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Review Article

Distribution and conservation status of amphibian and reptile species in the Lacandona rainforest, Mexico: an update after 20 years of research

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Abstract

Mexico has one of the richest tropical forests, but is also one of the most deforested in Mesoamerica. Species lists updates and accurate information on the geographic distribution of species are necessary for baseline studies in ecology and conservation of these sites. Here, we present an updated list of the diversity of amphibians and reptiles in the Lacandona region, and actualized information on their distribution and conservation status. Although some studies have discussed the amphibians and reptiles of the Lacandona, most herpetological lists came from the northern part of the region, and there are no confirmed records for many of the species assumed to live in the region. After reviewing databases of scientific collections and published herpetological lists, and adding new information from our 2007 to 2013 inventories of the southeastern Lacandona rainforest, we recorded 124 species (89 reptiles and 35 amphibians) for the region. Nine amphibians (25.7%) and 2 (2.2%) reptiles are endemic to the Mayan forest (from the Lacandona, in Mexico, to the Mayan Mountains in Belize). Four amphibians and three reptiles appeared to be restricted to the Montes Azules Biosphere Reserve, suggesting that they are particularly vulnerable to habitat loss and degradation. On average, the region shares less than 60% of the species with neighboring Mexican tropical forests (e.g., Las Choapas region and Los Tuxtlas, Calakmul, and Sian-Ka'an Biosphere Reserves). Of the herpetofauna evaluated, the Mexican government threatened species list (NOM 059) indicates that seven species (20%) are under a risk category, while the IUCN indicates that only seven species (10.1%) are at risk. Our findings indicate that Lacandona is of great importance for the conservation of the Mesoamerican herpetofauna. Nevertheless, increasing deforestation levels add further uncertainties to the maintenance of amphibians and reptiles among other vertebrates in the region.

Keywords: herpetofauna · Mesoamerican Biological Corridor · Montes Azules Biosphere Reserve · species richness

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Introduction

Biotic surveys and information on geographic distribution of the species are essential for biogeographic studies, and can provide a baseline for ecological and biodiversity conservation studies as a whole [1, 2]. This information is particularly important for amphibians and reptiles, as they are among the most threatened vertebrate animals in the world [3,4]. It is critical to improve herpetological surveys within wet tropical forests, the most species-rich biome on Earth [5], but at the same time, the most deforested and fragmented biome worldwide [6]. Deforestation and fragmentation are among the most important human-induced threatening factors for amphibians and reptiles [3, 4, 7], and monitoring habitats under degradation is urgent to assess real threats on species of these groups.

During recent decades, declines in the net rate of forest loss have been reported for some Neotropical countries (e.g., Mexico, Costa Rica, Panama, Puerto Rico; [6]), but deforestation in highly diverse tropical wet forests is still increasing [8]. This is particularly evident in Mexico, where wet tropical forests showed a net loss of 7,647 km^2 between 2000 and 2010 [8]. The Lancandona region has the largest rainforest remnant in Mexico, and one of the most important in Mesoamerica [9]. Although some large protected areas have been established within the region, including the Montes Azules Biosphere Reserve (ca. 331,000 ha), the Lacantún Biosphere Reserve (61,874 ha), the Communal Reserve Sierra La Cojolita (42,000 ha), several other Flora and Fauna Protection Areas (e.g., Chan-Kin, Metzabok, and Naha) and Natural Monuments (Bonampak and Yaxchilán), it has suffered a particularly high annual deforestation rate over the last four decades, particularly in the Marqués de Comillas and Ocosingo municipalities where 2.1% per year of the forest was lost between 1990 and 2010 [10]. Contemporaneous human colonization and expansion of the agriculture started in the late 1950´s, and nowadays, with a population over 10,000 people [11], only about 31% of the original old-growth forest remains outside the protected areas [10,12].

The Lacandona rainforest is highly diverse in terms of faunal species richness, with at least 112 species of mammals and 345 species of birds among vertebrates [13, 14]. The herpetofauna in the region is also highly diverse, but the total number of species is still uncertain. Although

hepetofaunal studies in the region started in the first half of the twentieth-century with Smith and Taylor expeditions [15], the first formal species list was published in 1992 [16], indicating a species richness of 23 amphibian and 54 reptile species for the region. Other complementary local studies have reported lower numbers of species, e.g., 14 amphibians and 41 reptiles for the Yaxchilán area [17]. Most species lists are preliminary, and focus on the northern part of the region, and many species were simply considered as “possibly present in the region" [16, 17] with no observation, photograph or voucher specimen available to certify them.

Here, we provide a comprehensive herpetofaunal survey in the Lacandona region to assess current composition, habitat type, distribution and conservation status of the amphibian and reptile species. Our study was largely based on four years of field work in the less surveyed southern portion of the Lacandona region, intensive literature review, and databases from scientific collections, noting the uniqueness of the herpetofauna composition of the Lacandona region compared to other neighboring tropical forest areas in Mexico and Guatemala.

Methods

Study Area

The Lacandona region is located in the southern part of Chiapas, Mexico (100 to 1,500 m elevation; Fig. 1). The region has an extension of 13,000 km^2, bordered to the north by the Mexican state of Tabasco and the Chiapas highlands, and to the south and east by Guatemala; Palenque National Park represents the northernmost limit of the region [18]. The Lacandona rainforest represents the westernmost part of the Mayan forest, which extends through Guatemala to the Belize Mayan Mountains, and north to the middle portion of the Yucatán Peninsula. Altogether it represents the largest forested area in Mesoamerica [19]. Several vegetation types comprise the Mayan forest. In the northern part, the Yucatán Peninsula (Calakmul and Sian Ka´an in Mexico) and northern Petén (in Guatemala), the vegetation is tropical seasonal dry forest (TDF) and evergreen tropical wet forests (TWF) in southern Petén, Cobán and Alta Verapaz (Guatemala); Lacandona (Mexico) and the Mayan Mountains (in Belize) the vegetation is tropical moist forests (TMF) and tropical wet forests (TWF; Table 1, [20]).

Herpetological inventories

Surveys were focused on low (< 500 m elevation) tropical rainforest areas, with a hot and humid climate (e.g., mean annual precipitation and temperature of 2,874 mm and 25 °C, respectively; [18]), along two adjacent areas separated by the Lacantún river: the Marqués de Comillas region (MCR) and the Montes Azules Biosphere Reserve (MABR), located in the southeastern Lacandona region at approximately 16° 04’ N; 90° 45’ W, with an altitude range of 100–500 m elevation (Fig. 1). In MCR, approximately 31% of the forest extends over different-sized forest fragments (< 1 to > 1,500 ha), surrounded by secondary forests, pastures, and agricultural lands [12]. The MABR is a fully preserved old growth natural forest [18].

Inventories were conducted during 2007 (February, April, July, September, November), 2008 (January, March, July), 2010 (July, October), 2011 (March and August), 2012 (May and June) and 2013 (February) as part of a M.Sc. thesis [21] and a Ph.D. thesis (O. Hernández-Ordóñez, unpublished data). In MCR, inventories were done in all available landscape elements in the region, including areas of continuous old-growth forest, old-growth forest patches, secondary forests, crops, bean fields, cocoa plantations, pastures, rivers and streams, human settlements,

and roads. We used multiple sampling techniques, including visual encounter surveys, acoustic encounter surveys, drift fences, pitfall traps, and boat tours through the Lacantún river (see details in [22-24]). We also included roadkill records and those of species found during fieldwork of other research projects carried out in the region. All collected specimens were sampled for DNA sequence, carefully prepared and shelved in the Colección Nacional de Anfibios y Reptiles, Instituto de Biología, UNAM.

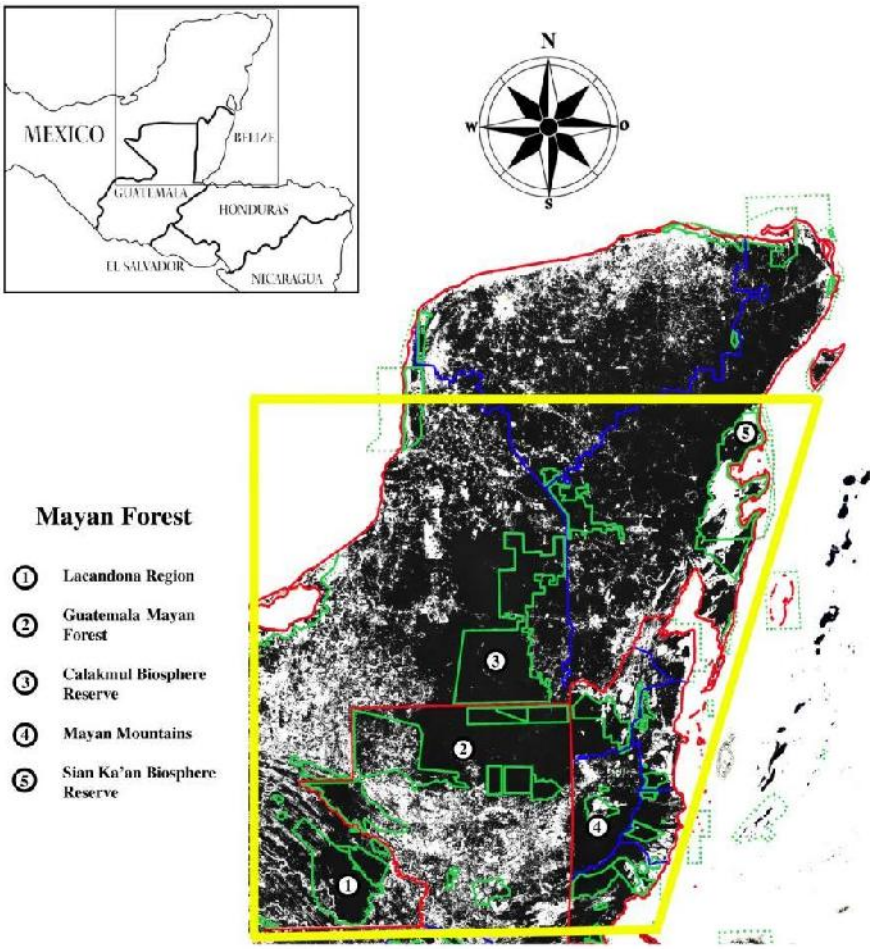

Fig. 1. Location of the Lacandona region (1) within the Mayan Forest (yellow square), indicating mayor Mayan Forest regions as nominated in each country (Belize, Guatemala, and Mexico). Country limits (in red), province limits (in blue) and main Natural Protected Areas (in green).

Species list of amphibians and reptiles

To update the list of amphibians and reptiles in the Lacandona rainforest, we reviewed all publications and range distribution notes from the region ([15-17, 25-33]; Fig. 2). We also consulted databases of the Colección Nacional de Anfibios y Reptiles (CNAR) of the Instituto de

Biología and the Museo de Zoología (Facultad de Ciencias), both at the Universidad Nacional Autónoma de México (Mexico City), and the Global Biodiversity Information Facility and HerpNet databases. We considered only the records from specimens shelved in scientific collections, with a catalog name and number.

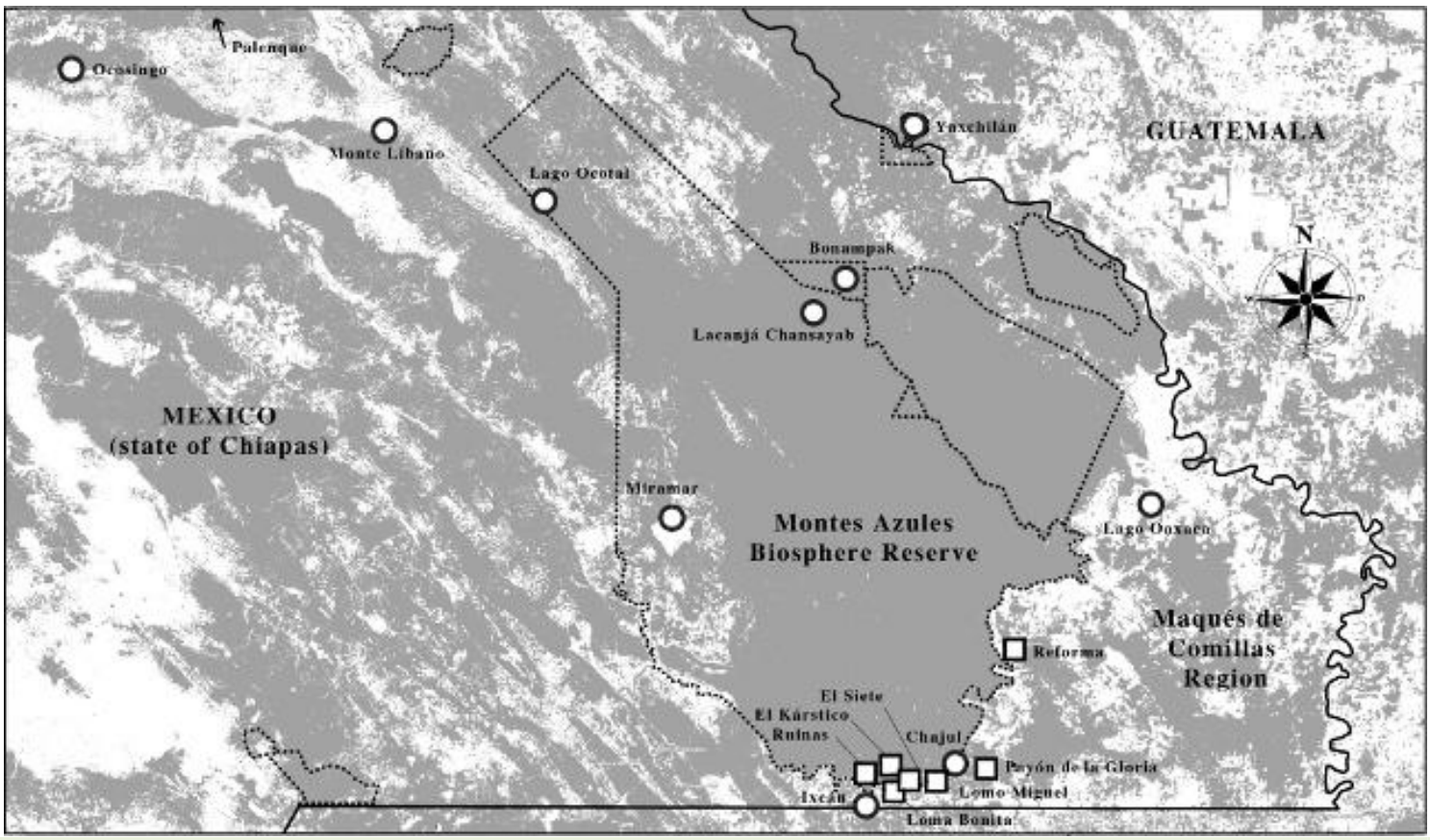

Fig. 2.Location of previous (circles) and new (squares) amphibian and reptile collecting sites within the Lacandona region. Forested areas are in gray and non-forested areas are in white.

Conservation status, geographic distribution, and habitat use

To assess the habitat used by each species, we considered only our herpetological surveys in the southeastern area of the Lacandona region. The geographic distribution of each species was evaluated based on information from different publications [15, 34-38]. Finally, we reviewed the conservation status and population trends of each species reported by the Mexican government threatened species list (NOM 059; [39]) and the IUCN Red List of Threatened Species [36].

Comparison with other Neotropical forests

To assess the importance of the Lacandona rainforest for the conservation of amphibians and reptiles, we compared the species richness and composition of amphibians and reptiles in this region with those found in other neighboring and well-studied Neotropical forests (Fig. 3; Table 1). Because we do not have data on the abundance of individuals within each study site, we based our comparisons on the Jaccard similarity index, which is based on presence/absence data [40].

The analysis includes all published species lists from the Guatemalan Mayan Forest [15, 34], the Calakmul [15, 41-44] and Sian-Ka'an Biosphere Reserves [15, 45, 46] in the Yucatán peninsula, farther sites such as Los Tuxtlas [47-49] and El Ocote Biosphere Reserves [50-52], and a well-known, not preserved area in Las Choapas region (southern Veracruz [53-55]. In all these comparisons, we considered only species reported for lowland tropical forests (0-500 m elevation). In general, Los Tuxtlas and Las Choapas, used as comparison sites, have tropical wet forests (with annual precipitation > 2,000 mm); and El Ocote has tropical dry forest (with annual precipitation < 2,000 mm) and tropical moist forest (with annual precipitation 2,000–2,800 mm; Table 1).

Results

Updated inventories

Our research, including our herpetological surveys and revision of scientific collection databases and published herpetological lists, revealed a total of 35 species of amphibians and 89 species of reptiles for the Lacandona rainforest (Table 1; Appendix 1). Among amphibians, the anurans had a high number of species (30 species), followed by salamanders (four species), and caecilians (one species). Squamates was the richest group among reptiles, with 51 species of snakes and 29 species of lizards, followed by seven turtles and two crocodiles (Table 1). We also found evidence for the probable occurrence of five additional species of amphibians and 16 species of reptiles based on the extrapolation of species distributed in the Guatemalan Mayan forest, as suggested by Lazcano-Barrero et al. [16], Lee [15] and Campbell [34]; (Table 2).

Table 1. Number of species of amphibians and reptiles in different protected tropical regions from Mexico (M) and Guatemala (G).

Regions	Amphibians			Total	SS (%)[a]	Reptiles				Total	SS (%)[a]	Vegetation type[b]	Annual precipitation (mm)
	Caecilians	Salamanders	Frogs			Lizards	Snakes	Turtles	Crocodiles				
Lacandona (M)	1	4	30	35	-	29	51	7	2	89	-	TMF	2,226
Calakmul (M)	0	2	18	20	51.3	26	38	8	1	73	48.1	TDF	1,076
El Ocote (M)	1	5	24	30	46.6	21	27	3	1	52	41.4	TDF and TMF	1, 200-2,500
Las Choapas (M)	1	2	19	22	48.7	21	27	7	1	56	44.4	TWF	3,500-4,500
Los Tuxtlas (M)	1	5	32	39	54.1	33	63	9	1	106	56.6	TWF	3,500
Mayan Forest (G)	2	6	32	40	81	35	52	9	1	97	75.8	TDF to TWF	1,000-3,000
Sian Ka'an (M)	0	2	19	21	50	28	43	6	1	78	45.6	TDF	1,300

[a]Percentage of shared species with the Lacandona rainforest (based on the Jaccard index of similitude).

[b] Following Gentry [20] , we grouped forest types into evergreen tropical wet forests (TWF, >2,800 mm rain/year), seasonal tropical moist forests (TMF: 2,000–2,800 mm rain/year) and seasonal tropical dry forests (TDF: < 2,000 mm rain/year).

Geographic distribution and habitat use

Overall, 25.7% of amphibians are endemic to the Mayan forest region (Appendix 1). Most amphibians (14 species, 40%) are widely distributed, ranging from southeastern Mexico to parts of Mesoamerica (Appendix 1). Moreover, 10 species (27.7%) are distributed from Mexico to northern South America, and seven species have Nearctic affinities. Endemic species (25%) are restricted to the Mayan forest, including southeastern Mexico, Guatemala and Belize: West Forest Caecilian (*Gymnopis syntrema*), Müller Mushroom-tongued Salamander (*Bolitoglossa mulleri*), Central American Worm Salamander (*Oedipina elongata*), Bromeliad Treefrog (*Bromeliohyla bromeliacia*), Yucatecan Casque-headed Treefrog (*Triprion petasatus*), Campbell's Rainforest Toad

(*Incilius campbelli*), Huge-crested Toad (*Incilius macrocristatus*), Broad-headed Rainfrog (*Craugastor laticeps*), and Palenque Robber Frog (*Craugastor palenque*), with a distributional range of less than 20,000 km^2. Similarly, most reptiles (45 species, 50.5%) are distributed from Mexico to northern South America, 42 species (47.1%) range from southeastern Mexico to parts of Mesoamerica, and two species (2.2%), Schwartze's Skink (*Mesoscincus schwartzei*) and Faded Black-striped Snake (*Coniophanes schmidti*), are restricted to southeast Mexico, Guatemala, Belize, and northern Honduras (Appendix 1).

Table 2. Additional species that have been suggested to be present in the Lacandona rainforest, Mexico, based on previous studies.

Class	Order	Family	Species	Common name	References[a]
Amphibia	Gymnophiona	Dermophiidae	*Dermophis mexicanus*	Mexican Caecilian	1, 2
	Urodela	Plethodontidae	*Bolitoglossa dofleini*	Doflein's Salamander	1
	Anura	Hylidae	*Ptychohyla euthysanota*	Cloud Forest Stream Frog	1
		Craugastoridae	*Craugastor chac*	Chac's Rainfrog	1,2
			C. psephosypharus	Warty Forestfrog	2
Reptilia	Squamata	Phrynosomatidae	*Sceloporus chrysostictus*	Yellow-spotted Spiny Lizard	3
		Polychrotidae	*Anolis petersi*	Peters's Anole	1
		Xenosauridae	*Xenosaurus grandis*	Knob-scaled Lizard	1
		Teidae	*Aspidoscelis angusticeps*	Yucatán Whiptail	3
		Xantusidae	*Lepidophyma mayae*	Mayan Tropical Night Lizard	2
		Leptotyphlopidae	*Epictia goudotii*	Black Threadsnake	1
		Typhlopidae	*Typhlops tenuis*	Coffee Blindsnake	1
		Colubridae	*Dendrophidion nuchale*	Peters's Forest Racer	3
			D. vinitor	Barred Forest Racer	1
			Ficimia publia	Blotched Hook-nosed Snake	1, 4
			Coluber mentovarius	Neotropical Whipsnake	1
			Conophis vittatus	Striped Road Guarder	3
			Storeria dekayi	Dekay's Brownsnake	2, 3
			Thamnophis proximus	Western Ribbonsnake	2
	Testudines	Kinosternidae	*Claudius angustatus*	Narrow-bridged Musk Turtle	1, 4
			Kinosternon scorpioides	Scorpion Mud Turtle	4

[a]References: 1) Lazcano-Barrero et al. [16] ; 2) Lee [15]; 3) Campbell [33]; 4) Ferreira-García and Canseco-Márquez [17].

Most species (75%; 31 amphibians and 62 reptiles) were recorded in our herpetological surveys in the southeastern part of the Lacandona rainforest (Appendix 1). Of these, 33 out of 93 species (35.4%) were recorded in old-grown forest within the Montes Azules Biosphere Reserve (MABR)

and neighboring forest patches (Appendix 1). Only seven species (7.5%), *Gymnopis syntrema,* Mexican Mushroom-tongued Salamander (*Bolitoglossa Mexicana*), Blue-spotted Mexican Treefrog (*Smilisca cyanosticta*), Alfred's Rainfrog (*Craugastor alfredi*), Spotted Dwarf Gecko (*Sphaerodactylus millepunctatus*), Big-headed Anole (*Anolis capito*), and Calico False Coral Snake (*Oxyrhopus petola*) appeared to be restricted to the continuous forest in the MARB, whereas 24 species (25.8%) were recorded in all habitat types, including old-growth forest, forest fragments, secondary forests, pastures, croplands, and human settlements (Appendix 1).

Comparison with other neighboring tropical forests

The herpetofauna diversity found in the Lacandona rainforest (125 species) is notably richer than that recorded in other neighboring tropical regions in Mexico (Las Choapas, El Ocote, Calakmul, and Sian-Ka'an), but poorer than others (Los Tuxtlas in Mexico, and the Guatemalan Mayan forest; Table 1). We found important differences between the composition of evergreen tropical wet forests (Los Tuxlas, Las Choapas, and El Ocote) and seasonal tropical dry forests (Calakmul and Sian-Ka'an; Fig. 3). Both amphibian and reptile assemblages of the Lacandona region were very similar to those found in the Guatemalan Mayan forest, with 81% of shared species in the case of amphibians, and 75.8% for reptiles (Fig. 3). These two rainforests shared 54% of the species with the Los Tuxtlas rainforest. However, neighboring tropical dry forests were very similar to each other, only sharing between 50% and 51% of the amphibian species and between 46% and 48% of the reptile species with the Lacandona rainforest (Fig. 3).

Conservation status and population trends

Mexican government threatened species list (NOM 059; [39]) considers that eight species of amphibians (22.8%) and 24 species of reptiles (26.9%) are subject to "Special protection," eight species of reptiles (9%) are "Threatened", and one species (1%) is "Endangered" (Appendix 1). This list, however, does not address species not considered threatened, or lacking ecological data.

All amphibian species recorded from the Lacandona rainforest have been evaluated by the IUCN [36]. Compared to NOM 059 list, the IUCN lists only one species of amphibian as "Endangered;" four as "Vulnerable;" and, three as "Near threatened" (Appendix 1). The remaining 25 species are considered of "Least Concern" and two species with "Data deficient" (Appendix 1). For reptiles, the IUCN has evaluated only the conservation status of 34 species (38.2% of the species reported for the Lacandona region). Only one species is classified as "Critically Endangered;" one as "Vulnerable," and five as "Near threatened." The remaining 27 species are of "Least Concern" (Appendix 1).

Considering all species recorded for the Lacandona, the IUCN identifies 12 amphibian species (34.3%) with population sizes decreasing, 16 species (45.7%) with stable populations, three species (8.6%) with increasing population sizes, and four species (11.4%) with unknown population trends. Within reptiles, most of the 34 species evaluated by IUCN (76%) have stable populations, and only one species (3%) has its population increasing, four (12%) have decreasing trends, and there is not enough information on the population trends of three species (9%; Appendix 1).

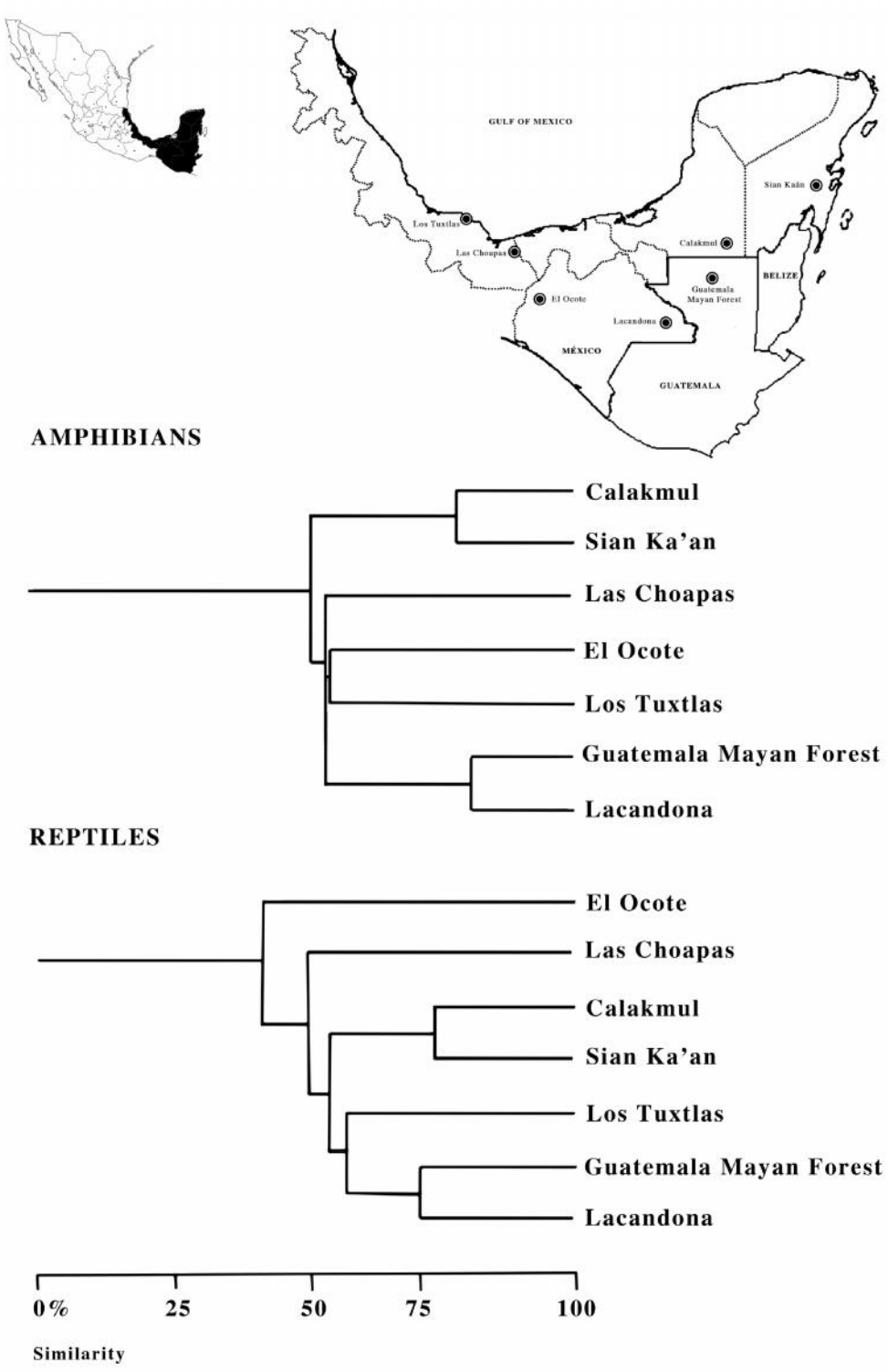

Fig. 3. Percentage of shared species (Jaccard index) of amphibians and reptiles between different tropical forests in southeastern Mexico and the Guatemala Mayan Forest.

Discussion

The number of amphibian and reptile species found in the Lacandona rainforest is particularly high (124 species; Table 1) and only the Los Tuxtlas rainforest (Veracruz, Mexico) and the Guatemalan Maya forest showed higher species richness (145 and 137 species, respectively). The Lacandona region is therefore one of the most species-rich Mexican forests in terms of herpetofauna.

It is particularly interesting that almost 25% of the amphibian species and 2% of the reptile species are endemic to the Lacandona and neighboring areas, and that Lacandona shares less than 60% of the species with neighboring Mexican tropical forests (Fig. 3). These results highlight the relevance of this region for the conservation of amphibians and reptiles. The Lacandona rainforest covers only 0.66% of the Mexican continental territory (about 2,000,000 km^2), but contains approximately 9.4% and 11% of the total number of Mexican amphibian and reptile species diversity, respectively [32, 37, 56]. These figures are of particular importance considering that Mexico is the second and fifth country in the world in numbers of reptile and amphibian species, respectively [57].

Climatic and biogeographic factors may explain differences in species composition between the Lacandona and other Mexican tropical forests. From a climatic point of view, in the northwestern part of the Mayan forest (Calakmul and Sian Ka'an) the vegetation is dominated by seasonal forests with less rainfall and humidity levels, and soils with very low water retention capacity [58]. These conditions may cause the absence of some amphibians as *Gymnopis syntrema, Bolitoglossa mexicana*, *B. mulleri*, *Oedipina elongata*, *Craugastor alfredi*, *C. laticeps*, *C. palenque*, (Fleischmann's Glass Frog) *Hyalinobatrachium fleischmanni*, *Incilius campbelli*, *Smilisca cyanosticta*) and reptiles as *Anolis capito*, (Lesser Scaly Anole) *A. uniformis*, (Common Green Iguana) *Iguana iguana*, (Rusty-headed Snake) *Amastridium sapperi*, *Oxyrhopus petola,* (Tabasco Mud Turtle) *Kinosternon acutum*, (Central American River Turtle) *Dermatemys mawii*, (Snapping Turtle) *Chelydra serpentina*, which usually inhabit more humid forests or need the presence of rivers and streams [15, 34]

Biogeographically, neighboring tropical forests Los Tuxtlas, Las Choapas, and El Ocote are part of the Veracruzan herpetofaunistic province [59]. This province shows endemic species of amphibians as San Martin Worm Salamander (*Pseudoeurycea orchimelas*), Broad-footed Salamander (*Bolitoglossa platydactyla*), Berkenbusch's Stream Frog (*Craugastor berkenbuschii*), Volcán San Martín Rainfrog (*C. vulcani*) and Mountain Toad (*Incilius cavifrons*) and reptiles as Chiszar's Arboreal Alligator Lizard (*Abronia chiszari*), Pajapan Tropical Night Lizard (*Lepidophyma pajapanensis*) and Tuxtla Tropical Night Lizard (*L. tuxtlae;* [49]) that are not present in the Lacandona region. The Lacandona region is more strongly influenced by the El Péten herpetofaunistic province [59], which includes the Guatemala Mayan forest, explaining why the Lacandona region shares up to 80% of species with the Guatemala Mayan forest (Fig. 3). The Lacandona region itself does not have any endemic species that is not shared with the Guatemala Mayan forest. Although five amphibians species *Gymnopis syntrema*, *Bolitoglossa mulleri*, *Oedipina elongata*, *Incilius campbelli*, and *Craugastor palenque* and two reptiles Eyelash Palm-Pitviper (*Bothriechis schlegelii*) and Rainforest Hog-nosed Pit Viper (*Porthidium nasutum*) are not endemic to Mexico, within the country their distribution is restricted to the Lacandona region [15, 35, 36]. The Mexican government considered them as part of its species protection policies. This

is particularly important to prevent their extinction, considering the strong deforestation rates that Guatemala is facing [8, 60].

The Mexican government threatened species list (NOM 059) considers only seven of the 89 species of reptiles in the Lacandona region to be high risk (either threatened or endangered), but not a single amphibian is listed. In contrast the IUCN considered in the high-risk categories (vulnerable, endangered and critically endangered) five amphibians and two reptiles. Strikingly, of all listed species, only the Central American River Turtle (*Dermatemys mawii*) coincides in both lists. Among amphibians *Craugastor laticeps,* listed as near threatened by IUCN, is on special protection according to the NOM 059, as are the lizard Rozella's Canopy Lizard (*Celestus rozellae*), the turtle *Kinosternon acutum*, and the Morelet's crocodile (*Crocodylus moreletii*) among reptiles. The Mexican Giant Musk Turtle (*Staurotypus triporcatus*), considered near threatened by IUCN, is not listed in the NOM 059.

Some species like *Gymnopis syntrema* recently recorded for Mexico [32], *Bolitoglossa mulleri* and *Craugastor palenque* are marginally distributed in Mexico, although their distribution range extends into Central America. These species tend not to be included in any risk category by Mexican standards, because they are not endemic. However, we consider that every country has the obligation to take care of its biota, independently of the species endemicity or distribution range. Local evaluations therefore need to consider only data of local populations. Preserving these species within country boundaries will provide additional local protection to every species worldwide. Four amphibian and three reptile species endemic to the Mayan forest appeared to be restricted to the Montes Azules Biosphere Reserve, suggesting that they can be particularly vulnerable to habitat loss and degradation.

The major threats affecting amphibian and reptile diversity are habitat loss and forest degradation [3, 4]. Within the Mayan forest, most amphibian and reptile species inhabit the evergreen wet forest along the Lacandona rainforest, the southern portion of the Guatemelan Mayan forest, and the southern Maya mountains in Belize [61, 62] (see [15, 34]; Table 1). The Mayan forest is considered one of the largest tropical forests worldwide [19] and a diversity hot spot [63]. Unfortunately, during recent decades the evergreen wet forests have been extremely fragmented and deforested [8, 60]. During the last four decades the Marqués de Comillas region in the Lacandona area (Fig. 2) has lost about 69% of its original forest cover, mainly to establish cattle ranches and agricultural lands [10]. In this scenario, the long-term conservation of amphibians and reptiles diversity in the Lacandona and Mayan forests is uncertain. Severe habitat modification caused by habitat degradation, fragmentation or habitat loss, will affect more amphibian and reptile species than any other vertebrate group. As ectotherms, their daily activity and fitness directly depend on environmental conditions [64, 65], and drastic shifts in environmental conditions caused by habitat modification could alter significantly their reproduction and survival performance [3, 66, 67]. Contrary to large mammals, bats, and birds, the low vagility of amphibians and reptiles will constrain their movements to other sites after habitat modification.

Synergic negative effects on the herpetofauna could emerge from global climate change and forest fragmentation [68]. Increasing environmental temperature and decreasing rainfall could be especially critical for the herpetofauna in deforested areas and small forest fragments. The low

dispersal capabilities of amphibians and reptiles make their movements between fragments very limited, preventing movement from unfavorable to favorable habitats [66, 67]. Although vegetation corridors could allow these species to move between habitats [68], the spatial configuration and functionality of such corridors needs to be studied.

Amphibians and reptiles face other important threats in fragmented landscapes, directly related to human activities such as hunting, or killing out of fear. The Central American River Turtle (*Dermatemys mawii*) is the most threatened species in the Lacandona region (Appendix 1), as it has been widely hunted and consumed [69]. However, other reptile species as *Iguana iguana*; Boa (*Boa constrictor*), Lancehead (*Bothrops asper*), Central American Snapping Turtle (*Chelydra rossignonii*), American crocodile (*Crocodylus acutus*) are principally hunted for their skin, eggs, or simply out of fear ([16], *personal observation*). Further studies are required to quantify the impact that these activities may have on the population size and structure of these and other threatened species.

Today there is a strong debate about the role played by secondary forests in maintaining biodiversity in human-modified landscapes [70, 71]. This role depends on the extent of old-growth forest remaining in the landscapes, the degree of connectivity among forest fragments, and the regimes of agricultural land uses [71]. In landscapes where remaining forest and connectivity are high, secondary forests may harbor high levels of biodiversity. Yet when agricultural landscapes are dominated by permanent monocultures extended over most landscape areas, secondary forests tend to be impoverished in biodiversity [71]. The Lacandona landscape is still in the middle of these two extremes, as it maintains about 31% of forest cover (including old-growth and secondary forests) immersed in a heterogeneous matrix of cattle pastures, shrub crops, tree crops and human settlements. However, extensive cattle pastures and oil palm plantations have increased over time [10]. Ecological studies in the Lacandona show that between 38 to 88% of the amphibian and reptile species found in old-grown forest are absent in secondary forests up to 25 years old [21]. We can predict that if current land-use changes continue, we could witness a strong decline of amphibian and reptile diversity in the following years in the region.

Implications for conservation

In the face of strong habitat modification rates in the Lacandona and other neighboring tropical rainforests, it is urgent to consider several management strategies to conserve amphibian and reptile faunas and biodiversity as a whole [71-73]. These strategies include: (1) to protect forest remnants with the participation of local, municipal, state, or federal governance mechanisms; (2) promote and support agroforestry and agro-ecological systems based on poly-cultures and compatible with conservation; (3) the inclusion of lengthy fallow periods; and (4) the restoration of degraded lands. Also, long-term monitoring programs of species diversity within reserves and agricultural landscapes are necessary to assess population and community trends, as well as the conservation status of the species and the effects of land-use policies and practices on such status. Finally, the creation and protection of new forest reserves are also urgent, particularly those with the participation of local people. Considering that Lacandona is part of an international forest (the Mayan forest), multinational conservation strategies should be enforced. The Mesoamerican Biological Corridor — a system of land planning coordinated by the governments of several Mesoamerican countries — would help to maintain the connections among Lacandona reserves

in Mexico, Guatemala and Belize. Such actions could have a crucial positive impact for the conservation of the herpetofauna in this Mesoamerican biodiversity hotspot [63].

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Appendix 1. Updated list of the amphibians and reptiles in the Lacandona rainforest, Mexico.

Taxa	Common Name*	Previous records[a]					Present study[b]		Geographic distribution[c]	IUCN[d]		Mexican government
		1	2	3	4	5	Record	Habitat		Status	Trend	
CLASS AMPHIBIA												
Order Gymnophiona												
Family Dermophiidae												
Gymnopis syntrema	West Forest Caecilian						R	MABR	E	DD	U	
Order Urodela												
Family Plethodontidae												
Bolitoglossa mexicana	Mexican Mushroom-tongued Salamander	P	R		R	R	R	MABR	MCA	LC	D	SP
B. mulleri	Müller's Mushroom-tongued Salamander	R				R	R	ISF, OGF	E	V	D	
B. rufescens	Northern Banana Salamander	R	P		R	R	R	ISF, OGF, MABR	MCA	LC	S	SP
Oedipina elongata	Central American Worm Salamander	P			R	R	R	ISF, OGF, MABR	E	LC	D	SP
Order Anura												
Family Bufonidae												
Incilius campbelli	Campbell's Rainforest Toad			R		R	R	OGF, MABR	E	NT	D	
I. macrocristatus	Hugh-crested Toad		R			R	R	OGF, MABR	MCA	V	D	
I. valliceps	Southern Gulf Coast Toad	R	R		R	R	R	All land covers	E	LC	S	
Rhinella marina	Cane Toad	R	R		R	R	R	All land covers	CASA	LC	I	
Family Rhinophrynidae												
Rhinophrynus dorsalis	Burrowing Toad	R	P		R	R	R	All land covers	MCA	LC	S	SP
Family Centrolenidae												
Hyalinobatrachium fleischmanni	Fleischmann's Glass Frog	R			R	R	R	ISF, OGF, MABR	CASA	LC	U	

Family Hylidae											
Agalychnis callidryas	Red-eyed Leaf Frog	R	R		R	R	R	ISF, OGF, MABR	CASA	LC	D	
Bromeliohyla bromeliacia	Bromeliad Treefrog		R						E	EN	D	
Dendropsophus ebraccatus	Hourglass Treefrog	R	R			R	R	OGF	CASA	LC	S	
D. microcephalus	Small-headed Treefrog	R			R	R	R	All land covers	CASA	LC	I	
Scinax staufferi	Stauffer's Long-nosed Treefrog	P	R	R	R	R	R	All land covers	MCA	LC	S	
Smilisca baudinii	Mexican Treefrog	R	R		R	R	R	All land covers	NE	LC	S	
S. cyanosticta	Blue-spotted Mexican Treefrog	R	R		R	R	R	MABR	MCA	NT	D	
Tlalocohyla loquax	Mahogany Treefrog	R			R	R	R	ISF, YSF	MCA	LC	S	
T. picta	Painted Treefrog	R	P		R	R	R	All land covers	MCA	LC	I	
Trachycephalus typhonius	Veined Treefrog	R	R			R	R	All land covers	CASA	LC	S	
Triprion petasatus	Yucatecan Casque-headed Treefrog			R					E	LC	S	SP
Family Microhylidae												
Gastrophryne elegans	Elegant Narrow-mouthed Toad	R				R	R	ISF, OGF, MABR	MCA	LC	S	SP
Hypopachus variolosus	Sheep Frog	R							NE	LC	S	
Family Ranidae												
Lithobates brownorum	Brown's Leopard Frog	R			R	R	R	All land covers	MCA	LC	S	SP
L. maculatus	Masked Mountain Frog					R	R	ISF, OGF, MABR	MCA	LC	D	
L. vaillanti	Vaillant's Frog	R	P		R	R	R	All	CASA	LC	S	
Family Craugastoridae												
Craugastor alfredi	Alfred's Rainfrog	R	R		R	R	R	MABR	MCA	V	D	
C. laticeps	Broad-headed Rainfrog	R	P		R	R	R	OGF, MABR	E	NT	U	SP
C. loki	Volcan San Martin Robber Frog		R		R		R	ISF, OGF, MABR	MCA	LC	D	

C. palenque	Palenque Robber Frog				R	R	OGF, MABR	E	DD	U	
Family Eleutherodactylidae											
Eleutherodactylus leprus	Leprus Chirping Frog	P	P			R	All land covers	MCA	V	D	
Family Leptodactylidae											
Leptodactylus fragilis	White-lipped Frog	R	P	R	R	R	All land covers	CASA	LC	S	
L. melanonotus	Sabinal Frog	P	P	R	R	R	All land covers	CASA	LC	S	
Family Leiuperidae											
Engystomops pustulosus	Túngara Frog	R						CASA	LC	S	
CLASS REPTILIA											
Order Squamata											
Family Anguidae											
Celestus rozellae	Rozella's Canopy Lizard	R	P	R	R	R	OGF, MABR	MCA	NT	D	SP
Family Gekkonidae											
Hemidactylus frenatus	Common House Gecko			R	R	R	R	DS	CASA	LC	S
Family Sphaerodactylidae											
Sphaerodactylus glaucus	Collared Dwarf Gecko	R	R	R	R	R	OGF, MABR	MCA	NYA		SP
S. millepunctatus	Spotted Dwarf Gecko		P	R	R	R	MABR	MCA	NYA		
Family Phyllodactylidae											
Thecadactylus rapicauda	Turniptail Gecko	P	R	R	R	R	OGF, MABR	CASA	NYA		
Family Eublepharidae											
Coleonyx elegans	Elegant Banded Gecko	P	R	R	R	R	OGF	MCA	NYA		Thr
Family Dactyloidae											
Anolis biporcatus	Giant Green Anole	R	R	R	R	R	ISF, OGF, MABR	CASA	NYA		SP
A. capito	Big-headed Anole	R	R		R	R	MABR	MCA	NYA		
A. lemurinus	Ghost Anole	R	R	R	R	R	All land covers	CASA	NYA		
A. pentaprion	Lichen Anole		R	R	R	R	OGF	MCA	NYA		SP

A. rodriguezi	Rodriguez's Anole	R	R		R	R	R	OGF, ISF, YSF, MABR	MCA	NYA	
A. sericeus	Silky Anole	R	R		R	R	R	DS	MCA	NYA	
A. tropidonotus	Greater Scaly Anole	R	P		R	R			MCA	NYA	
A. uniformis	Lesser Scaly Anole	R			R	R	R	ISF, OGF, MABR	MCA	NYA	
Family Phrynosomatidae											
Sceloporus serrifer	Rough-scaled Lizard		R	R		R			NE	LC	S
S. teapensis	Teapan Rose-bellied Lizard		P		R	R	R	DS	MCA	LC	S
Family Iguanidae											
Ctenosaura similis	Black Iguana				R	R			CASA	LC	S	Thr
Iguana iguana	Common Green Iguana	R	R		R	R	R	All land covers	CASA	NYA		SP
Family Corytophanidae											
Basiliscus vittatus	Brown Basilisk	R	R		R	R	R	All land covers	CASA	NYA	
Corytophanes cristatus	Smooth-headed Helmeted Basilisk	R	R		R	R	R	ISF, OGF, MABR	CASA	NYA		SP
C. hernandezi	Hernandez's Helmeted Basilisk	R	R		R	R			MCA	NYA		SP
Laemanctus longipes	Eastern Casquehead Iguana	P			R	R			MCA	NYA		SP
Family Scincidae											
Marisora unimarginata	Central American Mabuya	P			R	R			CASA	NYA	
Mesoscincus schwartzei	Schwartz's Skink		R	R		R	R	OGF, MABR	E	LC	S
Plestiodon sumichrasti	Sumichrast's Skink	R	P		R	R	R	OGF, MABR	MCA	NYA	
Scincella cherriei	Brown Forest Skink	R	R		R	R	R	YSF, ISF, OGF, MABR	CASA	NYA	
Family Teiidae											
Holcosus festivus	Middle American Ameiva	P	R		R	R	R	OGF, ISF	CASA	NYA	
H. undulatus	Rainbow Ameiva	R	R		R	R	R	All land covers	CASA	NYA	

Family Xantusidae											
Lepidophyma flavimaculatum	Yellow-spotted Tropical Night Lizard	R	R	R	R	R	ISF, OGF, MABR	MCA	NYA		SP
Family Boidae											
Boa constrictor	Boa	R	P	R	R	R	All land covers	CASA	NYA		Thr
Family Colubridae											
Adelphicos quadrivirgatus visoninum	Four-lined Middle American Earth Snake	P	P	R	R	R	ISF, OGF, MABR	MCA	LC	S	SP
Amastridium sapperi	Rusty-headed Snake			R		R	OGF, MABR	CASA	NYA		
Clelia clelia	Mussurana	R			R	R	ISF, OGF, MABR	CASA	NYA		
Coniophanes bipunctatus	Mottled-jaw Spot-bellied Snake	P	P	R	R	R	All land covers	MCA	NYA		
C. fissidens	Yellow-bellied Snake	R	P	R	R			CASA	NYA		
C. imperialis	Regal Black-striped Snake	R	P	R	R	R	ISF, OGF, MABR	NE	LC	S	
C. quinquevittatus	Five-striped Snake	R			R			CASA	LC	S	
C. schmidti	Schmidt's Black-striped Snake		R	R				E	LC	S	
Drymarchon corais	Indigo Snake	R		R	R			CASA	LC	S	
D. melanurus	Central American Indigo Snake		R					CASA	LC	S	
Drymobius margaritiferus	Speckled Racer	R	R	R	R	R	All land covers	CASA	NYA		
Geophis carinosus	Keeled Earth Snake			R				MCA	LC	S	
Imantodes cenchoa	Blunthead Tree Snake	R	R	R	R	R	ISF, OGF, MABR	CASA	NYA		SP
I. gemmistratus	Central American Tree Snake	P		R	R			CASA	NYA		SP
Lampropeltis triangulum	Milksnake	R	P	R	R			CASA	NYA		Thr
Leptodeira frenata	Rain Forest Cat-eyed Snake	R		R	R			MCA	LC	S	
L. septentrionalis	Northern Cat-eyed Snake	P	R	R	R	R	OGF, MABR	CASA	NYA		
Leptophis ahaetulla	Green Parrot Snake	R	R	R	R	R	OGF, MABR	CASA	NYA		SP

L. mexicanus	Mexican Parrot Snake	R	P	R	R	R	YSF, ISF, OGF, MABR	CASA	NYA		Thr
Mastigodryas melanolomus	Common Lizard Eaters	R	P		R	R	ISF, OGF	MCA	LC	S	
Nerodia rhombifer	Diamond-backed Watersnake			R	R			NE	LC	S	
Ninia diademata	Ring-necked Coffee Snake	P		R	R	R	YSF, ISF, OGF	MCA	LC	S	
N. sebae	Red-backed Coffee Snake	P	R	R	R	R	All land covers	CASA	NYA		
Oxybelis aeneus	Brown Vinesnake	P	P		R	R	OGF	CASA	NYA		
O. fulgidus	Green Vinesnake	R			R			CASA	NYA		
Oxyrhopus petola	Calico False Coral Snake	R	R	R	R	R	MABR	MCA	NYA		
Pliocercus elapoides	Variegated False Coralsnake	P	R	R	R	R	OGF	MCA	LC	S	
Pseudelaphe flavirufa	Tropical Ratsnake					R	OGF	MCA	LC	D	
Pseustes poecilonotus	Puffing Snake	R	R	R	R	R	OGF, MABR	MCA	LC	S	
Rhadinaea decorata	Striped Forest Snake	R	R	R	R			CASA	NYA		
Scaphiodontophis annulatus	Guatemala Neck-banded Snake	P	R	R	R	R	OGF	CASA	NYA		
Senticolis triaspis	Green Ratsnake	R			R	R	OGF	NE	NYA		
Sibon dimidiatus	Slender Snail Sucker	R	P	R	R	R	OGF, MABR	MCA	LC	S	
S. nebulatus	Cloudy Snail Sucker	R		R	R	R	OGF, MARB	CASA	NYA		
Spilotes pullatus	Tropical Tree Snake	R	R		R	R	All land covers	CASA	NYA		
Stenorrhina degenhardtii	Degenhardt's Scorpion-eating Snake	R	P	R	R			CASA	NYA		
Stenorrhina freminvillei	Freminville's Scorpion-eating Snake				R			MCA	LC	S	
Tantilla schistosa	Red Earth Centipede Snake		R					MCA	NYA		
Tantillita lintoni	Linton's Dwarf Short-tailed Snake	P	R			R	ISF, OGF	MCA	NYA		
Thamnophis marcianus	Checkered Gartersnake			R	R			NE	NYA		Thr
Tretanorhinus nigroluteus	Orange-bellied Swamp Snake	P	R		R	R	ISF, OGF	MCA	NYA		

Tropidodipsas sartori	Terrestrial Snail Sucker		P	R		R	OGF	MCA	NYA		SP
Xenodon rabdocephalus	False Fer-de-Lance	R	R	R	R	R	ISF, OGF, MABR	MCA	NYA		
Family Elapidae											
Micrurus diastema	Variable Coralsnake	R	R		R	R	ISF, OGF	MCA	LC	S	SP
M. elegans	Elegant Coralsnake	R			R			MCA	LC	U	SP
Family Viperidae											
Atropoides mexicanus	Mexican Jumping Pitviper	P	P			R	OGF, MABR	MCA	LC	S	SP
Bothriechis schlegelii	Eyelash Palm Pitviper	P				R	OGF, MABR	CASA	NYA		
Bothrops asper	Lancehead	R	R	R	R	R	All land covers	CASA	NYA		
Crotalus simus	Middle American Rattlesnake	P		R				MCA	NYA		
Porthidium nasutum	Rainforest Hog-nosed Pitviper	R	P		R	R	OGF, MABR	CASA	LC	S	SP
Order Testudines											
Family Emydidae											
Trachemys scripta	Pond Slider	R	P	R	R	R	LAC	NE	LC	S	SP
Family Geomydidae											
Rhinoclemmys areolata	Furrowed Wood Turtle	P		R	R			MCA	NT	D	Thr
Family Kinosternidae											
Kinosternon acutum	Tabasco Mud Turtle	R	P			R	ISF, OGF, MABR	MCA	NT	U	SP
K. leucostomum	White-lipped Mud Turtle	R	P	R	R	R	All land covers	CASA	NYA		SP
Staurotypus triporcatus	Mexican Giant Musk Turtle	R	P	R	R			MCA	NT	U	Thr
Family Dermatemydidae											
Dermatemys mawii	Central American River Turtle	R	R	R		R	LAC	MCA	CE	D	End
Family Chelydridae											
Chelydra rossignonii	Central American Snapping Turtle	R	P	R	R	R	LAC	CASA	LC	S	SP

Order Crocodylia										
Family Crocodylidae										
Crocodylus acutus	American Crocodile	R	P	R	R	LAC	NE	V	I	SP
C. moreletii	Morelet's Crocodile	R	P	R			MCA	NT	S	SP

[a]Previous records: 1. Lazcano-Barrero et al. [16]; 2. Ferreira-García and Canseco-Márquez [17]; 3. Paredes-León and Reynoso [25, 26, 27, 28] and Percino-Daniel et al. [30, 31]; 4. Lee [15]; 5. "Colección Nacional de Anfibios y Reptiles", "Museo de Zoología de la Facultad de Ciencias" (UNAM) and Global Biodiversity Information Facility [35] and HerpNet database [38].. We indicate the species recorded (R) or cited as probable (P) in each of these sources.

[b]Species recorded (R) in the present study. The habitat types in which they were recorded are: YSF (young secondary forest, 1-4 years); ISF (intermediate secondary forest, 10-25 years); OGF (old-growth forest fragments); MABR (continuous forest of the Montes Azules Biosphere Reserve), DS (disturbed sites, such as pastures, croplands, and urban settlements); LAC (Lacantúm River).

[c]Distribution: Endemic species for the Mayan Forest (E); Mexico and Central America (MCA); Mexico, Central America to South America (CASA); NE with Nearctic affinities.

[d]IUCN conservation status: NYA, not yet assessed; DD, data deficient; LC, least concern; NT, near threatened; VU, vulnerable; EN, endangered; CR, critically endangered. IUCN population trends: S, stable; D, decreasing; U, Needs updating unknown, or I, increasing. Mexican government (based on the NOM-059-ECOL-2010): SP, Special protection; Thr, Threatened; End, endangered.