

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/331960093>

# Morphology and reproductive patterns of an assemblage of anurans from the Chihuahuan Desert Region, Mexico

Article in *Journal of Arid Environments* · March 2019

DOI: 10.1016/j.jaridenv.2019.03.004

CITATIONS

5

READS

301

5 authors, including:



**Ricardo Javier Torres-Cervantes**  
Universidad de Guanajuato

3 PUBLICATIONS 100 CITATIONS

[SEE PROFILE](#)



**Aurelio Ramírez-Bautista**  
Autonomous University of Hidalgo

277 PUBLICATIONS 2,651 CITATIONS

[SEE PROFILE](#)



**Christian Berriozabal Islas**  
Universidad Politécnica de Quintana Roo

54 PUBLICATIONS 268 CITATIONS

[SEE PROFILE](#)



**Raciél Cruz-Elizalde**  
Autonomous University of Queretaro

71 PUBLICATIONS 529 CITATIONS

[SEE PROFILE](#)

Some of the authors of this publication are also working on these related projects:



Teach in Herpetology Class [View project](#)



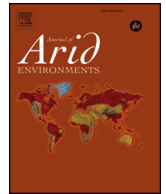
Ecología del Cambio Ambiental Global [View project](#)



ELSEVIER

Contents lists available at ScienceDirect

## Journal of Arid Environments

journal homepage: [www.elsevier.com/locate/jaridenv](http://www.elsevier.com/locate/jaridenv)

## Morphology and reproductive patterns of an assemblage of anurans from the Chihuahuan Desert Region, Mexico

Ricardo Torres-Cervantes<sup>a</sup>, Aurelio Ramírez-Bautista<sup>b,\*</sup>, Christian Berriozabal-Islas<sup>b</sup>,  
Raciél Cruz-Elizalde<sup>b</sup>, Uriel Hernández-Salinas<sup>c</sup>

<sup>a</sup> División de Ciencias Naturales y Exactas, Universidad de Guanajuato, Noria Alta S/n, 36050, Guanajuato, Guanajuato, Mexico

<sup>b</sup> Laboratorio de Ecología de Poblaciones, Centro de Investigaciones Biológicas, Instituto de Ciencias Básicas e Ingeniería, Universidad Autónoma del Estado de Hidalgo, Km 4.5 Carretera Pachuca-Tulancingo, 42184, Mineral de La Reforma, Hidalgo, Mexico

<sup>c</sup> Instituto Politécnico Nacional, CIIDIR Unidad Durango, Sigma 119, Fraccionamiento 20 de Noviembre II, Durango, Durango, 34220, Mexico

## ARTICLE INFO

## Keywords:

Amphibians  
Arid environments  
Reproduction  
Sexual dimorphism

## ABSTRACT

Amphibian communities in arid and semi-arid environments are highly dependent on environmental factors for breeding activities. A large number of species can also show different reproductive patterns and variation between sexes. In this study, the morphology and reproductive patterns in an assemblage of seven anuran amphibians from the southeast region of the Chihuahuan Desert were evaluated. Data on snout–vent length, weight (body mass), and morphological structures (head width and head, femur and tibia length) were recorded. Three size classes (small, medium and large) were identified, as well as three patterns of sexual dimorphism: i) females larger than males, ii) females larger than males in some morphological variables, and iii) females similar to males in all measured variables. Variation in clutch size and laying mass (weight) among species was also described, as well as three reproductive patterns (short season, long season, and continuous reproduction). This study expands our knowledge about sexual dimorphism and reproductive patterns in anurans from arid environments. Further studies analyzing the animals' use of resources are necessary to determine the arrangement and distribution of the resource space by amphibians in arid and semi-arid environments.

### 1. Introduction

Vertebrate adaptations in arid and semiarid regions have evolved through aspects of their biology, such as morphology, physiology, behavior and ecology (Louw and Seely, 1982; Ligon and Peterson, 2002). In these environments, reproduction in plants and animals is generally seasonal and controlled by both environmental (temperature, food, precipitation) and endogenous factors (hormone production) (Duellman and Trueb, 1994). In arid environments, the period of optimum conditions for primary production is very short (Becerra-López et al., 2017). At the beginning of spring, primary production (e.g., phenology of the plant community with production of leaves, flowers, fruits and seeds) supports a high diversity of arthropods (Williams and Tieleman, 2005), and as a consequence, an increase in density of vertebrate populations (Schmidt-Nielsen, 1979; Williams and Tieleman, 2005). This period is the most propitious for feeding, growing, and reproduction in most kinds of animals inhabiting these environments (Duellman and Trueb, 1994; Torres-Cervantes, 2003). Precipitation and temperature seem to be the most important factors that promote

reproductive activity for most vertebrates, especially amphibians (Louw and Seely, 1982; Boeing et al., 2014).

Amphibians from humid tropical environments show two main patterns of reproductive activity; continuous and seasonal reproduction (Vitt and Caldwell, 2014; Crump, 2015), while those in subhumid temperate, arid, and semiarid environments exhibit seasonal reproduction (Uribe-Peña et al., 1999). In arid and semiarid environments, the photoperiod begins to increase at the beginning of spring, which stimulates the hypothalamus to release hormones for reproductive activity in both females and males (Duellman and Trueb, 1994; Gribbins and Rheubert, 2011). In the summer, both photoperiod and precipitation influence the reproductive activity of amphibians (Licht, 1974; Duellman and Trueb, 1994; Vitt and Caldwell, 2014); consequently, most amphibian species exhibit reproductive activity during this season (Torres-Cervantes, 2003).

Unlike humid tropical environments, arid and semi-arid environments have fewer bodies of water to support anuran reproduction (Dayton et al., 2004). Consequently, in arid environments there is typically strong competition among males for the best breeding sites

\* Corresponding author.

E-mail address: [ramibautistaa@gmail.com](mailto:ramibautistaa@gmail.com) (A. Ramírez-Bautista).

<https://doi.org/10.1016/j.jaridenv.2019.03.004>

Received 20 June 2018; Received in revised form 29 January 2019; Accepted 11 March 2019

0140-1963/ © 2019 Elsevier Ltd. All rights reserved.

during the reproductive period (for calling and amplexus; Wells, 2007). Although competition among males for females has been tested as a factor in the evolution of male-biased sexual dimorphism in several groups of vertebrates, such as mammals (Mitani et al., 1996), birds (Fairbairn and Shine, 1993) and reptiles (Cox et al., 2003, 2009), in anuran amphibians most species exhibit female-biased sexual dimorphism (Shine, 1979; Kupfer, 2007; Liao et al., 2013).

Female-biased sexual dimorphism in anurans has usually been explained in terms of fecundity (Shine, 1979; Kupfer, 2007). Fecundity is highly variable among anuran groups; for example, species of the genera *Lithobates* and *Dryophytes* produce larger clutches than species of the genera *Eleutherodactylus* (Duellman and Trueb, 1994; Crump, 2015). This pattern generates a high degree of variation in sexual dimorphism, and species with aquatic and arboreal habits are more variable in the degree of body size of the sexual dimorphism (Liao et al., 2013) than species occurring in terrestrial habits, such as bufonids (Liao et al., 2013; Schalk et al., 2015).

Anuran communities from arid environments of the Chihuahuan Desert include species of the families Bufonidae, Hylidae, Scaphiropodidae, Ranidae, and Eleutherodactylidae (Boeing et al., 2014; Schalk et al., 2015; Cruz-Elizalde et al., 2016). Representative species of these different groups exhibit different reproductive patterns, life histories and morphological characteristics (Schalk et al., 2015), which are associated with the environmental conditions where these species occur, as well as resource availability (e.g., water bodies for reproduction or feeding; Torres-Cervantes, 2003; Vitt and Caldwell, 2014). For example, the levels of intensity and extent of rain could permit some species to lay two or three clutches, as seen in scaphiropodid toads from arid environments such as *Scaphiopus couchii* and *Spea hammondi* (Duellman and Trueb, 1994; Vitt and Caldwell, 2014).

Existing information on anuran assemblages in arid and semiarid environments, as well as variation in sexual dimorphism among species, indicates that very little is known about the patterns of reproduction and sexual dimorphism among desert-adapted species (Duellman and Trueb, 1994; Vitt and Caldwell, 2014; Schalk et al., 2015). Therefore, the goal of this study is to describe patterns of reproductive activity (reproductive period, clutch size, clutch mass) and sexual dimorphism (variation in morphological attributes) of an assemblage of anurans from an arid environment of the southern Chihuahuan Desert Region (as defined by Cruz-Elizalde et al., 2014). This study seeks to understand the dynamics of reproduction and sexual dimorphism in species from arid environments, for which there is little information compared to species from temperate or tropical environments (Duellman and Trueb, 1994; Crump, 2015).

## 2. Materials and methods

### 2.1. Study area

The study was carried out from May 1996 to June 1997, and from October 1998 to April 2001 at the southern end of the Chihuahuan Desert Region in the municipality of Guadalcázar (23° 7' 35", 22° 53' 41" N and 100° 24' 18", 100° 29' 3" W), San Luis Potosí, Mexico, at sites ranging in elevation from 1000 to 2230 m a.s.l. The vegetation community at these sites is composed of xerophytic plant associations of creosote bush scrub, rosetophyllous thorn scrub, and mesquite desert scrub (Rzedowski, 1994; Hernández et al., 2001). The area is dominated by extensive lowland plains interrupted by numerous mountain ranges of variable elevation. This area has a high diversity of climates, but the dominant type is dry semi-warm (BSH; García, 1981). It receives between 22.4 and 497.7 mm of precipitation annually (mean = 330.3 mm), with precipitation increasing with elevation and reaching a maximum of 800 mm in the mountains. The temperature of the region varies from 5 °C (coldest months, December to March; winter) to 45 °C (warmest months, April to September; spring-summer).

### 2.2. Sampling regime

Sampling was conducted during two-week periods every two months. All specimens were searched for and collected in or near water bodies and under adjacent rocks and logs, mostly at night. Nocturnal anurans were surveyed from 19:00 to 24:00 h; however, some individuals of toads (*Spea multiplicata*) and frogs (*Lithobates berlandieri*) were found under logs and small ponds during the day. We collected and analyzed 303 adult individuals of seven species of anurans: *Anaxyrus cognatus* ( $n = 10$ ), *A. debilis* ( $n = 16$ ), *A. punctatus* ( $n = 54$ ), *Incilius valliceps* ( $n = 28$ ), *Dryophytes eximius* ( $n = 34$ ), *L. berlandieri* ( $n = 127$ ), and *S. multiplicata* ( $n = 34$ ). Fieldwork was conducted according to the standards of the Herpetological Animal Care and Use Committee (2004), the national Mexican laws CT-CERN-001-91 (DOF, 1991), and NOM-PA-CRN-001/93 (DOF, 1993). Specimens were collected under scientific permit SGPA/DGVS/01902/11 provided by SEMARNAT. All preserved specimens were deposited in the amphibian and reptile collections of the Centro de Investigaciones Biológicas of the Universidad Autónoma del Estado de Hidalgo.

### 2.3. Morphological and reproductive characteristics

The following morphological traits were measured for males and females in this study: snout–vent length (SVL;  $\pm 0.01$  mm), head width (HW;  $\pm 0.01$  mm), head length (HL;  $\pm 0.01$  mm), forearm length (FL;  $\pm 0.01$  mm), and tibia length (TL;  $\pm 0.01$  mm) (Watters et al., 2016). To assess reproductive condition, preserved frogs were dissected ventrally, and eggs or gonads were removed and weighed ( $\pm 0.0001$  g). For females, we recorded clutch size and mass ( $\pm 0.0001$  g). To assess clutch sizes, eggs were placed in a petri dish and a stereoscopic microscope was used to count the eggs (Hernández-Austria et al., 2015). For males, we recorded testes mass (0.0001 g). Body and clutch sizes and reproductive period categories were classified according to the morphology, ecology and reproduction literature on anurans (Duellman and Trueb, 1994; Wells, 2007; Crump, 2015). Body size was classified as small (0–45 mm SVL), medium (40.1–69.5 mm) or large ( $\geq 70$  mm). Clutch size was classified as small (0–1000 eggs), medium (1001–4000) or large ( $\geq 4001$ ). Reproductive period was classified as seasonal and short (from June to August), seasonal and long (April–November), or continuous (February–November) (Duellman and Trueb, 1994; Wells, 2007; Crump, 2015).

### 2.4. Statistical analysis

For statistical analyses of sexual size dimorphism, we used a multivariate analysis of variance (MANOVA) to identify differences in body size (SVL) and other morphological characteristics as a function of species (Zar, 2010). A generalized discriminant function analysis (GDFA) was applied at the sex and species levels to detect differences between them. When significant variables were identified by the GDFA, we used non-parametric tests to compare these variables among species (Kruskal-Wallis tests) or between sexes (Mann-Whitney  $U$  tests). A correlation analysis was applied to determine the relationship between morphological traits (SVL) and clutch size. We used Kruskal-Wallis tests to evaluate differences in clutch size and egg mass among species. Statistical analyses and post hoc comparisons (when necessary) were calculated using Statistica version 7.0, and means are presented  $\pm 1$  SE (Zar, 2010).

## 3. Results

### 3.1. Body size and sexual dimorphism

A MANOVA including all traits showed statistically significant differences between sexes (Wilk's  $\lambda = 0.898$ ,  $F_{6, 291} = 5.488$ ,  $P < 0.001$ ), among species (Wilk's  $\lambda = 0.898$ ,  $F_{6, 291} = 5.48$ ,  $P < 0.001$ ), and in

**Table 1**

Morphological characteristics of females and males of seven anuran species from Guadalcázar, San Luis Potosí México. Female (F), male (M). Size class (small = S, medium = M, large = L). Mann-Whitney *U* test (ns = non-significant, \* = < 0.05, \*\* = < 0.0001).

Species	Sex	SVL (mm)	<i>P</i> -value	Body mass (g)	<i>P</i> -value	Size class
<i>Anaxyrus cognatus</i>	F	69.5 ± 5.2 (52.4–82.3, <i>n</i> = 6)	ns	40.7 ± 6.8 (20.2–62.0)	ns	M
	M	65.3 ± 6.5 (53.9–78.4, <i>n</i> = 4)		35.7 ± 8.9 (20.2–52.2)		
<i>Anaxyrus debilis</i>	F	43.2 ± 0.7 (41.8–44.0, <i>n</i> = 3)	*	10.0 ± 0.42 (9.2–10.7)	*	S
	M	36.6 ± 1.0 (31.5–45.3, <i>n</i> = 13)		6.0 ± 0.62 (3–9.5)		
<i>Anaxyrus punctatus</i>	F	59.0 ± 1.8 (49.8–70.4, <i>n</i> = 15)	**	25.7 ± 3.6 (11.0–53.6)	*	M
	M	52.0 ± 0.7 (37.3–60.0, <i>n</i> = 39)		17.2 ± 1.4 (4.4–52.0)		
<i>Incilius valliceps</i>	F	74.9 ± 2.2 (67.4–82.9, <i>n</i> = 8)	*	39.8 ± 4.3 (25.0–62.0)	*	L
	M	64.3 ± 1.7 (45.5–73.4, <i>n</i> = 20)		26.4 ± 2.1 (8.5–46.0)		
<i>Dryophytes eximius</i>	F	28.6 ± 1.1 (23.6–33.8, <i>n</i> = 10)	ns	1.5 ± 0.6 (2.5–2.5)	ns	S
	M	29.4 ± 0.49 (24.0–34.7, <i>n</i> = 24)		1.4 ± 0.10 (0.6–2.0)		
<i>Lithobates berlandieri</i>	F	61.6 ± 1.1 (47.9–85.1, <i>n</i> = 70)	**	25.8 ± 1.5 (9.0–72.0)	**	L
	M	53.6 ± 0.84 (36.5–68.8, <i>n</i> = 57)		17.5 ± 0.9 (3.1–38.0)		
<i>Spea multiplicata</i>	F	53.8 ± 0.77 (51.6–57.6, <i>n</i> = 8)	*	16.9 ± 0.57 (14.5–19.0)	*	M
	M	49.4 ± 1.2 (35.4–58.3, <i>n</i> = 26)		13.7 ± 1.1 (5.1–22.0)		
Kruskal Wallis	F	( <i>H</i> = 52.92, <i>P</i> < 0.0001)		( <i>H</i> = 50.7, <i>P</i> < 0.0001)		
	M	( <i>H</i> = 113.7, <i>P</i> < 0.0001)		( <i>H</i> = 107.7, <i>P</i> < 0.0001)		

the sex–species interaction (Wilk's  $\lambda = 0.889$ ,  $F_{1, 291} = 36.24$ ,  $P < 0.001$ ).

The G DFA showed that all species varied in the morphological characteristics analyzed, including SVL (Wilk's  $\lambda = 0.803$ ,  $F_{6, 291} = 11.864$ ,  $P < 0.0001$ ), HW (Wilk's  $\lambda = 0.750$ ,  $F_{6, 291} = 16.08$ ,  $P < 0.0001$ ), HL (Wilk's  $\lambda = 0.602$ ,  $F_{6, 291} = 31.95$ ,  $P < 0.0001$ ), FL (Wilk's  $\lambda = 0.750$ ,  $F_{6, 291} = 16.15$ ,  $P < 0.0001$ ) and TL (Wilk's  $\lambda = 0.219$ ,  $F_{6, 291} = 172.92$ ,  $P < 0.0001$ ). Also, the G DFA showed that three traits were different between sexes; SVL (Wilk's  $\lambda = 0.930$ ,  $F_{1, 291} = 36.24$ ,  $P < 0.0001$ ), HL (Wilk's  $\lambda = 0.986$ ,  $F_{1, 291} = 3.902$ ,  $P = 0.049$ ), and FL (Wilk's  $\lambda = 0.926$ ,  $F_{1, 291} = 23.09$ ,  $P < 0.001$ ), and the others showed no differences (HW: Wilk's  $\lambda = 0.997$ ,  $F_{1, 291} = 0.635$ ,  $P = 0.425$ ; TL: Wilk's  $\lambda = 0.999$ ,  $F_{1, 291} = 0.004$ ,  $P = 0.945$ ).

A Kruskal-Wallis test showed variation in SVL of females ( $H = 52.92$ ,  $P < 0.0001$ ) and males ( $H = 113.7$ ,  $P < 0.0001$ ) among species, and a similar pattern occurred in their body mass (Table 1). Our results indicate that there are three classes of anuran body size at our sites: small (*Anaxyrus debilis*, *D. eximius*), medium (*A. cognatus*, *A. punctatus* and *Spea multiplicata*), and large (*Incilius valliceps* and *L. berlandieri*; Table 1). A Mann-Whitney test showed that females were larger than males in *A. debilis*, *A. punctatus*, *I. valliceps*, *L. berlandieri*, and *S. multiplicata*, while the two sexes were similar in *A. cognatus* and *D. eximius* (Table 1). This pattern was similar for body mass in all species (Table 1). Three patterns of sexual dimorphism were found (Table 2), which are i) females larger than males in all traits (*A. punctatus* and *L.*

*berlandieri*; Table 2); ii) females larger than males only in some morphological traits, including some or all of WH, HL, FL, and TL (*A. debilis*, *I. valliceps*, and *S. multiplicata*; Table 2), and iii) females and males similar in all of these traits (*A. cognatus* and *D. eximius*; Table 2).

### 3.2. Reproductive characteristics

Reproductive characteristics, such as clutch size ( $H = 42.95$ ,  $P < 0.0001$ ) and egg mass ( $H = 29.77$ ,  $P < 0.0001$ ) varied among species (Table 3). Females of *D. eximius* showed smaller clutch sizes (870 ± 156 eggs) than *A. debilis*, *L. berlandieri*, or *S. multiplicata*, which had medium clutch sizes (2069–3, 277 eggs), which in turn were smaller than those of *A. cognatus*, *A. punctatus*, and *I. valliceps* with the largest clutch sizes (5191.8–12,096; Table 3). A Pearson correlation showed a positive relationship between SVL and species clutch size ( $r = 0.53$ ,  $P < 0.0001$ ).

The reproductive period varied among species; seasonal-short, from June to August (*A. cognatus*, *A. debilis*, and *D. eximius*), seasonal-long, from April to November (*A. punctatus* and *I. valliceps*), and continuous reproduction, from February to November (*L. berlandieri* and *S. multiplicata*; Table 3). The length of time of reproductive activity (gonadic mass) of females from all species was similar to the males except for *D. eximius* in which the reproductive period was longer in males (June–November; Table 3).

**Table 2**

Sexual dimorphism in seven anuran species from Guadalcázar, San Luis Potosí, México. Female (F), male (M). Head width (HW), head length (HL), forearm length (FL), and tibia length (TL). Mann-Whitney *U* test (ns = non-significant, \* = < 0.05, \*\* = < 0.0001).

Species	Sex	HW	<i>P</i>	HL	<i>P</i>	FL	<i>P</i>	TL	<i>P</i>
<i>Anaxyrus cognatus</i>	F	26.7 ± 2.0	ns	15.9 ± 1.0	ns	17.6 ± 1.5	ns	26.2 ± 1.6	ns
	M	24.7 ± 2.2		15.1 ± 1.1		16.6 ± 2.5		24.9 ± 2.2	
<i>Anaxyrus debilis</i>	F	15.4 ± 0.22	**	10.5 ± 0.68	ns	9.6 ± 0.46	ns	17.7 ± 0.52	**
	M	13.0 ± 0.31		10.2 ± 0.25		8.7 ± 0.52		14.5 ± 0.39	
<i>Anaxyrus punctatus</i>	F	21.1 ± 0.87	*	14.7 ± 0.51	*	13.4 ± 0.66	*	22.7 ± 0.76	*
	M	18.9 ± 0.42		13.4 ± 0.27		11.8 ± 0.35		20.6 ± 0.36	
<i>Incilius valliceps</i>	F	27.0 ± 0.70	**	21.1 ± 0.34	**	18.5 ± 0.61	ns	27.4 ± 0.62	*
	M	23.6 ± 0.55		18.5 ± 0.43		17.3 ± 0.53		25.0 ± 0.66	
<i>Dryophytes eximius</i>	F	8.7 ± 0.49	ns	10.1 ± 0.84	ns	6.4 ± 0.29	ns	13.9 ± 0.55	ns
	M	9.5 ± 0.24		9.9 ± 0.31		6.5 ± 0.12		14.2 ± 0.23	
<i>Lithobates berlandieri</i>	F	19.9 ± 0.36	**	20.4 ± 0.32	**	13.9 ± 0.30	*	34.7 ± 0.61	**
	M	17.6 ± 0.34		18.5 ± 0.25		12.9 ± 0.22		30.6 ± 0.49	
<i>Spea multiplicata</i>	F	19.9 ± 0.28	*	15.6 ± 0.42	ns	12.5 ± 0.47	*	19.1 ± 0.27	ns
	M	18.1 ± 0.38		14.5 ± 0.27		12.3 ± 0.37		18.5 ± 0.41	
Kruskal Wallis	F	( <i>H</i> = 56.50, <i>P</i> < 0.0001)		( <i>H</i> = 77.50, <i>P</i> < 0.0001)		( <i>H</i> = 53.14, <i>P</i> < 0.0001)		( <i>H</i> = 88.36, <i>P</i> < 0.0001)	
	M	( <i>H</i> = 118.32, <i>P</i> < 0.0001)		( <i>H</i> = 143.57, <i>P</i> < 0.0001)		( <i>H</i> = 110.59, <i>P</i> < 0.0001)		( <i>H</i> = 154.65, <i>P</i> < 0.0001)	

**Table 3**

Reproductive characteristics of females and males for seven anuran species from Guadalcázar, San Luis Potosí, México.

Species	Sex	SVL (mm)	Clutch size	Reproductive period												
				J	F	M	A	M	J	J	A	S	O	N	D	
<i>Anaxyrus cognatus</i>	F	69.5	12,026 ± 4879 (121–21,478, n = 5)						X	X	X					
	M	65.3														
<i>Anaxyrus debilis</i>	F	3.2	3277 ± 223 (2841–3,575, n = 3)						X	X	X					
	M	36.6														
<i>Anaxyrus punctatus</i>	F	59	5191.8 ± 10.61 (1947–12,070, n = 12)				X	X	X	X	X	X	X	X	X	
	M	52														
<i>Incilius valliceps</i>	F	74.9	8726.3 ± 1638 (4399–19,440, n = 8)				X	X	X	X	X	X	X	X	X	
	M	64.3														
<i>Dryophytes eximius</i>	F	28.6	870 ± 156 (431–1,563, n = 3)						X	X	X					
	M	29.4														
<i>Lithobates berlandieri</i>	F	61.6	2069 ± 141.5 (554–5,826, n = 61)			X	X	X	X	X	X	X	X	X	X	
	M	53.6														
<i>Spea multiplicata</i>	F	53.8	2519 ± 482.2 (1269–3,754, n = 5)			X	X	X	X	X	X	X	X	X	X	
	M	49.4														
Kruskal Wallis			(H = 42.95, P < 0.0001)													

## 4. Discussion

### 4.1. Morphology

The southeastern Chihuahuan Desert Region has a high diversity of anuran amphibians compared with the northern area (Dayton et al., 2004; Boeing et al., 2014; Cruz-Elizalde et al., 2016). This assemblage exhibits a high diversity of reproductive patterns compared to species from central Mexico, being comparable to some sites in dry ecosystems from Brazil (Vieira et al., 2009) and the southern United States (Schalk et al., 2015). The species that compose this assemblage have evolved in this arid zone by sharing resources such as space and food and have evolved over time to live in sympatry (Duellman and Trueb, 1994; Crump, 2015). Both females and males of this anuran assembly showed variation in SVL, body mass, and other morphological structures, such as HW, HL, FL, and TL, which could be explained in terms of differences in resource allocation, such as food and selected microhabitats, or access to sites for reproduction (Boeing et al., 2014; Crump, 2015; Schalk et al., 2015).

Morphological analysis revealed three patterns of body size; small, medium, and large. Small species (*A. debilis* and *D. eximius*) are able to share shallow grassy ponds, temporary ponds, and spaces under logs, because their small bodies allow them to occupy small shelters with some degree of moisture; medium-sized species (*A. cognatus*, *A. punctatus*, and *S. multiplicata*) can share water bodies that persist for longer periods of time; and large-sized species (*I. valliceps* and *L. berlandieri*) can share bodies of water that persist throughout the year (Schalk et al., 2015). Distribution of resource space among species from arid regions is a strategy to minimize resource overlap and competition; too much resource overlap would lead to exclusion of individuals of one species by others, and hence local extirpation of the less competitive species (Monte de Andrade et al., 2013; Schalk et al., 2015).

Differences in HW and HL between females and males (*A. debilis*, *I. valliceps*, *L. berlandieri*, and *S. multiplicata*) could be explained by their eating prey of different sizes, as has been reported for other species of anurans (Smith et al., 2011); however, studies on diet composition, and correlations between prey size and morphological structures of the head among species and between sexes will be necessary to support this hypothesis. On the other hand, differences in FL (*A. punctatus*, *L. berlandieri*, and *S. multiplicata*) and TL (*A. debilis*, *A. punctatus*, *I. valliceps*, and *L. berlandieri*) between females and males could be explained by the limbs helping females support their heavier bodies, especially during reproductive activity, when egg masses represent significant seasonal burdens (Duellman and Trueb, 1994; Vitt and Caldwell, 2014). Conversely, similarity in these characteristics between females and males in other species (*A. cognatus* and *D. eximius*) could be related to similar

body sizes in these species, which reflect their similar allometry (Schulte-Hostedde et al., 2011).

It is well known that in most anurans, females are larger than males (Shine, 1979; Kupfer, 2007), which could be explained by fecundity and mating position (amplexus type), because the female has to carry the male on her back during amplexus and fertilization (Duellman and Trueb, 1994; Vitt and Caldwell, 2014). In this study, we found that females were larger than males in three species of the genus *Anaxyrus*, as well as the species *L. berlandieri* and *S. multiplicata*; however, we recorded one other pattern; namely, similar body sizes in females and males in *A. cognatus* and *D. eximius*. All the species studied here exhibit axillary amplexus with the exception of *S. multiplicata*, which has inguinal amplexus (Duellman and Trueb, 1994; Crump, 2015); thus, variation in degree of sexual dimorphism in body size of the species from this assemblage is not related to their respective amplexus type (Duellman and Trueb, 1994).

We did not find sexual dimorphism in any of the other morphological characteristics we analyzed in this study, despite some studies showing that females are larger than males (Shine, 1979; Wells, 2007; Liao et al., 2013). This could be explained in terms of fecundity; for example, female *D. eximius* do not need to be larger than males given their smaller clutch size (mean = 870 eggs) compared to the other species studied (Table 3). In contrast, *A. cognatus* represents the other extreme, in that females exhibit the largest clutch sizes (mean = 12,026 eggs), possibly explained by females choosing the breeding sites visited for mate selection and amplexus (Torres-Cervantes, 2003). For example, females live in shelters near the ponds where amplexus occurs, so they do not need to move much when carrying eggs (Dayton et al., 2004; Boeing et al., 2014).

### 4.2. Reproductive activity

In arid environments, the reproductive period of the amphibian community would be expected to be restricted to the rainy season (in this case, May–October), when maximum precipitation occurs. The reproductive period varied substantially among species of the community, and in five species (*A. cognatus*, *A. debilis*, *A. punctatus*, *I. valliceps* and *D. eximius*; Table 3) reproduction was synchronized with maximum temperature (22–23 °C) and precipitation (70–72 mm), suggesting that reproduction in these species is equally dependent on these factors. However, it has been suggested that these species could simply be reproductive opportunists, meaning that they are able to reproduce at any time if environmental factors (humidity, presence of water puddles) are suitable (Wright and Wright, 1949; Justus et al., 1977; Degenhardt et al., 1996; Torres-Cervantes, 2003).

In contrast, *L. berlandieri* and *S. multiplicata* exhibited continuous

reproduction, behavior that has been noted by other authors (Degenhardt et al., 1996; Torres-Cervantes, 2003; Wells, 2007). These species have been considered to be opportunistic, because their reproduction can occur at any time of the year as long as there is a small amount of precipitation or pools available for reproduction, because sexually mature females and males are always available in these environments. This pattern is different in species such as *D. eximius* and others with a short reproductive season (Table 3) because they can use only a specific time of the year for reproduction (Kaplan and Ramírez-Bautista, 1996). Most species from arid environments have explosive reproduction, such as *S. multiplicata* and probably some or all of the species of genus *Anaxyrus*, as well as *D. eximius*. These strategies enable them to distribute their reproductive effort in time and space, ensuring greater survival of populations of these species in any environment, but especially in arid regions (Stearns, 1992).

## 5. Conclusion

We studied the morphology and reproductive activity of an assemblage of anuran amphibians in an arid environment in the southeastern Chihuahuan Desert Region. The species of this assemblage varied in size, body mass, and other morphological characteristics. Three patterns of body size (SVL) were found, enabling them to be classified as small, medium and large-sized species. Also, in contrast to the general pattern of sexual size dimorphism in anurans, where females are larger than males, we found that in two species (*A. cognatus* and *D. eximius*) female and males were similar in SVL, while in the other species, females were larger in SVL than males. A similar pattern was observed for other morphological characteristics (HW, HL, FL, TL) in which females of five species were larger than males, while in the other two species (*A. cognatus* and *D. eximius*) the sexes were similar. Females and males are synchronized in the timing of egg and sperm production in all seven species. Five species exhibited short-term reproductive activity, and two species showed continuous reproduction for a longer period of the year. Most of the species studied are likely to be opportunistic breeders in this arid environment.

## Author contributions

RTC and ARB designed the study and conducted the fieldwork; RTC, ARB and RCE analyzed the data; all authors drafted and revised the manuscript and approved its final form. All authors agree to be held responsible for the content herein.

## Conflicts of interest

The authors declare that they have no conflict of interest.

## Formatting of funding sources

This research did not receive any specific grant from funding agencies in the public, commercial, or non-profit sectors.

## Acknowledgments

We thank Xochitl Hernández Ibarra, Rafael Torres Colín and Héctor Hernández Macías for their help in the field. We also thank Barry P. Stephenson for his comments on the manuscript, and María del Coro Arizmendi for her support in UBIPRO laboratory. We thank the three anonymous reviewers for greatly improving the manuscript.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jaridenv.2019.03.004>.

## References

- Becerra-López, J.L., Ramírez-Bautista, A., Romero-Méndez, U., Pavón, N.P., Sánchez-Rojas, G., 2015. Effect of climate change on holophytic grasslands loss and its impact in the viability of *Gopherus flavomarginatus*. *Nat. Conserv-Bulgaria* 21, 39–55. <http://doi.org/10.3897/natureconservation.21.13614>.
- Boeing, W.J., Griffiths-Kyle, K.L., Jungles, J.M., 2014. Anuran habitat associations in the northern Chihuahuan Desert, USA. *J. Herpetol.* 48, 103–110. <https://doi.org/10.1670/12-184>.
- Cox, R., Skelly, S.L., John-Alder, H.B., 2003. A comparative test of adaptation hypotheses for sexual size dimorphism in lizards. *Evolution* 57, 1653–1669. <https://doi.org/10.1554/02-227>.
- Cox, R.M., Stenquist, D.S., Calsbeek, R., 2009. Testosterone, growth, and the evolution of sexual size dimorphism. *J. Evolution. Biol.* 22, 1586–1598. <https://doi.org/10.1111/j.1420-9101.2009.01772.x>.
- Crump, M.L., 2015. Anuran reproductive modes: evolving perspectives. *J. Herpetol.* 49, 1–16. <https://doi.org/10.1670/14-097>.
- Cruz-Elizalde, R., Ramírez-Bautista, A., Johnson, J.D., Moreno, C.E., 2014. Community structure of reptiles from the southern portion of the Chihuahuan Desert Region, Mexico. *North-West. J. Zool.* 10, 171–182.
- Cruz-Elizalde, R., Ramírez-Bautista, A., Hernández-Ibarra, X., Wilson, L.D., 2016. Species diversity of amphibians from arid and semiarid environments of the real de Guadalcázar state Reserve, San Luis Potosí, Mexico. *Nat. Area J.* 36, 302–309. <https://doi.org/10.3375/043.036.0310>.
- Dayton, G.H., Jung, R.E., Droegge, S., 2004. Large-scale habitat associations of four desert anurans in Big Bend National Park, Texas. *J. Herpetol.* 38, 619–627. <https://doi.org/10.1670/125-04N>.
- Degenhardt, W.G., Painter, C.W., Price, H., 1996. *Amphibians and Reptiles of New Mexico*. University of New Mexico Press, Albuquerque.
- DOF, 1991. Diario Oficial de la Federación, Acuerdo por el que se establecen los criterios ecológicos CT-CERN-001-91 que determinan las especies raras, amenazadas, en peligro de extinción o sujetas a protección especial y sus endemismos, de la flora y la fauna terrestres y acuáticas en la República Mexicana. [http://www.dof.gob.mx/nota\\_detalle.php?codigo=4720453&fecha=17/05/1991](http://www.dof.gob.mx/nota_detalle.php?codigo=4720453&fecha=17/05/1991).
- DOF, 1993. Diario Oficial de la Federación, Proyecto de Norma Oficial Mexicana NOM-PA-CRN-001/93, que determina las especies de flora y fauna silvestres terrestres y acuáticas, raras, endémicas, amenazadas, en peligro de extinción y las sujetas a protección especial. [http://dof.gob.mx/nota\\_detalle.php?codigo=4765974&fecha=02/08/1993](http://dof.gob.mx/nota_detalle.php?codigo=4765974&fecha=02/08/1993).
- Duellman, W.E., Trueb, L., 1994. *Biology of Amphibians*. The John Hopkins University Press, Baltimore.
- Fairbairn, D.J., Shine, R., 1993. Patterns of sexual size dimorphism in seabirds of the southern hemisphere. *Oikos* 68, 139–145. <https://doi.org/10.2307/3545319>.
- García, E., 1981. Modificaciones al Sistema de clasificación climática de Köppen, third ed. Universidad Nacional Autónoma de México. México City, México.
- Gribbins, K.M., Rheubert, J.L., 2011. The ophidian testis, spermatogenesis, and mature spermatozoa. In: Aldridge, R.D., Sever, D.M. (Eds.), *Reproductive Biology and Phylogeny of Snakes*. Science Publishes, Enfield, pp. 183–264. <https://doi.org/10.1201/b10879-7>.
- Herpetological Animal Care and Use Committee, 2004. Guidelines for Use of Live Amphibians and Reptiles in Field and Laboratory Research. American Society of Ichthyologists and Herpetologists, Miami.
- Hernández, H.M., Gómez-Hinojosa, C., Bárcenas, R.T., 2001. Diversity, spatial arrangement, and endemism of cactaceae in the Huizache area, a hot-spot in the Chihuahuan Desert. *Biodivers. Conserv.* 10, 1097–1112. <https://doi.org/10.1023/A:1016606216041>.
- Hernández-Austria, R., Lara-Tufiño, F., Ramírez-Bautista, A., 2015. Estado actual de la distribución y aspectos ecológicos generales de la rana de Moore *Lithobates johni* (Anura: Ranidae), endémica de México. *Rev. Mex. Biodivers.* 86, 269–271. <https://doi.org/10.7550/rmb.45631>.
- Justus, J.T., Sandomir, M., Urquhart, T., Ewan, B.O., 1977. Development rates of two species of toads from the desert southwest. *Copeia* 1977, 592–594.
- Kaplan, M., Ramírez-Bautista, A., 1996. Description of the tadpole of *Hyla plicata* with comments on the taxonomic value of the larval internal oral morphology. *J. Herpetol.* 30, 530–533. <https://doi.org/10.2307/1565697>.
- Kupfer, A., 2007. Sexual size dimorphism in amphibians: an overview. In: Fairbairn, D.J., Blanckenhorn, W.U., Székely, T. (Eds.), *Sex, Size and Gender Roles: Evolutionary Studies of Sexual Size Dimorphism*. Oxford University Press, pp. 50–59.
- Liao, W.B., Zeng, Y., Zhou, C.Q., Jehle, R., 2013. Sexual size dimorphism in anurans fails to obey Rensch's rule. *Front. Zool.* 10, 10. <https://doi.org/10.1186/1742-9994-10-10>.
- Licht, L.E., 1974. Survival of embryos, tadpoles, and adult of frogs *Rana aurora aurora* and *Rana pretiosa* sympatric in southwestern British Columbia. *Can. J. Zool.* 52, 613–627. <https://doi.org/10.1139/z74-079>.
- Ligon, D.B., Peterson, C.C., 2002. Physiological and behavioral variation in estivation among mud turtles (*Kinosternon* spp.). *Physiol. Biochem. Zool.* 75, 283–293. <https://doi.org/10.1086/342000>.
- Louw, G.N., Seely, M.K., 1982. *Ecology of Desert Organisms*. Longman, London and New York.
- Mitani, J.C., Gros-Luis, J., Richards, A.F., 1996. Sexual dimorphism, the operational sex ratio, and the intensity of male competition in polygynous primates. *Am. Nat.* 147, 966–980. <https://doi.org/10.1086/28588>.
- Monte de Andrade, M.J., Dantas Sales, R.F., Freire, E.M.X., 2013. Ecology and diversity of a lizard community in the semiarid region of Brazil. *Biota Neotropica* 13, 199–209. <https://doi.org/10.1590/S1676-06032013000300023>.

- Rzedowski, J., 1994. Vegetación de México. Limusa, México.
- Schalk, C.M., Montaña, C.G., Springer, L., 2015. Morphological diversity and community organization of desert anurans. *J. Arid Environ.* 122, 132–140. <https://doi.org/10.1016/j.jaridenv.2015.06.019>.
- Schmidt-Nielsen, K., 1979. *Desert Animals*. Dover, New York.
- Schulte-Hostedde, A.I., Kuula, S., Martin, C., Schank, C.C.M., Lesbarrères, D., 2011. Allometry and sexually dimorphic traits in male anurans. *J. Evolution. Biol.* 24, 1154–1159. <https://doi.org/10.1111/j.1420-9101.2011.02256.x>.
- Shine, R., 1979. Sexual selection and sexual dimorphism in the Amphibia. *Copeia* 1979, 297–306. <https://doi.org/10.2307/1443418>.
- Smith, G.R., Lemos-Espinal, J.A., Burner, A.B., Winter, K.E., Dayer, C.B., 2011. Diets of three species of bufonids (Amphibia, Anura) from Northern Mexico. *West. N. Am. Naturalist* 71, 563–569. <https://doi.org/10.3398/064.071.0415>.
- Stearns, S.C., 1992. *The Evolution of Life Histories*. Oxford University Press.
- Torres-Cervantes, R.J., 2003. Patrones reproductivos de la comunidad de anuros en el municipio de Guadalcázar, San Luis Potosí. Undergraduate thesis. Universidad Nacional Autónoma de México.
- Uribe-Peña, Z., Ramírez-Bautista, A., Casas-Andreu, G., 1999. Anfibios y reptiles de las Serranías del Distrito Federal, México. Cuadernos. Instituto de Biología, Universidad Nacional Autónoma de México, pp. 32.
- Vieira, W.L.S., Santana, G.G., Arzabe, C., 2009. Diversity of reproductive modes in anurans communities in Caatinga (dryland) of northeastern Brazil. *Biodivers. Conserv.* 18, 55–66. <https://doi.org/10.1007/s10531-008-9434-0>.
- Vitt, J.L., Caldwell, J.P., 2014. *Herpetology, an Introductory Biology of Amphibians and Reptiles*, fourth ed. Academic Press, Elsevier.
- Watters, J.L., Cummings, S.T., Flanagan, R.L., Siler, C.D., 2016. Review of morphometric measurements used in anuran species descriptions and recommendations for a standardized approach. *Zootaxa* 4072, 477–495. <https://doi.org/10.11646/zootaxa.4072.4.6>.
- Wells, K.D., 2007. *The Ecology and Behavior of Amphibians*. University of Chicago Press, Chicago.
- Williams, J.B., Tieleman, B.I., 2005. Physiological adaptation in desert birds. *Bioscience* 55, 416–425. [https://doi.org/10.1641/0006-3568\(2005\)055\[0416:PAIDB\]2.0.CO;2](https://doi.org/10.1641/0006-3568(2005)055[0416:PAIDB]2.0.CO;2).
- Wright, A.H., Wright, A., 1949. *Handbook of Frog and Toads of the USA and Canada*. Comstock Publishing Associates. Cornell University Press, Ithaca.
- Zar, J.H., 2010. *Biostatistical Analysis*. Pearson, United States.