REPRODUCTION IN THE VIVIPAROUS MEXICAN ENDEMIC LIZARD *ABRONIA GADOVII* (SQUAMATA: ANGUIDAE)

REPRODUCCIÓN DE LA LAGARTIJA VIVÍPARA Y ENDÉMICA DE MÉXICO *ABRONIA GADOVII* (SQUAMATA: ANGUIDAE)

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Resumen.– Las características reproductoras son factores determinantes en los procesos evolutivos de los reptiles; sin embargo, en muchas especies permanecen escasamente documentadas. En este trabajo evaluamos aspectos de la biología reproductora y determinamos la influencia del tamaño y el peso corporal sobre el esfuerzo reproductor de la lagartija *Abronia gadovii*, una especie de ánguido, de reproducción vivípara y hábitos terrestres, endémica de la Sierra Madre del Sur, México. Las hembras de *A. gadovii* (*N* = 8) dieron a luz a mediados de abril, con tamaños de camada que oscilaron entre 2 y 8 neonatos por individuo. El índice de masa relativa de la camada fue de 0.29, similar al reportado para algunos ánguidos de la subfamilia Gerrhonotinae (e.g., *Elgaria coerulea* = 0.28) pero inferior al de otras especies (e.g., *Gerrhonotus infernalis* = 0.44). No encontramos correlación entre el tamaño o el peso de las hembras grávidas y las características de sus camadas, en contraste con lo reportado en otras familias de lagartijas. Se requieren estudios adicionales, así como análisis comparativos más rigurosos, para identificar patrones generales de esfuerzo reproductor dentro de los ánguidos, cuya biología reproductora sigue siendo poco investigada.

Palabras clave.– Guerrero, lagartija caimán de Gadow, reproducción, Sierra Madre del Sur, tamaño de camada.

Abstract.– Reproductive characteristics are determining factors in the evolutionary processes of reptiles; however, they remain poorly documented in many species. In this study, we evaluated aspects of reproductive biology and determined the influence of body size and weight on the reproductive effort of the lizard *Abronia gadovii*, an anguid species that is viviparous and terrestrial, endemic to the Sierra Madre del Sur, Mexico. Females of *A. gadovii* (*N* = 8) gave birth in mid-April, with litter sizes ranging from 2 to 8 neonates per individual. The relative litter mass index was 0.29, similar to that reported for some anguids of the subfamily Gerrhonotinae (e.g., *Elgaria coerulea* = 0.28) but lower than that of other species (e.g., *Gerrhonotus infernalis* = 0.44). We found no correlation between the size or weight of gravid females and the characteristics of their litters, in contrast to previous studies in other lizard families. Additional studies, as well as more rigorous comparative analyses, are needed to identify broader patterns of reproductive effort within anguids, whose reproductive biology remains poorly studied.

Keywords.– Guerrero, Gadow's alligator lizard, litter size, reproduction, Sierra Madre del Sur.

Variation in reproductive mode, clutch/litter size, and embryonic development play key roles in species adaptation (Villamar-Duque et al., 2019; Lopez-Alcaide et al., 2020). Nonetheless, reproductive metrics remain undocumented or poorly documented for many species. In reptiles, reproductive effort has been defined as the total proportion of energy that an animal allocates to reproductive processes (Hirshfield & Tinkle, 1975). Reproductive effort is often influenced by several factors including body condition and size, foraging mode, and reproductive mode (Vitt & Price, 1982; Cuellar, 1984; Rodríguez-Romero et al., 2005). Additionally, environmental factors such as temperature, photoperiod, and precipitation are often determinants of reptile reproductive activity (Duvall et al., 1982; Abell, 1999; Wapstra & Swain, 2001). To quantify female reproductive effort, relative clutch/litter mass indices (RCM/RLM) are widely used methods (Tinkle, 1972; Vitt & Congdon, 1978; Cuellar, 1984; Shine, 1992; Rodríguez-Romero et al., 2005).

The lizard family Anguidae shows notable variation in reproductive mode, with both oviparous and viviparous species. The most species-rich genus of viviparous anguids is *Abronia*, with 42 recognized species (Gutiérrez-Rodríguez et al., 2021; Clause et al., 2024). These species generally inhabit high elevations and are threatened by habitat loss and illegal trade (Campbell & Frost, 1993; Ariano-Sánchez & Melendez, 2009; Auliya et al., 2016; Gutiérrez-Rodríguez et al., 2021; Moreno-Lara et al., 2022). To date, reproductive studies of *Abronia* have focused on describing the reproductive cycle or documenting litter size without assessing reproductive effort (Campbell & Frost, 1993; Wicknick, 1993; Schmidt-Ballardo & Mendoza-Quijano, 1999; Greene et al., 2006; Solano-Zavaleta et al., 2007; Ramírez-Pinilla et al., 2009; Goldberg, 2011; González-Porter et al., 2015; Schmidt-Ballardo et al., 2015; Clause et al., 2016; Villamar-Duque et al., 2019). In this study, we evaluated the reproductive effort of *Abronia gadovii*, a viviparous species that is distributed in high-elevation forests of the Sierra Madre del Sur in the Mexican states of Guerrero and Oaxaca (Fig. 1).

From 20–24 March 2023, between 9:41 and 18:23 hours, we collected eight pregnant females of *A. gadovii* in pine-oak forest at Carrizal de Bravo, municipality of Leonardo Bravo, Guerrero, Mexico (17.619888° N, 99.839081° W) (Fig. 1). This locality spans an elevational range of 2,181–2,670 m a.s.l. and has a humid temperate climate, with an average annual temperature of 15.8 °C (range: 6.3–24.5 °C) and an average annual precipitation of 1,431 mm (climatic data obtained through WorldClim version 2, with 2.5 min resolution; Fick & Hijmans, 2017).

We transported collected females to the Laboratorio Integral de Vida Silvestre de la Facultad de Ciencias Biológicas de la Universidad Autónoma de Guerrero. Upon arrival at the laboratory, we placed the females in individual plastic boxes measuring 30 x 16 x 20 cm, with a layer of soil approximately 2 cm thick and dry pine and oak leaves as substrate. Additionally,

Figura 1. Apariencia y hábitat de *Abronia gadovii* de Carrizal de Bravo, Guerrero, México: hembra preñada in situ (A); neonato nacido en laboratorio (B); y hábitat ocupado en la temporada seca, fotografia fechada el 23 de Marzo del 2023 (C). Fotos: Adán Bautista del Moral (A y C) y Diego M. Arenas Moreno (B).

Figure 1. Appearance and habitat of *Abronia gadovii* from Carrizal de Bravo, Guerrero, Mexico: pregnant female in situ (A); laboratory-born neonate (B); and occupied habitat in the dry season, photograph dated 23 March 2023 (C). Photos: Adán Bautista del Moral (A and C) and Diego M. Arenas Moreno (B).

we added shelters such as pieces of bark and stones (Muñoz-Nolasco et al., 2023; Vargas-Ramírez et al., 2023). We maintained these enclosures under a natural photoperiod with ambient temperatures of 25–30 °C (Bautista-del Moral, 2019). We provided each captive female with water, mealworm larvae (*Tenebrio molitor*), and domestic crickets (*Acheta domesticus*) ad libitum (Muñoz-Nolasco et al., 2023), and we checked the females at least twice a day until they gave birth. After collecting reproductive data, we released the females along with their offspring at their exact sites of original capture.

To evaluate reproductive effort, we recorded the following morphometric variables: total weight, defined as the female prepartum weight (TW); difference weight (DW), defined as the total weight minus litter weight; absolute weight (AW), defined as the female postpartum weight; litter size (LS); litter weight (LW); and the weight of each neonate (NW) (Rodríguez-Romero et al., 2005; Villamar-Duque et al., 2019; Muñoz-Nolasco et al., 2023). We measured all weights using a digital scale (± 0.01 g), and measured the snout-vent length (SVL) of adult females and neonates using digital calipers (± 0.01 mm). To define the reproductive effort of each female we calculated relative litter mass (RLM) following the method of Rodríguez-Romero et al. (2005): RLM = LW/AW. Finally, we performed linear correlations to evaluate the relationship between clutch characteristics (LS, LW, and RLM) with SVL and the weight of females before and after birth (TW and AW, respectively) (Rodríguez-Romero et al., 2005). We performed these analyses using PAST: Paleontological Statistics Software Package for Education and Data Analysis version 3.20 (Hammer et al., 2001).

Pregnant females had an average SVL of 81.9 ± 2.21 mm (mean ± standard deviation) and an average TW of 13.0 ± 1.25 g. Their average DW was 3.58 ± 0.99 g, meaning that postpartum females lost an average of 26.9% of their TW. Births occurred from 10–24 April. Most females took 2 days to give birth to all their offspring, but one female took 6 days. Newborns (N = 43) had an average SVL of 29.8 ± 1.21 mm and an average weight of 0.48 ± 0.05 g. The average litter size was 5.3 ± 1.8 (range = 2–8), while the RLM was 0.29 ± 0.11 (range = 0.08–0.46). Table 1 summarizes these and other traits of the pregnant females, their litters, and the neonates. The linear correlation analyses examining litter

Tabla 1. Rasgos de las hembras preñadas, sus crías y tamaño de camada de *Abronia gadovii*. SVL = Longitud hocico-cloaca; TW = Peso total; AW = Peso absoluto; DW = Peso de diferencia; LS = Tamaño de la camada; LW = Peso de la camada; RLM = Masa relativa de la camada; NW = Peso de los neonatos. Se presenta la media, desviación estándar (±), el valor mínimo y máximo (min – max) y el número de muestra (N).

Table 1. Traits of pregnant females, their offspring, and litter size for *Abronia gadovii* from Carrizal de Bravo, Guerrero, Mexico. SVL = Snout-vent length; TW = Total weight; AW = Absolute weight; DW = Difference weight; LS = Litter size; LW= Litter weight; RLM = Relative litter mass; NW = Neonatal weight. The mean, standard deviation (±), the minimum and maximum value (min – max) and the sample number (N) are presented.

Traits	Females
SVL (mm)	81.9 ± 2.21 (77.2 – 84.3) (8)
TW (g)	13.03 ± 1.25 (10.49 – 14.17) (8)
AW (g)	9.46 ± 1.52 (7.36 – 12.00) (8)
DW (g)	3.58 ± 1.00 (1.48 – 4.45) (8)
Lost weight (%)	26.9 ± 5.78 (14.11 – 31.40) (8)
Traits	**Litter**
LS	5.38 ± 1.85 (2 – 8) (8)
LW (g)	2.67 ± 0.94 (0.95 – 3.88) (8)
RLM (g)	0.29 ± 0.11 (0.08 – 0.44) (8)
Traits	**Neonates**
SVL (mm)	29.8 ± 1.20 (27.3 – 31.6) (43)
NW (g)	0.48 ± 0.04 (0.38 – 0.60) (43)

Tabla 2. Resultados de los análisis de correlación entre las características de la camada (LS = tamaño de camada; LW = Peso de la camada; RLM = Masa relativa de la camada) y talla y peso de las hembras preñadas de *Abronia gadovii* de Carrizal de Bravo, Guerrero, México (SVL = Longitud hocico-cloaca; TW = Peso total; AW = Peso absoluto).

Table 2. Results of the correlation analysis between litter characteristics (LS = Litter size; LW= Litter weight; RLM = Relative litter mass) and size and weight of pregnant females of *Abronia gadovii* from Carrizal de Bravo, Guerrero, Mexico (SVL = Snout-vent length; TW = Total weight; AW = Absolute weight).

Traits	SVL	TW	AW
LS	r= 0.34, P= 0.39	r= 0.11, P= 0.79	r= -0.32, P= 0.43
LW	r= 0.44, P= 0.26	r= 0.08, P= 0.83	r= -0.31, P= 0.44
RLM	r= 0.40, P= 0.32	r= -0.24, P=0.55	r= -0.61, P= 0.10

characteristics (LS, LW, and RLM) and characteristics of the pregnant females (SVL, TW, and AW) recovered no significant relationships between any of the variables (Table 2).

The early spring births of our *A. gadovii* neonates coincide with prior data on this species (Ramírez-Pinilla et al., 2009), and with other *Abronia* species (Campbell & Frost, 1993; Solano-Zavaleta et al., 2007; González-Porter et al., 2015; Schmidt-Ballardo et al., 2015; Clause et al., 2016; Villamar-Duque et al., 2019), suggesting that this genus may have a conserved reproductive cycle with summer ovulation, winter gestation, and spring births. This reproductive cycle is common in viviparous lizards inhabiting high-elevation temperate regions (Guillette & Casas-Andreu, 1980; Guillette & Casas Andreu 1987; Méndez-de la Cruz et al., 1988; Ramírez-Bautista et al., 2008; Ramírez-Bautista & Pavón 2009). The size of our *A. gadovii* neonates (SVL = 27.3–31.6 mm) is also consistent with those reported for the species by Ramírez-Pinilla et al. (2009) (SVL = 28.65–32 mm). Neonate size in *A. gadovii* is similar to those reported for the terrestrial anguids *A. monticola* (average SVL= 25.9 mm; Wicknick, 1993) and *Barisia imbricata* (SVL = 29.1 mm; Guillette & Casas Andreu, 1987), but is smaller than those of arboreal congeners *A. deppii* (average SVL= 34.2 mm; Schmidt-Ballardo et al., 2015), *A. graminea* (SVL = 34.3 mm; Clause et al., 2016), *A. mixteca* (SVL = 35.5 mm; Schmidt-Ballardo & Mendoza-Quijano, 1999), and A. taeniata (SVL = 31.4 mm; Solano-Zavaleta et al., 2007).

The average RLM index value that we obtained for female *A. gadovii* (0.29) indicates moderate reproductive effort (Rodríguez-Romero et al., 2005). Although similar to the viviparous gerrhonitine anguid *Elgaria coerulea* (RLM = 0.28; Vitt & Price, 1982) this was an unexpected result because anguid lizards generally have a high RLM index (Vitt and Price, 1982). For example, females of the oviparous *Gerrhonotus infernalis* invest more than 60% of their body weight in reproduction (RCM = 0.44; Vargas-Ramírez et al., 2023). These results suggest that in anguid lizards, clutch size has decreased with the evolution of viviparity, as suggested by Guillette (1981) and Meiri et al. (2012). Because viviparity is considered an adaptation to cold environments, reduced offspring production is thus correlated with environmental conditions (Guillette 1981; Meiri et al., 2012). However, further study of anguid lizard reproductive patterns is needed to support the hypothesis that climate drives viviparity and hence reduced offspring production. Other contributing factors could include various types of ecological and habitat-related trade-offs between oviparity and viviparity (López-Alcaide et al., 2020). For example, having a large litter increases a female's body weight and volume, thereby reducing her speed and agility and increasing the risk of predation (Shine, 1980; Vitt & Price, 1982). Having large litters can also limit access to small or narrow refuges, which are vital for escaping predators (Shine, 1980).

LS and RLM in reptiles are considered dependent on factors such as SVL, TW, female body morphology, foraging mode, and reproductive mode (Vitt & Congdon, 1978; Vitt & Price, 1982; Shine, 1992). However, in our study we found no statistically significant correlation between female and litter traits for *A. gadovii*. Because older female lizards tend to reduce their reproductive effort regardless of their size (Shine & Schwarzkopf, 1992; Massot et al., 2011), if our sample included females of mixed ages no clear relationship would be expected between female and litter traits. However, determining the precise age of female anguid lizards is challenging. Additionally, the absence of a correlation among these traits may have been due to our comparatively small sample size of just eight females, which could have limited our statistical power to detect correlations.

More studies are needed to examine in greater detail the characteristics and reproductive cycles of different anguid species (Campbell & Frost, 1993; Schmidt-Ballardo et al., 2015). Currently, there is insufficient available information to allow rigorous, quantitative comparative analysis of reproductive effort among the species of this family.

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