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# Sexual Dimorphism and Reproductive Characteristics of the Cozumel Spiny Lizard, *Sceloporus cozumelae* (Squamata: Phrynosomatidae) from Mexico

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**Abstract: We analyzed sexual dimorphism and reproductive characteristics (minimum size at sexual maturity, clutch size, and reproductive period) of females and males of *Sceloporus cozumelae*, a species endemic to the Yucatan Peninsula, Mexico, and which belongs to the *Sceloporus variabilis* group. Sexual dimorphism was recorded, with the males being larger in snout–vent length, head length, head width, forearm length, and tibia length. The average clutch size was 3.4. Females containing eggs and vitellogenic follicles were observed at the same time, indicating that the population produces at least two clutches annually. Minimum size at sexual maturity was similar for both sexes (40 mm), and reproduction, determined according to the months in which gonads were obtained, was synchronous between males and females. The species shows high similarity to populations of *S. variabilis* in sexual dimorphism and reproductive characteristics; however, it has smaller snout–vent length when compared to other populations of *S. variabilis* in Mexico.**

Key words: Endemic species; Life history characteristics; Morphological characteristics; *Sceloporus variabilis* group

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## Introduction

To date, extensive studies have been published on the natural history of both oviparous and viviparous lizard species (Fitch, 1970; Tinkle et al., 1970; Du et al., 2005; Wang et al., 2011). Classical studies often treated anecdotal data on the natural history of some species (Fitch, 1970). Subsequently, based on these studies, a high number of studies were carried out to test ecological and evolutionary hypotheses regarding life history evolution using lizards as models (Roitberg et al., 2015; Cruz-Elizalde and Ramírez-Bautista, 2016). These studies documented variation in some life history characteristics, such as fecundity (Ramírez-Bautista et al., 2011; Pincheira-Donoso and Hunt, 2017; Roitberg et al., 2015; Schwarz and Meiri, 2017), growth rate (Pérez-Mendoza et al., 2013; Pérez-Mendoza and Zúñiga-Vega, 2014), reproductive cycles (Cruz-Elizalde and Ramírez-Bautista, 2016; Ramírez-Bautista et al., 2017), and sexual size dimorphism (Cox et al., 2003). Nonetheless, these studies have been carried out on common species with wide distributions, and very little is known about uncommon or endemic species (Ramírez-Bautista et al., 2017; Zúñiga-Vega et al., 2017).

Reproduction and sexual size dimorphism of the genus *Sceloporus* are well documented not only in large populations of small-bodied oviparous species, such as *Sceloporus aeneus* (Manríquez-Morán et al., 2013; Ramírez-Bautista et al., 2016), *S. siniferus* (Hierlihy et al., 2013; Ramírez-Bautista et al., 2015), and *S. scalaris* (Ramírez-Bautista et al., 2017), but also in larger-bodied oviparous (*S. spinosus*, Valdéz-González and Ramírez-Bautista, 2002; Valencia-Limón et al., 2014; *S. variabilis*, Cruz-Elizalde and Ramírez-Bautista, 2016) and viviparous species (*S. formosus*, Ramírez-Bautista and Pavón, 2009; *S. grammicus*, Hernández-Salinas et al., 2010). Nothing is known about the natural history of endemic *Sceloporus* species with restricted distribution (microendemics). An example of these species is *S. cozumelae*, which is endemic to southeastern Mexico, and it has poorly studied with respect to its reproduction, sexual dimorphism, and general ecology (Lee, 1996).

*Sceloporus cozumelae* exhibits one of the smallest snout–vent length (SVL) of any species in the *Sceloporus variabilis* group (Leaché et al., 2016). This terrestrial lizard is oviparous and swift-moving, and inhabits beaches and coastal strands (Lee, 1996). We present information about the morphology and reproduction of a population from Puerto Morelos, Quintana Roo, Mexico. Our goal is to provide information on sexual size dimorphism and reproduction of males and females of *S. cozumelae* and to compare these data to those from populations of *S. variabilis*. Because this species belongs to the *Sceloporus variabilis* group, we expected some of its morphological and reproductive characteristics to be similar to those observed in populations of *S. variabilis*.

## Materials and Methods

### *Study site*

The data were obtained from April 1980 to September 1992 at Puerto Morelos, Quintana Roo (20°51'13" N, 86°52'31" W; datum WGS84) at elevations 3–5 m. The topography of this locality is uniform, with scarce relief; the climate is warm and subhumid. Mean annual temperature is 26.3°C, with a maximum temperature of 35.5°C and a minimum of 13°C in winter. Rains occur in summer and autumn (June–October); mean annual precipitation is 1,041 mm; cyclones and hurricanes are active from June to November (INEGI, 2017). For this study, we analyzed 87 adults (38 females and 49 males); these lizards came from scientific collections, including the Colección Nacional de Anfibios y Reptiles of the Instituto de Biología (CNAR-IBH) at the Universidad Nacional Autónoma de México (Appendix I). The first author verified the species identification in the scientific collection in 1999, which were collected from 1980 to 1992 (April, 1 female and 4 males; May, 14 females and 5 males; June, 14 females and 26 males; September, 9 females and 14 males). Because no differences were observed in the morphological and reproductive variables among years (ANCOVA, F=2.841, df=5, 84, P=0.211), they were pooled for analysis.

*Sexual dimorphism*

We took the following measurements of each lizard to the nearest 0.01 mm: SVL, head length (HL: distance from the anterior tip of the rostral scale to the posterior margin of the left ear), head width (HW: maximum width of the head measured as the distance between the posterior margin of the left and right ears), tibia length (TL: measured from the knee to the pad of the foot), and forearm length (FL: measured from the elbow to the pad of the foot) (Metzger and Herrel, 2005; Ramírez-Bautista et al., 2014). An analysis of covariance (ANCOVA) was conducted to analyze sexual dimorphism. The function of the ANCOVA was to eliminate the effect of SVL (covariate) on the dependent variables (HL, HW, TL, and FL) (Zar, 2010). The data are presented as mean±1SE.

*Reproduction*

The smallest female containing enlarged vitellogenic follicles or oviductal eggs was used as an estimator of minimum SVL at maturity (Lozano et al., 2014; Ramírez-Bautista et al., 2015, 2017). Males were considered sexually mature if they contained enlarged testes and highly convoluted epididymides, which typically are associated with sperm production (Lozano et al., 2015). Testes, non-vitellogenic follicles (NVF) (previtellogenic follicle), vitellogenic follicles (VF), and eggs (E) were removed and measured. These classes of follicles (NVF, VF, and E) were also used to measure gonad volume (Ramírez-Bautista et al., 2015). In addition, liver and fat body mass were removed and weighed (to the nearest 0.0001 g) (Ramírez-Bautista et al., 2015). A one-way analysis of variance (ANOVA) was performed on organ masses with month as a factor to determine whether there was significant monthly variation (Ramírez-Bautista and Vitt, 1997; Ramírez-Bautista and Pavón, 2009). ANOVA was also used to determine variation of liver and fat body mass among months for each sex.

*Clutch size*

Clutch size was quantified by counting the number of eggs in the oviduct of adult females during the reproductive season. Females with eggs and VF simultaneously were considered to have at least two clutches. Due to data that were not normally distributed (by the Kolmogorov-Smirnov test), mean clutch size based on the counts of VF and eggs, as well as SVL of the females containing them, were compared using a Mann-Whitney U-test. Pearson's correlation coefficient was used to test for a possible relationship between clutch size and the SVL of females (Ramírez-Bautista et al., 2015, 2016). We assessed significance at $P<0.05$. All statistical analyses were performed using Statistica 7.0 (StatSoft, Inc., Tulsa, OK, USA).

## Results

*Sexual dimorphism*

Males were larger ($\bar{x}$=48.1±0.67 mm; range=40.0–58.0) than females ($\bar{x}$=46.5±0.42 mm; 40.0–52.0) in SVL (Mann-Whitney U-test, U=574, P=0.007). All characteristics that were measured exhibited sexual dimorphism, with males always being larger than females (Table 1).

*Reproduction*

Males reached sexual maturity at the same size as females at 40 mm. Reproductive activity for males and females was recorded from April to September. No differences in gonad volume in males ($\bar{x}$=58.0±32.3 $mm^3$; range=0.628–1571.2 $mm^3$) were found among months (F=0.331, df=3, 44, P=0.994). The data showed that reproductive activity of males started in April (7.63±4.34 $mm^3$, n=4) and increased in May (38.9±6.91 $mm^3$, n=5), with a maximum in June (87.5±59.4 $mm^3$,

TABLE 1. Mean±1SE, with range in parentheses, of morphological characteristics of adult females and males of *Sceloporus cozumelae* from Puerto Morelos, Quintana Roo, Mexico (SVL=snout-vent length, HL=head length, HW=head width, FL=forearm length, and TL=tibia length). Comparisons were made with an ANCOVA taking SVL as the covariate, except for SVL for which Mann-Whitney U-test was conducted. *U value.

| Characteristics | Females (n=38) | Males (n=48) | ANCOVA | | |
|---|---|---|---|---|---|
| | | | F | df | P |
| SVL | 46.5±0.42 (40.0–52.0) | 48.1±0.67 (40.0–58.0) | 574* | na | 0.007 |
| HL | 12.1±0.10 (10.8–13.6) | 12.9±0.16 (10.7–15.9) | 9.77 | 1, 84 | 0.002 |
| HW | 8.3±0.11 (6.7–9.5) | 9.1±0.13 (6.7–10.9) | 11.53 | 1, 84 | 0.001 |
| FL | 7.2±0.07 (6.6–8.2) | 7.9±0.13 (5.7–9.8) | 11.48 | 1, 84 | 0.001 |
| TL | 10.8±0.13 (9.6–13.8) | 11.9±0.29 (10.1–13.9) | 4.53 | 1, 84 | 0.036 |

n=26), followed by a decrease in September (21.6 mm$^3$, n=13).

An ANOVA revealed no differences in gonad volume of females among months (F=1.684, df=3, 34, P=0.188). One female from April showed an egg volume of 15.97 mm$^3$, female egg volume then increased in May (203.63±48.2 mm$^3$, n=14), decreased in June (75.9±36.3 mm$^3$, n=14), and increased again in September (168.81±59.7 mm$^3$, n=9). One female from April showed VF; of 13 females from May, four had NVF and nine contained eggs; in June, of 14 females, four had NVF, and seven showed VF; and in September, of nine females, three had NVF, one showed VF, and five contained eggs. Females with NVF (SVL, $\bar{x}$=45.3± 0.91 mm, n=11), VF ($\bar{x}$=45.8±0.66 mm, n=10), and E ($\bar{x}$=46.7±mm, n=17) did not differ in SVL (F=0.998, df=2, 33, P=0.379).

*Clutch size*

Clutch size in VF ($\bar{x}$=3.2±0.32, n=9) and eggs ($\bar{x}$=3.5±0.42) were not different (Mann-Whitney U-test, U=37.5, P=0.567). Clutch size pooled from both VF and eggs was 3.4±0.29 (2–8 eggs), with egg volume of 302.11±31.5 mm$^3$ (145.2–506.1 mm$^3$). SVL of the females that contained VF and eggs did not significantly differ from each other (Mann-Whitney U-test, U=75.5, P=0.913). Clutch size was correlated with females' SVL (r=0.51, F=8.36, df=1, 25, P=0.008). Fat body mass was not different among months during reproductive activity for males (F=0.580, df=3, 25, P=0.634) or females (F=0.81, df=3, 22, P=0.503). A similar pattern occurred for liver mass in both males (F=1.9, df=3, 25, P=0.173) and females (F=0.407, df=3, 22, P=0.749).

## DISCUSSION

We know practically nothing about the natural history of *S. cozumelae* (Lee, 1996), and thus, our study on sexual dimorphism and reproduction represents the only information on those topics for the species. It is well known that in the genus *Sceloporus* sexual size dimorphism can follow any of three patterns; male-biased, female-biased, or no dimorphism (Fitch, 1978; Ramírez-Bautista et al., 2013; Jiménez-Arcos et al., 2017). Males of *S. cozumelae* were larger than females in all analyzed characteristics. This pattern in sexual size dimorphism is the most common in species of *Sceloporus* (Fitch, 1978; Ramírez-Bautista et al., 2013). For example, in *S. variabilis* (Cruz-Elizalde et al., 2017), *S. siniferus* (Ramírez-Bautista et al., 2015), and *S. aeneus* (Ramírez-Bautista et al., 2016), males were larger than females.

Males of many lizard species of the Phrynosomatidae family are known to be territorial (Fitch, 1978), and they are usually larger in many morphological traits and often brighter in color pattern (belly, chest, and throat) than are females (e.g., *S. formosus*, Ramírez-Bautista and Pavón, 2009; *Urosaurus bicarinatus*, Ramírez-Bautista et al., 1995). These patterns of morphology and coloration (bright colors) differences between males and females in phrynosomatid species have been favored mainly by male-biased sexual selection (Olsson et al., 2002; García-Rosales et al., 2017). Males of *S. cozumelae* might follow the same pattern, at least in morphology, because they are territorial, but the color patch has been reported to be lost in males (Ossip-Drahos et al., 2016).

Our data on reproduction show that males and females of *S. cozumelae* are synchronized with respect to gonadic activity. This species belongs to the *Sceloporus variabilis* group, in which males are reproductively active throughout the whole year (Ramírez-Bautista et al., 2006; Cruz-Elizalde and Ramírez-Bautista, 2016). Minimum SVL at sexual maturity for males and females were similar (40 mm), which is smaller when compared to populations of *S. variabilis* (42–57 mm) (Cruz-Elizalde and Ramírez-Bautista, 2016).

Male reproductive activity determined by high testes volume was observed during May, June, and September, a pattern similar to those found in populations of *S. variabilis* (Cruz-Elizalde and Ramírez-Bautista, 2016) and other species that display continuous reproduction, such as *S. siniferus* (Ramírez-Bautista et al., 2015). This continuous reproduction, as in many oviparous species, is related to the availability of food resources in the environment (Ballinger, 1979; Ramírez-Bautista and Vitt, 1997). In *S. cozumelae*, a high energetic cost would be invested in reproduction because minimum fat body size was in May and September. However, males showed the highest fat body and liver mass in June, which was the month of the reproductive peak. This pattern could also be related to and explained by the abundance and quality of food (insects) during the rainy season (Ballinger, 1977), at the beginning of June, as it is important for spermatogenesis, as well as vitellogenesis and embryonic development in females (Guillette and Casas-Andreu, 1987). Reproductive activity of females was similar to that of the males; i.e., synchronized. Females with VF were found in April, May, June, and September, and all females showed VF (in ovary) and eggs in the oviduct. Females produced the highest number of VF and eggs in May (9/13), June (10/14) and September (6/9) when fat body and liver mass decreased. Overall, continuous rain throughout the year with particularly high precipitation from June to October may lead to the high availability of food resources throughout the year and would enable males and females to have a long reproductive period, as occurs in other species of lizards (Méndez-de La Cruz et al., 1992; Ramírez-Bautista et al., 2006; Hernández-Salinas et al., 2010; Cruz-Elizalde and Ramírez-Bautista, 2016).

Females of *S. cozumelae* from this population had a mean clutch size of 3.4 eggs, which is similar to females in populations of *S. variabilis* (Benabib, 1994; Cruz-Elizalde and Ramírez-Bautista, 2016). However, this similarity in clutch size (3.3 eggs, Ramírez-Bautista and González-Romero, 1991; 3.4, García-Collazo et al., 1993; 3.4 and 4.3, Cruz-Elizalde and Ramírez-Bautista, 2016) varied by female SVL, with *S. cozumelae* being the smallest (Table 2). These results could be related to clutch frequencies, because females of *S. variabilis* have at least three clutches during the reproductive season (Cruz-Elizalde and Ramírez-Bautista, 2016), and female *S. cozumelae* very likely have at least two clutches each year, based on two females from our sample that had both eggs and vitellogenic follicles at the same time. Variations in clutch size and frequency have been found to be associated to the availability of food in the environment (Ballinger, 1977; Hernández-Salinas and Ramírez-Bautista, 2015). Small clutches in species with continuous reproduction are advantageous for females because they allow them to spread the reproductive effort over time and space, and

Table 2. Reproductive characteristics of females of *Sceloporus variabilis* from different populations (upper five) compared to *S. cozumelae* (Puerto Morelos).

| Population | Snout-vent length (mm) | Clutch size | Reproductive season | Source |
|---|---|---|---|---|
| Bastonal | 53.1±0.49 (44–68) | 4.6±0.14 (3–7) | November–September | Benabib (1994) |
| Los Tuxtlas | 56.6±0.35 (43.8–71) | 3.7±0.11 (2–6) | January–December | Ramírez-Bautista et al. (2006) |
| Atlapexco | 53.6±0.52 (45–63) | 3.4±0.21 (2–5) | January–December | Cruz-Elizalde and Ramírez-Bautista (2016) |
| San Pablo Tetlapayac | 52.7±0.51 (45–57) | 4.3±0.28 (3–6) | January–September | Cruz-Elizalde and Ramírez-Bautista (2016) |
| Santa Catarina | 54.5±0.57 (47–62) | 3.4±0.24 (2–5) | January–December | Cruz-Elizalde and Ramírez-Bautista (2016) |
| Puerto Morelos | 46.5±0.42 (40–52) | 3.4±0.29 (2–8) | April–September | This study |

consequently they increase the survival probabilities of the eggs and offspring (Anguilletta et al., 2001; Du et al., 2005). In many lizard species with continuous reproduction (multiple clutches), clutch size is not correlated with female SVL; for example, in *Urosaurus bicarinatus* (Ramírez-Bautista et al., 1995; Ramírez-Bautista and Vitt, 1998) and *S. siniferus* (Ramírez-Bautista et al., 2016). However, clutch size of *S. cozumelae* was correlated with female SVL, similar to other small-bodied lizards with continuous reproduction, such as *S. aeneus* (Ramírez-Bautista et al., 2016).

In summary, sexual size dimorphism of *S. cozumelae* is male-biased. Females and males reach sexual maturity at similar body size. Males and females are synchronized in their reproductive activity, indicating that this species presumably has continuous reproduction, similar to that observed in populations of *S. variabilis*, where females have multiple small clutches. Mean clutch size was similar to that in other female populations of *S. variabilis* with larger SVL, and mean clutch size was correlated with female SVL, a pattern that is not commonly observed in small-bodied species with continuous reproduction. Indeed, more studies on *S. cozumelae* are needed to fully understand their reproductive cycle, as well as on the rest of the species of the *Sceloporus variabilis* group. These studies could help us understand the extent of the role that phylogeny and the environment play in patterns of sexual dimorphism (Cox et al., 2003) and life history characteristics (Zamora-Abrego et al., 2007; Zuñiga-Vega et al., 2016) of populations and closely related species.

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## Appendix 1

Voucher numbers of the individuals of *Sceloporus cozumelae* used in this study. Specimens were obtained from Colección Nacional de Anfibios y Reptiles, Instituto de Biología, Universidad Nacional Autónoma de México.

Males: CNAR-IBH (4131, 4132, 5485, 5506, 5507, 5544, 5545, 6172, 6355, 7404, 7698, 7702, 7705, 7707, 05485-2, 05485-95, 05506-10, 05506-4, 05507-11, 05507-12, 05507-2, 05507-3, 05544-2, 05544-4, 05545-2, 05545-5, 05545-8, 05794-12, 05794-16, 05794-18, 4131-10, 4131-13, 4131-14, 4131-15, 4131-17, 4131-20, 4131-24, 4131-4, 4131-6, 4131-70, 4131-8, 6172-3, 6172-7, 6172-9, 6173-10, 6173-11).

Females: CNAR-IBH (5749, 5794, 6353, 6354, 7697, 7701, 05485-3, 05506-2, 05506-8, 05506-9, 05507-6, 05543-3, 05794-11, 05794-13, 05794-14, 05794-15, 05794-4, 05794-5, 05794-7, 06355-2, 06356-2, 06356-3, 4131-11, 4131-12, 4131-16, 4131-18, 4131-2, 4131-21, 4131-3, 4131-5, 4131-9, 5507-7, 6172-2, 6172-4, 6172-5, 6172-6, 6172-8, 7696-2).