Natural History of *Dendropsophus tapacurensis* (Hylidae) in Rainforest Enclaves of Northeastern Brazil

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ARTÍCULO DE INVESTIGACIÓN / RESEARCH ARTICLE

NATURAL HISTORY OF *Dendropsophus tapacurensis* (Hylidae) IN RAINFOREST ENCLAVES OF NORTHEASTERN BRAZIL

Historia natural de *Dendropsophus tapacurensis* (Hylidae) en enclaves de selva tropical del noreste de Brasil

Running head: Natural history of *Dendropsophus tapacurensis*.

Kássio de Castro Araújo[1,2,a*], Dalilange Batista-Oliveira[1,b], Tatiana Feitosa Quirino[3,c], Sâmia Caroline Melo Araújo[4,d], Etielle Barroso de Andrade[2,e], Robson Waldemar Ávila[1,3,5,f]

[1] Programa de Pós-Graduação em Ecologia e Recursos Naturais, Departamento de Ciências Biológicas, Universidade Federal do Ceará, Campus do Pici, Av. Mister Hull, s/n, Fortaleza, Brasil

[2]Grupo de Pesquisa em Biodiversidade e Biotecnologia do Centro-Norte Piauiense, Instituto Federal de Educação, Ciência e Tecnologia do Piauí, Campus Pedro II, Rua Antonino Martins de Andrade, 750, Pedro II, Brasil

[3]Programa de Pós-Graduação em Sistemática, Uso e Conservação da Biodiversidade, Departamento de Ciências Biológicas, Universidade Federal do Ceará, Campus do Pici, Av. Mister Hull, s/n, Fortaleza, Brasil

[4]Programa de Pós-graduação em Zoologia, Universidade Estadual de Santa Cruz, Campus Soane Nazaré de Andrade, Rodovia Jorge Amado, km 16, Bairro Salobrinho, Ilhéus, Brasil

[5]Núcleo Regional de Ofiologia, Bloco 905, Universidade Federal do Ceará, Campus do PICI, Avenida Humberto Monte, s/n, Fortaleza, Ceará 60455-760, Brasil

[a] ORCID: https://orcid.org/0000-0003-4091-8521, email: kassio.ufpi@gmail.com

[b] ORCID: https://orcid.org/0000-0002-4140-6643, email: dalilangebatista@gmail.com

[c] ORCID: https://orcid.org/0000-0001-8184-8705, email: tata_tatifeitosa@hotmail.com

[d] ORCID: https://orcid.org/0000-0002-8817-8406, email: carolinesamia93@gmail.com

[e] ORCID: https://orcid.org/0000-0002-5030-1675, email: etlandrade@ifpi.edu.br

[f] ORCID: https://orcid.org/0000-0003-3641-8321, email: robsonavila@gmail.com

* ***For correspondence:*** **kassio.ufpi@gmail.com**

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ABSTRACT

Understanding aspects related to the natural history of species is crucial for plans aimed at their preservation and conservation. In this manuscript, we present data on the diet composition, microhabitat use, geographic distribution, and vocalization of *Dendropsophus tapacurensis*, a recently described tree frog endemic to the Atlantic Forest and some rainforest enclaves in Northeastern Brazil. This study was carried out in two mountains in the state of Ceará, northeast of Brazil. We collected 49 individuals (43 males and six females) of *D. tapacurensis*, of whom 27 had food items in their stomachs. Although mosquitoes and beetles were the most abundant prey categories, this species appears to have a generalist diet. Like most species of the *D. decipiens* group, this tree frog is associated with lentic water ponds and generally forages on submerged herbaceous plants. The acoustic parameters recorded at the announcement song agree with the original description of the species, except for the variation in the duration of the last pulse. Future studies are required to evaluate

possible inter-population variations in the announcement song of *D. tapacurensis*. This study contributes to understanding the natural history of mountain tree frogs in the Caatinga biome.

Keywords: Dendropsophini, advertisement call, diet composition, microhabitat-use.

RESUMEN

Comprender aspectos relacionados con la historia natural de las especies es crucial para los planes encaminados a su preservación y conservación. En este manuscrito presentamos datos sobre la composición de la dieta, el uso del microhábitat, la distribución geográfica y la vocalización de *Dendropsophus tapacurensis*, una rana arborícola recientemente descrita y endémica a la Mata Atlántica y algunos enclaves de selva tropical en el noreste de Brasil. Este estudio se realizó en dos montañas del estado de Ceará, noreste de Brasil. Recolectamos 49 individuos (43 machos y seis hembras) de *D. tapacurensis* de los cuales 27 tenían ítems alimenticios en su estómago. Aunque los mosquitos y los escarabajos fueron las categorías de presas más abundantes, esta especie parece tener una dieta generalista. Como la mayoría de las especies del grupo *D. decipiens*, esta rana arbórea está asociada a estanques de agua léntica y generalmente forrajea en plantas herbáceas sumergidas. Los parámetros acústicos registrados al canto de anuncio concuerdan con la descripción original de la especie, excepto por la variación en la duración del último pulso. Se requiere futuros estudios para evaluar posibles variaciones inter poblacionales en el canto de anuncio de *D. tapacurensis*. Este estudio contribuye a conocer la historia natural de las ranas arborícolas de montaña del bioma Caatinga.

Palabras Clave: Dendropsophini, Llamada de anuncio, composición de la dieta, uso del microhábitat.

INTRODUCTION

Species need some niche differences to coexist with other species (Gotelli, 2009; Vignoli and Luiselli, 2011), with food and space being important resources driving community structure (Leite-Filho et al., 2017; Caldas et al., 2019). Thus, knowing the natural history traits of species is important because they are useful for understanding species needs, their distribution, and their coexistence in biotic communities (Leibold and McPeek, 2006; Birkeland, 2009). Hence, reinforcing the importance of descriptive studies about the species natural history.

Amongst vertebrates, anurans are one of the most diverse groups with recurrent new species discoveries (e.g., Mônico et al., 2023; Folly et al., 2024; Menéndez-Guerrero et al., 2024). Added to this, anurans have been used as models to address questions in population and community ecology (Hopkins, 2007), including the impact of human disturbances on global biodiversity (Wake and Vredenburg, 2008). Studies dealing with the natural history of anurans might focus on aspects related to their feeding habits, breeding biology, forage mode, and vocalization, for instance (e.g., Freitas et al., 2008; Guimarães et al., 2011; Oliveira et al., 2011; Roberto and Cascon, 2023). Although there has been an increase in these studies, some anurans remain understudied, mainly recent-described species.

Hylidae represents the most diverse anurans family in the world, with 1.056 known species well distributed in South America (Frost, 2024). Among hylids, the genus *Dendropsophus* Fitzinger, 1843, has 107 species recognized and divided into nine groups (Orrico et al., 2020; Frost, 2024). More specifically, concerning the *Dendropsophus decipiens* group, six species are known that share a brownish or pale-yellow dorsum

coloration with a frame-like pattern, besides other phenomic and genomic synapomorphies (Orrico et al., 2020). All these species present eggs laying on leaves above lentic environments and exotrophic tadpoles that fall and complete development in the water (Silva et al., 2019).

Within the *Dendropsophus decipiens* group, *D. tapacurensis* Oliveira, Magalhães, Teixeira, Moura, Porto, Guimarães, Giaretta, and Tinôco, 2021 was the latest described species. It is known data about its advertisement call, forage habitat, and breeding activity only from its type locality in the São Lourenço da Mata municipality, Pernambuco State, Northeast Brazil (Oliveira et al., 2021). To fill some gaps regarding its natural history, we described the diet composition, microhabitat use, advertisement call, and we also recognized populations of *D. tapacurensis* in montane relicts from Ceará state, Northeast Brazil.

MATERIAL AND METHODS

Study area

The present study was carried out in the mountains of Baturité and Maranguape, both located in Ceará State, Northeastern Brazil (Fig. 1). These highlands are considered rainforest enclaves inserted in the lowlands of Brazilian semiarid, characterized by arboreal vegetation and high levels of epiphytic, fern, and bryophytic species at high altitudes (Moro et al., 2015). The climate of these mountains is milder in relation to the low surrounding regions, with higher precipitation and rainfall. The mean temperatures of these mountains range from 21.9 ºC to 24.4 ºC, and the annual rainfall is usually higher than 1200 mm (Medeiros and Cestaro, 2019).

Sampling

We conducted the fieldwork from April 19 to May 1, 2019 in two sampling points within Baturité Mountain: "Vale das Nuvens" (-4.268 S, -38.910 W, 805 m a.s.l.) and "Parque das Trilhas" (-4.270 S, -38.930 W, 912 m a.s.l.), and three within Maranguape Mountain: "Riacho Beija Flor" (-3.896 S, -38.720 W, 900 m a.s.l.), "Lagoa Verde" (-3.904 S, -38.720 W, 700 m a.s.l.), and "Lagoa Velha" (-3.910 S, -38.720 W, 740 m a.s.l.). We used acoustic and visual searches as sampling methods (Heyer et al., 1994). Anuran sampling started collecting around 6:00 p.m. and ended at 11:59 p.m., in which for each individual collected, we recorded the type of substrate used in vocalization and foraging activities.

We carried the specimens collected in plastic bags to the laboratory, where we measured the snout-vent-length (SVL) using a digital caliper (0.1 mm precision) and weighed each one using a Pesola Micro Spring Scale 10 g (0.1 g precision). We euthanized the specimens collected using lidocaine injection (2 %), following the ethical procedures of the Conselho Federal de Medicina Veterinária (CFMV, 2013), and subsequently had their stomachs removed. We analyzed the stomach contents of each collected individual using a magnifying glass. Voucher specimens were housed in the Núcleo Regional de Ofiologia of the Universidade Federal do Ceará, Fortaleza, Brazil.

Trophic parameters

We estimate the volume of each prey using the ellipsoid formula: $V = 4/3.\pi(L/2).(W/2)^2$, where V = volume, L = length, and W = width, and the Index of Relative Importance (IRI) to measure the relative contribution of each prey category by the following formula: IRI = (F % + N % + V % / 3), where F, N, and V represent the

percentual values of frequency of occurrence, numerical abundance, and volume of each prey, respectively (Powell et al., 1990). We identified the prey items to the lowest possible taxonomic level using specialized literature (Rafael et al., 2024).

We used Linear mixed-models (LMMs) framework (function 'lme') fitted by restricted maximum likelihood with random effects (random = ~1) as implemented in the package nlme (Pinheiro and Bates, 2000) to investigate the relationship of SVL and mass (weight) with the volume of each prey consumed by the individuals of *D. tapacurensis*. The sex of the frogs was used as the random effect. Statistical analyses were performed in R software (R Core Team, 2023).

Bioacoustics parameters

Of the 49 collected individuals, we recorded 132 advertisement calls of five individuals of *D. tapacurensis* using a professional digital recorder Marantz PMD 660 with an external directional microphone Yoga EM-9600, at a sample rate of 44.1 kHz and sample size of 16 bits. The recorder was positioned at an approximate distance of 0.7 meters from the vocalizing male, and each recording lasted five minutes. Thereafter, the individuals were collected manually and placed in plastic bags. We used the Raven Pro 1.3 software (Bioacoustic Research Program, 2008) to analyses the acoustic parameters using the following settings: window size = 512 samples; window type = Hann; 3dB filter bandwidth = 124 Hz; window overlap = 85 % (locked); hop size = 76 sample; DFT size = 1024 samples (locked); grid spacing = 43.1Hz. Note and call terminologies follow Köhler et al. (2017). Oscillogram and audiospectrogram were generated using the R packages Seewave and Tuner with the following settings: window = Hanning; FFT size = 512 samples; FFT overlap = 90 %; color scale = 30 dB relative.

RESULTS

Of the 49 *D. tapacurensis* (snout-vent length = 19.4 ± 1.35 mm in males and 21.4 ± 1.51 mm in females.), 47 were associated with lentic water ponds and usually foraging in herbaceous plants submerged, and the other two were found in shrub vegetation. The species remains in calling activity from 6:00 to 10:40 p.m. Additionally, we observed that this species presents eggs laying on leaves above lentic water. Each spawning usually was around two meters from the water and had about 20 tadpoles each (Fig. 2). In Ceará state, it is distributed in well-preserved humid forests of the Baturité and Maranguape Mountains (above 700 m a.s.l.).

Of the individuals analyzed (43 males and six females), 27 had full stomachs. We identified 16 prey categories, of which Coleoptera, Hymenoptera, Isoptera, and Formicidae had the highest indexes of relative importance (IRI). These four orders represented about 75 % of the total volume of stomach content and almost 60 % of the total ingested prey. In contrast, Collembola, Odonata, and Phthiraptera had the lowest IRI values (Table 1). Although this prey item diversity was high, we found a mean of 1.63 ± 1.02 prey categories per individual necropsied. In addition, the volume of each prey consumed by individuals was unrelated to its body size ($p = 0.41$) or weight ($p = 0.72$). Random effects have no significant influence on fixed effects for both SVL (intercept = 5.673664e-05) and mass (intercept = 1.304619e-06).

The advertisement calls of *D. tapacurensis* from Maranguape Mountain consist of one to three multi-pulsed notes (Fig. 3). The call duration was 545 ± 156 ms (282–848 ms), whereas the duration of each note was 44 ± 14 ms (17–10.3 ms), and the inter-note interval

was 234 ± 46 ms (163–396 ms). The duration of each pulse was 3 ± 0.9 ms (1–9 ms), and the dominant frequency was 5041.4 ± 202.71 Hz (4687.5–5250 Hz). Furthermore, we observed a small ascending frequency modulation until the first third of the note and a progressively descending frequency modulation at the end of the note. Our results were similar to the advertisement call recorded in the Atlantic Forest for this species (except frequency modulation and dominant frequency), but differed from other congenerics (Table 2).

DISCUSSION

The populations of *D. tapacurensis* found in the rainforest enclaves of Ceará State, Northeastern Brazil, were previously recognized as *D.* aff. *decipiens* (Roberto and Loebmann, 2016). Actually, it is known that these populations are *D. tapacurensis* and occur in Baturité, Maranguape, and likely in Aratanha Mountain, around 10 km from Maranguape (Roberto and Loebmann, 2016). Its distribution is limited to pristine environments with humid forests at high elevations, likely due to its reproduction mode once it breeds in lentic environments with marginal vegetation and high humidity and deposits the eggs on leaves above the water ponds (see Silva et al., 2019 to consult reproductive modes in the *D. decipiens* group). Although individuals of *D. tapacurensis* deposit their eggs leaves of shrubs above the water ponds (Fig. 2), most of them were found vocalizing on plant herbaceous submersed, along with other *Dendropsophus* species such as *D. minutus* (Peters, 1872) and *D. minusculus* (Rivero, 1971).

Although *D. tapacurensis* ate large quantities of gnats and beetles, we observed the general pattern for anuran feeding with a generalist diet (Duellman and Trueb, 1994). Other

trophic ecology studies of *Dendropsophus* species from distinct environments found different diet compositions, including flies, spiders, and larvae (Castro et al., 2016; Leivas et al., 2018). These findings reinforce the opportunist and generalist patterns of the anuran diet composition (Duellman, 1978). In addition, the low number of prey per stomach might indicate a "sit-and-wait" strategy of foraging (Toft, 1980). *Dendropsophus* species usually eat a great diversity of invertebrates, but these prey items vary according to the environmental characteristics of each sampling area (Castro et al., 2016; Leivas et al., 2018). Among the *D. decipiens* group, the diet composition is known just for *D. oliveirai* (Bokermann, 1963) from Atlantic rainforest fragments, in which Larvae, Dipterans, Coleopterans, and Hemipterans were the most consumed prey (Leite-Filho et al., 2017; Caldas et al., 2019). This causes obstacles to finding a general pattern of prey items consumed by the species of this group.

The hypothesis that larger frogs eat prey more volumetrically has support in some species (e.g., Duré et al., 2009; Maragno and Souza, 2011). In contrast, the opposite pattern was already reported (e.g., Sabagh et al., 2010). In this study, adult females were slightly larger than males, but the size of each prey consumed by the anurans seemed not to be influenced by predator sizes, regardless of sex. Thus, considering intraspecific approaches and without pronounced sexual dimorphism, females and males of anuran species tend to eat similar prey volumes, including *Dendropsophus* species (e.g., Castro et al., 2016; present study). Apparently, the predator's body size might exert only a marginal influence on prey selection (Blanco-Torres et al., 2020).

Species in the *D. decipiens* group have multipulsed calls with a number of notes per call ranging from 1–11, and lower dominant frequencies in *D. berthalutzae* (Bokermann,

1962) (3881–4294 Hz; Forti et al., 2012) or higher frequencies in *D. oliveirai* (5685–6869 Hz; Santana et al., 2011). In general, the acoustic parameters observed here tended to be similar to the original description of the species (Oliveira et al., 2021). However, we found no variation in the duration of the last pulse, as was observed for individuals recorded in Pernambuco State. Despite some acoustic parameters varying according to environment and situation (Annibale et al., 2020), additional studies are essential to detect possible acoustic variations between populations of *D. tapacurensis* in the states of Ceará and Pernambuco.

CONCLUSION

This study contributes to understanding the natural history of mountain treefrogs in humid forest enclaves of the Caatinga biome. However, there are still some gaps regarding this species natural history. For instance, we found the spawning of *D. tapacurensis*, but there is no data on the tadpoles of this species. Therefore, additional studies on reproductive ecology and data on larval morphology and ecology will be fundamental to fully understanding the natural history of *D. tapacurensis*.

AUTHOR'S PARTICIPATION

Kássio de Castro Araújo – Conceptualization, Data Collection, Formal Analysis, Visualization, Writing.

Dalilange Batista-Oliveira – Data Collection, Formal Analysis, Visualization, Writing.

Tatiana Feitosa Quirino – Formal Analysis, Visualization, Writing.

Sâmia Caroline Melo Araújo – Formal Analysis, Visualization, Writing.

Etielle Barroso de Andrade – Formal Analysis, Visualization, Writing, Reviewing.

Robson W. Ávila – Formal Analysis, Visualization, Writing, Reviewing.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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TABLE AND FIGURES.

Table 1. Absolute values and proportions (%) of frequency (F), number (N), volume (V) (in mm^3) and index of relative importance (IRI) of each prey category consumed in the diet of *Dendropsophus tapacurensis*.

PREY CATEGORY	N (%)	V (%)	F (%)	IRI
ARACHNIDA				
Acari	2 (4.3)	0.55 (0.1)	2 (4.7)	3.0
Araneae	3 (6.4)	40.4 (6.6)	3 (7.0)	6.7
HEXAPODA				
Blattodea	1 (2.1)	9.13 (1.5)	1 (2.3)	2.0
Coleoptera	9 (19.1)	95.9 (15.7)	8 (18.6)	17.8
Collembola	1 (2.1)	0.05 (0.0)	1 (2.3)	1.5
Dermaptera	1 (2.1)	1.77 (0.2)	1 (2.3)	1.6
Diptera	4 (8.5)	2.0 (0.3)	3 (7.0)	5.3
Hymenoptera (Formicidae)	9 (19.1)	36.0 (5.9)	7 (16.3)	13.8
Hymenoptera	5 (10.6)	165.3 (27.1)	5 (11.6)	16.5
Isoptera	4 (8.5)	164.2 (26.9)	4 (9.3)	14.9
Odonata	1 (2.1)	0.01 (0.0)	1 (2.3)	1.5
Phthiraptera	1 (2.1)	0.12 (0.0)	1 (2.3)	1.5
Plecoptera	1 (2.1)	9.46 (1.5)	1 (2.3)	2.0
Psocoptera	1 (2.1)	46.2 (7.5)	1 (2.3)	4.0
OTHER ITEMS				
Larvae not identified	1 (2.1)	5.86 (0.9)	1 (2.3)	1.8

Plant material	3 (6.4)	32.4 (5.3)	3 (7.0)	6.2
∑	47 (100)	609.6 (100)		100

Table 2. Parameters of advertisement calls described for the species within the *Dendropsophus decipiens* group.

Species	**Number of calls**	**Notes per call**	**Pulses per note**	**Pulse duration**	**Note duration**	**Inter-note intervals (s)**	**Dominant frequency (Hz)**
D. berthalutzae1	32	1-2	2-12	-	0.01-0.04	0.18-0.25	4315–4765
D. berthalutzae2	139	1-9	2-6	-	0.01-0.09	-	3881–4294
D. bromeliaceus	28	2	3-8	-	0.12-0.38	-	4800–5600
D. decipiens	16	4-11	-	-	0.02-0.13	0.06-020	4770–5230
D. Haddadi	86	1-4	1-8	-	0.00-0.05	-	4312–4875
D. oliveirai	28	1	5-14	0.001-.007	0.06-0.15	-	5685–6869
D. tapacurensis1	83	3-9	9–29	0.002-.007	0.03–0.11	0.14-0.36	5578–6422
D. tapacurensis2	132	1-3	5-24	0.001-.009	0.01-0.10	0.16-0.39	4687.5–5250

References: *D. berthalutzae1* (Moura et al. 2012); *D. berthalutzae2* (Forti et al. 2012); *D. bromeliaceus* (Ferreira et al. 2015); *D. decipiens* (Abrunhosa et al. 2001); *D. Haddadi* (Ruas et al. 2012); *D. oliveirai* (Santana et al. 2011); *D. tapacurensis1* (Oliveira et al. 2021); and *D. tapacurensis2* (Present study).

FIGURE 1. Schematic map of the study area where the individuals of *Dendropsophus tapacurensis* were collected in the mountains of Maranguape and Baturité, Ceará state (CE), Northeastern Brazil.

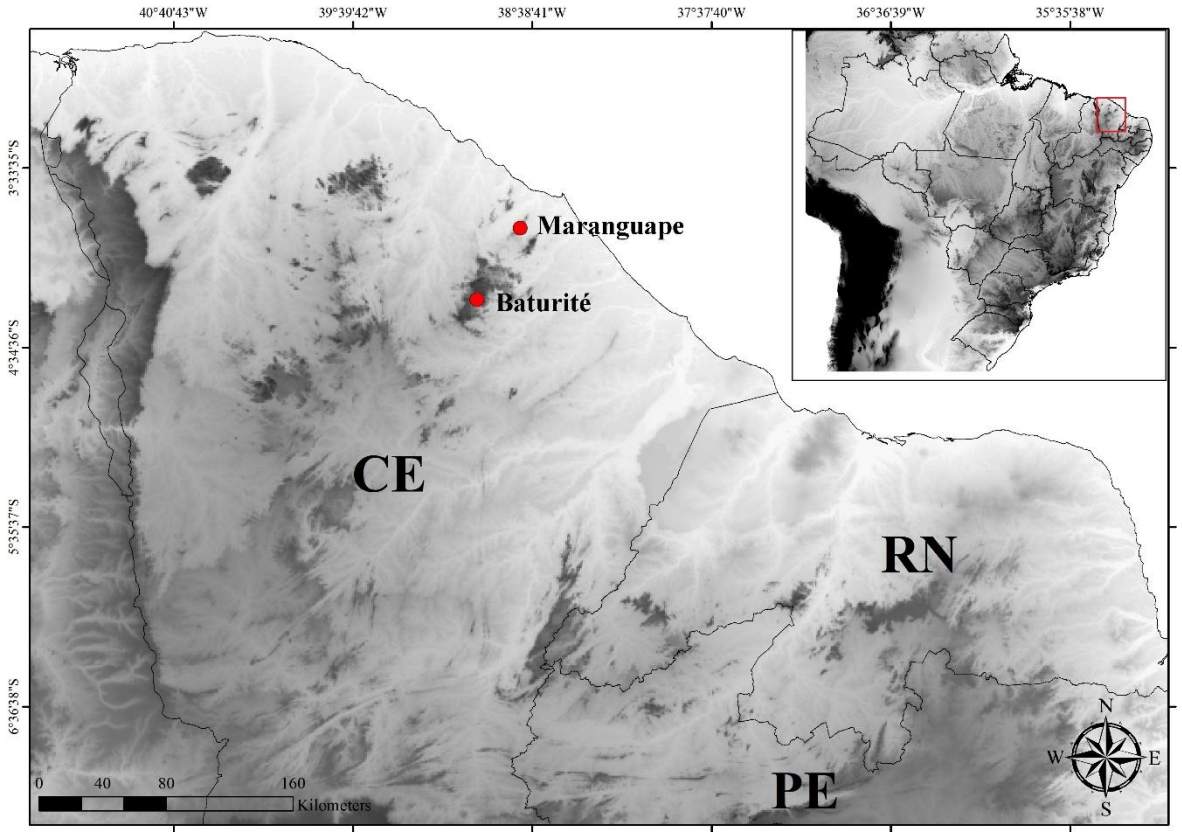

FIGURE 2. Adult male of *Dendropsophus tapacurensis* (left) with its egg mass deposited on leaves overhanging at standing water (right) in Maranguape mountain, Ceará state, Brazil.

FIGURE 3. Audiospectrogram and oscillogram of the advertisement call of *Dendropsophus tapacurensis* recorded in the rainforest enclaves of Ceará, Northeastern Brazil.