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Feeding Ecology, Reproductive Biology, and Parasitism of *Gymnodactylus geckoides* Spix, 1825 from a Caatinga Area in Northeastern Brazil

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Abstract.—**Neotropical lizards belonging to the genus *Gymnodactylus* are endemic to South America, occurring in the Caatinga, Cerrado and Atlantic Forests in Brazil. We collected specimens of the Naked-toed Gecko (*Gymnodactylus geckoides*) using pitfall traps and Time Constrained Searches in two areas of Caatinga and studied diet, reproduction, sexual dimorphism, and parasite burden. *Gymnodactylus geckoides* has continuous reproduction and sexual dimorphism. The species is a dietary generalist and preyed on invertebrates, mainly Orthoptera and Aranae and Isopoda, and had a low parasite richness.**

Key Words.—diet; reproductive; helminth; sexual dimorphism; Naked-toed Gecko

Introduction

The Geckos (Gekkota), numbering more than 1,600 species, are distributed worldwide and represent one of the most species-rich and arguably evolutionarily successful clades of living lizards (Gamble et al. 2011). They are the only such lineage to be primarily nocturnal (Kluge 1967; Pianka and Huey 1978). The gecko genus *Gymnodactylus* is endemic to South America, occurring in the Caatinga, Cerrado, and Atlantic Forests in Brazil (Vanzolini 1953, 1982, 2004, 2005; Kluge 1993). This genus comprises five species of small lizards that are mainly nocturnal (Pellegrino et al. 2005). One of these, the Naked-toed Gecko (*Gymnodactylus geckoides*), which is endemic to Caatinga Domain (Vanzolini 1953). Prior studies of the ecology of *G. geckoides* have examined studies of reproduction, diet, and sexual dimorphism (Vitt 1986, 1995; Souza-Oliveira et al. 2017), and parasitology (Ávila and Silva 2010; Brito et al. 2014; Lima et al. 2017).

Understanding the feeding ecology, reproductive biology, and parasites of a species can be important in the study of biological communities (Huey and Pianka 1981; Barden and Shine 1994; Rocha et al. 2000). Parasites influence the evolution of their hosts (Phillips et al. 2010) and are good indicators of healthy ecosystems, which is essential for conservation and maintenance of host populations (Marcogliese 2005). The characterization of the parasite population and of ecological characteristics of species within the Caatinga domain is essential, especially for future studies on species conservation. In this study, we present data on the reproduction, diet, and parasitism of *G. geckoides* in two Caatinga areas of Brazil.

Materials and Methods

Field sampling.—We conducted the study from 2012 to 2013 in two areas of Caatinga from the Neotropical Semiarid Region: the Estação Ecológica (ESEC) from the municipality of Aiuaba (6°49’S, 40º44’W) and the Cuncas District (7°10'S, 38°46'W) in the municipality of Barro, both in the Ceará state of northeastern Brazil. The sites are approximately 164 km apart. The Caatinga is composed of vegetation mosaics that contain the predominant vegetation of this region (Velloso et al. 2002). At our sites, the vegetation is characterized by Thorny Deciduous Forest (Instituto de Planejamento do Estado do Ceará. 2018 - Anuário Estatístico do Ceará. Perfil Básico dos Municípios: an online reference.

Available from http://www.ceara.gov.br/municipios-cearenses/781-municipios-com-a-letra-b#munic-pio-barro. [Accessed 22 January 2019]).

We collected specimens of *Gymnodactylus geckoides* using pitfall traps with drift fences and Time Constrained Searches (TCS; Martins and Oliveira 1999; Cechin and Martins 2000). For each individual, we used a digital caliper (± 0.01 mm) to measure snout-vent length (SVL). After we had captured and measured each specimen, we killed the specimen with a lethal injection of Sodium Tiopenthal 2%, fixed it in 10% formalin, and then preserved it in 70% ethanol. We deposited voucher specimens at the Coleção Herpetológica da Universidade Regional do Cariri, Crato, Ceará, Brazil (URCA-H).

Feeding ecology.—We removed stomachs from preserved specimens and examined them under a stereomicroscope to identify prey items to the most inclusive taxonomic level possible (e.g., order). We excluded prey items that were too fragmented to allow a reliable estimate of volume. We measured the length (L) and width (W) from intact prey and evaluated their volumes (V) using the ellipsoid formula:

$$V = \frac{4}{3}\pi\left(\frac{W}{2}\right)^2\left(\frac{L}{2}\right)$$

where V = volume, W = Width, and L = length. We calculated numerical and volumetric niche breadth (B) using the inverse of the Simpson diversity index (Simpson 1949):

$$B = \frac{1}{\sum_{i=1}^{n} Pi^2}.$$

The values range from 1 (exclusive use of a single category of prey) to n (equal use of all categories of microhabitat used by each species). To determine the relative contribution of each prey category, we calculated the Index of Relative Importance (IRI) using the formula (Powell et al. 1990):

$$IRI = (F\% + N\% + V\%)/3$$

where F = frequency, N = number of prey, and V = volume of prey. To investigate the relationship between prey dimensions and morphological head measurements, we performed a canonical correlation analysis (CCA) (Tabachnick and Fidell 1996) between two variable groups (maximum prey length and width versus head length, width, and height).

Reproduction.—We determined the sex of individuals by dissection and direct observation of gonads. We considered females as reproductively active based on the presence of vitellogenic follicles or oviductal eggs. We considered follicles vitellogenic when they were yellow and larger than 3 mm in diameter (Van-Sluys 1993) and considered males as reproductively active based on the presence of enlarged testes and convoluted epididymides (Ballestrin et al. 2010). We used Student's *t*-test (α= 0.05) to examine intersexual differences in adult SVL, and to examine if there is correlation between female size and clutch size. We performed a Spearman Rank Correlation (α= 0.05) to test relationships between both eggs and testicle sizes and female and male SVL, respectively. We recorded the lengths and widths of eggs, follicles, and testicles, and estimated their volumes using the ellipsoid formula described above.

Parasitism.—To assess parasitism, we examined the abdominal cavity and the gastrointestinal, respiratory, and urinary tracts of lizards. We collected, counted, and cleaned helminths prior to fixing them in alcohol (70%) and processed them following classical methods (Amato et al. 1991). For species identification, we stained cestodes with hydrochloric carmine and cleared them with creosote. We cleared nematodes in lactophenol (Andrade 2000). After identification, we deposited the helminths in the parasitological collection of the Universidade Regional do Cariri, Crato, Ceará state, Brazil. We calculated the overall prevalence (number of parasitized host individuals divided by the total number of individuals), mean intensity of infection (number of helminths divided by total number of individuals in the sample), and mean abundance of parasites (number of helminths divided by the number of parasitized individual; Bush et al. 1997).

Results

We collected 66 *G. geckoides* (Fig. 1), 30 from Aiuaba, 33 from Barro. Of the collected individuals, 21 had content in their gastrointestinal tracts. We identified six prey categories in the diet of *G. geckoides*. Orthoptera was the most important prey type both numerically

Figure 1. Adult male Naked-toed Gecko (*Gymnodactylus geckoides*) from Estação Ecológica de Aiuaba, Ceará, Brazil. (Photographed by Herivelto F. Oliveira).

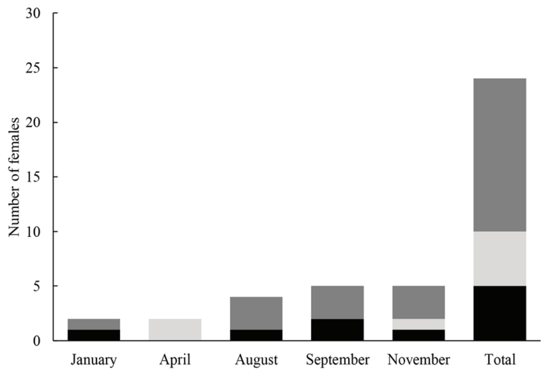

Figure 2. Number of females analyzed of Naked-toed Gecko (*Gymnodactylus geckoides*) collected per month from a Caatinga Ceará state, Brazil (black: juvenile females, dark grey: adult female with vitellogenic follicles, grey: adult female with eggs).

(50%), and volumetrically (46.9%), in addition to being the most frequent prey type in the diet (52.2%) and having the highest IRI value (50.4%). Aranae and Isopoda (both 12.5%) were the second most important prey type numerically. Aranae was the second most important prey type volumetrically (28.4%) and had the second highest IRI value (17.8%; Table 1), followed by Isopoda in both volume (12.9%) and IRI (11.2%). Trophic niche breadth for *G. geckoides* was 3.14 in number and 3.06 in volume. Head measurements and prey dimensions were not significantly associated (P = 0.602).

The smallest reproductive female measured 36.3 mm SVL, whereas the smallest sexually mature male measured 29.8 mm SVL. The clutch size varied from one (73.3%) to two eggs (26.7%) per female (n = 15). Females carrying two eggs were not larger than those with a clutch of one egg (t = -0.061; df = 13; P = 0.952). The average egg length was 6.5 mm (n = 15) and the average width was 4.3 mm (n =15). We found reproductive females (all of them carrying eggs, n = 15) throughout the year (Fig. 2). We found no relationship between female SVL and size of eggs (P = 0.122) or between male SVL and testicle volume (P = 0.777). Reproductive males ranged in size from 29.8 to 45.8 mm SVL, whereas reproductive females ranged in size from 36.3 to 45.2 mm SVL. The sexes differ significantly in size (P = 0.042), with females being larger than males.

From the 66 specimens of *G. geckoides* analyzed, 15 individuals were infected with at least one helminth species (22.7% overall prevalence). We found 40 nematodes, with a mean abundance of 0.9 ± 0.18 (standard deviation) and a mean intensity of 2.66 ± 0.60. The richness of helminth fauna associated with *G. geckoides* was comprised by three taxa: cystacanths (Acanthocephala), *Parapharyngodon alvarengai*, and larva of *Physaloptera* sp. The nematoda *P. alvarengai* was the only species that occurred in both areas (Table 2).

Discussion

In our study, the most frequent prey items were Orthoptera and Aranae. Both Isoptera and Orthoptera were the predominant prey types of *G. geckoides* in a Restinga area (Souza-Oliveira et al. 2017), and Isoptera was reported as the main ingested prey for *G. geckoides* from a Caatinga area (Vitt 1995) and for *G. amarali* from a Cerrado area of Brazil (Colli et al. 2003). Orthoptera and Isopoda were the most frequent items for *G. darwinii* in a rainforest area (Almeida-Gomes et al. 2011). The prey we found most abundantly, Orthoptera and Aranae, can be very evasive and hard to capture and swallow, but consumption of this type of prey may be favored by the large size of individual prey (Diaz and Carrascal 1991, 1993; Moreno-Rueda et al. 2017). Higher intake of Orthoptera and Aranae may also be related to the energetic balance of individuals because the intake of larger prey may have a lower cost to benefit ratio than ingesting smaller prey (Gomez-Mesa et al. 2017). The absence of Isoptera in the diet of *G. geckoides* in our study may be related to differences in the abundance

Table 1. Number of lizard with alimentary content in their gastrointestinal tracts (n), percentage frequency of occurrence of a particular prey item (F%), percentage number of particular prey items (N%), volume percentage of prey (V%), and Index of Relative Importance (IRI) of each prey category in the diet of the Naked-toed Gecko (*Gymnodactylus geckoides*) from Caatinga in Ceará State, Brazil.

	General (n = 21)				Barro (n = 14)				ESEC Aiuaba (n = 7)			
Category	F%	N%	V%	IRI	F%	N%	V%	IRI	F%	N%	V%	IRI
Invertebrates												
Aranae	13.04	12.5	28.43	17.82	7.14	6.25	0.13	4.51	22,2	22.2	40.74	28.39
Formicidae	8.69	8.33	2.12	6.27	14.28	12.5	7.01	11.26	0	0	0	0
Isopoda	8.69	12.5	12.86	11.19	7.14	12.5	40.06	19.9	11.11	11.11	1.02	7.75
Lepidoptera larvae	8.69	8.33	9.54	8.75	7.14	6.25	15.25	9.55	11.11	11.11	7.05	9.75
Orthoptera	52.17	50	46.93	50.37	50	50	37.18	45.72	55.55	55.55	51.17	54.09
Vertebrate												
Ecdise	8.69	8.33	0.11	5.60	14.28	12.5	0.36	9.04	0	0	0	0

Table 2. Prevalence (P; percentage), mean abundance (MA; ± standard error), mean intensity of infection (IMI; ± standard error), range intensity of infection (RII), and site of infection of the helminth parasites (SI: small intestine; LI, large Intestine; S, stomach) found in Naked-toed Geckos (*Gymnodactylus geckoides*) from the Barro site, the Estação Ecológica from the municipality of Aiuaba (ESEC Aiuaba), and combined sites from the Caatinga in Ceará state, Brazil.

Helminths	P (%)	MA ± SE	IMI ± SE	RII	SI
Acanthocephala - Cystacanths					
Combined	1.5	0.02 ± 0.02	1	1	S
Barro	0	0	0	0	
ESEC Aiuaba	2.7	0.4 ± 0.4	1	1	
Nematoda - *Parapharyngodon alvarengai*					
Combined	19.7	0.7 ± 0.2	3 ± 0.7	1–9	SI; LI
Barro	20	0.6 ± 0.3	3.8 ± 1.4	1–6	
ESEC Aiuaba	19.5	0.7 ± 1.1	2.1 ± 0.3	1-4	
Larvae of *Physaloptera* sp.					
Combined	1.5	0.02 ± 0.02	1	1	S
Barro	2.7	0.03 ± 0.03	1	1	
ESEC Aiuaba	0	0	0	0	

of Isoptera in the areas we sampled compared to sites studied by Vitt (1995), Almeida-Gomes et al. (2011), and Souza-Oliveira et al. (2017), although we have no data to support this.

Geckos have invariant clutch size and almost all species are able to produce more than one clutch per season (Fitch 1970; Vitt 1986). For *Gymnodactylus*, clutch size varies from one to two eggs (Vitt 1986; Colli et al. 2003; Souza-Oliveira et al. 2017). The unpredictability of rainfall in the Caatinga is known to influence lizard reproduction, causing continuous reproduction throughout the year (Albuquerque et al. 2018; Colli et al. 2003; Mesquita and Colli 2003). Continuous reproduction was reported for *Gymnodactylus* in both predictable (Restinga) and unpredictable (Caatinga) environments (Vitt 1986; Souza-Oliveira et al. 2017; this study), but seasonal reproduction was reported in a predictable (Cerrado) environment (Colli et al. 2003). In our study, clutch size varied from one to two eggs, similar to the findings of Colli et al. (2003) for *G. amarali* from the Cerrado. This differs from previous studies of *G. geckoides* in Caatinga (Vitt 1986) and Restinga (Souza-Oliveira et al. 2017) in which the clutch size was one egg; however, 40% of females of *G. amarali* carried two eggs (Colli et al. 2003) compared with 26.7% of *G. geckoides* in our study. In semiarid environments, water availability is a crucial factor for plant productivity, with consequences for lizards because of food availability, microhabitat use, hatchling survival, and lizard reproduction (Garda et al. 2012; Collins et al. 2014; Ryan et al. 2016).

The richness of parasites associated with *G. geckoides* was low (only three species). This might be related to the body size of the species (mean SVL 38.3 mm). According to Ávila et al. (2010), smaller lizard species tend to show considerably lower helminthes richness compared to larger lizard species. The low richness, prevalence, and infection rates of helminthes found for *G. geckoides* might be related to the foraging type and also to intrinsic characteristics of the species.

The lizard *Gymnodactylus geckoides* has been reported infected by the nematodes *Aplectana* sp., *Parapharyngodon alvarengai*, *Strongyluris oscari*, *Spauligodon oxkcutzcabiensis*, *Physaloptera lutzi*, and *Trichospirura* sp., by the trematode *Paradistomum rabusculum*, and by cestodes *Oochoristica* sp. and *Piratuba* sp. (Ávila and Silva 2010; Brito et al. 2014; Lima et al. 2017). Our study is the first to record Acanthocephala (Cystacanths) infecting *G. geckoides,* contributing to a better understanding of the helmintofauna associated with this lizard. Our data on diet, reproductive biology, and parasitism of a population of *G. geckoides* from Caatinga can be used for future ecological studies of lizards in Caatinga. In addition, these data can contribute to the development of future conservation strategies of lizards from Caatinga biome. The development of new research in other areas of the biome is essential to enhance our scientific knowledge of the ecology and diversity of helminths associated with lizards.

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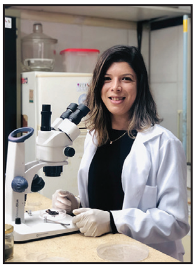

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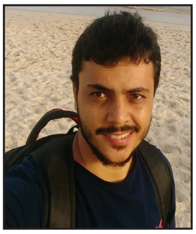

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