variance-ratio test shows no differences in standard deviations between urban and wild lizards in any of the three considered components (PC1: *P* = 0.8553; PC2: *P* = 0.3668; PC3: *P* = 0.7494). Multifactorial ANOVA reveals that, independently of sex and municipality, there are significant differences in PC1 (df = 105; F = 62.33; P < 0.0001) and PC2 (df = 105; F = 13.26; *P* = 0.0004) but not in PC3 (df = 105; F = 1.14; *P* = 0.2879).

The univariate analysis of morphological variation showed differences in just four of 12 variables: AGL, HLL, SO and FP (Tables 1 and 2), this agrees with the results of multivariate analysis. The morphometric traits present a higher variation in urban lizards (Table 1) and meristic traits in wild lizards (Table 2). The univariate comparison of morphological shifts showed that the morphology of *A. costatus costatus* differs significantly between habitat types in most of the evaluated characteristics. Urban lizards have longer limbs, smaller longest finger length, smaller heads and a minor axilla-groin length. In addition, there is a difference in the number of femoral pores in which wild population have a higher median than urban lizards (Tables 1 and 2).

Discussion

Variation in urban populations is commonly reduced, at the genetic level, by the isolation occasioned by human construction (Delaney et al. 2010). The urban population of *A. costatus costatus* that we studied is highly isolated and abundant (more than 50 individuals inhabiting 0.27 ha), its morphological variation is equal to wild lizards so, anthropogenic-related isolation does not affect morphological variation in this species. Hoffmann and Hercus (2000) reported that environmental stress caused by adverse environmental conditions, could produce changes in the morphological characteristics of reptiles. Our comparison of morphometric and meristic characteristics shows that the urban population of *A. costatus costatus* is different from wild populations in most of the evaluated characteristics.

Canalization refers to an organisms' capacity to follow a predetermined embryonic development pathway perhaps of habitat and genetic perturbations, then, it reduces phenotypic variation directing the intraspecific development in a similar way (Zakharov 1992; Willmore et al. 2007). If under stress conditions, canalization often becomes less restrictive

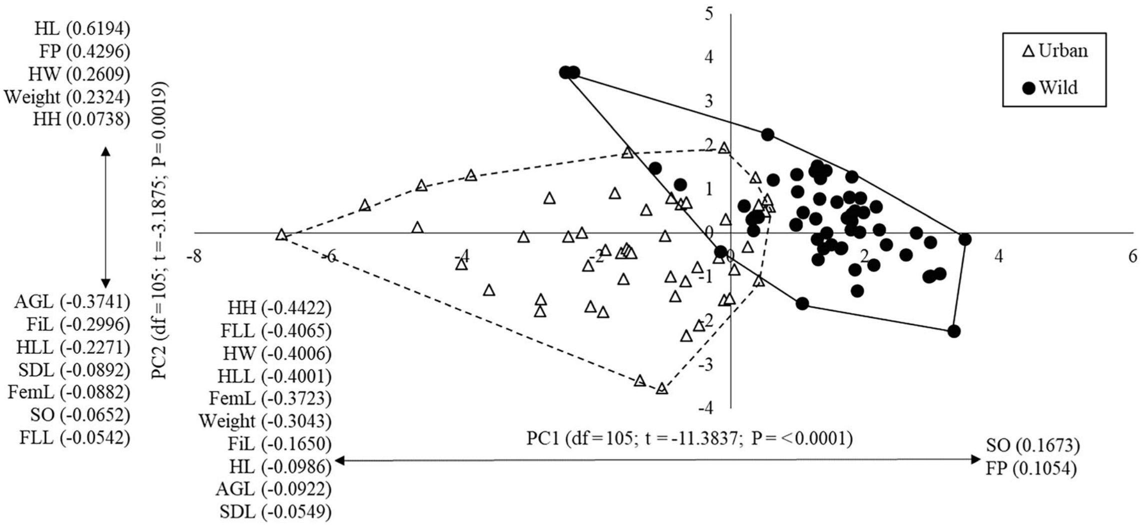

Fig. 1 Principal components analysis of morphometric and meristic traits of *Aspidoscelis costatus costatus* in urban and wildland habitats from Ixtapan de la Sal and Tonatico, Estado de México, México. At both sides of the axis are the PC loads for each variable

(Rutherford 2000), stress due to urbanization has been reported as a canalization's antagonist in the lizard *Podarcis muralis* (Lazić et al. 2015), considering this, phenotypic variation is expected to increase. Our results indicate that morphological variation in *A. costatus costatus* shows differences in measures of central tendency in the first two principal components but equal variation between population types, and significant difference on variation in only four univariate traits. These results show no effect of urbanization in the canalization of lizards (i. e. both, urban and wild lizards, are following a determined developmental pathway, even when that pathway is different inter-population, it is equal intrapopulation), and therefore, no influence on variation, which differs from the results commonly observed (Delaney et al. 2010; Lazić et al. 2015).

Urbanization of Ixtapan de la Sal (from 13,703 people in 1970 to 33,541 people in 2010; INEGI 1970, 2010) is a recent process, perhaps too recent for genetic changes. Due of the presence of morphological shifts and the similarity of morphological variation, we conclude that plasticity plays an important role in the stability of the "urban morphology" of the *A. costatus costatus* population from the city. The consensus results in both, morphological variation and morphological shifts, between univariate and multivariate ways denote the robustness of our results.

Some of the characteristics in which we found a significant difference could be related to escape behavior (higher mean of FemL, HLL and FLL). These results accord with those obtained by Batabyal et al. (2017) who reported that males of *Psammophilus dorsalis*, an agamid lizard species, presents changes in its escape strategies when it inhabited urban systems. The number of subdigital lamellae is another indicator of the influence of flight in the urban population. Although it does not present a significant difference in the number of subdigital lamellae, there is a difference in the length of the longest finger, in which these scales are found, with the wild lizards having a major longest finger length. Therefore, the same number of subdigital lamellae is distributed in a smaller area in the urban lizards allowing them to generate more force

Table 1 ANCOVA to compare the means of the morphometric traits and variance-ratio test to compare the standard deviation of the morphometric traits of *Aspidoscelis costatus costatus* between two habitat types (urban and wildland) from Ixtapan de la Sal and Tonatico, Estado de México, México. Table shows mean ($\bar{x}$) ± standard deviation (SD), the statistical test (ANCOVA = F and variance-ratio = F) and the significance level (P), highlighting the significant values in bold

	Urban habitat $\bar{x}$ ±SD	Wildland habitat $\bar{x}$ ±SD	ANCOVA		Variance-ratio test	
			F	P	F	P
Weigth	18.9 ± 10.2	22.8 ± 8.8	2.26	0.1359	0.8259	0.4967
AGL	43.1 ± 8.7	46.5 ± 5.6	76.61	**<0.0001**	3.4208	**<0.0001**
FemL	17.3 ± 3.9	15.0 ± 2.2	199.85	**<0.0001**	0.8605	0.5940
HLL	30.2 ± 6.4	25.4 ± 2.9	108.16	**<0.0001**	4.8173	**<0.0001**
FLL	17.6 ± 3.8	15.6 ± 2.1	5.82	**0.0176**	1.6725	0.0633
FiL	21.3 ± 3.4	22.0 ± 2.5	24.78	**<0.0001**	1.4557	0.1741
HW	11.7 ± 2.5	12.0 ± 1.8	91.90	**<0.0001**	0.6917	0.1899
HH	10.7 ± 2.1	10.5 ± 1.3	1.71	0.1944	1.3554	0.2705
HL	17.1 ± 3.3	19.2 ± 2.5	11.62	**0.0009**	1.7034	0.0545

Table 2 Mann-Whitney's *U* test to compare the medians and Levene's test to compare the variance of the meristic traits of *Aspidoscelis costatus costatus* between two habitat types (urban and wildland) from Ixtapan de la Sal and Tonatico, Estado de México, México. Table shows the median (Me), the statistical test (Mann-Whitney = *U*), variance (σ^2) and significance level (P) of the Levene's test, highlighting the significant values in bold

	Urban habitat Me [σ^2]	Wildland habitat Me [σ^2]	Mann-Whitney test		Levene's test
			U	P	P
SO	8 [0.2]	8 [0.5]	1515	0.2777	**0.0439**
FP	34.5 [2.8]	35.5 [6.5]	1854	**0. 0036**	**0.0089**
SDL	33 [3.6]	32 [3.7]	1205	0. 2118	0.5760

on the ground during the escape and to hold on better to smooth surfaces, a conclusion also reached by Winchell et al. (2016). This could be tested with a rail experiment using soft and rough substrate to compare speed between urban and wild lizards and assess the correlation of the speed in different substrates with morphological characteristics related to fleeing. Urbanization can modify some biotic interactions that are often related to these changes in morphology and escape behavior. Tyler et al. (2016) demonstrated that urban lizards have the greatest amount of autotomized tails in the studied populations (reflecting a higher predator encounter rate and/or a higher survival rate). Additionally, Chejanovski and Kolbe (2019) found a relationship with body size in *Anolis sagrei* and predator abundance in urban habitats. Even if the predator abundance or the encounter rate do not increase, animals can perceive humans as potential predators (Frid and Dill, 2002) inducing species to flee.

The number of femoral pores is used as a measure to determine how much the species invest and engage in chemical signaling; fewer receptors would indicate a lower energy investment in signaling which may be affected by adverse environmental conditions (Baeckens et al. 2014). When transmission is hampered, animal species will no longer use the chemical method and will seek other alternatives (Endler 1993; Hews and Benard 2001; Stevens 2013). The urban population studied may have reduced the number of femoral pores to avoid an energetic expense that does not have any benefit, since the signaling is interrupted by urbanization conditions such as chemical contamination (Candolin and Wong 2012), but further studies to assess the relationship between some air contaminants and femoral pores number are needed.

According to Gómez-Benitez et al. (accepted), the ontogenetic change in both dorsal and ventral color pattern occurs in the urban studied population just as in wild populations (based on Zweifel 1959), denoting no relationship between ontogenetic change in dorsal color pattern and the habitat conditions. However, our study of morphological variation and morphological shifts in urbanized animal populations can provide information about environmental stress occasioned by anthropogenic activities across time. Those measures let us know if the species inhabiting urban habitats will need management strategies for its conservation or the morphologic changes registered allow them to survive, in this case, *A. costatus costatus* could survive by its own in urban ecosystems. We suggest the use of the procedures used in this study to assess lizard species health in urban habitats. The presence of teiid lizards in urban habitats may be used as indicator of environmental health (De Andrade et al. 2019), in addition, we can track the principal characteristics of urbanization that affects animals analyzing the modified traits and establish conservation strategies for both, perturbed habitat and lizards. Finally, our study can be replicated and extended to other herpetofauna taxa which inhabits the zone (i. e., *Sceloporus*, *Urosaurus* and *Eleutherodactylus*).

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Authors contribution All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Aldo Gómez-Benitez, Ana Esthela López-Moreno and Oswaldo Hernández-Gallegos. The first draft of the manuscript was written by Aldo Gómez-Benitez, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

Scientific Collector Permit FAUT 0186, SEMARNAT.

The whole study was conducted following ethical norms for animal experiments and procedures for research at the Universidad Autónoma del Estado de México.

Welfare of animals All the organisms collected were returned to the exact place where they were found without any kind of injuries.

Conflict of interest The authors declare that they have no conflict of interest.

Availability of data and material The data that support the findings of this study are available from the corresponding author, Gómez-Benitez, A.

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