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The lizards along the road BR-319 in the Purus-Madeira interfluve, Brazilian Amazonia (Squamata, Lacertilia)

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Abstract. Here we present data on the identity and geographic distribution of lizard taxa in the Purus-Madeira interfluve, along the road BR-319 in Brazilian Amazonia. We sampled 10 modules located at least 40 kilometres from each other. Data collection was performed through active search on vegetation and leaf-litter along 250 m-long transects, and by occasional encounters. Twenty-five taxa from 16 genera and eight families were recorded. The present assessment reinforces the importance of this area to the conservation of Amazonian lizards and should be considered as basis for studies of ecology and environmental impact regarding lizard communities in this threatened region.

Keywords. Amazonas, Brazil, Inambari, Reptiles, Species richness

Introduction

Despite the relevance of the Amazon Forest to the world biodiversity, studies regarding the biodiversity of Amazonia are scattered in the literature, reflecting on incomplete knowledge about the patterns of distribution and identity of species (Magnusson et al., 2016). Since the 1990s, a huge portion of the Amazon Forest has been irreversibly deforested mainly due to farming and logging activities (Fearnside et al., 2009). For the year 2016, in comparison with 2015, it is possible to identify an advance of 29% (6,207 km²) of deforestation for the entire Brazilian Amazonia (INPE, 2016).

Squamate reptiles are, in general, vulnerable to environmental disturbances and degradation, making information about the distribution of these species essential to understand and conserve the Amazonian herpetofauna (Böhm et al., 2013). The richness of lizard species in the Brazilian Amazonia is estimated in 138 described species (Ribeiro-Júnior, 2015; Ribeiro-Júnior and Amaral, 2016). However, this number may be underestimated because most of the studies were performed on the proximity of large urban centres (Rodrigues and Ávila-Pires, 2005; Vitt et al., 2008; Turci and Bernarde, 2008; Ávila-Pires et al., 2018). Recent taxonomic assessments indicate high cryptic diversity in Amazonian species (e.g., Ávila-Pires and Hoogmoed, 2000; Peloso et al., 2011; Murphy and Jowers, 2013; Murphy et al., 2016; Ferrão et al., 2016; Oliveira et al., 2016; Melo-Sampaio et al., 2018), leading to the description of new species or changes in taxonomic status (e.g. Bergmann and Russell, 2007; Geurgas and Rodrigues, 2010; D'Angiolella et al., 2011).

The Purus-Madeira interfluve, where the road BR-319 was constructed during the decade of 1970, is a site of high biodiversity, both described and undescribed (Ferrão et al., 2017; Ortiz et al., 2018), located in an important endemism area called Inambari (Cracraft, 1985). It is estimated that most of this biodiversity is threatened by the construction and recent paving of part of the road, which crosses the region linking the city of Manaus, in the state of Amazonas, to the city of Porto Velho, in the state of Rondônia (Fearnside and Graça, 2006). Simulations to assess the impacts of the road construction associated with human settlements predicted a resulting deforestation of up to 5.4 million hectares by 2050, reinforcing the need of mitigating measures to avoid the loss of biological diversity

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(Maldonado et al., 2012). In the face of such prospect of increase in the frequency of anthropic disturbances and imminent loss of biodiversity, we sampled multiple standard units over a transect of 620 km in the Interfluve Purus-Madeira aiming to: 1) inventory the lizards (Squamata, Lacertilia); and 2) characterize the geographic distribution of the taxa within this interfluvial zone.

Materials and Methods

Study site.—The research was conducted along the road BR-319, which crosses the Purus-Madeira interfluve, distributed almost linearly over 620 km, from central Amazonia (municipality of Careiro da Várzea, state of Amazonas) to southwest Amazonia (municipality of Humaitá, state of Amazonas). The area has mainly a plane topography and the elevation ranges from 30 to 50 m. Approximately 80% of the area is composed of lowland ombrophilous dense forest, with occurrence of medium to large-sized trees and clean forest understory. Such formation is limited to high temperatures (25°C on average,) high rainfall (well distributed throughout the year), and the dry period varies from 0 to 60 days per year. In the southern region of our sample (near the municipality of Humaitá), the interfluve is formed by ombrophilous open forest and present more than 60 dry days per year (Maldonado et al., 2012).

We used 10 research modules installed along the BR-319 according to the RAPELD- Rapid Assessments and Long-term Ecological Research (in Portuguese, *Pesquisas Ecológicas de Longa Duração Associadas a Levantamentos Rápidos*) (Magnusson et al., 2005).

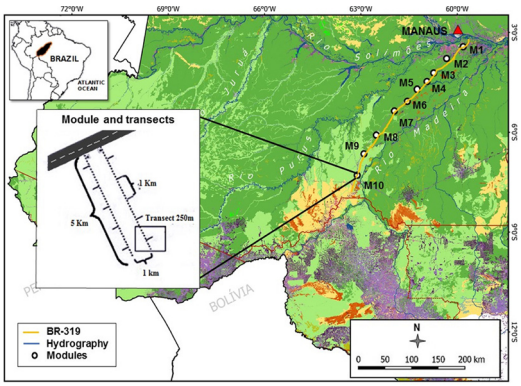

Figure 1. Location of the study area with the surveyed modules (M1–M10) along the road BR-319, state of Amazonas, northern Brazil, and schematic illustration of the modules from the RAPELD sampling system, composed by two 5 km-long tracks containing 5 terrestrial transects (250 meters long each).

These modules are part of a network of permanent standardized transects installed in the Amazon by *Programa de Pesquisa em Biodiversidade* (Biodiversity Research Program) of the Brazilian Science, Technology, Innovations and Communications Ministry (Magnusson et al., 2013). The 10 modules are located 40 to 100 kilometres from each other (Table 1) and are composed of two 5 km-long tracks (Figure 1). Each track contains 5 terrestrial transects (250 meters long) with standardized distance of one km between neighbouring transects. Each transect follows the contour line of the terrain,

Table 1. Location, geographic coordinates (Datum WGS 84) and elevation of survey modules (M1–10) installed along the road BR-319 in the Purus-Madeira interfluve, state of Amazonas, northern Brazil.

Location in highway	Geographic coordinates	Elevation
M1: Purupuru, BR-319 km 34	-3.2112°S, -59.5120°W	35 m
M2: Manaquiri, BR-319 km 100	-3.4122°S, -60.2062°W	42 m
M3: Taboca, BR-319 km 168	-4.1739°S, -60.4343°W	43 m
M4: Taquara, BR-319 km 220	-4.2234°S, -60.5655°W	47 m
M5: Igapó-açu, BR-319 km 260	-4.3634°S, -61.1501°W	52 m
M6: Orquestra, BR-319 km 300	-4.5922°S, -61.3347°W	48 m
M7: Rio Novo, BR-319 km 350	-5.1558°S, -61.5558°W	59 m
M8: Jarí, BR-319 km 450	-5.5726°S, -62.2920°W	70 m
M9: Aracá, BR-319 km 540	-6.3347°S, -62.5611°W	77 m
M10: Puruzinho, BR-319 km 620	-7.1210°S, -63.1306°W	49 m

minimising the edaphic variation within the transects. The coordinates were obtained through GPS Garmin GPSMAP 76CSx (Datum WGS 84).

Data Collection.—The lizard assemblage surveys lasted from October 2010 to September 2011. In order to maximize the taxa detection and to minimize false absences, we employed the visual transect census method using active search both in the vegetation and in the leaf-litter (Crump and Scott, 1994). In addition, we recorded occasional encounters along the transect displacement in the modules. The visual transect census consisted of inspecting the environment by looking for terrestrial, arboreal and semi-arboreal lizards throughout the 250 m of each transect. The active search in the litter consisted of rummaging the substrate (leaf litter, stems and organic matter remnants) along the transect. The sampling team consisted of one researcher and one assistant properly trained for lizard sampling. Due to the logistical restrictions faced in the region — difficulty of access to sections of the highway that are not paved and financial costs — four modules installed closer to the municipality of Manaus (M1, M2, M3, and M4) were sampled in all three campaigns, while the remaining modules were sampled just during the first campaign. Campaign I occurred between October 24 and December 5, 2010, with a total of 100 hours/observer and 312 km covered throughout the sampling modules; Campaign II occurred from January 9 to 24, 2011 with 40 hours/observer and 128 km of modules covered; Campaign III occurred from September 12 to 27, 2011, with 40 hours/observer and 135 km of modules covered. The active search in each transect had a duration of one hour. Considering the displacement between transects, the daily effort varied, but averaged eight hours of active search per day. The sampling was concluded after 75 days of fieldwork, totalling 180 hours/observer (360 sampling hours) in the transects, with a total displacement of 1,150 km within the modules, and a total of 1,234 km travelled when considering the distance between the base camps and the sampling modules. The captured specimens were killed with peritoneal injection of 10% lidocaine chloralhydrate, and fixed in 10% formaldehyde for 24 hours, subsequently transferred to 70% ethanol and deposited at the herpetological collection of the Instituto Nacional de Pesquisas da Amazônia (INPA-H) in the municipality of Manaus, state of Amazonas, Brazil. The identification of all taxa followed the taxonomic keys available in Peters and Donoso-Barros (1970), Ávila-Pires (1995), and Vitt et al. (2008). The collection licenses were granted by ICMBio/IBAMA under permits 25685 and 29069.

Results

Twenty- five taxa (including *Plica umbra* subspecies) of eight families and 16 genera were sampled along the 10 modules (Figure 2; Appendix 1). The family Gymnophthalmidae was represented by six taxa: *Arthrosaura reticulata* (O'Shaughnessy, 1881); *Cercosaura argulus* Peters, 1863; *Cercosaura ocellata* (Wagler, 1830); *Loxopholis osvaldoi* (Ávila-Pires, 1995); *Loxopholis percarinatum* (Müller, 1923); and *Tretioscincus agilis* (Ruthven, 1916). The family Dactyloidae was represented by five taxa: *Anolis fuscoauratus* D'Orbigny, 1837; *Anolis ortonii* Cope, 1868; *Anolis punctatus* Daudin, 1802; *Anolis tandai* Ávila-Pires, 1995; and *Anolis transversalis* Duméril, 1851. The family Teiidae was represented by four taxa: *Ameiva ameiva* (Linnaeus, 1758); *Kentropyx altamazonica* (Cope, 1876); *Kentropyx pelviceps* (Cope, 1868); and *Tupinambis cuzcoensis* Murphy, Jowers, Lehtinen, Charles, Colli, Peres, Hendry and Pyron, 2016. The family Sphaerodactylidae was represented by three taxa: *Chatogekko amazonicus* (Andersson, 1918); *Gonatodes hasemani* (Griffin, 1917); and *Gonatodes humeralis* (Guichenot, 1855). Tropiduridae was also represented by three taxa: *Plica umbra umbra* (Linnaeus, 1758); *Plica umbra ochrocollaris* Spix, 1825; and *Uranoscodon superciliosus* (Linnaeus, 1758). Scincidae was represented by two taxa: *Copeoglossum nigropunctatum* (Spix, 1825); and *Varzea bistriata* (Spix, 1825). The family Alopoglossidae was represented by one taxon: *Alopoglossus atriventris* Duellman, 1973. The family Phyllodactylidae also presented one taxon: *Thecadactylus solimoensis* Bergmann and Russell, 2007 (Table 2).

The locations showing the highest taxa richness were modules M1 with 15 taxa (60% of the taxa) and M2 with 13 taxa (52%), followed by M3 with 11 taxa (44%) and M10 with 10 taxa (40%), M4 with 9 taxa (36%), M5 with 7 taxa (28%), and modules M8 and M9 with 6 taxa each (24%) (Figure 3). The modules with the lowest number of species were M06 and M07 with five sampled taxa (20%). The module M10 was sampled only once, but some taxa were found only in this module: *Cercosaura ocellata, Gonatodes hasemani, Tretioscincus agilis,* and *Tupinambis cuzcoensis*. Two taxa (*Chatogekko amazonicus* and *Kentropyx altamazonica*) were recorded in all modules, whereas *Ameiva ameiva* was recorded in 9 out of 10 modules (Table 2).

Figure 2. Lizards recorded in the surveyed modules (M1–10) along the road BR-319 in the Purus-Madeira interfluve, state of Amazonas, northern Brazil. (A) *Anolis tandai* (male, INPA-H 33522); (B) *Anolis punctatus* (male, INPA-H 33691); (C) *Anolis fuscoauratus* (female, INPA-H 33549); (D) *Plica umbra ochrocollaris* (male, INPA-H 33736); (E) *Tupinambis cuzcoensis* (male, INPA-H 33739); (F) *Kentropyx pelviceps* (male, INPA-H 33708); (G) *Arthrosaura reticulata* (INPA-H 33543); (H) *Chatogekko amazonicus* (INPA-H 33584); (I) *Plica umbra umbra* (male, INPA-H 33021); (J) *Gonatodes humeralis* (male, INPA-H 33421); (K) *Ameiva ameiva* (male, INPA-H 33473); (L) *Anolis ortonii* (INPA-H 33462); (M) *Thecadactylus solimoensis* (INPA-H 33373); (N) *Copeoglossum nigropunctatum* (INPA-H 33592; (O) *Loxopholis percarinatum* (INPA-H 30374). Photos by Pedro H. Leitão, Albertina P. Lima, and Gabriela M. Peixoto.

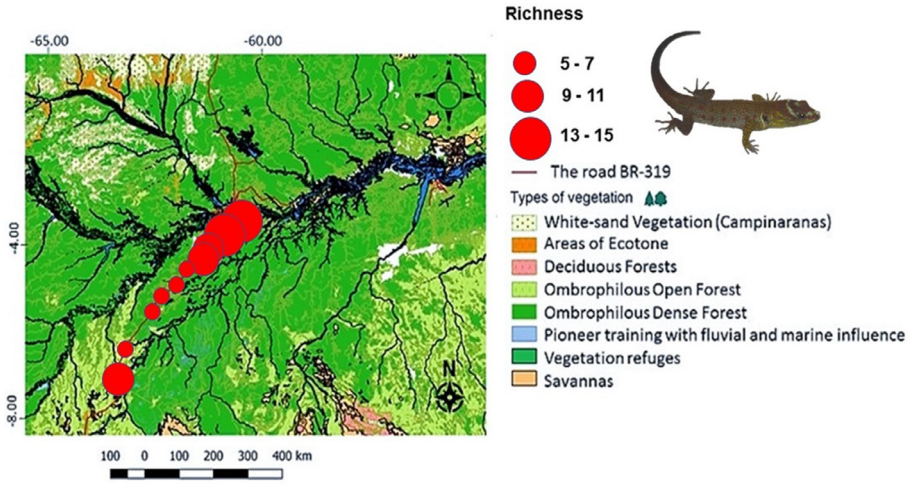

Figure 3. Richness of lizards recorded in the surveyed modules (M1–10) along the road BR-319 in the Purus-Madeira interfluve, state of Amazonas, northern Brazil.

Discussion

Variations in local species richness and composition in the Amazon Basin would rely on its configuration, which is a mosaic of distinct phytophysiognomical regions (Schietti et al., 2014). Such variations also result from the different geological ages and formations among distinct fractions of the basin, which leads to historical evolutionary differences among areas and, consequently, their biotas (Wesselingh et al., 2010; Ortiz et al., 2018). Structural complexity of the vegetation in the Madeira-Purus interfluve is strongly affected by groundwater and soil characteristics (Moulatlet et al., 2014; Schietti et al. 2014), which may also explain differences in faunal composition along the gradient (Marciente et al., 2015).

The number of taxa found in this study is consistent with other studies performed in Brazilian Amazonia which recorded a minimum local richness of 22 species and a maximum of 44 species of lizards per inventory area (Ávila-Pires et al., 2009; Magalhães-Silva et al., 2011; Prudente et al., 2013; Ribeiro-Júnior and Amaral, 2016). Studies in the Amazonian biome that showed higher species richness were carried out using complementary techniques such as pitfall traps, were conducted in environments with greater habitat heterogeneity including flooded and nonflooded forests, or considered seasonal variability (e.g. Waldez et al., 2013; Almeida et al., 2015). In relation to the richness of lizards by modules, we can associate the greater values of the modules M1–3 with the highest sampling efforts employed in these sites. However, module M4 was also sampled three times and showed fewer taxa. This suggests that the northernmost modules of the interfluve have richer lizard assemblages. Another relevant exception is module M10, which presented a richness (10 taxa) that resembles the richness found in M4 (nine taxa), although module M10 was sampled only once. This module is inserted within the open ombrophylous forest phytophysiognomy, unlike the other modules that are inserted within dense ombrophylous forest, and possibly has greater environmental heterogeneity, which may explain the presence of exclusive taxa in this module.

A study carried out along Purus-Madeira interfluve in five conservation units between November 2012 and November 2013 registered 26 species of lizards, distributed among 19 genera and eight families (Almeida et al., 2015). The broadest herpetological survey conducted in the region was the Environmental Impact Assessment (EIA) of Jirau and Santo Antônio Hydroelectric Power Plants in the state of Rondônia (upper Madeira river), with a larger number of species (n = 33) recorded (Lima et al., 2004). Among the sampled species, five were not observed in our study, despite the proximity of the areas: *Cnemidophorus* aff. *lemniscatus* Linnaeus, 1758; *Enyalioides laticeps* (Guichenot, 1855); *Enyalius leechii* (Boulenger, 1885); *Kentropyx calcarata* (Spix, 1825); and *Plica plica*

Table 2. Lizard taxa recorded in the surveyed modules (M1–10) installed along the road BR-319 in the Purus-Madeira interfluve, state of Amazonas, northern Brazil, and the distance sampled at each module during the three campaigns. The symbol "+" indicates the presence of the species and "-" indicates its absence.

Family/ Taxa	M 1	M 2	M 3	M 4	M 5	M 6	M 7	M 8	M 9	M 10
ALOPOGLOSSIDAE										
Alopoglossus atriventris (Duellman, 1973)	-	+	+	-	-	-	-	-	-	-
DACTYLOIDAE										
Anolis fuscoauratus D'Orbigny, 1837	+	+	+	+	+	-	+	+	-	+
Anolis ortonii Cope, 1868	-	-	+	-	-	-	-	-	-	-
Anolis punctatus Daudin, 1802	+	-	-	-	-	-	-	-	-	-
Anolis tandai Ávila-Pires, 1995	+	+	+	+	+	-	+	+	-	-
Anolis transversalis Duméril, 1851	-	-	+	-	-	-	-	-	-	-
GYMNOPHTHALMIDAE										
Arthrosaura reticulata (O'Shaughnessy, 1881)	+	-	-	-	-	-	-	-	-	-
Cercosaura argulus (Peters, 1863)	-	+	-	-	-	-	-	-	-	-
Cercosaura ocellata (Wagler, 1830)	-	-	-	-	-	-	-	-	-	+
Loxopholis osvaldoi Ávila-Pires, 1995	+	+	-	-	-	+	-	+	-	-
Loxopholis percarinatum Müller, 1923	-	+	-	+	+	-	-	-	-	-
Tretioscincus agilis (Ruthven, 1916)	-	-	-	-	-	-	-	-	-	+
PHYLLODACTYLIDAE										
Thecadactylus solimoensis Bergmann and Russell, 2007	+	-	-	-	-	-	-	-	-	+
SCINCIDAE										
Copeoglossum nigropunctatum (Spix, 1825)	+	-	+	+	-	+	-	-	-	-
Varzea bistriata (Spix, 1825)	+	-	-	-	-	-	-	-	-	-
SPHAERODACTYLIDAE										
Chatogekko amazonicus (Andersson, 1918)	+	+	+	+	+	+	+	+	+	+
Gonatodes hasemani (Griffin, 1917)	-	-	-	-	-	-	-	-	-	+
Gonatodes humeralis (Guichenot, 1855)	+	+	-	-	-	-	-	-	+	-
TEIIDAE										
Ameiva ameiva (Linnaeus, 1758)	+	+	+	+	+	-	+	+	+	+
Kentropyx altamazonica (Cope, 1876)	+	+	+	+	+	+	+	+	-	+
Kentropyx pelviceps (Cope, 1868)	+	+	+	+	+	-	-		+	-
Tupinambis cuzcoensis Murphy et al., 2016	-	-	-	-	-	-	-	-	-	+
TROPIDURIDAE										
Plica umbra ochrocollaris (Linnaeus, 1758)	+	+	-	-	-	-	-	-	+	+
Plica umbra umbra (Linnaeus, 1758)	-	-	+	+	-	+	-	-	-	-
Uranoscodon superciliosus (Linnaeus,1758)	+	+	-	-	-	-	-	-	+	-
First campaign (km)	27	31	33	27	27	39	36	30	32	30
Second campaign (km)	38	32	33	25	-	-	-	-	-	-
Third campaign (km)	36	31	39	29	-	-	-	-	-	-
Total distance sampled (km)	**101**	**94**	**105**	**81**	**27**	**39**	**36**	**30**	**32**	**30**

(Linnaeus,1758). During the EIA of the road BR-319 (UFAM/DNIT, 2009), 23 lizard species of 15 genera and six families were recorded, and just four of them were not sampled in our study: *Alopoglossus angulatus* (Linnaeus, 1758); *Iphisa elegans* Gray, 1851; *Kentropyx calcarata*; and *Ptychoglossus brevifrontalis* Boulenger, 1912. Except for *Kentropyx calcarata*, the absence of the above-mentioned species in our survey is probably

due to the active sampling method employed here (without use of pitfall and funnel traps), which is not adequate to detect species with fossorial or secretive habits (Andrade et al., 2013).

On the other hand, four species recorded in this study were not listed in the EIA conducted along the BR-319 (UFAM/DNIT, 2009): *Copeoglossum nigropunctatum*, *Leposoma osvaldoi, Thecadactylus solimoensis*, and *Varzea bistriata*. The sampling of the EIA was restricted to a section of the road (km 285 to km 615). In fact, the species *Thecadactylus solimoensis* and *Varzea bistriata* were previously recorded only for the lower Purus River, at Piagaçu-Purus Sustainable Development Reserve, which is located 84 km distant from the module 5 of our study (Waldez et al., 2013).

Regarding the record of *Plica umbra ochrocollaris*, it is known that *P. umbra* comprises more than one independent lineage, with distinct evolutionary units along different areas of endemism in the Amazon. This suggests that these lineages may represent distinct species, including multiple taxa within the Purus-Madeira interfluve (Carvalho et al., 2006; Oliveira et al., 2016).

Large body-sized species such as *Dracaena guianensis* (Daudin, 1802) and *Crocodilurus amazonicus* (Spix, 1825) were not observed in the present study, probably because they are associated to the environments of flooded forest (Almeida et al., 2015). Hence, the sampled environments along the road BR-319 are probably not suitable to these species, since most of the modules are normally installed in areas of plane topography and not subjected to flooding. Landscape management and conservation strategies require an understanding of species distributions. This understanding also includes predictions of species' distributions under anthropogenic impacts. These approaches are essential for the long-term maintenance of the forest and its biodiversity (Fearnside et al., 2009). Amazonian lizards are likely under threat because of human disturbance, given the pace of modification in the Amazon Basin and the lack of public policies for the effective conservation of biodiversity (Magnusson et al., 2018). The construction of roads in natural environments, such as BR-319, is an alarming scenario for biological conservation because it increases the wildlife mortality by roadkill (Brum et al., 2018) and it tends to favour the illegal colonization of the region, thus allowing the development of activities such as mining, illegal hunting, and land real estate speculation (Laurance and Balmford, 2013). These activities may negatively affect the local fauna, especially species that rapidly respond to changes in forest cover (Ferrão et al., 2016). In this context, this study complements the most recent list on the distribution of lizards in the Brazilian Amazon (Ribeiro-Júnior and Amaral, 2016) and it reinforces the importance of the Purus-Madeira interfluve for the conservation of Amazonian reptiles, a region whose biodiversity is rich, with great potential for new discoveries (De-França et al., 2011; Ferrão et al., 2016; De-Abreu et al., 2018). Finally, this list can be used as a basis for future ecological and environmental impact studies in Amazonian lizard assemblages.

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Appendix 1. Voucher specimens for the lizard taxa recorded in the surveyed modules (M1–10) along the road BR-319 in the Purus-Madeira interfluve, state of Amazonas, northern Brazil and deposited at the herpetological collection of the Instituto Nacional de Pesquisas da Amazônia (INPA-H).

Alopoglossidae: *Alopoglossus atriventris* (INPA-H 33600, 33601); **Dactyloidae:** *Anolis fuscoauratus* (INPA-H 33480, 33482, 33494, 33516, 33530, 33531, 33536); *Anolis ortonii* (INPA-H 33424, 33471, 33583, 33702)*; Anolis punctatus* (INPA-H 33368, 33371, 33519, 33547); *Anolis tandai* (INPA-H 33496, 33683, 33684, 33695, 33696, 33722)*; Anolis tranversalis* (INPA-H 33640, 33641, 33642, 33643); **Gymnophthalmidae:** *Arthrosaura reticulata* (INPA-H 33514, 33570, 33651, 33671, 33672)*; Cercosaura argulus* (INPA-H 33423, 33673, 33832)*; Cercosaura ocellata* (INPA-H 33389, 33430, 33438, 33470, 33534, 33543)*; Leposoma osvaldoi* (INPA-H 25664, 30375, 30376); *Leposoma percarinatum* (INPA-H 28245, 28248, 30374); *Tretioscincus agilis* (INPA-H 28265, 33435, 33436, 33568); **Phyllodactylidae***: Thecadactylus solimoensis* (INPA-H 33373, 33381, 33386, 33413, 33414, 33418, 33433); **Scincidae:** *Copeoglossum nigropunctatum* (INPA-H 33592, 33594, 33595, 33635, 33638, 33639); *Varzea bistriata* (INPA-H 33511, 33683, 33684, 33695, 33722); **Sphaerodactylidae:** *Chatogekko amazonicus* (INPA-H 33445, 33447, 33448, 33449, 33451, 33452, 33456, 33457, 33458, 33459, 33495, 33537, 33538, 33539)*; Gonatodes hasemani* (INPA-H 33834); *Gonatodes humeralis* (INPA-H 33403, 33404, 33443, 33576, 33612, 33613); **Teiidae:** *Ameiva ameiva* (INPA-H 33431, 33473, 33671); *Kentropyx altamazonica* (INPA-H 33730); *Kentropyx pelviceps* (INPA-H 33504, 33399, 33653); *Tupinambis cuscoensis* (INPA-H 33739); **Tropiduridae:** *Plica umbra umbra* (INPA-H 33658); *Plica umbra ochrocollaris* (INPA-H 33474, 33656, 33736); *Uranoscodon superciliosus* (INPA-H 33604, 33677, 33678).

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