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Modeling the potential geographic distribution of the poorly known Neotropical lizard *Anotosaura vanzolinia* Dixon, 1974 (Squamata, Gymnophthalmidae) in Northeast Brazil

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Abstract: During faunal rescue activities for the construction of a wind farm in the Northeast Region of Brazil, a single specimen of the gymnophthalmid lizard *Anotosaura vanzolinia* was captured, which represents the first record of the species for the state of Piauí. We used this record, along with records found in the literature, to model the potential distribution of the species according to environmental suitability using the maximum entropy algorithm MaxEnt. The occurrence records of *A. vanzolinia*, as well as the model of its potential geographical distribution, revealed that it is more broadly distributed than previously considered. *Anotosaura vanzolinia* has a disjoint and relictual geographic distribution pattern due to its association with remnant forest environments within the Caatinga Domain. The variables that contributed the most to the model of its ecological niche were annual precipitation (48.9%), soil type (17.5%), and mean diurnal range (10.5%). The species remains endemic to the forest enclaves within the Caatinga Domain.

Key words: Caatinga, ecological niche modeling, Eupleopodini, gymnophthalmid, maximum entropy algorithm, suitable environmental areas, tropical dry forest

The gymnophthalmid genus *Anotosaura* currently comprises two named species: *Anotosaura collaris* Amaral, 1933 and *Anotosaura vanzolinia* Dixon, 1974. *Anotosaura vanzolinia* (Figure 1) was described as *A. collaris vanzolinia* by Dixon (1974) based on specimens from the municipality of Agrestina, in the Agreste region of the state of Pernambuco, Brazil. Two years later, Vanzolini (1976a) elevated *A. c. vanzolinia* to specific rank. It is an insectivorous species that feeds mainly on ants and termites, as well as other arthropods of the edaphic microfauna (Oliveira and Pessanha, 2013). It has a cryptic and semifossorial habit, and it inhabits microhabitats with warmer temperatures, abundant leaf litter, and no incidence of direct sunlight (Delfim and Freire, 2007; Freire et al., 2009). The species has a disjunct and relictual distribution within the Caatinga Domain, where it is found only in mesic areas (Rodrigues, 1986, 2003). The geographical distribution of the species has been based on 12 different locations reported in the literature for the states of Bahia, Alagoas, Pernambuco, Paraíba, and Rio Grande do Norte (Delfim and Freire, 2007; Freire et al., 2009; Gonçalves et al., 2012; Garda et al., 2013).

The use of techniques for modeling suitable areas for the occurrence of species is especially valuable for species with scarce data about their distribution, which are poorly sampled and/or have cryptic habits (Pearson et al., 2007). The lack of geographic distribution information hampers efforts to understand the biogeography of species. Although new data focusing on the richness and composition of the squamate fauna of the semiarid region of Brazil are constantly being added to the literature (e.g., Guedes et al., 2014), there remains a lack of information about the distribution of some rare species. Herein we expand the known geographic distribution of *A. vanzolinia* to include the state of Piauí and attempt to clarify its distribution pattern using this new occurrence record and ecological niche modeling of its potential distribution.

On 28 October 2016, a single specimen of *A. vanzolinia* was obtained during faunal rescue for the installation of a wind farm in the municipality of Curral Novo do Piauí in the semiarid region of the state of Piauí, Brazil. Although none of the authors participated of the fieldwork, the specimen was collected (MFCH 4399, Figure 1) and is housed in the Herpetological Collection of the Museu de

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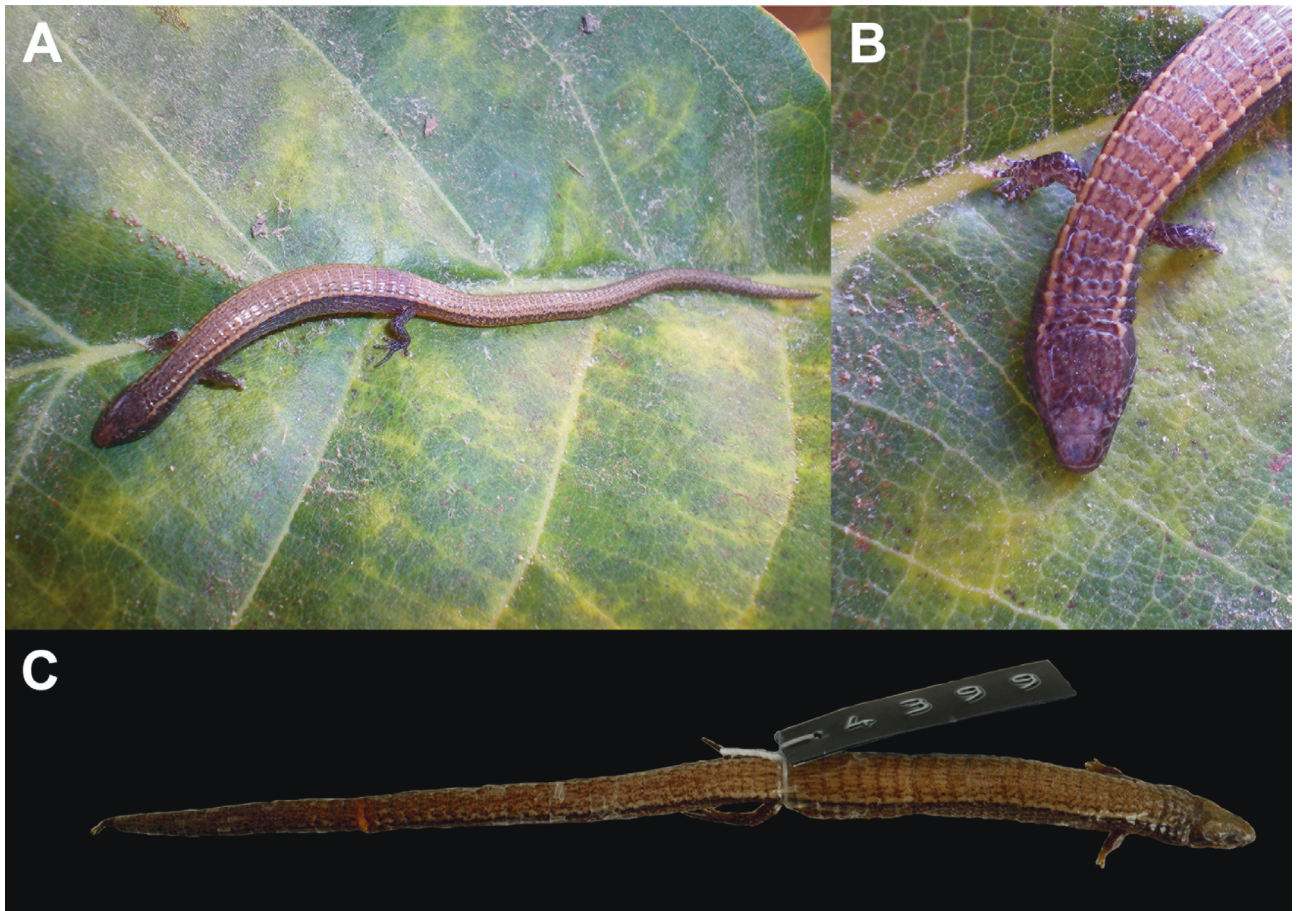


Figure 1. Specimens of *Anotosaura vanzolinia*. Total view (A) and close-up of the head (B) of the specimen (43 mm SVL, CHBEZ 2925) collected in Tenente Laurentino Cruz, state of Rio Grande do Norte, Brazil. (C) Specimen (ca. 52 mm SVL, MFCH 4399) from the new geographic record in Piauí State, Brazil. Photos A) and B) by Marcelo Kokubum; C) by Leonardo Ribeiro.

Fauna da Caatinga, located at the Centro de Conservação e Manejo de Fauna da Caatinga (CEMAFAUNA), Universidade Federal do Vale do São Francisco - UNIVASF (Federal University of San Francisco Valley), municipality of Petrolina, state of Pernambuco, Brazil.

The collection site is influenced by Chapada do Araripe and is located within APA Araripe-Apodi (Araripe-Apodi Environmental Protection Area), which includes the Araripe basin. The area possesses a mosaic of phytophysognomies including “carrasco” (closed, tall-shrubby, xerophilous vegetation on quartz sand soils), savannah enclaves, and typical Caatinga vegetation, with extensive and secondary forests (Ribeiro et al., 2009). The region ranges in altitude from 800 to 900 m a.s.l. and is located in the northwest portion of the Depressão Sertaneja Meridional, in the southeast portion of state of Piauí.

We estimated the potential distribution of *A. vanzolinia* based on areas with suitable environments for the species

by ecological niche modeling using the maximum entropy algorithm MaxEnt (Phillips et al., 2006; Costa et al., 2010; Giovanelli et al., 2010). The MaxEnt algorithm has demonstrated good predictive performance with few occurrence records or presence-only datasets (Elith et al., 2010). Nineteen bioclimatic variables obtained from the WorldClim database (BIO_1 – BIO_{19}) (Worldclim.org; Fick and Hijmans, 2017), plus six other variables [1 - percentage of tree cover (Hansen et al., 2003); 2 - vegetation type (Veloso et al., 1991); 3 - drainage network density (https://hydrosheds.cr.usgs.gov/webappcontent/HydroSHEDS_TechDoc_v10.pdf); 4 - elevation (<http://srtm.csi.cgiar.org>); 5 - slope (<http://srtm.csi.cgiar.org>); and 6 - soil type (EMBRAPA, 1999)] were used to design the ecological niche model. We chose the six most explanatory variables after removing those with high correlations ($r > 0.8$) to minimize multicollinearity among layers (Sales et al., 2015). The analysis was performed using Past statistical software. The variables chosen were: 1 - BIO_1 annual

mean temperature; 2 - BIO₂ mean diurnal range [mean of monthly (max temp–min temp)]; 3 - BIO₁₂ annual precipitation; 4 - BIO₁₆ precipitation of wettest quarter; 5 - BIO₁₈ precipitation of warmest quarter; and 6 - soil type. All variables were used as generic grids with a resolution of 30 arc-seconds (~1 km) and limited to Northeast Brazil. The following settings were chosen for MaxEnt (version 3.3.3k): maximum number of background points = 10,000; maximum number of iterations = 500; regularization multiplier = 1; and no threshold (Phillips et al., 2006). The calibration area was restricted to the Brazilian territory with 25% of the points being used as random background sampling to create replicas of the models in which, for each replicate, the occurrence dataset was randomly divided with 75% of the replicates used to fit the models and 25% used for evaluation (Elith et al., 2011). We evaluated the ecological niche model with pattern discrimination statistics [area under the curve (AUC) of receiver operating characteristic (ROC) curve and omission error (OE)]. The AUC provides a single measurement of the performance of the model, regardless of the choice of any prior decision limit (Phillips et al., 2006; Pearson et al., 2007). The closer the AUC is to 1.0, and more distant from 0.5, the more accurate the model (Elith et al., 2010). We applied the jackknife test to evaluate the importance and heuristic estimate of the relative contributions of the variables of each predictor in the generated model (Phillips et al., 2006). Finally, a potential distribution map was created by 5% of omission errors to create the logistic model. This is appropriate for high precision of occurrence records data (Norris, 2014).

We used the software QGIS (version 2.4) for handling the dataset of environmental variables and raster matrices and the preparation of potential distribution maps. Maps were built by performing an extensive search for species records in the literature using online bibliographic databases (Web of Science, JSTOR, Scielo, Scopus, and Google Scholar). Priority areas for conservation in the Caatinga were determined according to the administrative ruling of the Ministry of the Environment (No. 223, of 21 June 2016).

Thirteen different occurrence records were established for *Anotosaura vanzolinia* (Table). Of these, our new record (Figure 2) extends the known geographical distribution of the species about 430 km westward from the nearest record in the state of Paraíba — in the municipality of São José dos Cordeiros, 305 km northwest of Estação Ecológica Raso da Catarina in the state of Bahia — and 534 km westward from the type-locality in Agrestina, Pernambuco. The new record also represents the highest recorded elevation for the species (Table). *Anotosaura vanzolinia* is recorded from only two strict protection areas: Reserva Particular do Patrimônio Natural Fazenda Almas (Paraíba State,

3505 ha) and Estação Ecológica Raso da Catarina (Bahia State, 99,772 ha).

The potential distribution revealed areas with suitable environmental conditions for the occurrence of *A. vanzolinia* in the states of Bahia, Sergipe, Pernambuco, Ceará, and Piauí, although specimens have yet to be collected in Sergipe and Ceará. The ecological niche model showed to be reliable in its predictions (AUC = 0.981 ± 0.018) with a low rate of omission errors (5%). The potential distribution (i.e. areas with suitable environments for occurrence) of *A. vanzolinia* (Figure 2) was estimated to be 22,500 km². The variables that contributed the most to the ecological niche model were annual precipitation (48.9%), soil type (17.5%), and mean diurnal range (10.5%). The ecological niche model corroborates the previously recognized disjoint and relictual geographic distribution pattern for *A. vanzolinia*.

Vanzolini and Ramos (1977) proposed that microteiid lizards that are associated with sites with more mesic conditions, such as *A. vanzolinia* and *Acratosaura mentalis* (Amaral, 1933), have their distributions limited by the arid environmental matrix, where they encounter heterogeneous marginal situations without opportunities favorable for range expansion. This was previously observed for *A. mentalis*, which is associated with a phytoecological unit of the Caatinga that occurs on sedimentary formations in the state of Ceará (Roberto and Loebmann, 2016). According to Vanzolini (1981) and Rodrigues (2003), the current distributions of *A. vanzolinia* and *Acratosaura mentalis* have likely been influenced by expansions and retractions of rainforest and Caatinga (tropical dry forest). The presence of *A. vanzolinia* in relictual forest enclaves with milder temperatures may be indicative of past relationships between the Caatinga and the Atlantic Forest/Amazon Forest. With the expansion of forests in wetter times, forest species were able to occupy broader areas that were subsequently reduced and are currently surrounded by arid areas (Vanzolini and Ramos, 1977; Borges-Nojosa and Caramaschi, 2003; Carnaval and Bates, 2007; Mesquita et al., 2017). These forest enclaves are very important areas for the existence of the relictual fauna present therein and embedded within the xeric matrix.

The entire tribe Ecleopodini, including *Dryadosaura* and *Colobosauroides* (the two genera in close association with *Anotosaura* based on molecular data), is composed predominantly of forest lizards (Pellegrino et al., 2001; Rodrigues et al., 2005; Rodrigues et al., 2007; Goicoechea et al., 2016), which suggests that the disjoint pattern of distribution observed for *A. vanzolinia* is the result of past forest retraction and the current presence of the Caatinga Domain (Rodrigues, 2003). Ecological niche modeling of another related species of Ecleopodini, *Colobosauroides*

Table. Summary of the reviewed literature records of *Anotosaura vanzolinia* distribution. Asterisks indicate that the altitude (in meters) was estimated through Google Earth.

Locality	State	Longitude	Latitude	Altitude	Reference
1. Ruy Barbosa	Bahia	-40.3731	-12.2708	550	Freitas and Moisés, 2009
2. Estação Ecológica Raso da Catarina	Bahia	-38.49222	-9.80806	701	Garda et al., 2013
3. Traipu (Serra da Mão)	Alagoas	-36.94639	-9.75278	503	Gonçalves et al., 2012
4. Agrestina (type-locality)	Pernambuco	-35.93556	-8.46417	441*	Dixon, 1974
5. Bezerros (district of Serra Negra)	Pernambuco	-35.79333	-8.27333	544*	Rodrigues, 1986
6. Sumé	Paraíba	-36.88	-7.67167	522*	Delfim and Freire, 2007; Freire et al., 2009
7. São José dos Cordeiros	Paraíba	-36.80778	-7.39083	529*	Delfim and Freire, 2007; Freire et al., 2009
8. Cabaceiras	Paraíba	-36.28722	-7.48889	384*	Rodrigues, 1986
9. Reserva Particular do Patrimônio Natural Fazenda Almas (São José dos Cordeiros/Sumé)	Paraíba	-36.87028	-7.46667	612*	Delfim and Freire, 2007
10. Campina Grande (district of São José da Mata)	Paraíba	-35.975	-7.18333	700	Delfim and Freire, 2007; Oliveira et al., 2017
11. Complexo Aluizio Campos Forest Park (Campina Grande)	Paraíba	-35.88528	-7.27611	500	Queiroz et al., 2010; Oliveira and Pessanha, 2013; Oliveira et al., 2017
12. Tenente Laurentino Cruz (Serra Nova)	Rio Grande do Norte	-36.719	-6.109	704	Gogliath et al., 2010
13. Curral Novo do Piauí	Piauí	-40.61889	-8.03944	826*	This study

carvalhoi Soares & Caramaschi, 1998, obtained very similar results to those of the present study (Magalhães et al., 2017). Using evidence from travertine deposition and megafauna and paleobotanical elements, Auler et al. (2004) indicated the presence of semideciduous forest in the past (peak in 900 kyr BP) within what is now dry Caatinga. In this sense, forest expansion into what is now semiarid Caatinga allowed the establishment of a link between mesic forests, consequently allowing the migration of species to and from the Amazonian and Atlantic rainforests.

The elevation of the Brazilian shield, and the consequent formation of the Caatinga in the interplanaltic and intermontane depressions of the Brazilian Northeast, may have been an important factor in determining the restricted distributions of some species (Rodrigues, 2003). The mesic habitats of enclaves of highland forest within the Caatinga (“brejos de altitude”) are known to contain species that are closely related to species in the moister neighboring forests (Rodrigues, 2003; Loebmann and Haddad, 2010; Ribeiro et al., 2012). These “brejos” are relicts of a once more widespread forest cover that retreated at the onset of drier conditions and provide moisture and milder temperatures to the areas where they occur. This has already been observed for *A. vanzolinia* in Traipu, state of Alagoas, and Tenente Laurentino Cruz, state of Rio Grande do Norte, where individuals were collected in forest enclaves within the Caatinga Domain at elevations of 503 m and 704 m, respectively (Gogliath et al., 2010;

Gonçalves et al., 2012). Specimens were found distributed in areas with the accumulation of leaves in the soil and the formation of litter, which are necessary to form the habitat typically used by these lizards (Vanzolini, 1976b; Rodrigues, 1986; Gogliath et al., 2010).

The environmental variables used to predict the potential distribution of *A. vanzolinia* (annual precipitation, soil type, and mean diurnal range) corroborate the association of this species with mesic environments. In this sense, two important areas stand out with high potential for the occurrence of *A. vanzolinia* (see A and B in Figure 2). The first area (Area A) is located near a government-defined priority area for the conservation of Pedra Branca, state of Ceará, in the Depressão Sertaneja Setentrional ecoregion, under the influence of the Complexo Ibiapaba-Araripe ecoregion with seasonal deciduous forest. The second area (Area B) is a significant portion of the government-defined priority area for the conservation of Pilão Arcado, state of Bahia, in the Depressão Sertaneja Meridional ecoregion, which is influenced by the Complexo Ibiapaba-Araripe and Dunas do São Francisco ecoregions. The Caatinga area of Pilão Arcado represents a region of transit of species between remnants of the APA Dunas do São Francisco and remnant areas of Serra da Capivara and Serra das Confusões National Parks in the state of Piauí. The regions of these national parks are characterized by arboreal vegetation formations (arboreal Caatinga formations and enclaves of semideciduous forests). It is important to highlight

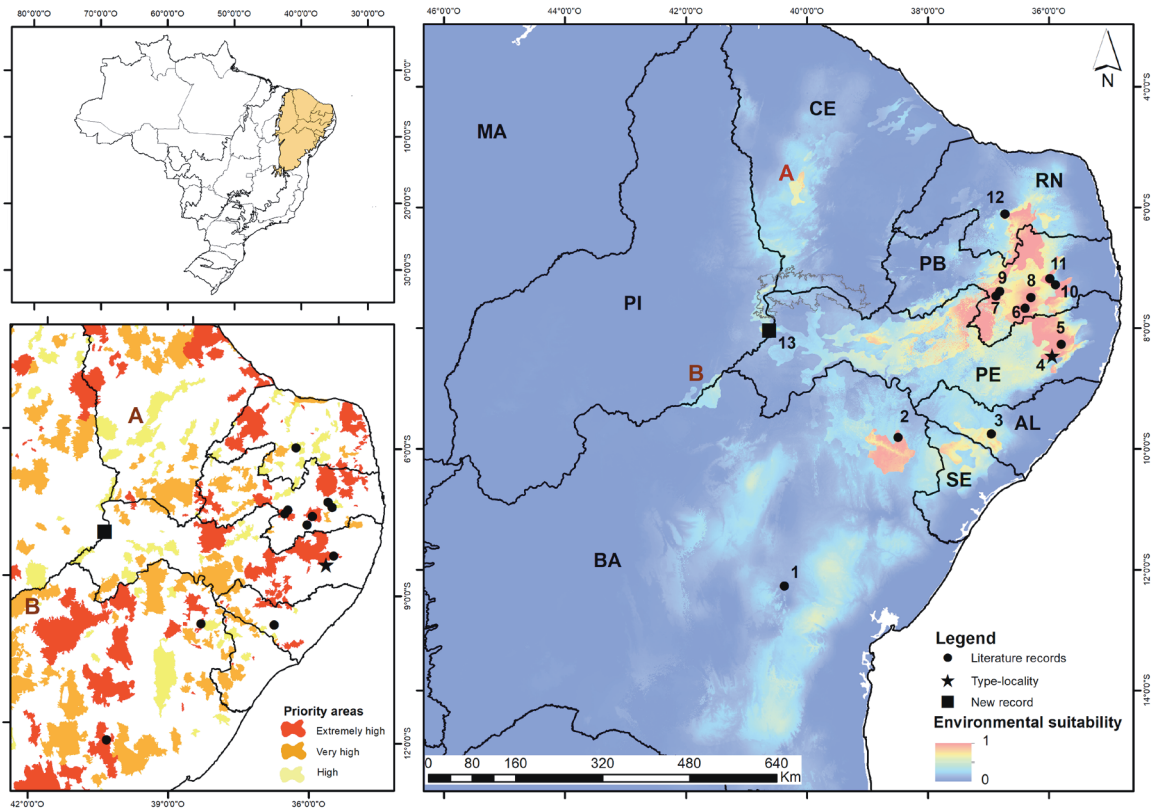


Figure 2. Known and potential distributions of *Anotosaura vanzolinia* in the Caatinga of Northeast Brazil: Bahia (BA), Alagoas (AL), Pernambuco (PE), Paraíba (PB), Rio Grande do Norte (RN), and Piauí (PI). See Table for explanation of the numbers. The area delimited in gray immediately above point 13 represents the Chapada do Araripe. Color scale indicates the environmental suitability predicted by the model, which ranges from 0 (blue) to 1 (red). The probability of occurrence of *Anotosaura vanzolinia* in two significant priority areas for the conservation are represented: A) Pedra Branca, Ceará State (high priority) and B) Pilão Arcado, Bahia and Piauí States (very high priority).

that despite the high squamate diversity of the Caatinga, which includes 112 species of snakes and more than 50 species of other squamates, and many cases of endemism (Rodrigues, 2003; Guedes et al., 2014; Ribeiro et al., 2018), only about 7.5% of its species are located inside a protected area, and only about 1% in areas under some form of integral protection, still lacking adequate monitoring and management (<http://www.mma.gov.br/biomas/caatinga>). The two potential areas of occurrence of *A. vanzolinia* mentioned above (Pedra Branca and Pilão Arcado, with high and very high priorities for conservation) suffer from deforestation, burning and hunting, and agricultural and mining activities (<http://www.mma.gov.br/biomas/caatinga>). Therefore, further research to determine whether *A. vanzolinia* occurs at these locations is essential. If confirmed, additional investigations focusing on population data will be necessary in order to better evaluate the status of the species and the development of management and conservation strategies.

In summary, the finding reported herein reinforces the dependence of *A. vanzolinia* on the remaining forest enclaves. The area of this new record is considered a very high priority for the conservation of herpetofauna (Rodrigues, 2003). In addition, it is the first record of *A. vanzolinia* for the state of Piauí and represents an important advance in understanding the relictual distribution of squamate reptiles. Future phylogeographic and population studies can help to provide insight into the evolution and dispersion of squamates among Caatinga forest enclaves.

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