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ECOLOGY OF A POPULATION OF THE EARTHSNAKE *CONOPSIS BISERIALIS* in the MEXICAN TRANSVOLCANIC AXIS

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Abstract.*—Information about the ecology of Mexican snakes, such as *Conopsis biserialis*, is minimal. This species has low population densities and may be in decline over much of its historical range, apparently caused by destruction and fragmentation of the temperate forest habitat in central Mexico. We describe general life-history traits of this specialist fossorial species in a natural population from the State of Mexico. We captured 84 snakes from February 2003 to December 2004. *Conopsis biserialis* has a unimodal abundance pattern of eight to nine months with a peak in the rainy season (June to September). Of the 84 snakes we found, males and females have the same body size, mass, cloacal temperature, and a similar number of ventral scales, but males have longer tails, heads, and more caudal scales than females. We observed few neonates or juveniles during our surveys, and only one adult female was gravid with four palpable embryos. The sex ratio of adults was close to 1:1. We found 96% of snakes under rocks with a cloacal temperature 6° C greater than rock temperature. Our data suggest a specialized diet of ground-burrowing invertebrate prey (arthropod larvae). These data are broadly consistent with information from earlier studies on *C. biserialis* and other fossorial species, but are insufficient to detail the ecological characteristics of reproduction in this snake. The ability of *C. biserialis* to persist is constrained by anthropogenically altered habitat in central Mexico. We need to develop appropriate techniques for the study of these fossorial species to learn enough about these animals to plan effectively for their conservation.

Key Words.—abundance; *Conopsis*; diet; ecology; microhabitat; reproduction; State of Mexico

INTRODUCTION

Ecological information on snake species from the Mexican Transvolcanic Axis is limited (Seigel and Collins 1993). Studies on this topic for snakes in Mexico are rare, especially when compared to the numerous studies on snakes in the northern United States and Canada (Seigel and Collins 1993). Field data biased toward the northern species limit our knowledge about ecology of Mexican snake species. Most small fossorial snakes remain unstudied because they tend to be highly secretive, cryptic, and infrequently active (Seigel 1993; How and Shine 1999; Goodyear and Pianka 2008).

The genus *Conopsis* Günther, 1858, is a group of specialist fossorial snakes (Greene 1997) composed of five morphologically variable Mexican species characterized by taxonomic instability (Goyenechea 2000; Goyenechea and Flores-Villela 2002, 2006). The Earthsnake, *Conopsis biserialis* (Fig. 1), is the most taxonomically stable species compared with the other species of the genus (Goyenechea and Flores-Villela 2006), but the ecological characteristics of this species have not been well studied. The existing data for *C. biserialis* are isolated and not unified. Uribe-Peña et al. (1999) reported the use of the bunchgrass *Mulenbergia macroura* as a possible microhabitat, whereas litter and ground burrows were reported by Goyenechea (2000). *Conopsis biserialis* eats beetles, moths, butterflies, and occasionally spiders (Uribe-Peña et al. 1999). Data on reproduction are also limited. It is known to be viviparous and mates in August, but further data are lacking (Greer 1966; Fitch 1970; Uribe-Peña et al. 1999; Estrada-Virgen and Alvarado-Díaz 2003). This species may be in decline over much of its historical range, apparently caused by destruction and fragmentation of the temperate forest habitat in central Mexico (Flores-Villela and Gerez 1994). Small fossorial species may be at particular risk from this anthropogenic disturbance. These kinds of snakes are poorly suited to moving long distances across open areas, especially across artificial substrates that preclude burrowing (How and Shine 1999). Thus, small fossorial species may be strongly disadvantaged by habitat fragmentation.

In our work, we focused on increasing the knowledge of an endemic and poorly known fossorial Mexican species located within an area highly disturbed by the

FIGURE 1. Earthsnake (*Conopsis biserialis*) from Ocoyoacac, México. (Photographed by Javier Manjarrez)

fragmentation of the forest. We describe some aspects of the ecology of *C. biserialis* from the State of Mexico. Specifically, we describe the temporal abundance, body size, reproductive condition, body temperature, and diet. We compare our data with other fossorial-snake species.

MATERIALS AND METHODS

Study site.—The population of *C. biserialis* we studied was located at Ocoyoacac, 18 km S of Toluca City (19°12'N, 99°19´W) at an elevation of 2,800 m. This site is within the Mexican Transvolcanic Axis, characterized by a temperate forest surrounded by a mosaic of agricultural land and small reforested patches. The specific habitat of the study site consisted of pine-oak forest (*Pinus leiophylla-Quercus crassipes*) with grasslands (Vázquez 2001). Rainfall averages 242 mm/y, most falling June to September. The mean annual environmental temperature is 13.1° C (García 1988).

Data collection.—We visited the approx. 1 km^2 study site biweekly from February 2003 to December 2004 from 0900 to 1500, although visits were less frequent during winter (November to January) when snakes are usually inactive. We looked for snakes under rocks or fallen branches, on grassland, and in ground burrows. We collected snakes by hand, and we recorded the body temperature and under-rock temperature using a Schultheis thermometer (Miller & Weber Inc., Ridgewood, New York, USA). Except for pregnant females, we obtained stomach contents by making the snakes regurgitate. As an alternative method of diet determination, we obtained feces by manually pressing the anterior-vent region (Fitch 1987). The feces were washed with water to eliminate plant debris and soil, clarified with 10% potassium hydroxide, and preserved in 70% alcohol.

We weighed snakes with a precision balance (± 0.01 g) and measured snout-vent length (SVL) and tail length (TL) using a metric scale (mm). We measured head length and head width with digital calipers. We also counted the number of ventral and caudal scales on each snake (Rossman et al. 1996). We determined the sex of each adult snake by the thickness of the tail (Conant and Collins 1998) and by hemipenis eversion in newborn (< 96 mm SVL, *sensu* Goyenechea 2000) and juvenile (96–185 mm SVL) snakes. We counted the number of embryos by ventral palpation of pregnant females and we also estimated the relative clutch mass (RCM: clutch mass/female postparturient mass; Fitch 1987). All snakes were released within three to six days of capture.

Data analysis.—We compared the SVL and ventral and caudal scales between the sexes with a one-way ANOVA. Because head dimensions vary with body length, we used the SVL as a covariate in an analysis of covariance (ANCOVA) to compare head dimensions between the sexes. We used the Spearman test to explore the relationship between the frequency of snakes captured and the rainfall and temperature, and between the body and under-rock temperature. We tested for sexual differences in the frequency of the snakes captured and the contained, identifiable prey with the Chi-square test (χ^2). Statistical tests were made using STATISTICA 8.0 (StatSoft Inc., Tulsa, Oklahoma, USA). We present descriptive statistics as the mean ± 1 SD, we set alpha at 0.05, and we tested all data for normality.

RESULTS

Temporal abundance.—*Conopsis biserialis* had a unimodal abundance pattern (Fig. 2). During both years, we captured 84 snakes; 41 in 2003 (49%) and 43 in 2004 (51%). The annual period of activity was eight to nine months. The first date we captured a snake was 7 February in 2003 and 12 February in 2004. The last snakes we captured were on 11 October in 2003 and 5 September in 2004. We captured 87% of the snakes in the rainy season (June to September). The frequency of captured snakes was highly correlated with monthly rainfall (r_S = 0.85, df = 10, P < 0.001; n = 12; Fig. 2), but not with the monthly temperature (r_S = 0.37, df = 10, P = 0.23; n = 12).

Body size.—Most snakes we found during fieldwork (63%; n = 53) were adults (> 190 mm SVL,), averaging 235 ± 31 mm SVL (190–330 mm). Juveniles averaged 132 ± 29 mm SVL (96–185 mm, n = 31). Adult females were slightly, but not significantly, larger than adult males ($F_{1,51}$ = 0.93, P = 0.33; Fig. 3). Adult males had tails that measured 15% longer than females ($F_{1,51}$ = 7.61, P = 0.008). Males also had significantly longer heads than females ($F_{1,82}$ = 11.81, P = 0.001; Fig. 3), but

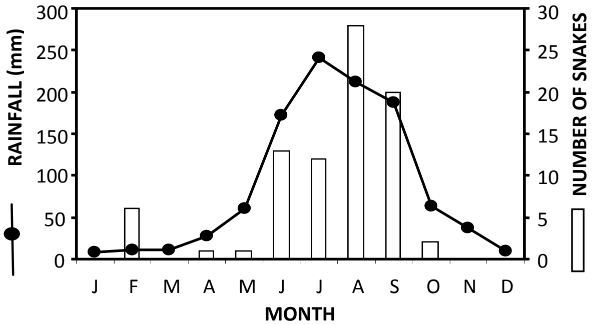

FIGURE 2. The total number of *Conopsis biserialis* collected monthly, and mean monthly rainfall at Ocoyoacac, México, in 2003 and 2004.

the width of the head was similar between sexes ($F_{1,82}$ = 1.91, P = 0.17). Males and females did not have a significantly different mass ($F_{1,82}$ = 0.19, P = 0.66; Fig. 3). Males have significantly more caudal scales (37 ± 4; n = 34) than females (31 ± 3; n = 50; $F_{1,82}$ = 6.3, P = 0.01), but not significantly more ventral scales (males: 130 ± 5; 117–144; n = 34; females 130 ± 9; n = 50; $F_{1,82}$ = 1.01, P = 0.31).

Reproductive condition and sex ratio.—One of the 23 adult female *C. biserialis* we collected during our study was gravid, with four palpable embryos. It was captured in February 2003 (SVL = 250 mm) and gave birth in the laboratory in late spring (3 June). The mean size and mass of the four offspring were 71 ± 4 mm SVL (68–75 mm; n = 4) and 0.87 ± 0.04 g (0.8–0.91 g) and the relative clutch mass (RCM) was 0.35. Likely due to this low incidence of reproduction, we saw few neonates or juveniles. We did not observe sexual interactions except for one incidence in August 2004 when we found a male-female pair of *C. biserialis* under a rock. The female had a milky white secretion on the snout that we later confirmed as sperm by observation under an optical microscope. The overall sex ratio of pooled juvenile and adult snakes captured was not significantly different than 1:1 (34 males; 50 females; χ^2 = 3.06, df = 1, P = 0.08). The juvenile sex ratio was biased in favor of females (1:7; χ^2 = 17.06, df = 1, P < 0.001), but the sex ratio of adults was close to 1:1 (χ^2 = 1.23, df = 1, P = 0.27).

Body temperatures.—We found all snakes under rocks (mean rock diameter 299 ± 81 mm; 211–475 mm; n = 81). The body temperature (24.9° C ± 4.1; 7.2-31.6° C) was 6.2° C greater than the mean temperature under the rocks (18.7 ± 3.9° C; 11.6–29.4° C; n = 62; t_{60} = 6.2, P < 0.001) and both were positively correlated (r_s = 0.31, df = 59, P = 0.01). Males (n = 24) and females (n = 33) did not have a significantly different body temperatures (24.3 ± 5.5° C and 24.9 ± 4.2° C; t_{55} = 0.47, P = 0.32).

Diet.—We obtained the stomach contents of three of 46 snakes palpated to regurgitate and all contained Jerusalem Crickets (Orthoptera: Stenopelmatidae), Lepidoptera larvae, and hyaline eggs. Individual samples of 43 feces contained larvae of four items identified as Lepidoptera, Arachnids, Hymenoptera, and Orthoptera (Table 1). Adult insect items were present in 10% of feces and were from Lepidoptera, Scorpionida, Acaridae, and Diptera (Table 1). In addition, the feces also contained earth and plant debris, including moss, roots, and grass. The proportion of snakes containing identifiable prey in feces was not significantly different between females (27 of 43 = 63%) and males (16 of 43 = 37%; χ^2 = 2.81, df = 1, P = 0.09).

DISCUSSION

Temporal abundance.—Our results are broadly consistent with information from earlier studies (Greer 1966; Fitch 1970; Uribe-Peña et al. 1999; Goyenechea 2000; Estrada-Virgen and Alvarado-Díaz 2003). We collected *Conopsis biserialis* from February to October with an abundance peak in summer–early autumn that was related to the monthly rainfall. This abundance pattern in general is common among the temperate terrestrial and American fossorial snakes (Gibbons and Semlitsch 1987; Wilson and Dorcas 2004; Todd et al. 2008), and similar to that reported by Uribe-Peña et al. (1999) and Goyenechea (2000) for *C. biserialis* in Central Mexico.

Body size.—The mean adult SVL of C. *biserialis* in Ocoyoacac of 235 mm is the largest that has been reported from any location in the geographic distribution within central Mexico (range 196.8–211 mm SVL; Uribe-Peña et al. 1999; Goyenechea 2000; Castro-Franco and Bustos-Zagal 2006; Ramírez-Bautista et al. 2009), suggesting a possible geographic pattern in the variation of SVL. The small body size of *C. biserialis* has strong implications for fossoriality because a shorter and thinner body facilitates movement, allowing snakes to move easily through burrows (Greene 1997). Consistent with this interpretation, most fossorial snakes are relatively short (How and Shine 1999; Willson and Dorcas 2004; Goodyear and Pianka 2008). A shorter body also decreases metabolic costs (Shine 1994), which is favorable in seasonal climatic conditions (How and Shine 1999) because seasonal precipitation may cause substantial variation in larval prey availability. Our data lends some support to this idea because the peak in snake abundance actually occurs one month after the peak in rainfall. This time lag is what one would expect if the prey availability were limited by rainfall and *C. biserialis* were maximizing metabolic efficiency.

Sexual dimorphism in SVL was not detected in this study. However, adult *C. biserialis* males have a greater tail length, head length, and more caudal scales than females. The sex-size dimorphism in the tail length and

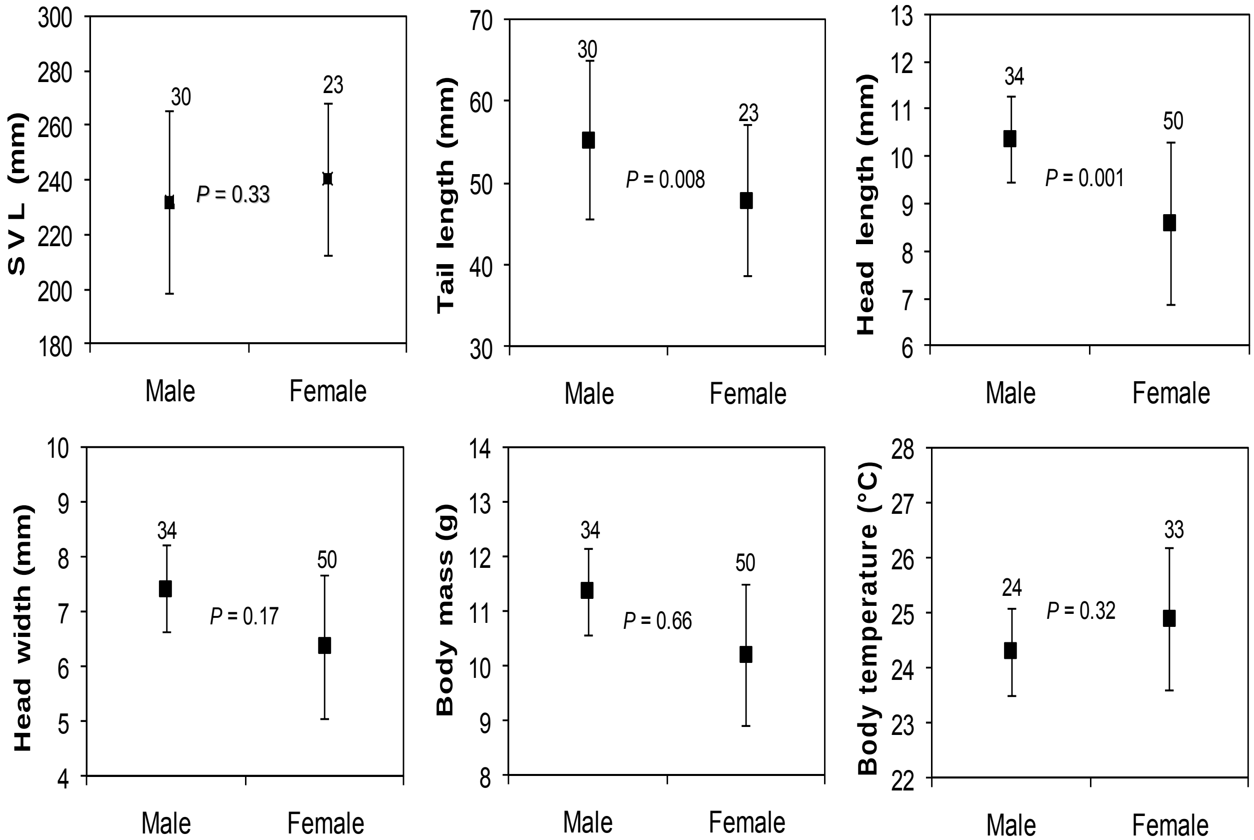

FIGURE 3. Sexual dimorphism expressed as the mean (mm ± SD) of snout-vent length (SVL), tail length, head length, head width, body mass, and body temperature for *Conopsis biserialis* from Ocoyoacac, México. *P* values indicate significance ($\alpha = 0.05$) based on statistical tests (see Results). Numbers of snakes are shown above lines.

caudal scales is common for many snake species (King 1989; Shine 1993; Shine et al. 1999), but the larger head length in males than females is uncommon because female snakes are commonly the larger sex in colubrid snakes (Shine 1993). This scenario suggests a possible differential sex-gap limitation with potential implications for differential consumption of prey. However, our study had a limited availability of snakes and large sample sizes are needed to explore this possibility and determine if sex difference in the head width of *C. biserialis* is a result of prey specialization.

Reproductive condition and sex ratio.—The only gravid female we found was in February with four embryos, which suggests a less-than-annual reproductive frequency in female *C. biserialis*. The litter size and RCM in this species are consistent with previous reports of two to eight newborns per litter from studies in central Mexico (Fitch 1970; Ramirez-Bautista et al. 1995; Estrada-Virgen and Alvarado-Díaz 2003) and the RCM of 0.31 reported from Tancítaro, Michoacan (Estrada-Virgen and Alvarado-Díaz 2003). Compared with fossorial, viviparous species, the RCM is similar to species such as *Anilius scytale* from South America (Cisneros-Heredia 2005), but lower than *Storeria occipitomaculata* in North America (Brodie and Ducey 1989).

The birth we observed was in spring (3 June), which is an extremely early time of parturition for any temperate North American viviparous snake (Seigel et al. 2000). The only other reported Mexican snake that gives birth so early is *Thamnophis eques* (30 April; Manjarrez 1998). Parturition in spring, coupled with activity from February to October, suggests that *Conopsis biserialis* in Ocoyoacac may grow for up to six months in their first year (May–October) before the onset of winter when potentially lethal temperatures are likely to occur. However, our limited data do not allow us to detail the ecological characteristics of the reproduction of this snake.

The sex ratio in juveniles of *C. biserialis* was biased in favor of females, but in adults there is no bias. The difference in the sex ratios of adults and juveniles may be attributed to behavioral, ontogenic changes, differential mortality, or small males becoming reproductive at an earlier age than females, as seen in *Phrynosoma* lizards (Zamudio 1998). The sex ratios measured in fossorial snakes are commonly male biased, (e.g., How and Shine 1999; Goodyear and Pianka 2008; Todd et al. 2008), and usually only deviate from equality

TABLE 1. Prey items in 43 individual samples of feces of *Conopsis biserialis* from Ocoyoacac, México.

Items	Percentage
Larvae	
Lepidoptera	49
Arachnids	26
Hymenoptera	10
Orthoptera	5
Adults	
Lepidoptera	3
Scorpionida	3
Acaridae	3
Diptera	1

when there are sex differences in behavior, habitat, or mortality.

In general, snakes exhibit limited sexual dimorphism in size that seems likely to put one sex at greater risk of mortality (Shine 1993; Sperry and Weatherhead 2009). If sexual differences in mortality occur in *C. biserialis*, we would expect sex body-size differences, but the adult means were similar for both sexes. Thus, it is unclear whether the sex-ratio deviation reflects actual population structure or simply a sampling bias of different behavioral, habitat, or mortality traits of females and males of *C. biserialis*.

Body temperatures.—We found *C. biserialis* at Ocoyoacac only under rocks, consistent with previous reports for this species and other fossorial species (Ramirez-Bautista 1994; Greene 1997; Civantos et al. 2003; Cicek and Mermer 2007). The microhabitat preferences of snakes are related to thermal requirements (Christian et al. 1983; Peterson 1987; Huey et al. 1989; Grover 1996), foraging activity (Reinert 1993; Mullin and Cooper 2000), prey availability (Huey and Pianka 1981), or reproductive condition (Reinert 1984; Siegel and Collins 1993). For *C. biserialis*, foraging activity probably influences body temperature because snakes have a body temperatures 6.2° C greater than the mean temperature under the rocks. A study focused on microhabitat preferences and their environmental determinants in *C. biserialis* would be useful.

Diet.—Consistent with earlier information, our data suggest a specialized diet of ground burrow prey, mainly arthropod larvae of Orthoptera, Lepidoptera, and Arachnids. Arthropods in the diet of snakes are poorly documented (Arnold 1980; Daltry et al. 1998; Holycross and Mackessy 2002; Vincent et al. 2004a, b) but it seems to be a common pattern in small, fossorial species (Cicek and Mermer 2007; Todd et al. 2008). *Conopsis biserialis* ingest these prey at low feeding rates (6.5% of snakes with an available stomach content). Low feeding rates may result in snakes in the field being thin, growing slowly, and reproducing infrequently (Fitzgerald et al. 2004). The seasonality of precipitation and prey availability at Ocoyoacac can affect the ecological traits of *C. biserialis*, both as direct proximate effects and as evolutionary selection pressures.

The ability of *C. biserialis* to persist is constrained by human-induced habitat alterations of the temperate forest habitat in central Mexico. Small fossorial species, such as *C. biserialis*, may be strongly disadvantaged by habitat fragmentation. Therefore, conservation efforts should be directed to areas where suitable ecological variables prevail and especially when the anthropogenic process probably affects prey availability and fossorial microhabitat. Because capture of small snakes is often so low, comprehensive ecological studies are difficult to make and are rarely available. We need to develop appropriate techniques for the study of these small, cryptic, and virtually unobservable snakes, particularly of ecological traits and life-history attributes for fossorial species. In consequence, most of what we know about these kinds of snakes comes from occasional captures of active animals. New techniques are needed if we are to learn enough about these animals to plan effectively for their conservation.

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