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## Reptile surveys reveal high species richness in areas recovering from mining activity in the Brazilian Cerrado

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**Abstract:** Our study determines the reptile species richness, composition, and habitat use in three areas recovering from mining activity in addition to the adjacent pristine and anthropized areas of a priority region for biodiversity conservation of the Brazilian Cerrado. We also compared our data with published surveys on the Cerrado domain in order to identify areas with unique species composition and/or areas where the reptile composition is more homogeneous. The survey was conducted in the municipality of Niquelândia, northern Goiás state, central Brazil, and involved reptile samplings from different physiognomies and water bodies. We found 47 species, including one crocodylian, one chelonian, two amphisbaenians, 17 lizards, and 26 snakes. The list includes 37 species with large geographic distribution, occurring in other morphoclimatic domains, as well as 10 species which are endemic to the Cerrado. Some species recorded for the region are listed in the Appendices I and II of the CITES. Many reptile species were frequently associated with anthropogenic habitats, while others seem to depend on remnants of pristine habitats. Low similarity was found among the 32 sites considered across the Cerrado domain. Ten sites located in Cerrado regions in contact with the adjacent domains have unique reptile composition, whereas most sites largely located in the central area of the domain have reptile communities which are more homogeneous among them. It is important to conduct long-term studies to have patterns of reptile species composition recognized as well as population decline and/or local extinctions and effective reptile conservation actions, with focus on these sites considering their unique species.

**Key words:** amphisbaenians; biodiversity conservation; chelonian; crocodylian; lizards; reptile communities; snakes

**Abbreviations:** ACA, adjacent Cerrado areas; ANA, anthropic areas; ARM, areas recovering from mining activity; VSM, visual search method; PTD, pitfall traps with drift-fences method; BA, Bahia state; DF, Distrito Federal; GO, Goiás state; MA, Maranhão state; MG, Minas Gerais state; MS, Mato Grosso do Sul state; MT, Mato Grosso state; PI, Piauí state; SP, São Paulo state; TO, Tocantins state

### Introduction

The Cerrado morphoclimatic domain is among the 35 priority areas for global biodiversity conservation and is regarded as a hotspot for its high amount of endemic

and endangered species (Mittermeier et al. 2004). This morphoclimatic domain has a heterogeneous complex of vegetation physiognomies that is essential to determine their rich biota, which has been severely threatened by human activities (Oliveira & Marquis 2002; Mittermeier

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et al. 2004; Klink & Machado 2005). The current loss of biodiversity in the context of the Cerrado results from activities such as mining, construction of hydroelectric dams, and agricultural expansion (Silvano & Segalla 2005).

Despite the intensive habitat loss and fragmentation, recent studies based on systematic data have revealed that the Cerrado ecoregion has a rich herpetofauna, containing at least 209 amphibian species (108 endemics) and 282 reptile species (103 endemics) (Nogueira et al. 2011; Valdujo et al. 2012). However, this herpetofauna richness is considered underestimated and still poorly understood with most of its areas remaining inadequately sampled (Nogueira et al. 2010).

Studies on environmental impact analysis and wildlife monitoring in hydroelectric projects, despite the enormous environmental and social impacts of dam constructions, often provide valuable information on regional herpetofauna in the context of the affected areas (e.g., Vaz-Silva et al. 2007; Santos et al. 2011; Tavares et al. 2012; Silva et al. 2015). This is the case for the Serra da Mesa mountain range, in northern Goiás state, central Brazil. Regarded as a priority area for Cerrado bio-

diversity conservation (MMA 2007), new species have been continuously described for Serra da Mesa, such as *Amphisbaena anaemariae* (Vanzolini, 1997), *A. mensae* (Castro-Mello, 2000), *Apostolepis cerradoensis* (Lema, 2003), and *Proceratophrys bagnoi* (Brandão, Caramaschi, Vaz-Silva & Campos, 2013). The filling of the Serra da Mesa hydroelectric power plant reservoir has led the region to lose a total of 1,784 km<sup>2</sup> of a mosaic of Cerrado physiognomies. However, studies on environmental impacts, faunal rescue operations, and monitoring programs have identified a rich herpetofauna in the affected area (Silva Jr. et al. 2005). After the complete flooding of the reservoir, approximately 280 islands were formed with the isolation of hill tops, leading to negative changes in species richness as well as abundance of amphibian anurans and lizards in these new habitats (Brandão & Araújo 2008).

The municipality of Niquelândia is located at Serra da Mesa and known for its nickel ore richness, which implies a modification in its natural landscape by intensive mining activities (Fernandes & Pessôa 2011). Recent studies on anuran diversity encompassing areas recovering from mining activity on Niquelândia have

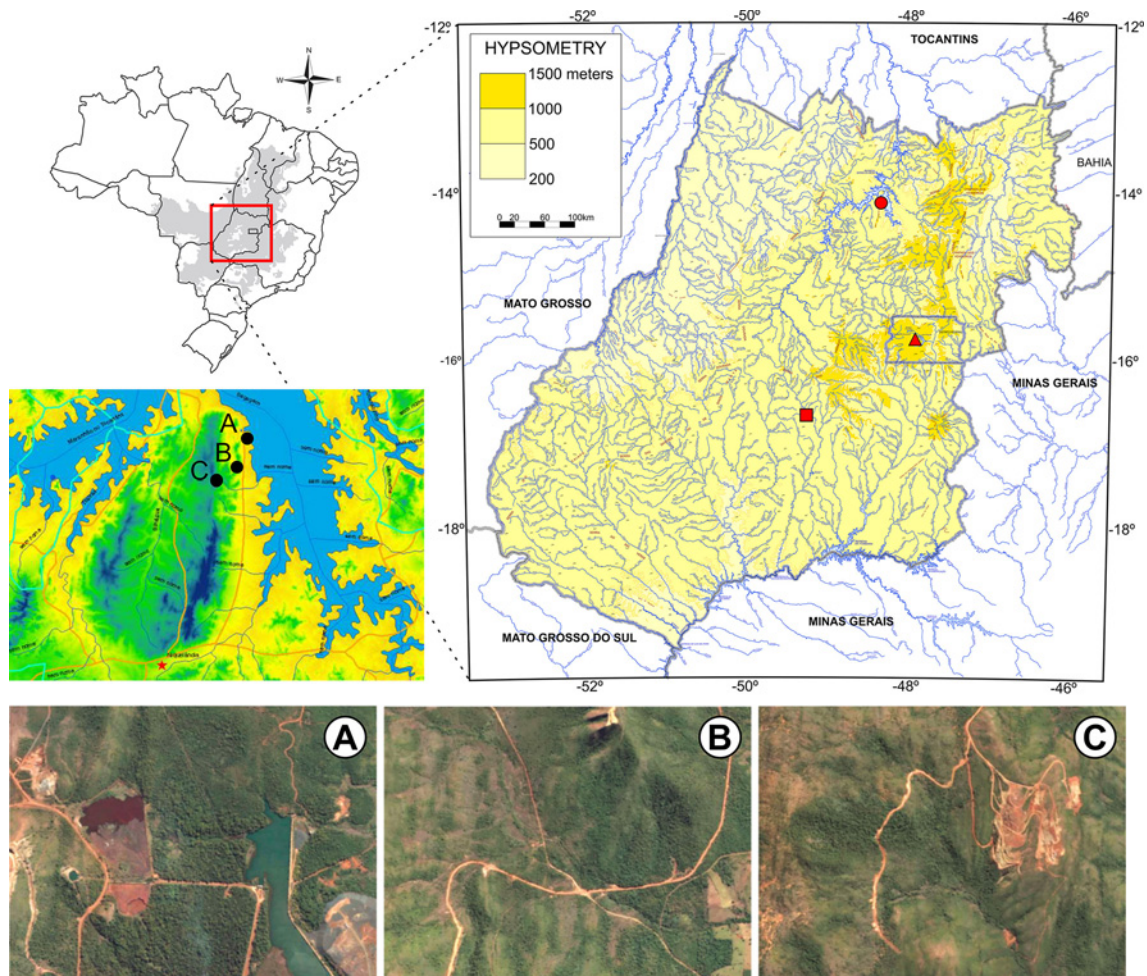


Fig. 1. Schematic map showing the municipalities of Niquelândia (red circle), Brasília (red triangle, Distrito Federal), and Goiânia (red square). Sites surveyed in 2005/2006 and 2009/2010 for areas recovering from mining activity: ARM 1 (A), ARM 2 (B), ARM 3 (C). See surveyed sites descriptions in Table S1 (electronic supplementary material). Map of Goiás state modified from Mapa Físico IBGE (2015).



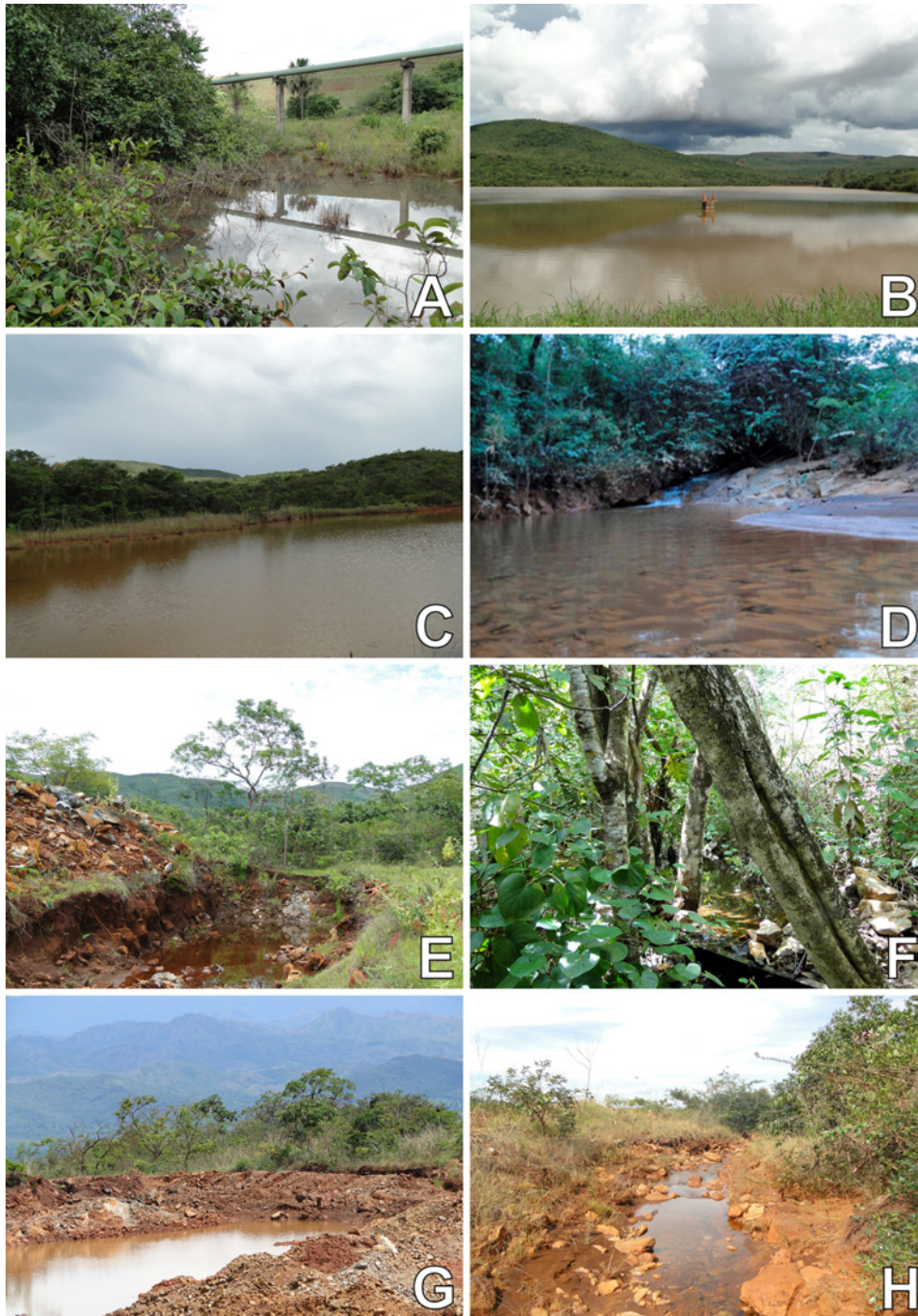


Fig. 2. Cerrado physiognomies, anthropized areas, and water bodies surveyed using visual search method in February and May 2014 in adjacent Cerrado areas in the Serra da Mesa region, municipality of Niquelândia, northern Goiás state, central Brazil: VSM 1.3 (A), VSM 1.4 (B), VSM 1.5 (C), VSM 2.1 (D), VSM 2.2 (E), VSM 2.3 (F), VSM 2.4 (G), VSM 2.5 (H). See surveyed sites descriptions in Table S2 (electronic supplementary material). Photos: Drummond L.O. (all photos).

found high species richness due to habitat heterogeneity provided by the recovering vegetation associated with the natural water bodies and artificial ponds formed inside exhausted mines (Oda et al. 2009; Nomura et al. 2012). However, there is no record of ecological information regarding the reptiles found in areas recovering from mining activity in this region.

Our study brings information on the species richness, composition, habitat use, and conservation status of reptile species obtained from surveys in areas

recovering from mining activity as well as from an environmental impact study encompassing the municipality of Niquelândia, Serra da Mesa region, northern Goiás state, central Brazil. We also surveyed the herpetofaunal list of species in the literature along the Cerrado domain in order to understand the structuring of the species composition across the area, identifying areas with unique species composition and/or areas where the herpetofaunal composition is more homogeneous among the selected sites.



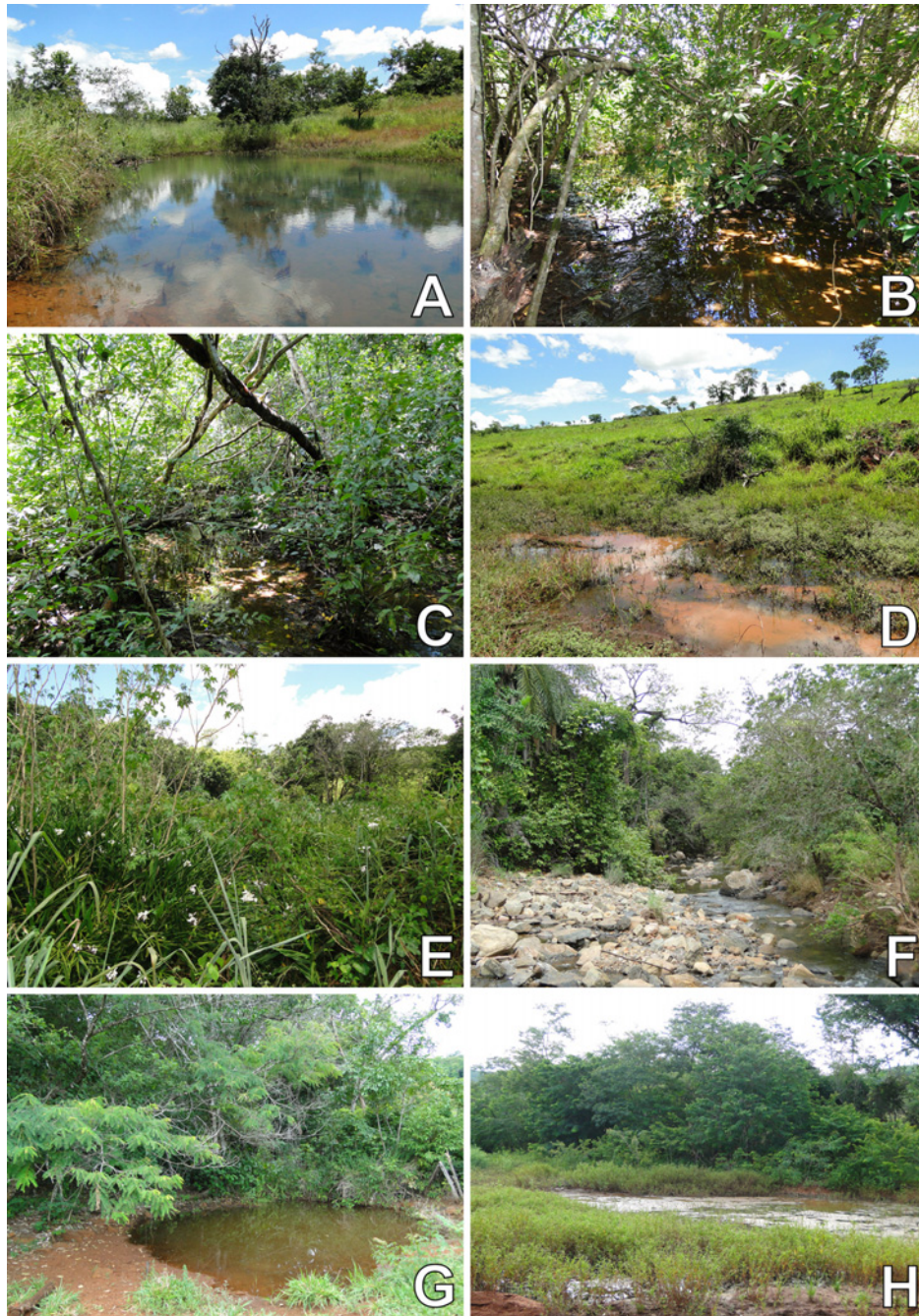


Fig. 3. Cerrado physiognomies, anthropized areas, and water bodies surveyed using visual search method in February and May 2014 in adjacent Cerrado areas in the Serra da Mesa region, municipality of Niquelândia, northern Goiás state, central Brazil: VSM 3.1 (A), VSM 3.2 (B), VSM 3.3 (C), VSM 3.4 (D), VSM 3.5 (E), VSM 4.1 (F), VSM 4.3 (G), VSM 4.4 (H). See surveyed sites descriptions in Table S2 (electronic supplementary material). Photos: Drummond L.O. (all photos).

## Material and methods

### Study areas

Our study was conducted in the municipality of Niquelândia ( $14^{\circ}09'34''$  S,  $48^{\circ}20'06''$  W), located in the Serra da Mesa region, Upper Tocantins River basin, northern Goiás state, central Brazil (Fig. 1). This region presents great variety of rocks from its crystalline base with high levels of laterites (Latrubesse 2005). It has a tropical climate marked with two well-defined seasons (wet summer and dry winter), classified as Aw in the Köppen classification system (Peel et al. 2007). The original vegetation in the region consisted of different Cerrado physiognomies (Oliveira-Filho & Ratter 2002) and

a structure highly influenced by the variation in concentrations of nickel, cobalt, chromium, and magnesium in soil (Brooks et al. 1990).

### Reptile surveys

In order to analyze the reptile fauna of three areas recovering from mining activity (ARM), we surveyed water bodies and the following physiognomies within areas: cerrado *sensu stricto* (CE), valley-side marshy grasslands – *veredas* (VE), hydromorphic grassland (HG), rocky grassland – *campo rupestre* (RG), mesophytic semideciduous forest (SF), and closed woodland – *cerradão* (CW; see detailed description of sampled points in supplementary Table S1).



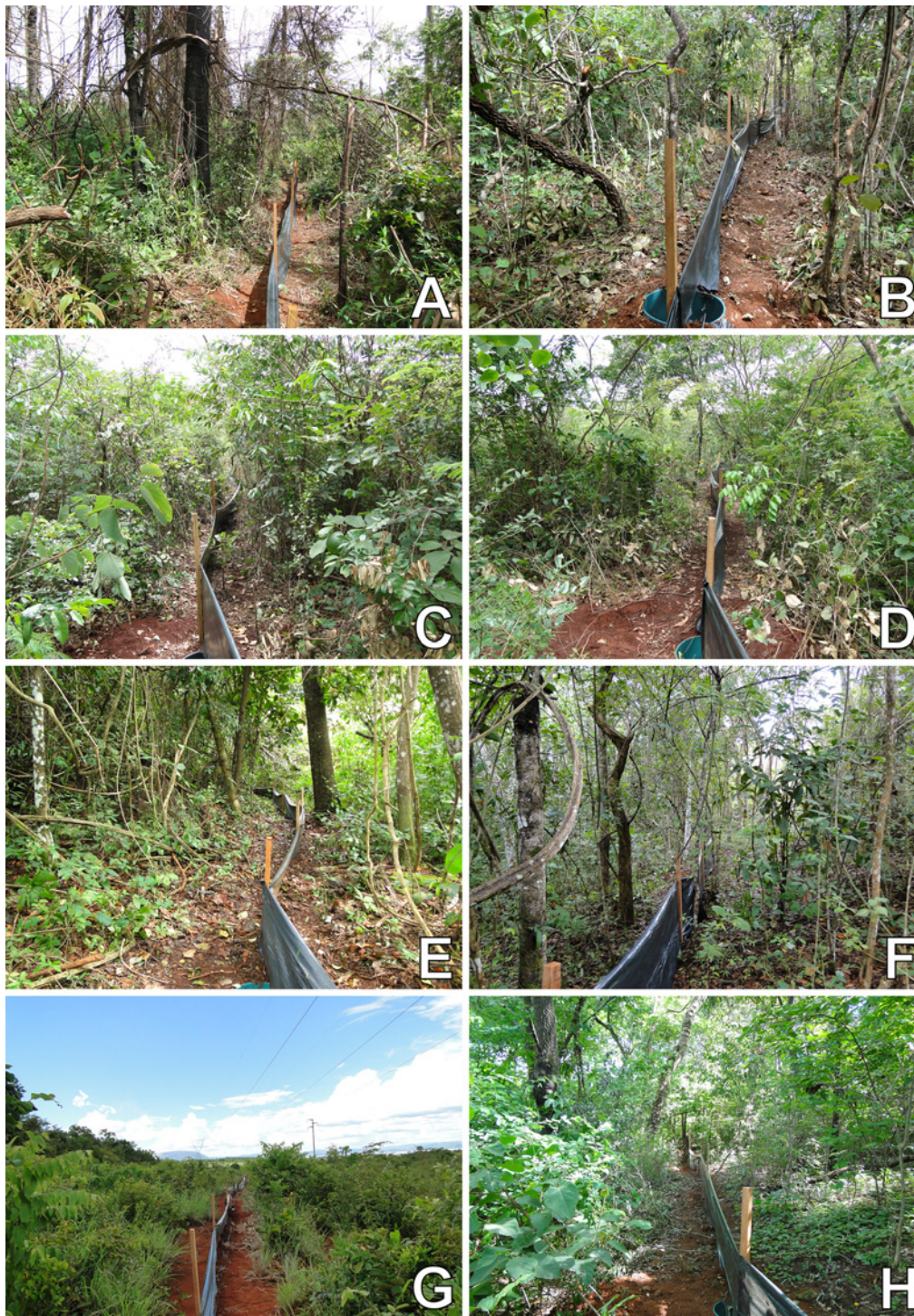


Fig. 4. Cerrado physiognomies and anthropized areas surveyed using pitfall traps with drift-fences in February and May 2014 in adjacent Cerrado areas in the Serra da Mesa region, municipality of Niquelândia, northern Goiás state, central Brazil: PTD 1.1 (A), PTD 1.2 (B), PTD 2.1 (C), PTD 2.2 (D), PTD 3.1 (E), PTD 3.2 (F), PTD 4.1 (G), PTD 4.2 (H). See surveyed sites descriptions in Table S3 (electronic supplementary material). Photos: Drummond L.O. (all photos).

These areas had been explored along approximately 30 years for extraction of soil with high nickel concentrations. The nickel extraction was conducted through the surface mining method (i.e., open pit mining), which is used to extract minerals found near the surface by means of a surface pit, excavated with one or more horizontal benches (Hartman & Mutmanský 2002). Mining activity in Niquelândia has not only changed its local landscape and topography due to soil

extraction, it has also led to habitat loss with the deforestation of the mining areas (Nomura et al. 2012). Since 2007, though, the exhausted mines have been reconstituted and reforested (Nomura et al. 2012).

We performed the surveys over two time periods. The first inventory occurred between October 2005 and August 2006 and included eight field surveys of six days each, totaling 48 days of sampling. The second inventory occurred

Table 1. Locations within the Cerrado domain with comparison of its reptile assemblages and the respective record for the municipality of Niquelândia, Goiás state, central Brazil. Only squamata reptile species were considered in the analyses.

N	Location	Ns	Ch	Cr	Lz	Am	Sn	Source
1	Serra do Gado Bravo, MA	29	2	-	12	2	13	Barreto et al. (2007)
2	Paquetá farm, PI	31	1	1	14	1	14	Silva et al. (2015)
3	Uruçuí-Una Ecological Station, PI	64	1	1	19	4	39	Dal Vechio et al. (2013)
4	Serra das Confusões National Park, PI	47	2	-	21	4	20	Dal Vechio et al. (2016)
5	Grande Sertão Veredas National Park, BA/MG	50	-	-	18	2	9	Recoder & Nogueira (2007)
6	Campo das Vertentes and Serra das Vertentes, MG	31	2	-	9	2	18	Sousa et al. (2010)
7	Unilavras-Boqueirão Biological Reserve, MG	17	-	-	11	-	6	Novelli et al. (2012), Lucas et al. (2016)
8	Serra do Ouro Branco, MG	43	-	-	15	-	28	São Pedro & Pires (2009), Rosário Cruz et al. (2014)
9	Serra de São José, MG	29	-	-	12	1	16	Rios et al. (2017)
10	Batalha Hydroelectric Power Plant, MG/GO	54	2	1	17	2	32	Lagos et al. (2017)
11	Assis Ecological Station and municipality of Assis, SP	53	-	-	10	4	39	Araujo & Almeida-Santos (2011)
12	Aporé-Sucuriú Complex, MS/SP/MG/GO	36	-	1	17	4	14	Uetanabaro et al. (2006)
13	Serra da Bodoquena National Park, MS	25	1	1	15	1	7	Uetanabaro et al. (2007)
14	Ponte de Pedra Hydroelectric Power Plant, MT/MS	72	2	1	23	8	40	Silva Jr. et al. (2009)
15	Middle Aporé River, MS/GO	33	-	1	14	-	18	Ramalho et al. (2014)
16	Meandros do rio Araguaia Environmental Protection Area, GO/MT	28	-	-	13	15	-	Santos et al. (2008)
17	Manso Hydroelectric Power Plant region, MT	78	2	2	26	4	44	Strüssmann (2000)
18	Entre Rios Hydroelectric Power Plant, MT	24	1	-	12	11	-	Silva et al. (2015)
19	Municipality of Alto Araguaia, MT	13	1	-	8	4	-	Mendes-Pinto & Miranda (2011)
20	Municipality of Nobres, MT	28	-	-	13	14	1	Santos et al. (2011)
21	Santa Edwiges I and II Hydroelectric Power Plant, GO	45	-	-	14	3	28	Cintra et al. (2009)
22	Southeastern Goiás state, GO	40	2	1	13	21	3	Santos et al. (2014)
23	National Forest Silvânia, GO	32	1	-	14	17	-	Morais et al. (2012)
24	Upper Tocantins River, GO	47	-	-	13	27	7	Moreira et al. (2009)
25	Emas National Park, GO	87	-	-	27	54	6	Valdujo et al. (2009)
26	Espora Hydroelectric Power Plant, GO	71	2	1	18	45	5	Vaz-Silva et al. (2007)
27	Areas recovering and municipality of Niquelândia, GO	47	1	1	17	2	26	This study
28	Luis Eduardo Magalhães Hydroelectric Power Plant, TO	111	6	2	26	7	70	Pavan & Dixon (2004)
29	Jalapão region, TO	88	1	2	27	6	52	Vitt et al. (2005), Recoder et al. (2011)
30	Águas Emendadas Ecological Station, DF	52	2	2	17	2	29	Brandão & Araújo (1998)
31	Cafuringa Environmental Protection Area, DF	48	3	-	19	2	24	Brandão et al. (2006)
32	IBGE Biological Reserve, DF	63	1	-	20	5	37	Colli et al. (2011)

Abbreviations: Ns – number of species; Ch – Chelonian; Cr – Crocodylian; Lz – Lizard; Am – Amphisbaenian; Sn – Snake.

between October 2009 and April 2010 and involved seven field surveys of six days each, numbering 42 days of sampling.

Reptile specimens were surveyed using diurnal and nocturnal visual searches (VSM; Crump & Scott Jr. 1994), pitfall traps with drift-fences (PTD; Cechin & Martins 2000), and occasional encounters. We conducted the visual searches at the margin of water bodies (streams, ponds, and reservoirs) as well as in both open and forested areas. We used ten groups of pitfall traps per area, each consisting of three buckets (60 L) arranged in three “Y”-shaped drift-fences (50 cm × 10 m), numbering 30 buckets. Incidental encounters corresponded to records of reptiles found alive or dead both inside and outside the studied areas, as well as in anthropic areas (ANA): access roads (AR), vicinity of human habitations (VH), pasture areas (PT), eucalypt forest (EF), and water bodies (WB). In addition to the reptiles found during our study, we improved our species list by using records based on the specimens collected (with the same

above mentioned survey methods, but including pitfalls arranged in linear transects constituted of 10 buckets; see detailed description and photos of the sampling areas in electronic supplementary Table S2 and S3 and Figs 2–4) from an environmental impact study performed between February and May 2014, which took place in adjacent Cerrado areas (both pristine and anthropized; ACA) to the study site. Voucher specimens were housed at the Zoological Collection of the Universidade Federal de Goiás (ZUFUG).

*Conservation status, reptile species list surveys and data analysis*

We obtained the conservation status of each reptile species from the Appendices of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES 2015) as well as from the red list of threatened Brazilian Fauna (MMA 2014).

In order to assess the similarity between the compositions of reptile communities in other surveyed sites of the Brazilian Cerrado, we established a comparison of our data

Table 2. Reptile species recorded in areas recovering from mining activity and adjacent Cerrado areas in the municipality of Niquelândia, northern Goiás state, central Brazil.

Species	Surveyed areas					Regions	Conservation status	
	2005/2006 and 2009/2010				2014		CITES	Brazil
	ANA	ARM 1	ARM 2	ARM 3	ACA			
Chelonia								
Chelidae								
<i>Phrynops geoffroanus</i> (Schweigger, 1812)	WB	WB	WB	WB	WB	Am, Af, Ca	NA	LC
Crocodylia								
Alligatoridae								
<i>Paleosuchus palpebrosus</i> (Cuvier, 1807)	WB	WB	WB		WB	Am, Af, Ca, Pn*	II	LC
Squamata								
Anguillidae								
<i>Ophiodes</i> sp. (aff. <i>striatus</i> )	AR					Ca, Af, Ch	NA	NA
Dactyloidae								
<i>Norops brasiliensis</i> (Vanzolini & Williams, 1970)		SF, CE	SF, CE		SF, CE	Am, Ca	NA	LC
Gekkonidae								
<i>Hemidactylus mabouia</i> (Moreau de Jonnés, 1818)	VH				VH	Am, Af, Ch, Ca, Pn	NA	NA
Gymnophthalmidae								
<i>Micrablepharus atticolus</i> Rodrigues, 1996			CE	CE, VE	CE	END	NA	LC
<i>Micrablepharus maximiliani</i> (Reinhardt & Luetken, 1862)					CE	Ca, Ch	NA	LC
<i>Colobosaura modesta</i> (Reinhardt & Luetken, 1862)		SF		VE	SF, CE	Am	NA	LC
<i>Cercosaura ocellata</i> Wagler, 1830					PT	Am, Af	NA	LC
Iguanidae								
<i>Iguana iguana</i> (L., 1758)	VH				AR	Am, Ca	II	LC
Mabuidae								
<i>Copeoglossum nigropunctatum</i> (Spix, 1825)		SF, CE	SF, CE		SF	Am	NA	LC
<i>Notomabuya frenata</i> (Cope, 1862)		SF, CE	SF, CE			Ch, Af	NA	LC
Phyllodactylidae								
<i>Gymnodactylus amarali</i> Barbour, 1925					SF	END	NA	NA
Polychrotidae								
<i>Polychrus acutirostris</i> Spix, 1825		SF		HG	SF	Ca, Ch	NA	NA
Sphaerodactylidae								
<i>Coleodactylus brachystoma</i> (Amaral, 1935)		SF, CE	SF, CE		SF, RF	END	NA	NA
Teiidae								
<i>Ameiva ameiva</i> (L., 1758)		SF, CE	SF, CE	VE, HG	EF, PT	Am, Af, Ch, Ca	NA	NA
<i>Ameivula ocellifera</i> (Spix, 1825)				RG	PT	Am, Af, Ch, Ca	NA	NA
<i>Salvator merianae</i> (Duméril & Bibron, 1839)		SF, CE	SF, CE	RG		Af, Am, Ca	II	NA
Tropiduridae								
<i>Tropidurus oreadicus</i> Rodrigues, 1987		SF, CE	SF, CE	VE	SF, RF, CE, PT	Am	NA	NA
Amphisbaenidae								
<i>Amphisbaena alba</i> L., 1758	VH, AR				VH	Am, Ca, Af, Ch	NA	LC
<i>Amphisbaena anaemariae</i> Vanzolini, 1997					SF	END	NA	LC
Aniliidae								
<i>Anilius scytale</i> (L., 1758)					SF	Am	NA	NA
Anomalepididae								
<i>Liotyphlops</i> cf. <i>beui</i>					SF	Af	NA	NA
Boidae								
<i>Boa constrictor</i> (Stull, 1932)	VH					Am, Ca, Ch, Af,	I/II	NA
<i>Epicrates crassus</i> Cope, 1862					PT	END	NA	NA
<i>Euneptes murinus</i> (L., 1758)	WB					Am, Ch	II	NA
Colubridae								
<i>Chironius flavolineatus</i> (Jan, 1863)					PT	END	NA	NA
<i>Drymarchon corais</i> (Boie, 1827)			CE			Am, Af, Ca	NA	NA
<i>Mastigodryas boddaerti</i> (Sentzen, 1796)			CE			Am	NA	NA
<i>Orybelis aeneus</i> (Wagler in Spix, 1824)				CW		Am, Ca	NA	NA
<i>Spilotes pullatus</i> (L., 1758)	VH		CE	VE		Am, Af	NA	NA



Table 2. (continued)

Species	Surveyed areas					Regions	Conservation status	
	2005/2006 and 2009/2010				2014		CITES	Brazil
	ANA	ARM 1	ARM 2	ARM 3	ACA			
<b>Dipsadidae</b>								
<i>Atractus pantostictus</i> Fernandes & Puorto, 1994	VH					Af	NA	NA
<i>Sibynomorphus mikanii</i> (Schlegel, 1837)	AR				SF	Pp, Af	NA	NA
<i>Taeniophallus occipitalis</i> (Jan, 1863)	AR					Ch, Ca	NA	NA
<i>Philodryas olfersii</i> (Liechtenstein, 1823)	VH			VE	PT	Am, Af, Ch, Ca, Pp	NA	NA
<i>Oxyrhopus trigeminus</i> Duméril, Bibron & Duméril, 1854		SF			VH, AR	Ca, Ch	NA	NA
<i>Phimophis guerini</i> (Duméril, Bibron & Duméril, 1854)	PT					Ch, Pn	NA	NA
<i>Pseudoboa nigra</i> (Duméril, Bibron e Duméril, 1854)					AR	Ca	NA	NA
<i>Erythrolamprus almadensis</i> (Wagler in Spix, 1824)	AR					Ch, Ca	NA	NA
<i>Erythrolamprus poecilogyrus</i> (Wied, 1825)			CE			Am, Af, Ca, Ch	NA	NA
<i>Erythrolamprus reginae</i> (Amaral, 1935)					EF	Am, Af, Ca, Ch	NA	NA
<i>Xenodon merremii</i> (Wagler, 1824)	VH		CE	VE	SF	Ch, Ca	NA	NA
<i>Xenopholis undulatus</i> (Jensen, 1900)		SF				END	NA	NA
<b>Leptotyphlopidae</b>								
<i>Trilepida fuliginosa</i> (Passos, Caramaschi & Pinto, 2006)		SF			PT	END	NA	NA
<b>Viperidae</b>								
<i>Bothrops moojeni</i> Hoge, 1966			CE		SF, RF	END	NA	NA
<i>Bothrops pauloensis</i> Amaral, 1925	VH					END	NA	NA
<i>Crotalus durissus</i> L., 1758	AR		CE	HG	PT	Ca, Am	III	NA
Species richness by area	18	15	18	13	31			

Surveyed areas: ANA – anthropic areas; ARM – areas recovering from mining activity; ACA – adjacent Cerrado areas (pristine and anthropic areas). Surveyed habitats: WB – water bodies; AR – access roads; PT – pastures areas; VH – vicinity of human habitations; EF – eucalypt forest; SF – mesophytic semideciduous forest; RF – riparian forest; CE – cerrado *sensu stricto*; VE – valley-side marshy grasslands; HG – hydromorphic grassland; CW – closed woodland; RG – rocky grassland. Regions: Am – Amazonia; Af – Atlantic Forest; Ca – Caatinga; Ch – Chaco; Pn – Pantanal (\* = Pantanal surrounding areas); Pp – Pampas; END – Cerrado endemic (Distribution patterns of squamate reptiles based on Nogueira et al. 2011; crocodylian on Campos et al. 2013; and chelonian based on Vogt et al. 2015). Conservation status: Appendices CITES: I – containing species threatened with extinction (trade in specimens of these species is permitted only in exceptional circumstances); II – containing species not necessarily threatened with extinction, but whose trade must be controlled in order to avoid utilization incompatible with their survival; NA – not assessed.

and published surveys on this same morphoclimatic domain (Table 1). Specifically, we generated a presence/absence matrix derived from the nominal reptile species found at each site, ignoring species which had not been identified until specific level. This database was used to calculate the “local contribution to beta diversity” (LCBD; sensu Legendre & De Cáceres 2013) of each site. In summary, the LCBD values represent the degree of uniqueness of the sampling units in terms of community composition (Legendre & De Cáceres 2013). Later on, sites which contribute more (large LCBD values) or less (lower LCBD values) to the overall reptile composition in the Cerrado domain could be detected among the selected sites. Since the variation in species composition among sites can be related to either species turnover or loss of species, we decomposed the LCBD values into turnover and nestedness components (Legendre 2014) in order to enable the identification of the beta diversity components pronounced on the beta diversity structure of the reptile species composition. The LCBD values, as well as the turnover and nestedness indices, were derived from the Jaccard dissimilarity index of the Baselga fam-

ily presence-absence data, as described in Legendre (2014). These analyses were run in R using the scripts provided in Legendre & De Cáceres (2013) and Legendre (2014).

**Results**

Areas surveyed between 2005/2006 and 2009/2010 (ARM and ANA), presented local species richness varying from 13 to 18 (mean ± standard deviation: 16 ± 2.45 species), numbering 37 species. Areas surveyed in 2014 (ACA) presented 31 reptile species. Considering all inventories, we recorded a total of 47 reptile species distributed in 20 families, including 26 snakes, 17 lizards, two amphisbaenians, one chelonian (*Phrynops geoffroanus*), and one crocodylian (*Paleosuchus palpebrosus*) (Table 2; Fig. 5). Regarding lizards, the most speciose families were Gymnophthalmidae and Teiidae, with four species each, followed by Mabuyidae, and Amphisbaenidae, with two species each, as well as Anguidae,

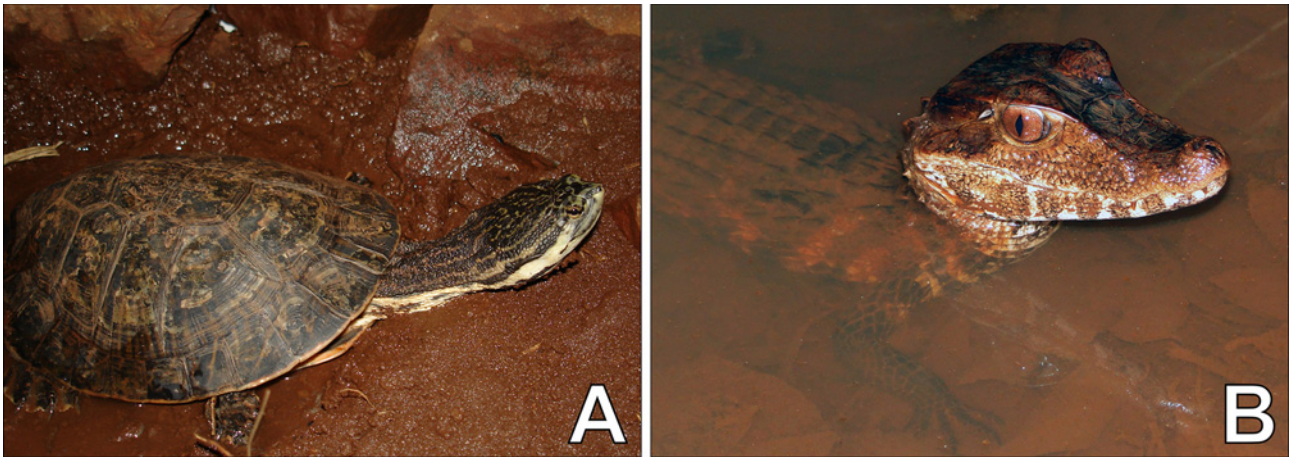


Fig. 5. Chelonian and crocodilian species recorded in the municipality of Niquelândia, northern Goiás state, central Brazil. *Phrynops geoffroanus* (A), *Paleosuchus palpebrosus* (B). Photos: Oda F.H. (A), Drummond L.O. (B).

Dactyloidae, Gekkonidae, Phyllodactylidae, Polychrotidae, and Sphaerodactylidae, with a single species each (Table 2; Fig. 6). Amongst the snakes, the family with the highest species richness was Dipsadidae (12 species), followed by Colubridae (five species), Viperidae (three species), Boidae (three species), Leptotyphlopidae, Aniliidae, and Anomalepididae (one species each) (Table 2; Figs 7–8).

Regarding habitat use, we found chelonians (*Phrynops geoffroanus*) and crocodilians (*Paleosuchus palpebrosus*) associated only with water bodies of different types (e.g., ponds, streams and reservoirs) within pristine and anthropic areas. *Amphisbaena alba* was found exclusively in anthropic areas (VH, AR), and *A. anaemariae* only in pristine areas (SF). Amongst lizards, five species (29%) were recorded in only one type of environment (AR, VH, CE, PT, SF). Anthropic areas had the lowest species richness – only seven species, including four recorded exclusively in this type of environment, while pristine areas had 10 out of 13 species in the same condition. Open and forested pristine environments presented similar species richness, with respectively three and one species being exclusively recorded in each, and nine species recorded in both types of environments (Table 2).

Most of the snake species (69%) were recorded in only one type of environment (VH, PT, WB, CE, CW, AR, EF, SF). Anthropic areas had the highest species richness – 11 out of 18 species recorded exclusively for this environment, while pristine areas had slightly lower species richness, with 15 species, including eight recorded only in this type of environment. Open and forested environments presented similar species richness, with respectively six and seven species recorded exclusively for each, and two species recorded in both open and forest environments (Table 2).

Our list of reptiles included 37 species (79%) with distribution encompassing more than one morphoclimatic domain, and 10 species (21%) endemic to the Cerrado (*Micrablepharus atticolus*, *Gymnodactylus amarali*, *Coleodactylus brachystoma*, *Amphisbaena anaemariae*, *Epicrates crassus*, *Chironius flavolinea-*

*tus*, *Xenopholis undulatus*, *Trilepida fuliginosa*, *Bothrops moojeni*, and *Bothrops pauloensis*). None of the species registered are listed in the current Brazilian official list of endangered species, but some of the medium and large reptile species recorded in the region, such as *Paleosuchus palpebrosus*, *Iguana iguana*, *Salvator merianae*, *Boa constrictor amarali*, *Eunectes murinus*, and *Crotalus durissus*, are listed in the Appendices I and II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (Table 2).

Local herpetofauna composition in the inventories inside the Cerrado domain surveyed in this study was found to have low similarity (Fig. 9), which is mainly determined by species turnover among areas, with low contribution of species loss (Fig. 9). Among the 32 sites considered across the Cerrado domain, ten have differentiated species composition, i.e. higher number of exclusive reptile species occurring at these sites, as indicated in their high and significant Local Contribution to Beta Diversity values (pLCBD < 0.05) (Fig. 10). These sites are mainly located in Cerrado regions in contact with the adjacent domains, such as the Pantanal floodplain, Atlantic and Amazon Forests (Fig. 10). In contrast, most sites, especially those in the central region of Cerrado, have low LCBD values, meaning that the reptile communities are more homogeneous (Fig. 10).

## Discussion

Our study has a reptile richness corresponding to about 46% of the regional species pool (103 species) known to inhabit the Tocantins River Valley (Silva Jr. et al. 2005). Considering that the size of the surveyed areas or the sampling effort may influence the amount of species surveyed, our records on species richness are similar to those from termite mounds in contiguous reservoir areas of the Serra da Mesa and Cana Brava hydroelectric power plant (47 species; Moreira et al. 2009) as well as other areas in the Cerrado (Recoder et al. 2011). Some of the surveyed sites in Cerrado have been reported to show lower reptile richness than recovering





Fig. 6. Lizard and amphisbaenian species recorded in the municipality of Niquelândia, northern Goiás state, central Brazil: *Ophiodes* sp. (aff. *striatus*) (A), *Norops brasiliensis* exhibiting the dewlap (B), *Norops brasiliensis* (C), *Micrablepharus maximiliani* (D), *Colobosaura modesta* (E), *Cercosaura ocellata* (F), *Iguana iguana* (G), *Copeoglossum nigropunctatum* (H), *Notomabuya frenta* (I), *Gymnodactylus amarali* (J), *Polychrus acutirostris* (K), *Coleodactylus brachystoma* (L), *Ameiva ameiva* (M), *Ameivula ocellifera* (N), *Salvator merianae* (O), *Tropidurus oreadicus* (P), *Amphisbaena alba* (Q), *Amphisbaena anaemariae* (R). Photos: Kopp K.A. (A), Oda F.H. (C, H, I, P), Drummond L.O. (B, D, E, F, J, K, L, M, N, Q, R), Pinheiro D.G. (G), Heming N.M. (O).



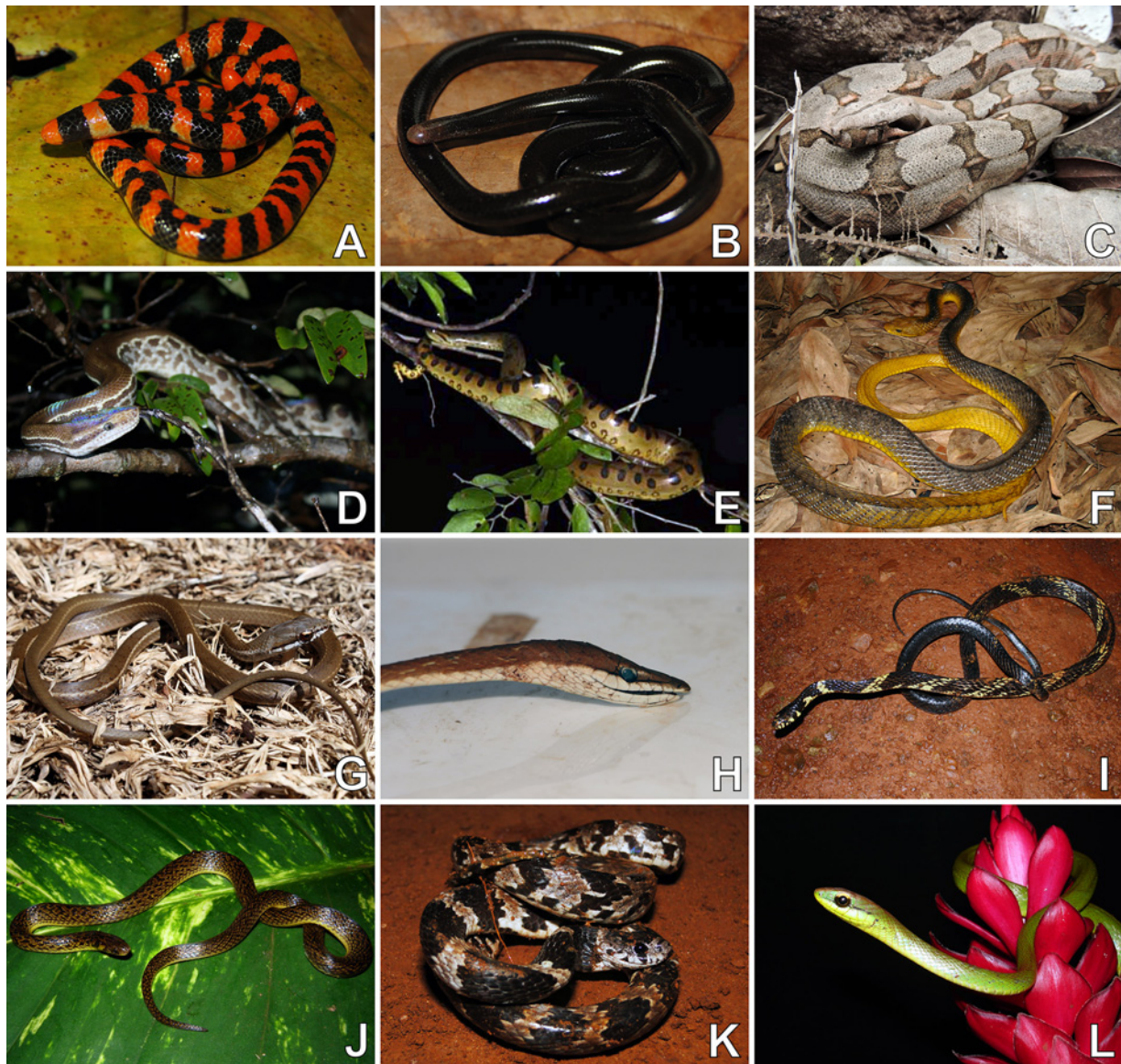


Fig. 7. Snake species recorded in the municipality of Niquelândia, northern Goiás state, central Brazil: *Anilius scytale* (A), *Liotyphlops cf. beui* (B), *Boa constrictor amarali* (C), *Epicrates crassus* (D), *Eunectes murinus* (E), *Drymarchon corais* (F), *Mastigodryas boddaerti* (G), *Oxybelis aeneus* (H), *Spilotes pullatus* (I), *Atractus pantostictus* (J), *Sibynomorphus mikanii* (K), *Philodryas olfersii* (L). Photos: Drummond L.O. (A, B, K), Assis T. (C), Guerra V. (D, G, I), Heming N.M. (E), Oda F.H. (F, H, J, L).

areas in Niquelândia (Uetanabaro et al. 2007; Morais et al. 2012; Ramalho et al. 2014; Santos et al. 2014; Silva et al. 2015), while other studies have reported higher richness against our results (Silva Jr. et al. 2005, 2009; Valdujo et al. 2009; Araujo & Almeida-Santos 2011). Nevertheless, as most species of reptiles, particularly snakes, tend to have low population densities and/or secretive habitats, the complete inventory of a given place demands a great amount of time and collection effort; consequently, it is highly possible that all above mentioned studies collected only a fraction of the total reptile richness of their study areas.

The reptile species richness in Niquelândia are probably underestimated considering that some species which are widely distributed in the Cerrado domain have not been recorded, such as the lizard species *Norops meridionalis*, the snake *Leptodeira annulata*, and the tortoises of the genus *Chelonoidis* (Vaz-Silva

et al. 2007; Morais et al. 2012; Guarnizo et al. 2015). Moreover, fossorial reptiles are expected to present a higher amount of species than actually found, including lizards of the genus *Bachia* and snakes of the genus *Typhlops*. Colli et al. (2002) suggested that only two sympatric species of amphisbaenians are expected to locally occur in Cerrado areas (such as our record); however, Strüssmann & Mott (2009) argued for a larger number (5–9) of sympatric species. Likewise, other aquatic reptiles recorded in nearby areas are expected to occur in the studied areas, such as snakes of the genus *Helicops* and *Hydrodynastes* (Ramalho et al. 2014; Silva Jr. et al. 2005).

Even though specimens of the dwarf caiman *Paleosuchus palpebrosus* can be found in anthropogenic areas, the construction of artificial pounds for human activities, such as mining, may be unfavorable for this species, differently from other crocodylians for which





Fig. 8. Snake species recorded in the municipality of Niquelândia, northern Goiás state, central Brazil. *Oxyrhopus trigeminus* (A), *Phimophis guerini* (B), *Erythrolamprus almadensis* (C), *Erythrolamprus poecilogyrus* (D), *Erythrolamprus reginae* (E), *Xenodon merremii* (F), *Xenopholis undulatus* (G), *Trilepida fuliginosa* (H), *Bothrops moojeni* (I), *Bothrops pauloensis* (J), *Crotalus durissus* (K). Photos: Drummond L.O. (A, E, H), Guerra V. (B, I, J), Oda F.H. (C, G), Ribeiro R. (D), Heming N.M. (K), Nunes A.V. (F).

impoundments allows the establishment of higher densities (Borteiro et al. 2008). Habitat requirements for *P. palpebrosus* in the Cerrado generally include closed-canopy areas, with springs and headwaters of fast-running streams, which tends to turn rapidly destroyed after human occupation (Carvalho Jr. & Batista 2013; Campos et al. 2013). Thus, habitat restoration in degraded areas of mining activity, mostly in gallery forests, may favor the maintenance of populations of the dwarf caiman.

Many reptile species found in this study are frequently associated with anthropogenic habitats, such as the exotic gekkonid *Hemidactylus mabouia* and the native lizards *Ameiva ameiva*, *Cercosaura ocellata*, *Iguana iguana*, *Tropidurus oreadicus*, as well as the snakes *Boa constrictor*, *Epicrates crassus*, *Chironius flavolineatus*, *Sibynomorphus mikanii*, and *Oxyrhopus trigeminus* (Carvalho & Nogueira 1998; Sousa et al.

2012; França & Braz 2013). Nevertheless, some species depend on remnants of pristine habitats, such as the fossorial reptiles *Amphisbaena anaemariae*, *Anilius scytale*, and *Trilepida fuliginosa*, reinforcing the importance of the recovering areas in the maintenance of local reptile diversity.

As observed in other studies encompassing the Cerrado domain, most species of lizards were found in open habitats (Colli et al. 2002; Nogueira et al. 2005), although some species were also associated, exclusively or not, with forest formations. Cerrado lizards are habitat specialists with abundance varying among habitats resulting in low overlap of species found in open and forested environments (Nogueira et al. 2009). Most lizards were observed in foraging activity or at rest while sunbathing during the day. In contrast, snakes were observed generally at low density during the day with many species exhibiting cryptic or secretive habits,

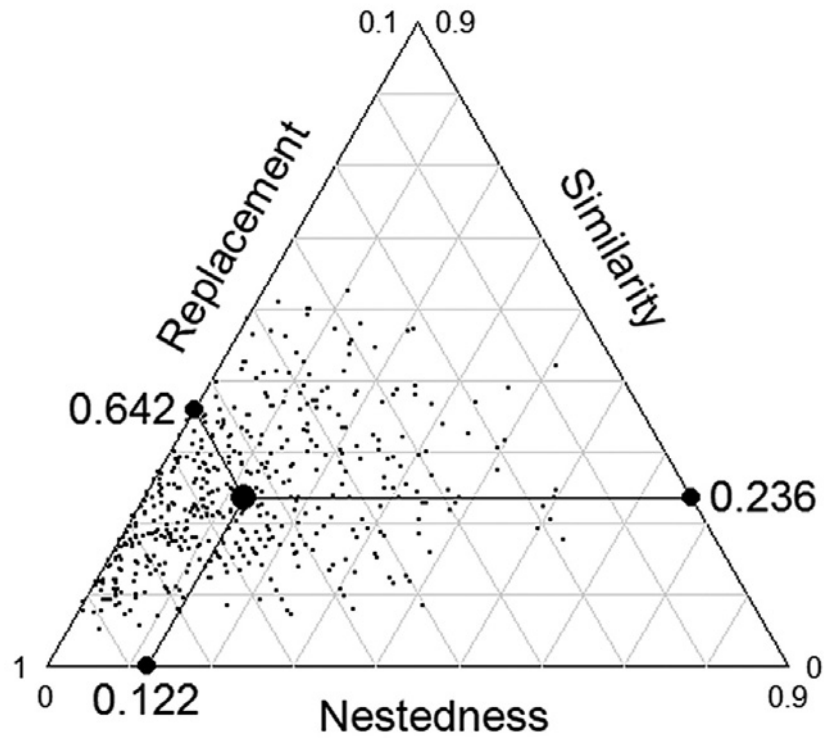


Fig. 9. Triangular plot of the relationships among the 496 pairs of sites selected along the Cerrado domain. Each point represents a pair of selected locations and its position is determined by a triplet of values from the  $S = (1 - \text{dissimilarity})$  (similarity), replacement and nestedness, determined from the Jaccard index (see Methods).

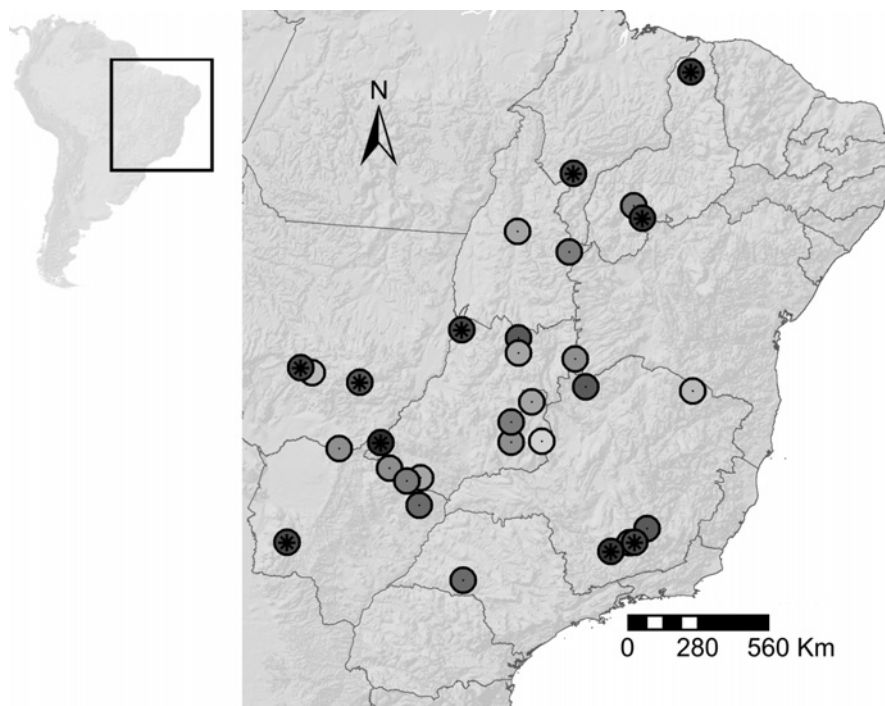


Fig. 10. Map of the selected locations showing the local contributions to beta diversity (LCBD) of the reptile communities. The gradient of light-dark grey is proportional to the LCBD values. \* = sites having significant LCBD at the 0.05 significance level (see Legendre & De Cáceres 2013).

which made them relatively difficult to sample (Sazima & Haddad 1992). Previous studies have recorded most snakes associated with forest formations (Ramalho et al. 2014) or with Cerrado physiognomies (Araujo et

al. 2010). In Niquelândia, we found most snakes associated with anthropic areas, which is probably related to the conversion of forest habitats into open areas and the simplification of the environment, leading



species to be more conspicuous and more easily observed.

Increase in beta diversity is broadly generated by geographical distance and environmental differences, where habitat heterogeneity is usually important and climate conditions explain the geographical variation in composition among regions (Melo et al. 2009). Therefore, low similarity in reptile composition, as found herein, is probably related to habitat heterogeneity among the sites within the Cerrado domain. Locations with unique reptile composition were found to be in contact areas with adjacent domains, whereas more homogeneous reptile composition is found mostly in areas of the central Cerrado, as reported for other animals and plants (Diniz-Filho et al. 2009; Françoso et al. 2016). Valdujo et al. (2013) found amphibian beta-diversity in the Cerrado to be related to environmental conditions of adjacent biomes and endemism patterns linked to phylogenetic niche conservatism within species groups which had invaded the Cerrado from adjacent domains. In turn, Nogueira et al. (2011) highlighted the importance of elevated savannas in the squamate Cerrado diversity, with higher levels of endemism in isolated plateaus. Therefore, ecotonal and tableland areas can be considered as relevant for effective reptile conservation because of their unique species composition.

## Conclusions

This study presents important data on the reptiles of areas recovering from mining activity, as well as adjacent pristine and anthropized areas in Upper Tocantins River, central Brazil. It presented high local species richness, reflecting the increase in habitat heterogeneity due to the recovery of vegetation cover associated with the topography reformation (Leite & Neves 2008), contributing to high diversity of reptiles, as observed to anurans in these same areas (Oda et al. 2009; Nomura et al. 2012). Further research efforts are important to reach an understanding on the ecological processes driving the restoration of the original reptile diversity in recovering areas. Thus, it is necessary have long-term studies carried out in order to recognize patterns of reptile species composition, population decline and/or local extinctions, as well as regarding the development of conservation strategies.

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