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Effects of Agricultural Land Use in Abundance and Microhabitat Use of the Generalist Lizard *Tropidurus hispidus*

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Abstract**.—The conversion of natural vegetation areas for agriculture causes the local extinction of many species, although a few species may benefit from the conversion. We evaluated how agricultural land use affects the abundance and microhabitat use of the generalist Neotropical Lava Lizard (*Tropidurus hispidus*) in three vegetation types (Caatinga, Cerrado, and Relictual Humid Forest) in the Caatinga domain of Brazil by comparing areas with natural vegetation and agricultural areas. The abundance of *T. hispidus* was higher in agricultural areas in the Relictual Humid Forest than in natural habitat, while in Cerrado and Caatinga areas, the species remained stable. We did not identify clear patterns of change in spatial niche amplitude in agricultural areas, indicating that this species is versatile in microhabitat use, but that it showed distinct use of some microhabitat categories between agricultural and natural areas, such as tree trunk and fence stake, possibly reflecting the availability of these resources in different environments. This work contributes to a better understanding of how agricultural land use affects abundance and microhabitat use of *T. hispidus* and gives us clues as to how Neotropical generalist lizards may respond to these changes.**

Key Words.—agricultural areas; anthropic disturbance; Squamata; Tropiduridae

***Resumo.*— A conversão de áreas de vegetação natural em áreas agrícolas causa a extinção local de muitas espécies, embora algumas possam se beneficiar desta conversão. Nós avaliamos como o uso agrícola do solo afeta a abundância e o uso do microhabitat do generalista Lagarto de Lava Neoptropical (*Tropidurus hispidus*) em três tipos de vegetação (Caatinga, Cerrado e Floresta Úmida Relictual) no domínio da Caatinga do Brasil, comparando áreas com vegetação natural e áreas agrícolas. A abundância de *T. hispidus* foi maior em áreas agrícolas na Floresta Úmida Relictual do que em habitat natural, enquanto que em áreas de Cerrado e Caatinga a espécie permaneceu estável. Não identificamos padrões claros de mudança na amplitude de nicho espacial em áreas agrícolas, indicando que esta espécie é versátil no uso de microhabitat, mas que apresentou uso distinto de algumas categorias de microhabitat entre áreas agrícolas e áreas naturais, como tronco de árvore e estaca de cerca, possivelmente refletindo a disponibilidade desses recursos nos diferentes ambientes. Este trabalho contribui para uma melhor compreensão de como o uso do solo afeta a abundância e o uso do microhabitat de *T. hispidus* e nos dá indícios de como os lagartos generalistas neotropicais podem responder a essas mudanças.**

Palavras-chave.—áreas agrícolcas; distúrbio antropogênico; Squamata; Tropiduridae

Introduction

Habitat loss and fragmentation are the greatest threats to biodiversity (Leal et al. 2005; Rogan and Lacher 2018). Among the main forms of change in habitat use, the conversion of pristine areas into agricultural areas stands out (Ellis et al. 2010; https://ourworldindata.org/land-use). Anthropogenic alterations in habitats cause variations in the environment that prevent some species from surviving but improve conditions for others (Scott et al. 2006; Gonthier et al. 2014). Generalist species tend to survive environmental changes more effectively (Canning et al. 2017), some species even benefiting from them, while increasing in density and abundance (Sutton et al. 2014; Flores et al. 2017), due in part to changes in conditions and resources (Nogueira 2009; Campbell et al. 2018).

In addition to changes in abundance, another aspect of organisms that can be affected by environmental changes is microhabitat use (Sutton et al. 2014). More extreme environments may increase restrictions on the microhabitat, due, for example, to a lower availability of resources, resulting in narrower niches (Caldas et al. 2019), but the opposite is also possible. Ecological release can be generated by changes in competition, parasitism, and predation; it also presents the consequence of a wider range of resource use by benefited species and can often occur in newly colonized environments (Des Roches et al. 2011; Herrmann et al. 2020). In addition to the amplitude in the spatial niche, species can change the selection of microhabitat due to changes in the environment (Caruccio et al. 2010). Thus, characteristics in the macrohabitat can influence microhabitat selection (Kanno et al. 2012).

In this work, we evaluated how abundance and microhabitat use of the generalist lizard, the Neotropical Lava Lizard (*Tropidurus hispidus*) were affected by agricultural land use. *Tropidurus hispidus* is a tropidurid lizard that is a sit-and-wait predator as its main foraging strategy (Kolodiuk et al. 2009) and feeds predominantly on insects (Ribeiro and Freire 2011). In natural areas, it uses tree trunks as an important habitat for foraging and thermoregulation (Albuquerque et al. 2018). These lizards can be found both in natural environments and in anthropic areas, even seeming to benefit from anthropization (Andrade 2019), making them good models to test the effects of agricultural land use. We expected that *T. hispidus* would: (1) increase in abundance in agricultural areas, (2) increase in the spatial niche breadth in agricultural areas, and (3) differ in microhabitat use classes between natural and agricultural areas.

Materials and Methods

Study area.—We collected data in the vicinity of three protected areas in Brazil: (1) Sete Cidades National Park (SCNP; 4°06’58.8”S 41°43’41.8”W), located in the north of the state of Piauí, in open Cerrado areas, in a marginal area close to the Caatinga; (2) the Ubajara National Park (UNP; 3°50’31.2”S 40° 54’00.5”W), located in the northwest of the state of Ceará, in Caatinga and Relictual Humid Forest areas; and (3) the Aiuaba Ecological Station (AES; 6°41’03.4”S 40°12’52.3”W), located in the state of Ceará, in Caatinga areas (Table 1). Among the differences between the two Caatinga areas are that rainfall is higher in UNP (Table 1), and aridity is higher in AES (Caitano et al. 2011).

Caatinga is a Seasonally Dry Tropical Forest (STDF) distributed throughout the northeast of Brazil. It has a high annual evapotranspiration, causing a water deficit for most of the year, and for this reason, it has predominantly deciduous vegetation (Prado 2003). Along this vegetation formation, exceptional areas can be found, such as Relictual Humid Forests (Moro et al. 2015). These forests have less seasonality than the Caatinga that surrounds it, greater rainfall, and perennial vegetation (Medeiros and Cestaro 2019). These forests are believed to have formed through the expansion and retraction of tropical forests (Amazon and Atlantic Forest) in the past (Santos et al. 2007; Castro et al. 2019). Its fauna is composed of many forest species that are not present in Caatinga (Garda et al. 2017; Mesquita et al. 2017). In addition, on the margins of Caatinga it is also possible to find vegetation from other biomes with which they have contact, such as the Cerrado (Veloso et al. 2002). The Cerrado (Tropical Savanna) may have different phytophysiognomies, but the predominant one is the open Cerrado (Cerrado *stricto sensu*), which contains spaced trees, with adaptations to fire, and a considerable grass cover (Santos et al. 2020).

Sample design.—Initially, we designed maps for each area. In each area, we delimited four transects, except in UNP, where we established three transects in Relictual Humid Forest and three transects in Caatinga. We established transects with a minimum distance of 3 km from each other, seeking to cover a wide area around protection areas while trying to maintain independence between the transects. For each transect, we delimited two circles outside the protected area, with a radius of 1 km each, to select the points within each radius. We used circles to delimit the dispersion of points in each transect. Within the delimited sampling radius, we used random stratification to select sampling points representing natural vegetation and agricultural areas. For this purpose, we used a 500 × 500 m grid on each circle in which all patches of the same categories were enumerated, taking into account density and color of the vegetation, designating areas with higher plant density as natural areas and areas with plantations as agricultural areas. In each transect, we selected two natural area points and two agricultural area points, one of each category per circle, totaling four points on each transect. Each point presented a minimum distance of 500 m from other points in the same transect (Fig. 1). We used these

Table 1. Environmental descriptors of the studied areas. Rainfall refers to the annual average in millimeters. Abbreviations are Sur. = surroundings, UNP = Ubajara National Park. AES = Aiuaba Ecological Station, and SCNP = Sete Cidades National Park. Sources of information are Instituto de Pesquisa e Estratégia Econômica do Ceará. -IPECE - avaiable from https://www.ipece.ce.gov.br/perfil-municipal-2017/ (Accessed 22 October 2019) [See Freicheiranha, Aiuaba and Ubajara cities], and Santos (2018).

Research Area	Vegetation type	Rainfall (mm)	Elevation (m)	Vegetation characteristics
UNP sur.	Relictual Humid Forest	1,483.5	848	evergreen forest
UNP sur.	Caatinga *stricto sensu*	1,139.2	121	deciduous vegetation
AES sur.	Caatinga *stricto sensu*	568.4	466	deciduous vegetation
SCNP sur.	Cerrado *stricto sensu*	1,337.0	100–280	savanna

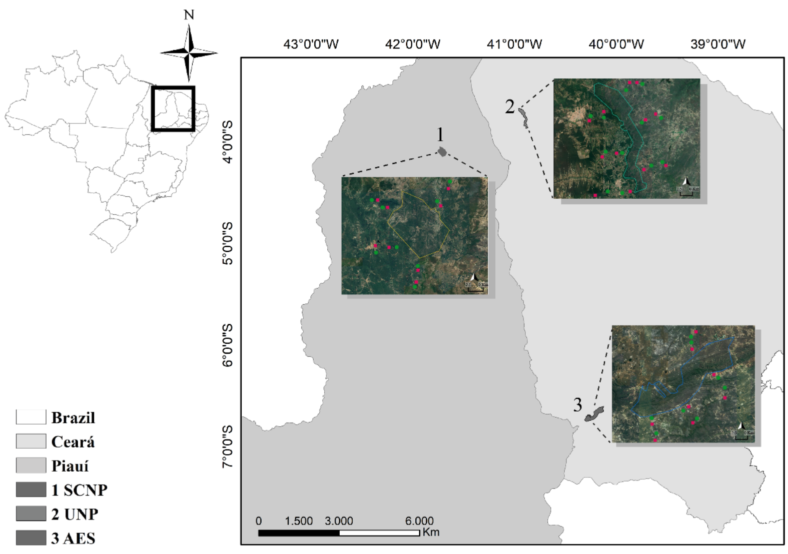

Figure 1. Sampling points in study areas of Sete Cidades National Park (1), Ubajara National Park (2), and Aiuaba Ecological Station (3). Green circles are natural areas, and pink squares are agricultural areas.

values to try to achieve spatial independence between the points and cover a wide area around the preservation areas.

The mapping was done through a supervised classification and then refined with the OpenLayers Plugin tool in QGis with Google satellite images. Supervised classification uses algorithms to classify pixels of an image to represent the evaluated classes. We used the random function in Excel to randomly select the points for each class. We repeated this procedure for all classes and recorded geographic coordinates of the selected points in GPS for field location. We confirmed the classes with field visits and with the use of an unmanned aerial vehicle (UAV). We used QGIS v 2.18.19 (QGIS Development Team 2019) for map design, classification, and demarcation of points.

In traditional subsistence agricultural areas in northeastern Brazil (slash-and-burn), soil preparation involves felling the vegetation, removing the fallen logs, burning the remaining vegetation (fallen branches, trunks, herbs), and then planting crops (Oliveira et al. 2020). Irrigation is used in some regions to keep crops growing throughout the year, such as in Planalto da Ibiapaba, in the state of Ceará, Brazil (Girão et al. 2001), where the areas of Relictual Humid Forest assessed in this region are located. Agricultural areas in Caatinga and Cerrado were abandoned during the dry season, but they were irrigated in the Relictual Humid Forest. Therefore, we visited abandoned agricultural areas in Caatinga and Cerrado and cultivated areas in the Relictual Humid Forest during the dry season. All agricultural areas were cultivated during the rainy season. The crops in Caatinga and Cerrado were predominantly maize, maize with beans, maize with cassava, and in the Relictual Humid Forest, maize with beans in addition to cultivars (avocado, passion fruit, banana, tomato).

Sampling of lizards.—We carried out three expeditions in each study area, between 2018 and 2020: two expeditions during the rainy season and a third during the dry season. In SCNP surroundings, however, we carried out three expeditions during the rainy season and another one during the dry season. We collected data during the daytime, between 0800–1700, and we spent 60 min at each point. In one of the expeditions in the rainy season, there were two collectors in the field and in the others, four collectors. In SCNP surroundings, where there were four expeditions: two collectors made two expeditions in the rainy season and four collectors made two expeditions. We used Visual Encounter Surveys (VES) to sample lizards (Crump and Scott 1994). Because *T. hispidus* is a common species, which often inhabits conspicuous places, we considered this technique adequate to observe the species.

We sampled 16 points in the areas with four transects (eight of natural areas and eight of agricultural areas), and 12 points in the areas with three transects (six of natural areas and six of agricultural areas). We sampled for 147 h, 13 min in AES surroundings (71 h, 3 min in the agricultural areas of Caatinga and 76 h, 10 min, in its natural areas), 138 h, 31 min in UNP surroundings (64 h, 6 min in the agricultural areas of Caatinga and 64 h, 25 min in its natural areas), 127 h, 8 min in UNP surroundings (61 h, 24 min in the agricultural areas of Relictual Humid Forest and 65 h, 44 min in its natural areas), and 192 h, 31 min in SCNP surroundings (91 h, 37 min in the agricultural areas of Cerrado and 100 h, 54 min in its natural areas), taking into account the collection time at each point by the total number of collectors. During the search period, we explored different microhabitats inhabited by lizards (exposed soil, fallen trunk, leaf litter, rock, soil between vegetation, fence stake, termite nest, tree trunk, wall). When first detected, we noted the substrate used by each observed specimen (Werneck et al. 2009).

Statistical analysis.—To test the abundance of lizards between natural and agricultural areas, we developed a Generalized Linear Mixed Effects Model (glmmPQL) that allows the inclusion of temporal correlation structures (corAR1), as we went more than once to each location, with a Quasi-Poisson distribution (used for counting data). As an explanatory variable, we used the type of area (natural or agricultural area) in interaction with the study sites and the abundance of *T. hispidus* as response variable. We used as a random effect the study site, collection points, and season (dry or rainy). To evaluate the pairwise differences between each category by location, we used a post-hoc test (lsmeans).

To evaluate the difference in spatial niche width, we used the inverse of Simpson's Diversity Index (Simpson 1949). Values ranged from 1 (exclusive use of a single category) to n (similar use of all categories). We divided the niche range by the number of categories used in each location, thus generating a value between zero and one, which was easier to compare. To evaluate the differences in the proportion of microhabitat use classes between natural and agricultural areas, we used the Z-test when categories were > 5 and Fisher's Exact Test when at least one of the categories were < 5. For all tests, we assigned the significance level $\alpha = 0.05$. We performed all analyses using R v.3.4.3 software (R Core Team 2021).

Results

Abundance of lizards.—We recorded 472 encounters of *T. hispidus* (191 in natural areas and 281 in agricultural areas). The abundance of lizards in agricultural areas was significantly greater than natural areas in the Relictual Humid Forest (Estimate = -3.04, t = -3.82, P = 0.007; Fig. 2). Abundance has not changed in Caatinga areas (AES surroundings, Estimate = -0.38, t = -1.13, P = 0.940; UNP surroundings, Estimate = -0.20, t = -0.58, P = 0.990) or in Cerrado (Estimate = -0.01, t = -0.01, P = 0.990; Fig. 2).

Spatial niche breadth and microbohabitat use.—The spatial niche breadth was greater in agricultural areas in one of the Caatinga areas (UNP) and in the Relictual Humid Forest. The latter, however, presented a very low sample size in natural areas (n = 2). In Caatinga areas (UNP surroundings), the niche width in natural areas was 2.67 (with adjustment, 0.66, n = 36), and the most frequently used category was tree trunk (47.2%; Fig. 3). In agricultural areas, the niche width was 5.47 (with adjustment, 0.91, n = 66) and the most frequently used category was rock (30.3%; Fig. 3). In the Relictual Humid Forest (UNP surroundings), the niche width of *T. hispidus* in natural areas was 1.00 (n = 2) and the most frequently used category was fallen trunk (100%). In agricultural areas, the niche width was 6.64 (with adjustment, 0.83, n = 41) and the most used category was fence stake (19.5%; Fig. 3). It was not possible to perform the statistical analysis for Relictual Humid Forest (Fig. 3) due to the small sample size in natural areas (n = 2).

In Caatinga areas in AES surroundings, the niche width of *T. hispidus* in natural areas was 4.28 (with adjustment, 0.61, n = 63) and the most frequently used category was tree trunk (39.6%). In agricultural areas, the niche width was 3.77 (with adjustment, 0.41, n = 91) and the most frequently used category was fence stake (45%); Fig. 3). In Cerrado (SCNP surroundings), the niche width of *T. hispidus* in natural areas was 5.97 (with adjustment, 0.85, n = 63) and the most frequently used microhabitat category was tree trunk (28.5%). In agricultural areas, the niche width was 2.59 (with adjustment, 0.41, n = 71) and the most frequently used microhabitat categories were fence stake (23.9%) and rock (23.9%; Fig. 3). Some categories have changed in frequency of use between natural and agricultural areas, such as fence stake (higher in agricultural areas) and tree trunks (higher in natural vegetation; Fig. 3).

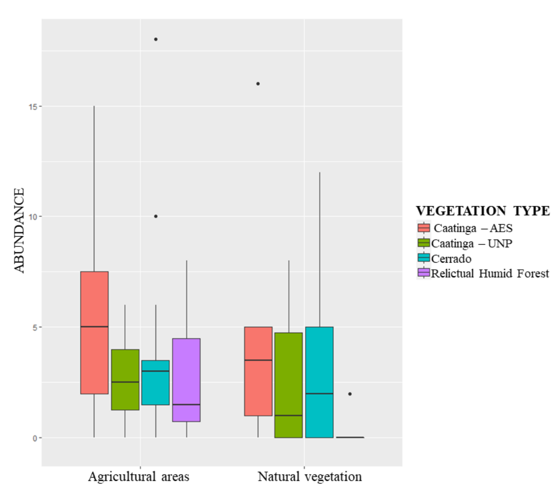

Figure 2. Abundance of Neotropical Lava Lizards (*Tropidurus hispidus*) between agricultural areas and natural vegetation in the different study areas in Brazil.

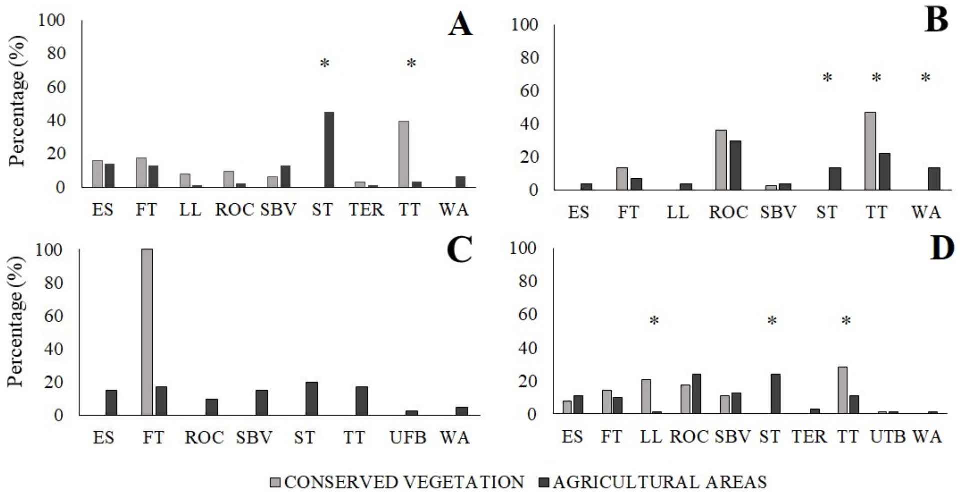

Figure 3. The percentage of microhabitat categories used by Neotropical Lava Lizards (*Tropidurus hispidus*) between the study areas in natural vegetation and agriculture in Brazil. (A) Caatinga *stricto sensu* (Aiuaba Ecological Station [AES] surroundings, (B) Caatinga *stricto sensu* (Ubajara National Park [UNP] surroundings, (C) Relictual Humid Forest [UNP] surroundings, (D) Cerrado *stricto sensu* Sete Cidades National Park [SCNP] surroundings. Abbreviations are ES = exposed soil, FT = fallen tree trunk, LL = leaf litter, ROC = rock, SBV = soil between vegetation, ST = fence stake, TER = termite nest, TT = tree trunk, UFB = under fence stake bark, UTB = under tree bark, and WA = wall. An asterisk (*) indicates differences between natural and agricultural areas in microhabitat use.

Discussion

Abundance of lizards.—As expected, we registered an increase in the abundance of *T. hispidus* in agricultural areas, however, only in the Relictual Humid Forest. *Tropidurus hispidus* is a habitat and diet generalist and is among the most abundant species in natural areas of Caatinga (Vitt 1995; Gonçalves-Sousa et al. 2019). This species is typical of open areas (Ribeiro-Júnior 2015), which explains its lower number in areas of natural vegetation in the Relictual Humid Forest. In these environments, it is found mainly in forest edges (Albuquerque et al. 2018), as the interior of the forest may restrict the necessary conditions for thermoregulation and, consequently, obtaining food (Vitt et al. 1998). The increase in abundance of generalist species is observed in different organism groups associated with land use (e.g., birds, Macgregor-Fors et al. 2017; bees, Flores et al. 2017; and lizards, Sutton et al. 2014). In Cerrado and Caatinga areas, they did not show a decline while maintaining abundance, despite the agricultural land use. The success of some species in surviving in anthropic environments may be associated with more suitable conditions for them, such as less competition (Des Roches et al. 2011) and greater availability of resources (Marques et al. 2020).

Spatial niche breadth and microhabitat use.—We corroborated our hypothesis of increase in niche width in agricultural areas only in UNP surroundings (Caatinga and Relictual Humid Forest). In other Caatinga areas (AES surroundings) and Cerrado (PNSC surroundings), there was a reduction in niche width in agricultural areas. *Tropidurus hispidus* is a generalist species and can adapt well to new types of environments (Andrade 2019). It is likely that increased density, reduced competition, and predation are aspects that can expand the organism's niche width, although this correlation is not always recorded (Novosolov et al. 2017). It is possible, however, that lizards show changes in the category of microhabitat used, between sites with a greater or lesser degree of modification (Pelegrin et al. 2013), which we identified in this study.

Differences in microhabitat use classes between natural and agricultural areas for some microhabitat use categories also matched our expectations. In natural areas, the microhabitat tree trunks was used more than in agricultural areas, and in agricultural areas fence stake was used more than in natural areas, for example. In urban areas, the preferential use of anthropogenic substrates has also been registered for this species (Andrade 2019), possibly due to changes in resource availability. The differential use of microhabitat, depending on its availability, has already been identified for another iguanid lizard (Balouch et al. 2022). Trees, for example, are less frequently found in agricultural areas, while anthropogenic microhabitats such as fence stakes and walls are found only in anthropogenic areas. The most used microhabitat in agricultural areas was fence stakes, which were predominantly located on the edge of these environments. The assessment how the interior of agricultural areas houses *T. hispidus* contributes to understanding how large-scale agricultural crops can affect the survival of this species (Biaggini and Corti 2021).

In our study, we identified that agricultural land use increased (Relictual Humid Forest) or maintained (Caatinga and Cerrado) the abundance of the generalist lizard *T. hispidus*, even with the increase in disturbance level, in relation to natural areas. Although we have not identified a standard variation in spatial niche amplitude between the different areas, we identified a distinct predominance of microhabitat use classes, which may reflect the availability of resources between these different environments (agricultural areas or natural vegetation). This way, we have broadened our knowledge on some aspects of the biology of this species in response to agricultural land use, which contributed to a better understanding of how environmental disturbances affect ecological aspects of Neotropical generalist lizards.

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Literature Cited

Albuquerque, R.L., A.S. Protázio, L.B.Q. Cavalcanti, L.C.S. Lopez, and D.O. Mesquita. 2018. Geographical ecology of *Tropidurus hispidus* (Squamata: Tropiduridae) and *Cnemidophorus ocellifer* (Squamata: Teiidae) in a neotropical region: a comparison among Atlantic Forest, Caatinga, and Coastal populations. Journal of Herpetology 52:145–155.

Andrade, A.C. 2019. Metropolitan lizards? Urbanization gradient and the density of lagartixas (T*ropidurus hispidus*) in a tropical city. Ecology and Evolution 10:1–11. https://doi.org/10.1002/ece3.5518.

Balouch, S., D.A. Driscoll, A. Naseer, M. Rais, and T.S. Doherty. 2022. Impacts of land cover on reptile movement and habitat use in farming landscapes. Animal Conservation 25:837–848.

Biaggini, M., and C. Corti. 2021. Occurrence of lizards in agricultural land and implications for conservation. Herpetological Journal 31:77–84.

Caitano, R.F., F.B. Lopes, and A.S. Teixeira. 2011. Estimativa da aridez no Estado do Ceará usando Sistemas de Informação Geográfica. Anais XV Simpósio Brasileiro de Sensoriamento Remoto 8.904–8.911

Caldas, F.L., A.A. Garda, L.Q.B. Cavalcanti, E. Leite-Filho, R.G. Faria, and D.O. Mesquita. 2019. Spatial and trophic structure of anuran assemblages in environments with different seasonal regimes in the Brazilian Northeast Region. Copeia 107:567–584.

Campbell, M.J., W. Edwards, A. Magrach, M. Alamgir, G. Porolak, D. Mohandass, and W.F. Laurance. 2018. Edge disturbance drives liana abundance increase and alteration of liana-host tree interactions in tropical forest fragments. Ecology and Evolution 8:4237–4251.

Canning, A.D., R.G. Death, and E.M. Gardner. 2017. The effect of forest canopy and flood disturbance on New Zealand stream food web structure and robustness. Austral Ecology 43:352–358.

Caruccio, R., R.C. Vieira, and L. Verrastro. 2010. Microhabitat use by *Cnemidophorus vacariensi*s (Squamata: Teiidae) in the grasslands of the Araucaria Plateau, Rio Grande do Sul, Brazil. Zoologia 27:902–908.

Castro, D.P., J.F.M. Rodrigues, M.J. Borges-Leite, D.C. Lima, and D.M. Borges-Nojosa. 2019. Anuran diversity indicates that Caatinga relictual neotropical forests are more related to the Atlantic Forest than to the Amazon. PeerJ 6: e6208 https://doi.org/10.7717/peerj.6208.

Crump, M.L., and N.J. Scott, Jr. 1994. Visual encounter surveys. Pp.84–91 *In* Measuring and Monitoring Biological Diversity - Standard Methods for Amphibians. Heyer, W.R., M.A.R. Donnelly, W. McDiarmid, L.A.C. Hayek, and M.S. Foster (Eds.). Smithsonian Institution Press, Washington, D.C., USA.

Des Roches, S., J.M. Robertson, L.J. Harmon, and E.B. Rosenblum. 2011. Ecological release in White Sands lizards. Ecology and Evolution 1:571–578.

Ellis, E.C., K.K. Goldewijk, S. Siebert, D. Lightman, and N. Ramankutty. 2010. Anthropogenic transformation of the biomes, 1700 to 2000. Global Ecology & Biogeography Letters 19:589–606.

Flores, L.M.A., L.R.S. Zanette, and F.S. Araujo. 2017. Effects of habitat simplification on assemblages of cavity nesting bees andwasps in a semiarid neotropical conservation area. Biodiversity and Conservation 27:311–328.

Garda, A.A., M.G. Stein, R.B. Machado, M.B. Lion, F.A. Juncá, and M.F Napoli. 2017. Ecology, biogeography, and conservation of amphibians of the Caatinga. Pp. 133–149 *In* the Largest Tropical Dry Forest Region in South America. Silva, J.M.C., I.R. Leal, and M. Tabarelli. (Eds.). Springer, Cham, Germany.

Girão, A.R., I. Dutra, and F. Souza. 2001. Área irrigada e métodos de irrigação no Estado do Ceará segundo o Censo Agropecuário 1995–1996. Revista Brasileira de Engenharia Agrícola e Ambiental 5:161–165.

Gonçalves-Sousa, J.G., D.O. Mesquita, and R.W. Ávila. 2019. Structure of a lizard assemblage in a semiarid habitat of the Brazilian Caatinga. Herpetologica 75:301–314.

Gonthier, D., J. Ennis, S. Farinas, Hsun-Yi Hsieh, A.L. Iverson, P. Batáry, J. Rudolphi, and T. Tscharntke. 2014. Biodiversity conservation in agriculture requires a multi-scale approach. Proceedings of the Royal Society B: Biological Sciences 281:20141358. https://doi.org/10.1098/rspb.2014.1358

Herrmann, N.C., J.T. Stroud, and J.B. Losos. 2020. The evolution of "Ecological Release" into the 21st Century. Trends in Ecology & Evolution https://doi.org/10.1016/j.tree.2020.10.019.

Kanno, Y., C.U. Schmidt, S.B. Cook, and H.T. Mattingly. 2012. Variation in microhabitat use of the threatened Spotfin Chub (*Erimonax monachus*) among stream sites and seasons. Ecology of Freshwater Fish 21:363–374.

Kolodiuk, M.F., L.B. Ribeiro, and E.M.X. Freire. 2009. The effects of seasonality on the foraging behavior of *Tropidurus hispidus* and *Tropidurus semitaeniatus* (Squamata: Tropiduridae) living in sympatry in the Caatinga of northeastern Brazil. Zoologia 26:581–585.

Leal, I.R., J.M.C. Silva, M. Tabarelli, and T.E. Jr Lacher. 2005. Changing the course of biodiversity conservation in the Caatinga of Northeastern Brazil. Conservation Biology 19:701–706.

MacGregor-Fors, I., J. Quesad, J.G.H. Lee, and P.J. Yeh. 2017. Space invaders: House Sparrow densities along three urban-agricultural landscapes. Avian Conservation and Ecology 12:11. https://doi.org/10.5751/ACE-01082-120211.

Marques, P.S., L.R. Manna, T.C. Frauendorf, E. Zandonà, R. Mazzoni, and R. El-Sabaawi. 2020. Urbanization can increase the invasive potential of alien species. Journal of Animal Ecology 89:2345–2355.

Medeiros, J.F, and L.A. Cestaro. 2019. As diferentes abordagens para definir brejos de altitude, áreas de exceção do nordeste brasileiro. Sociedade e Território 31:97–119.

Mesquita, D.O., G.C. Costa, A.A. Garda, and F.R. Delfim. 2017. Species composition, biogeography, and conservation of the Caatinga lizards. Pp. 133–149 *In* The Largest Tropical Dry Forest Region in South America. Silva, J.M.C., I.R. Leal, and M. Tabarelli. (Eds.) Springer, Cham, Germany.

Moro, M.F., M.B. Macedo, M.M. Moura-Fé, A.S.F. Castro, and R.C. Costa. 2015. Vegetação, unidades fitoecológicas e diversidade paisagística do estado do Ceará. Rodriguésia 66:717–743.

Nogueira, C., G.R. Colli, and M. Martins. 2009. Local richness and distribution of the lizard fauna in natural habitat mosaics of the Brazilian Cerrado. Austral Ecology 34:83–96.

Novosolov, M., G.H. Rodda, A.M. Gainsbury, and S. Meiri. 2017. Dietary niche variation and its relationship to lizard population density. Journal of Animal Ecology 87:285–292.

Oliveira, L.S., A.M. Sousa, J.I. Pinheiro, D.B. Nogueira, and M.G. Silva. 2020. Diagnóstico de uso e conservação do solo por agricultores no Nordeste brasileiro. Enciclopédia Biosfera, Centro Científico Conhecer 17:287–295.

Pelegrin, N., J.M. Chani, A.L. Echevarria, and E.H. Bucher 2013. Habitat degradation may affect niche segregation patterns in lizards. Acta Oecologica 51:82–87.

Prado, D. 2003. As caatingas da América do Sul. Pp. 3–73 *In* Leal, I.R., M. Tabarelli, and J.M.C. Silva (Eds,). Ecologia e conservação da Caatinga. Editora Universitária da UFPE, Recife, Brasil.

QGIS Development Team. 2019. QGIS Geographic Information System. Open Source Geospatial Foundation Project. http://qgis.osgeo.org.

R Core Team. 2021. R: a language e environment for statistical computing R Foundation for Statistical Computing. Austria, Vienna. http://www.R-project.org.

Ribeiro, L.B., and E.M. Freire. 2011. Trophic ecology and foraging behavior of *Tropidurus hispidus* and *Tropidurus semitaeniatus* (Squamata, Tropiduridae) in a Caatinga area of northeastern Brazil. Iheringia Série Zoologia 101:225–232.

Ribeiro-Júnior, M.A. 2015. Catalogue of distribution of lizards (Reptilia: Squamata) from the Brazilian Amazonia. I. Dactyloidae, Hoplocercidae, Iguanidae, Leiosauridae, Polychrotidae, Tropiduridae. Zootaxa 3983:1–110.

Rogan, J.E., and T.E. Lacher. 2018. Impacts of habitat loss and fragmentation on terrestrial biodiversity. Reference Module in Earth Systems and Environmental Sciences https://doi.org/10.1016/B978-0-12-409548-9.10913-3.

Santos, A.M.M., D.R. Cavalcanti, J.M.C. Silva, M. Tabarelli. 2007. Biogeographical relationships among tropical forests in north-eastern Brazil. Journal of Biogeography 34:437–446.

Santos, F.A. 2018. Análise Integrada da Paisagem em Trabalho de Campo no Parque Nacional de Sete Cidades (PI). Geografia 27:103–119.

Santos, L.A.C., S.C. Miranda, and C.M.S. Neto. 2020. Fitofisionomias do Cerrado stricto sensu: definições e tendências. Élisée - Revista de Geografia da UEG 9: e922022. https://revista.ueg.br/index.php/elisee/article/view/10907.

Scott, D.M., D. Brown, S. Mahood, B. Delton, A. Silbum, and F. Rakotondraparany. 2006. The impacts of forest clearance on lizard, small mammal and bird communities in the arid spiny forest, southern Madagascar. Biological Conservation 127:72–87.

Simpson, E.H. 1949. Measurement of diversity. Nature 163:688–688.

Sutton, W.B., Y. Wang, C.J. Schweitzer, and D.A. Steen. 2014. Lizard microhabitat and microclimate relationships in southeastern Pine-hardwood forests managed with prescribed burning and thinning. ForScience 60:180–190.

Veloso, A., E.V.S.B. Sampaio, A.M. Giulietti, M.R.V. Barbosa, A.A.J.F. Castro, L.P. Queiroz, A. Fernandes, D.C. Oren, L.A. Cestaro, A.J.E. Carvalho, et al. 2002. Ecorregiões propostas para o bioma Caatinga. Instituto de Conservação Ambiental, The Nature Conservancy do Brasil, Associação Plantas do Nordeste, Aldeia, Brasil.

Vitt, L.J. 1995. The ecology of tropical lizards in the Caatinga of northeast Brazil. Occasional Papers of the Oklahoma Museum of Natural History 1:1–29.

Vitt, L.J., T.C. Avila-Pires, J.P. Caldwell, and V.R.L. Oliveira. 1998. The impact of individual tree harvesting on thermal environments of lizards in Amazonian rain forest. Conservation Biology 12:654–664.

Werneck, F.P., G.R. Colli, and L.J. Vitt. 2009. Determinants of assemblage structure in neotropical dry forest lizards. Austral Ecology 34:97–115.

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