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Research Article

The amphibians and reptiles of Cusuco National Park, Northwest Honduras: updates from a long-term conservation programme

Alexandra E. Laking[1], José M. Solís[1,2], Tom Brown[1,3], Simon T. Maddock[1,4], Oliver Burdekin[1,5], Peter Taylor[1], George Lonsdale[1], Stephen E. W. Green[6], Thomas E. Martin[1,7], Josue R. Galdamez[1,3], Jonathan E. Kolby[1,8,9], Jesse Erens[1], Merlijn Jocque[1,10]

1 Operation Wallacea, Wallace House, Old Bolingbroke, Lincolnshire, UK
2 Grupo de Investigación de Reptiles y Anfibios de Honduras (GIRAH), Tegucigalpa, Honduras
3 Kanahau Utila Research and Conservation Facility, Utila Island, Honduras
4 School of Natural and Environmental Sciences, Newcastle University, Newcastle Upon Tyne, UK
5 Oxford University Department for Continuing Education, University of Oxford, Oxford, UK
6 Newquay University Centre, Cornwall College, Wildflower Lane, Trenance Gardens, Newquay, Cornwall, TR7 2LZ, UK
7 School of Natural Sciences, College of Environmental Sciences and Engineering, Bangor University, Bangor, UK
8 One Health Research Group, James Cook University, Townsville, Australia
9 Honduras Amphibian Rescue & Conservation Center, Lancetilla Botanical Garden, Tela, Honduras
10 Aquatic and Terrestrial Ecology (ATECO), Royal Belgian Institute of Natural Sciences (RBINS), Vautierstraat 29, 1000 Brussels, Belgium

Corresponding author: Alexandra E. Laking (lakinga@hotmail.ca)

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Abstract

Mesoamerican cloud forests support a rich and unique biodiversity but face severe threats from increasing habitat degradation and climate change. Here, we present an updated overview of the amphibians and reptiles of Cusuco National Park (CNP), an isolated cloud forest in the Sierra de Omoa, Northwest Honduras. Based on surveys conducted over a 17-year period, we report the presence of 105 confirmed species of amphibians (30) and reptiles (75) within the reserve. This includes numerous threatened and regionally endemic amphibian species, as well as several reptile species previously unrecorded within the park. Given that it harbours approximately 26% of all recorded Honduran herpetofauna, our study highlights CNP as the most diverse forest region in Honduras with respect to the reptile and amphibian diversity documented to date. Our findings reinforce the plea to actively protect CNP as a globally valuable biodiversity hotspot and a centre of herpetofaunal endemicity. Furthermore, in the face of rapid deforestation across Mesoamerica, our findings highlight the need for expanded biodiversity studies across extant forest regions in Honduras to refine species distribution ranges and facilitate timely and effective conservation measures.

Resumen

Los bosques nublados de Mesoamérica soportan una diversidad rica y única, pero por otro lado sufre de severas amenazas debido a la degradación del hábitat y el cambio climático. En este manuscrito presentamos un listado general de los anfibios y reptiles del parque Nacional Cusuco (CNP), un bosque nublado en la sierra de Omoa, noroccidente de Honduras. Basados en muestreos durante un periodo de 17 años reportamos la presencia de al menos 105 especies de anfibios (30) y reptiles (75) en la reserva. Dicha herpetofauna incluye numerosas especies endémicas y amenazadas de anfibios, así como algunos reptiles no registrados previamente en el área. Esto alberga el 26% de toda la herpetofauna conocida para Honduras, nuestro estudio remarca que CNP es la región forestal en Honduras con mayor diversidad de anfibios y reptiles con respecto a la diversidad documentada hasta la fecha. Nuestros encuentros refuerzan el hecho que se debe proteger activamente el CNP como un centro de alto valor global de biodiversidad y como un núcleo de endemicidad de herpetofauna. Además, en vista de la acelerada deforestación a través de los ecosistemas remanentes en Mesoamérica, nuestros datos son un llamado a realizar estudios a través de las regiones forestales existentes en Honduras, para refinar los rangos de distribución de las especies que permitan tomar las medidas efectivas de conservación.

Key words: Biodiversity hotspot, Cloud Forest, herpetofauna, IUCN status, Mesoamerica, Nuclear Central America, population monitoring, species list

Introduction

Positioned centrally in Mesoamerica, Honduras is characterised by an extensive interior highland area (the Chortis Block) that extends from western Guatemala to Nicaragua (Alvarado et al. 2007; Townsend 2014). Biodiversity in this region is shaped by a multitude of environmental gradients and includes a range of isolated mountains topped by evergreen cloud forests, which can be broadly defined as "tropical forests frequently covered in a cloud of mist" (Stadtmuller 1987). These high-elevation forests exhibit highly specific bioclimatic conditions, constituting rare and unique ecosystems. Owing to their geographic isolation, Mesoamerican cloud forests form an array of 'sky islands' that provide habitat to a diverse and highly endemic fauna and flora. The diversity of the region is threatened by the rapid habitat degradation occurring throughout Mesoamerica's forests (Brooks et al. 2002; Jung et al. 2022), with high-elevation ecosystems disproportionately impacted (Bubb et al. 2004). Despite their biological importance and elevated threat status, most remaining cloud forest habitats in Mesoamerica remain scientifically under-explored, hampering insights into the distribution of biodiversity across extended geographic areas (the Wallacean shortfall; Lomolino 2004). A better understanding of species diversity, abundance, and distributions is imperative to the timely and effective implementation of conservation measures.

Cusuco National Park (CNP), in northwestern Honduras, is an isolated, biologically diverse, yet threatened cloud forest ecosystem. CNP supports a rich herpetofaunal (reptile and amphibian) community, including many threatened and nationally or regionally endemic species. The park harbours four micro-endemic amphibian and four micro-endemic reptile species that are only known to occur at this single locality (Fig. 1). The forest ecosystem of CNP first gained protection for its value in protecting the watershed of the nearby city of San Pedro Sula. It is situated within the Mesoamerican biodiversity hotspot (Myers et al. 2000) and is globally recognised by the Alliance for Zero Extinction (2018) for the critical habitat it provides to its endemic amphibian fauna. Likewise, CNP was included in a global list of the most irreplaceable protected areas on the basis of its amphibian, bird, and mammal diversity (Le Saout et al. 2013) and is considered a Key Biodiversity Area by the IUCN. This illustrates the vital role of extant cloud forest systems in providing ecosystem services to nearby human communities (Bubb et al. 2004; Bruijnzeel et al. 2010).

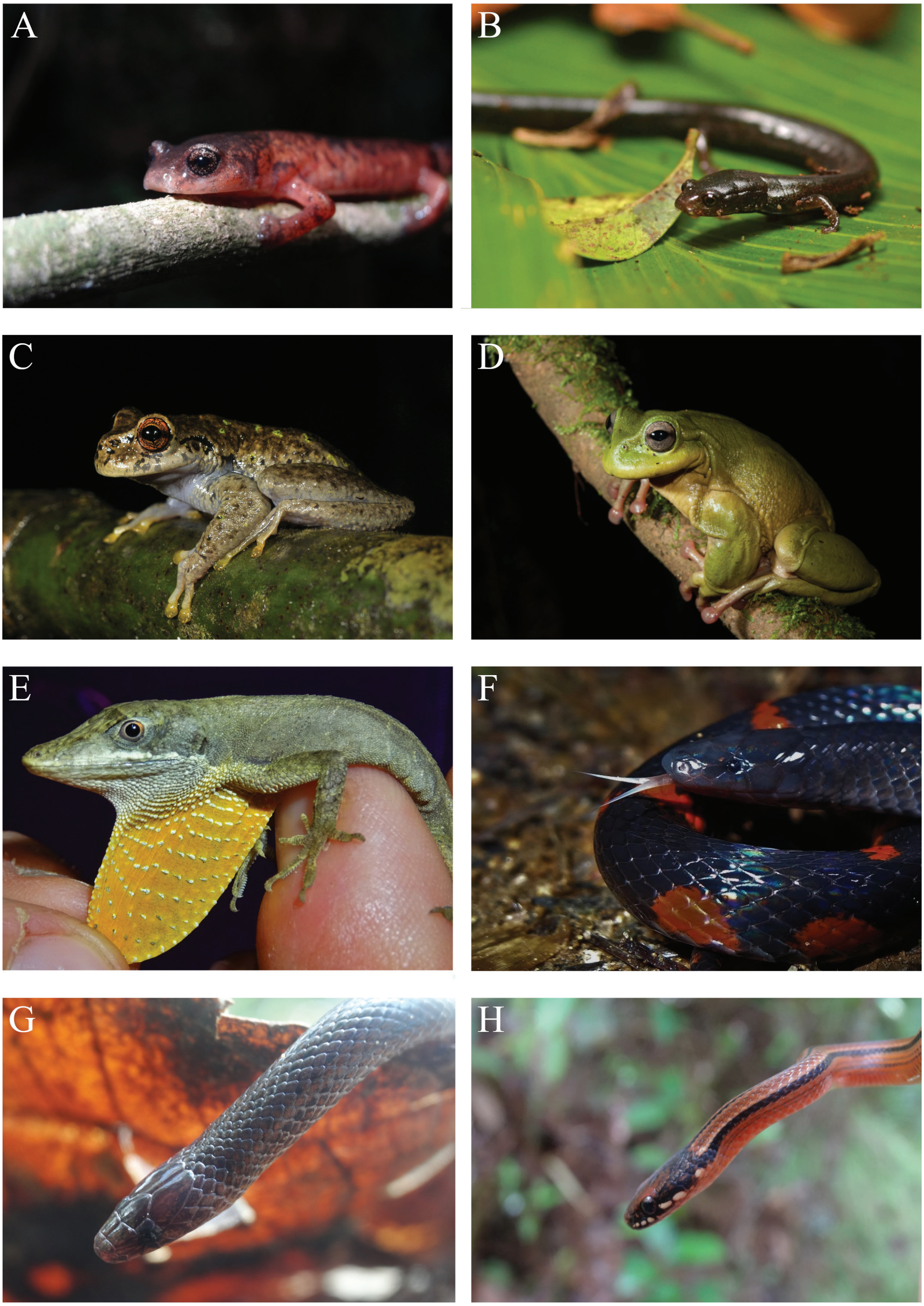

Figure 1. The four amphibian and four reptile micro-endemic species currently known only to occur in Cusuco National Park. **A** *Bolitoglossa diaphora* **B** *Oedipina tomasi* **C** *Plectrohyla dasypus* **D** *Plectrohyla exquisita* **E** *Anolis amplisquamosus* **F** *Geophis nephodrymus* **G** *Omoadiphas aurula* **H** *Rhadinella pegosalyta* (Photographs provided by: Tom Brown **A, E, F, G, H**; Jesse Erens **B**; Achyuthan Srikanthan **C, D**).

More than 400 species of reptiles and amphibians have been recorded in Honduras to date, of which around 27% are endemic to the country (Solís et al. 2014; McCranie 2015). The first overview of the herpetofauna of CNP was presented by Wilson and McCranie (2004), which provided a list of 30 identified species based on surveys conducted from the late 1970s to the early 2000s. These findings prompted the start of a long-term monitoring programme to assess the herpetological diversity of the national park. As a result, the number of recorded species grew over subsequent years, and an updated inventory was published by Townsend et al. (2006), which increased the number of species identified in CNP to 50. This updated inventory was comprised of five salamanders, 12 frogs, 12 lizards, and 21 snakes, which were detailed in a subsequent field guide (Townsend and Wilson 2008). Whereas in the more recent works of Solís et al. (2017) and Martin et al. (2021), we included tentative overviews of the park's reptiles and amphibians, these were different in scope and comprised incomplete species accounts. Hence, we here provide detailed results of the herpetofaunal surveys carried out in CNP across the subsequent 17 years spanning the period 2007–2023 and confirm the presence of 105 species of amphibians and reptiles within the park's boundaries. In addition to providing an overview of all recorded herpetofauna, we discuss the global conservation significance of the reserve in view of continuing environmental change.

Methods

Study area - Cusuco National Park and delineation

CNP is located in the Sierra de Omoa, the northernmost extension of the Sierra del Merendón, in the region of Cortés, northwestern Honduras (Fig. 2A). Ranging up to 2,243 m in elevation, the park is located among the highest regions of the Sierra de Omoa, while its lower ranges extend to around 500 m above sea level (m/asl) (Martin and Blackburn 2009). Consequently, its elevational gradient supports a large range of vegetation types. Tropical montane cloud forests are prevalent around 1,200–2,000 m/asl and are characterised both by broadleaved and pine vegetation, while elevations above 2,000 m/asl are characterised by *bosque enano*, or elfin 'dwarf' forests. Towards lower elevations between 500 and 1,200 m/asl, broadleaved forests are dominant, with increasing fragmented forest sections and agricultural clearances further down the mountain slopes (Hamilton et al. 1995). CNP and its direct environs are covered by a variety of protected areas (*cf*. Martin et al. 2021). On the basis of the Cloud Forest Act (Act 87-1987), the original delineation of CNP comprised a core zone that includes all terrain above 1,800 m/asl and a buffer zone that expands 2 km outwards from the 1,800 m/asl boundary (Fig. 2B) (Bonta 2005). This initial definition of CNP provided the focus of most early herpetofaunal inventories in the reserve (see Wilson and McCranie 2004). Following this original demarcation, however, the Corporación Hondureña de Desarrollo Forestal (COHDEFOR) published an updated management plan for CNP that substantially expanded the core zone and buffer zone (Fig. 2B). This latter delineation presents the study area in which all research efforts in the period 2007–2023 were concentrated, and hence the zonation that is used throughout this report (although this interpretation of the park's borders is not universally accepted).

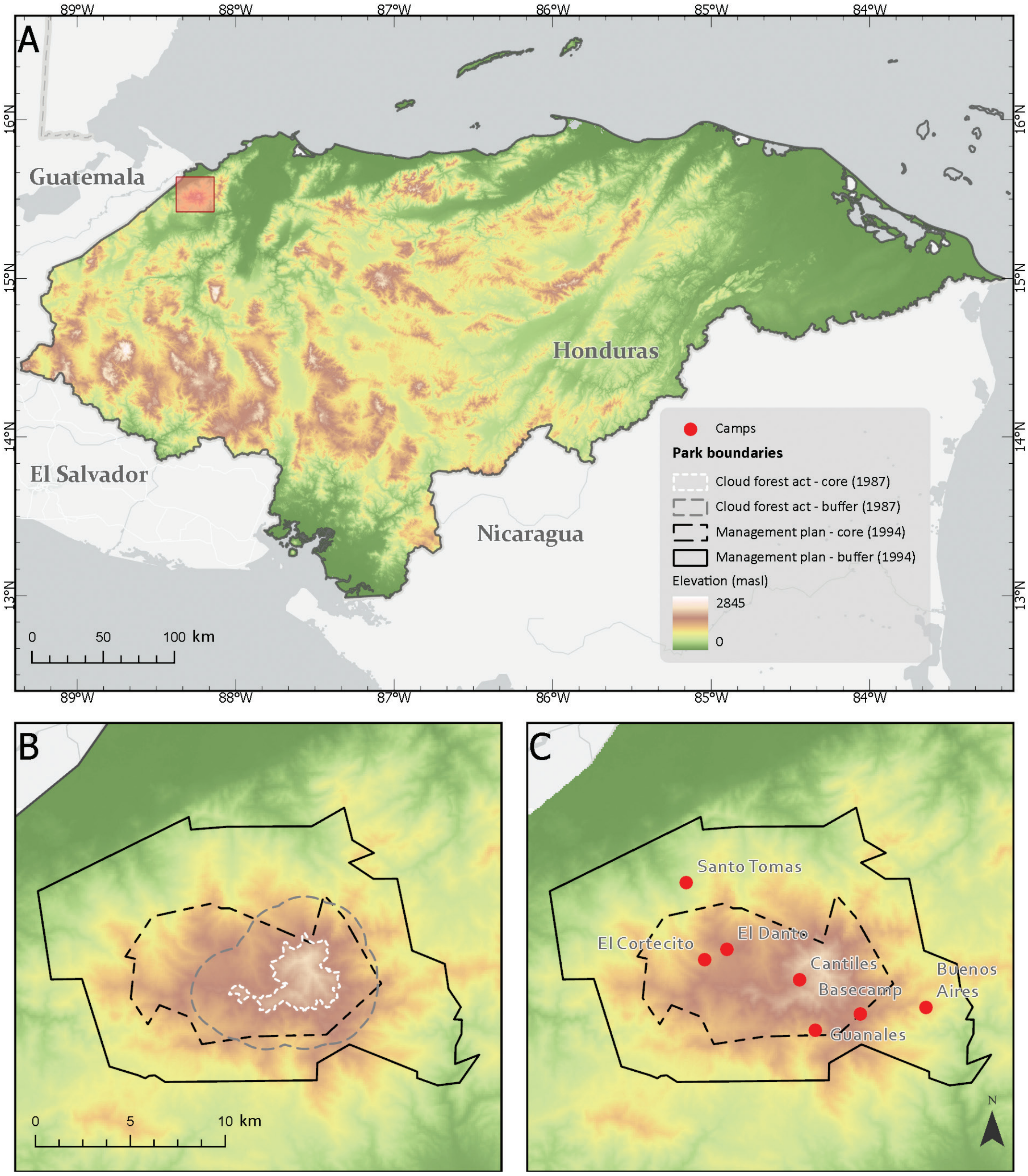

Figure 2. The location of Cusuco National Park (CNP) in northwestern Honduras, the different interpretations of its borders, and an overview of study camps **A** CNP is situated in the northern ranges of the Sierra del Merendón, highlighting the isolated position of the cloud forest reserve in relation to other high-altitude regions **B** our study area is based on the management plan of the Corporación Hondureña de Desarrollo Forestal (black dashed and solid outlines), shown in reference to the original delineation of CNP as based on the 87–1987 Cloud Forest Act (white dotted and grey dashed outlines) **C** an overview of the field sites surveyed during the study period of 2007–2023. A black dashed line indicates the delineation of the reserve's core zone, while the solid line indicates the delineation of the buffer zone. Digital elevation model from Jarvis et al. (2008); basemap from ESRI (2017).

Data collection

Annual surveys were conducted from early-June to early-August each year between 2007 and 2023 (with the exception of 2020–2021 due to the COVID-19 pandemic) as part of an ongoing long-term biodiversity monitoring programme run by Operation Wallacea, a non-governmental conservation and research organisation. These annual surveys are carried out by teams of students and volunteers under the supervision of a rotating team of experienced herpetologists.

All survey activities were concentrated around seven field camps situated in the park's core and buffer zones (Fig. 2C). In each of these seven camps, three to four standardised transects were monitored across successive years to assess herpetofaunal diversity throughout CNP. Across the research period, transects were studied by means of diurnal visual encounter surveys in the morning until midday, in which the time, distance, and number of participants were recorded to quantify search effort. This involved visually searching for amphibians and reptiles along the defined transects, and when an individual was encountered, recording the species, the distance along the transect, and the perpendicular distance from the transect. Encountered species were caught when possible, and the sex, weight, snout-to-vent length (SVL), and photographs (dorsal, lateral, ventral, and close-up of the head) were obtained. Nocturnal opportunistic searches along portions of these transects or near water bodies were also conducted, with the same information being recorded for these surveys. Within some study seasons, a single drift fence array with three pitfall traps was opportunistically set up in suitable habitat at each camp and checked daily to investigate the potential presence of small (semi-)fossorial species likely to remain undetected by active searches. As this research was conducted by people of varying levels of experience, only species occurrences with photographic evidence or verification by an expert were included. Photographic vouchers of all amphibian and reptile species recorded in CNP are provided in Suppl. materials 1, 2.

The conservation status of all included species was assessed based on the IUCN Red List (2022) and the Environmental Vulnerability Score (EVS) following Johnson et al. (2015). While the former was used as a central representation of species conservation status, the latter provides an integrative conservation index for all Mesoamerican reptile and amphibian species, based on their extant geographic distribution, habitat occupation, reproductive mode (for amphibians), or human persecution (for reptiles). As such, the EVS also provides a valuable indication of the conservation status of species that remain unassessed by the IUCN Red List.

Results

Following recurring survey efforts in the period 2007–2023, a total of 105 amphibian and reptile species have been confirmed in CNP: 30 amphibians (Table 1) and 75 reptiles (Table 2). Fig. 3 provides an overview of the cumulative number of species recorded over consecutive field seasons.

Amphibians

Since the inventory of 2006 (Townsend et al. 2006), an additional 13 amphibian species were recorded within the 17-year study period, of which a provisional overview was provided in Solís et al. (2017). Among some of the most notable records, the secretive species *Nototriton brodiei* Campbell & Smith, 1998 and *Ecnomiohyla salvaje* (Wilson et al. 1985) were both found in the high-elevation habitats of the CNP core zone. *N. brodiei* is a cryptic salamander that is typically found in dense leaf litter layers and in moss mats of intact montane forests (Kolby et al. 2009). The canopy-dwelling frog species *E. salvaje*, which is endemic to the region, is a cryptic species that is likely facing significant threats.

Table 1. The amphibian fauna of Cusuco National Park (CNP). Species conservation status is based on the assessment criteria of the IUCN Red List (IUCN 2022) and environmental vulnerability scores (EVS) (Johnson et al. 2015). Species are listed alphabetically by family. Geographic Distribution is characterised as either widespread (found outside of nuclear Central America), NCA (restricted to localities in nuclear Central America), or endemic (restricted to Honduras), while endemic taxa in bold are only known from CNP. An asterisk (*) indicates species that were formerly thought to be endemic to CNP. Conservation Status follows the IUCN Red List (2022): CR, Critically Endangered; EN, endangered; NT, Near Threatened; LC, Least Concern; NE, Not Evaluated. Environmental Vulnerability Scores (EVS) indicate low (3–9), medium (10–13), or high (14–20) vulnerability to environmental degradation. The presence of the species reported in previous studies is indicated by an x.

Nr.	Taxon	Geographic Distribution	Wilson & McCranie (2004)	Townsend et al. (2006)	CNP zonation	Conservation Status	EVS Score
	Order: Caudata (Salamanders)						
	Family: Plethodontidae						
1	*Bolitoglossa conanti*	NCA	x	x	Core, Buffer	VU	16
2	*Bolitoglossa diaphora*	**Endemic**	x	x	Core	EN	18
3	*Bolitoglossa dofleini*	NCA			Core, Buffer	NT	15
4	*Bolitoglossa dunni*	NCA	x	x	Core	EN	16
5	*Bolitoglossa mexicana*	NCA			Buffer	LC	8
6	*Bolitoglossa nympha*	NCA			Buffer	LC	16
7	*Cryptotriton nasalis*	NCA*	x	x	Core	EN	18
8	*Nototriton brodiei*	NCA*			Core	EN	17
9	*Oedipina tomasi*	**Endemic**		x	Core	CR	18
	Order: Anura (Frogs)						
	Family: Bufonidae						
10	*Incilius campbelli*	NCA			Buffer	LC	12
11	*Incilius valliceps*	Widespread	x		Buffer	LC	6
12	*Rhinella horribilis*	Widespread			Buffer	LC	3
	Family: Centrolenidae						
13	*Hyalinobatrachium fleischmanni*	Widespread			Buffer	LC	8
	Family: Craugastoridae						
14	*Craugastor* cf. *chac*	Widespread			Core, Buffer	LC	16
15	*Craugastor charadra*	NCA		x	Core, Buffer	VU	15
16	*Craugastor coffeus*	Endemic			Buffer	CR	18
17	*Craugastor* aff. *nefrens*				Buffer	NE	NA
18	*Craugastor laevissimus*	NCA			Buffer	EN	12
19	*Craugastor laticeps*	NCA			Core, Buffer	LC	12
20	*Craugastor milesi*	Endemic	x	x	Core	CR	16
21	*Craugastor rostralis*	NCA	x	x	Core, Buffer	VU	16
	Family: Hylidae						
22	*Bromeliohyla bromeliacia*	NCA	x	x	Core, Buffer	LC	17
23	*Bromeliohyla melacaena*	Endemic		x	Core, Buffer	EN	20
24	*Duellmanohyla soralia*	NCA	x	x	Core, Buffer	EN	12
25	*Ecnomiohyla salvaje*	NCA			Core	EN	19
26	*Plectrohyla dasypus*	**Endemic**	x	x	Core, Buffer	CR	14
27	*Plectrohyla exquisita*	**Endemic**	x	x	Core, Buffer	CR	15
28	*Ptychohyla hypomykter*	NCA	x	x	Core, Buffer	VU	10
29	*Smilisca baudinii*	Widespread		x	Core, Buffer	LC	3
	Family: Ranidae						
30	*Rana maculata*	NCA	x		Core, Buffer	LC	5

Table 2. The reptile fauna of Cusuco National Park. Species conservation status is based on the assessment criteria of the IUCN Red List (IUCN 2022) and environmental vulnerability scores (EVS) (Johnson et al. 2015). Species are listed alphabetically by family. Geographic Distribution is characterised as either widespread (found outside of nuclear Central America), NCA (restricted to localities in nuclear Central America), or endemic (restricted to Honduras), while endemic taxa in bold are only known from Cusuco National Park. Conservation Status follows the IUCN Red List (2022): CR, Critically Endangered; EN, endangered; NT, Near Threatened; LC, Least Concern; NE, Not Evaluated. Environmental Vulnerability Scores (EVS) indicate low (3–9), medium (10–13), or high (14–20) vulnerability to environmental degradation. The presence of the species reported in previous studies is indicated by an x.

Nr.	Taxon	Geographic Distribution	Wilson & McCranie (2004)	Townsend et al. (2006)	CNP zonation	Conservation Status	EVS Score
	Order: Squamata (Lizards)						
	Family: Anguidae						
1	*Abronia moreletii*	NCA	x	x	Core, Buffer	LC	8
	Family: Corytophanidae						
2	*Basiliscus vittatus*	NCA			Buffer	LC	7
3	*Corytophanes cristatus*	Widespread			Buffer	LC	10
4	*Corytophanes hernandesii*	Widespread			Buffer	LC	13
5	*Laemanctus julioi*	Endemic			Buffer	NE	NA
6	*Laemanctus longipes*	NCA			Buffer	LC	9
	Family: Dactyloidae						
7	*Anolis amplisquamosus*	**Endemic**	x	x	Core, Buffer	CR	17
8	*Anolis biporcatus*	Widespread			Buffer	LC	9
9	*Anolis capito*	Widespread		x	Core, Buffer	LC	11
10	*Anolis cusuco*	Endemic	x	x	Core, Buffer	CR	17
11	*Anolis johnmeyeri*	Endemic	x	x	Core, Buffer	EN	16
12	*Anolis lemurinus*	Widespread			Buffer	LC	7
13	*Anolis mccraniei*	NCA			Core, Buffer	NE	NA
14	*Anolis ocelloscapularis*	Endemic		x	Core, Buffer	VU	15
15	*Anolis petersii*	NCA		x	Core, Buffer	NT	9
16	*Anolis rodriguezii*	NCA			Buffer	LC	10
17	*Anolis uniformis*	Widespread			Core, Buffer	LC	13
18	*Anolis unilobatus*	Widespread			Buffer	LC	7
19	*Anolis yoroensis*	Endemic			Core	EN	15
	Family: Diploglossidae						
20	*Siderolamprus montanus*	Endemic		x	Core, Buffer	EN	15
	Family: Gekkonidae						
21	*Coleonyx mitratus*	Widespread			Buffer	LC	14
22	*Hemidactylus frenatus*	Introduced			Core, Buffer	LC	NA
	Family: Phrynosomatidae						
23	*Sceloporus schmidti*	Endemic	x	x	Core, Buffer	NE	NA
24	*Sceloporus variabilis*	Widespread		x	Core, Buffer	LC	5
	Family: Sphaenomorphidae						
25	*Scincella cherriei*	Widespread	x		Core, Buffer	LC	7
26	*Scincella incerta*	NCA		x	Core, Buffer	LC	15
	Family: Sphaerodactylidae						
27	*Sphaerodactylus continentalis*	NCA			Buffer	NE	8
	Family: Teiidae						
28	*Holcosus festivus*	Widespread			Buffer	LC	10
	Family: Xantusiidae						
29	*Lepidophyma flavimaculatum*	NCA			Core, Buffer	LC	9
	Order: Squamata (Snakes)						
	Family: Colubridae						
30	*Dendrophidion rufiterminorum*	Widespread			Buffer	NE	16

Nr.	Taxon	Geographic Distribution	Wilson & McCranie (2004)	Townsend et al. (2006)	CNP zonation	Conservation Status	EVS Score
31	*Drymarchon melanurus*	Widespread	x		Core, Buffer	LC	6
32	*Drymobius chloroticus*	Widespread	x	x	Core, Buffer	LC	8
33	*Drymobius margaritiferus*	Widespread			Core, Buffer	LC	6
34	*Lampropeltis abnorma*	Widespread		x	Core, Buffer	LC	9
35	*Leptophis modestus*	NCA			Core	VU	14
36	*Leptophis praestans*	NCA	x	x	Core, Buffer	NE	NA
37	*Mastigodryas dorsalis*	NCA	x	x	Core, Buffer	LC	14
38	*Mastigodryas melanolomus*	Widespread			Buffer	LC	11
39	*Oxybelis koehleri*	Widespread			Buffer	NE	NA
40	*Phrynonax poecilonotus*	Widespread		x	Core, Buffer	LC	7
41	*Scolecophis atrocinctus*	Widespread			Core, Buffer	LC	13
42	*Senticolis triaspis*	Widespread			Buffer	LC	7
43	*Spilotes pullatus*	Widespread			Buffer	LC	6
44	*Stenorrhina degenhardtii*	Widespread	x		Core, Buffer	LC	9
45	*Stenorrhina freminvillei*	Widespread			Buffer	LC	7
46	*Tantilla schistosa*	Widespread	x	x	Core	LC	7
47	*Tantillita lintoni*	NCA			Buffer	LC	12
	Family: Dipsadidae						
48	*Adelphicos quadrivirgatum*	Widespread		x	Core, Buffer	LC	10
49	*Amastridium sapperi*	Widespread			Buffer	LC	10
50	*Coniophanes imperialis*	Widespread			Core, Buffer	LC	9
51	*Geophis nephodrymus*	**Endemic**		x	Core	VU	16
52	*Geophis sartorii*	NCA			Core, Buffer	LC	10
53	*Hydromorphus concolor*	Widespread			Buffer	LC	12
54	*Imantodes cenchoa*	Widespread	x	x	Core, Buffer	LC	6
55	*Leptodeira septentrionalis*	Widespread			Core, Buffer	LC	7
56	*Ninia diademata*	Widespread			Core, Buffer	LC	6
57	*Ninia espinali*	NCA	x		Core	NT	14
58	*Ninia sebae*	Widespread			Core, Buffer	LC	4
59	*Omoadiphas aurula*	**Endemic**		x	Core, Buffer	VU	16
60	*Pliocercus elapoides*	Widespread			Core, Buffer	LC	10
61	*Rhadinella kinkelini*	NCA			Core, Buffer	LC	13
62	*Rhadinella montecristi*	NCA		x	Core	VU	14
63	*Rhadinella pegosalyta*	**Endemic**		x	Core	VU	16
64	*Sibon dimidiatus*	Widespread			Core	LC	10
65	*Sibon nebulatus*	Widespread			Core, Buffer	LC	5
66	*Xenodon rabdocephalus*	Widespread			Buffer	LC	11
	Family: Elapidae						
67	*Micrurus diastema*	Widespread	x	x	Core, Buffer	LC	9
68	*Micrurus nigrocinctus*	Widespread			Core, Buffer	LC	10
	Family: Sibynophiidae						
69	*Scaphiodontophis annulatus*	Widespread		x	Core, Buffer	LC	11
	Family: Typhlopidae						
70	*Amerotyphlops stadelmani*	Endemic			Core	VU	12
	Family: Viperidae						
71	*Metlapilcoatlus mexicanus*	NCA		x	Core, Buffer	LC	11
72	*Bothriechis marchi*	Endemic	x	x	Core, Buffer	EN	16
73	*Bothriechis schlegelii*	Widespread			Buffer	LC	11
74	*Bothrops asper*	Widespread		x	Core, Buffer	LC	10
75	*Cerrophidion wilsoni*	NCA	x	x	Core, Buffer	NE	15

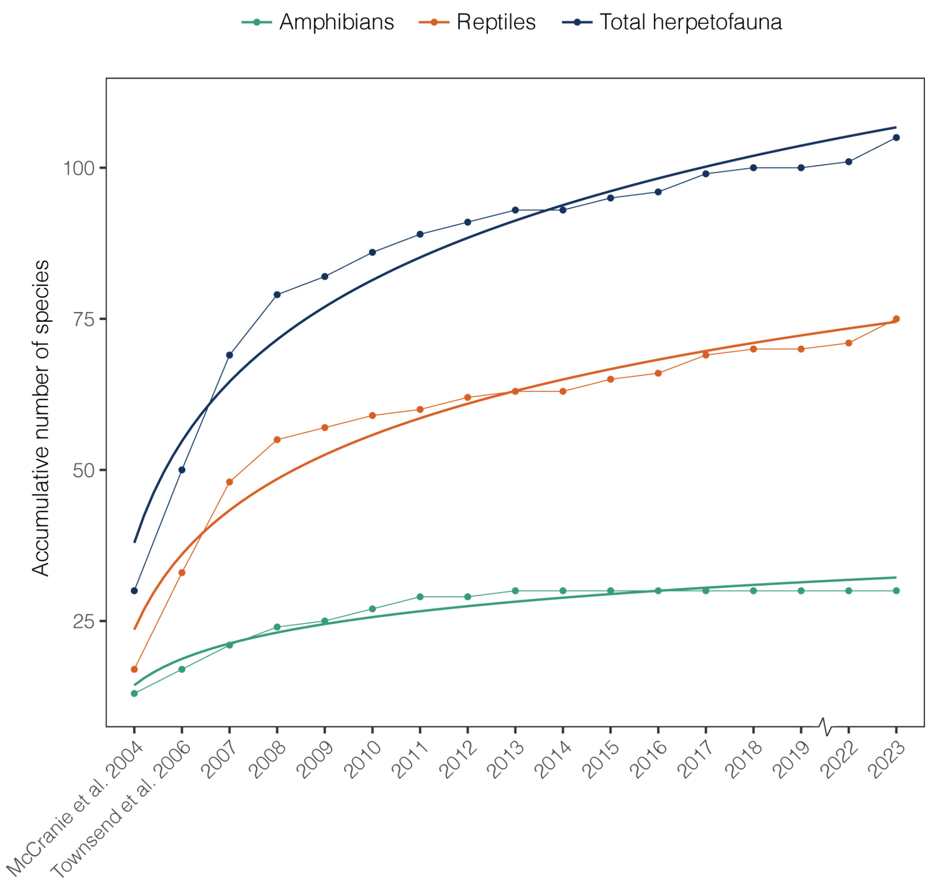

Figure 3. Species accumulation curves and logarithmic approximation of the reptile and amphibian species recorded in Cusuco National Park in the study period 2007–2023, following the earlier works of Wilson and McCranie (2004) and Townsend et al. (2006).

There were only seven total reported adult individuals in Honduras, five of whom were observed in the core zone of CNP from 2009–2018 (Solís et al. 2017; Thorp et al. 2021). The park represents a crucial stronghold for this little-known species, as forests in Quebrada Grande, Copán, have disappeared, making the forests of CNP its main refuge.

The other newly recorded amphibians were mostly observed within lower-elevation habitats, largely within the buffer zone of CNP. Additions to the park's salamander diversity stemming from these lower areas include *Bolitoglossa dofleini* (Werner 1903) and *Bolitoglossa nympha* Campbell et al., 2010, which are both endemic to nuclear Central America. The more widely distributed *Bolitoglossa mexicana* Duméril et al., 1854 was the final salamander species to be registered for CNP, with the first observation in 2013. Like the latter two salamanders, it seems to thrive in the areas of cattle pastures and agricultural plantations around Santo Tomas. Important anuran records include the Critically Endangered Honduran endemic *Craugastor coffeus* (McCranie and Köhler 1999), observed around the field site of Santo Tomas (also see Kolby 2009). We furthermore highlight the presence of the endangered *Craugastor laevissimus* (Werner 1896) (Suppl. material 1: plate 3) within CNP, following evaluation of photographic and bioacoustic observations made around the field site of Santo Tomas. The toad species *Incilius campbelli* (Mendelson 1994), endemic to nuclear Central America, was the final anuran reported for CNP, with a single individual observed close to Santo Tomas in 2013. No additional amphibian species were recorded in CNP during the subsequent decade (Fig. 3).

In addition to the four amphibian species that are endemic to CNP, three species in the park (and putatively *Craugastor* aff. *nefrens*) are endemic to Honduras, and 17 are endemic to nuclear Central America (Table 1). Almost half of the recorded amphibian species are presently listed as either Critically Endangered (five) or Endangered (eight), and four species are listed as Vulnerable (IUCN 2022). The threatened status of the amphibian diversity in CNP is reflected by their respective Environmental Vulnerability Scores (EVS), with a total of 18 amphibian species present in the park being attributed a high EVS (14–20), while just five species show a medium EVS (10–13), and six relatively widespread species show a relatively low EVS (3–9). Threatened amphibian species were found to be distributed across both the core and buffer zones, with the core zone presenting the sole refuge for several highly endangered taxa (Fig. 4).

Reptiles

Since the inventory of Townsend et al. in 2006, an additional 46 reptile species were recorded across the 17-year study period: 18 lizard species and 28 snake species. These records double the reptile diversity documented in CNP up until 2007 and constitute around 26% of the 264 species known from Honduras (McCranie 2015). Novel records from within the reserve's high-elevation core zone include the snake species *Leptophis modestus* (Günther 1872) (Suppl. material 2: plate 7), a cloud forest specialist that is endemic to nuclear Central America. The majority of the newly added reptile species were recorded at relatively

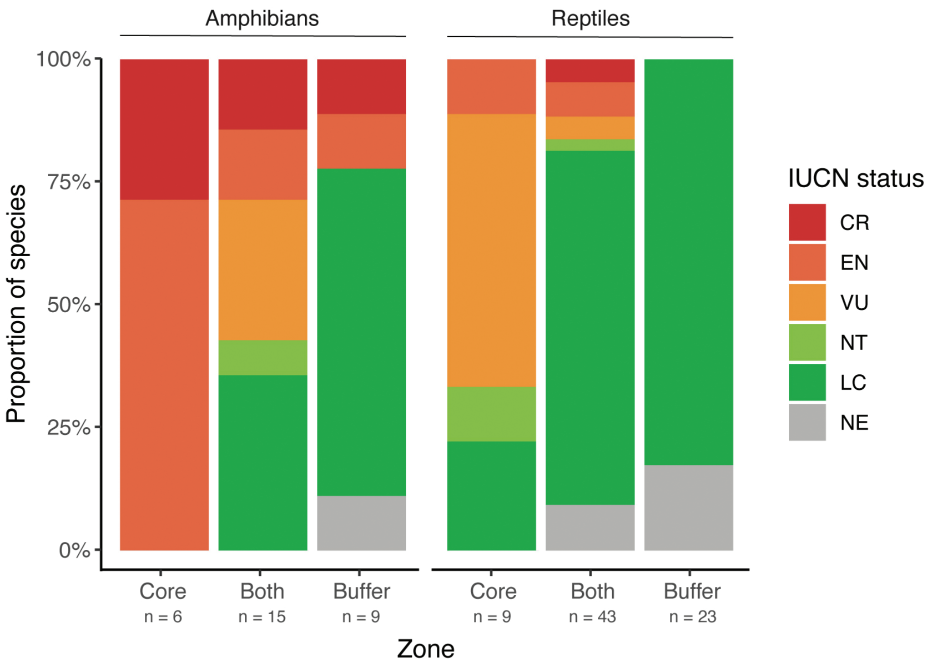

Figure 4. The IUCN status of amphibian and reptile species recorded in the core and/or buffer zone of Cusuco National Park in the period 2007–2023. The delimitation of the core and buffer zones is based on the management plan of the Corporación Hondureña de Desarrollo Forestal (see Fig. 1). IUCN status: Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near-Threatened (NT), Least Concern (LC), and Not Evaluated (NE).

low altitudes, with observations centred around the field sites of Buenos Aires and Santo Tomas. These include the presence of *Amerotyphlops stadelmani* (Schmidt 1936), a Honduran endemic blind snake that is known from just a few individual records and localities. A single individual was found dead around forest clearings near the intersection of the core and buffer zones in the vicinity of Santo Tomas. The occurrence of the Honduran endemic lizard, *Laemanctus julioi* McCranie, 2018, was confirmed by a single individual captured near Buenos Aires in 2023. Considering a recent range extension (Antúnez Fonseca et al. 2021), CNP may be the most north-westerly record for *L. julioi* in the Atlantic versant of Honduras, an important record for a species that was previously considered exclusive to the south-central Pacific versant (McCranie 2018a). Among the herpetofauna recorded in CNP, the gecko species *Hemidactylus frenatus* Duméril & Bibron, 1836 thus far presents the only confirmed introduced species.

Besides the four reptile micro-endemic species only found in CNP, seven taxa are Honduran endemics, and 18 species are restricted to nuclear Central America (Table 2). Of all presently recorded reptile species, two are listed as Critically Endangered on the IUCN Red List, four are listed as Endangered, and seven species are listed as Vulnerable (IUCN 2022). However, the conservation status of eight reptile species, mostly newly revised taxa, remains unassessed. Of the 13 species that are listed under a threatened category in the IUCN Red List, 12 species similarly show a high EVS (14–20). Among the taxa with a lower IUCN threat level, six species also show a high EVS, 23 species show a medium EVS (10–13), while 28 species were attributed a relatively low EVS (3–9). Reptile species of high conservation concern were found to be distributed across both the reserve's core and buffer zones, with the highest relative proportion of endangered taxa occurring towards the core zone (Fig. 4).

Taxonomic changes, notes, and decisions

Since the last overview of amphibians and reptiles in CNP was published by Townsend et al. (2006), the Mesoamerican herpetofauna has been subject to numerous taxonomic discoveries and revisions. We provide here a brief outline of the taxonomic decisions made in our species list in view of recent changes in nomenclature and ongoing taxonomic debate, as well as recent molecular studies and range extensions.

For the amphibians, this includes several generic revisions, with the placement of the former *Isthmohyla melacaena* in the genus *Bromeliohyla* (Faivovich et al. 2018), as well as the revision of *Rana maculata* following paraphyletic relationships recovered in the genus *Lithobates* (Yuan et al. 2016). Among the amphibian species present in CNP, members of the genus *Craugastor* comprise significant cryptic diversity. A recent molecular assessment was therefore performed to characterise the species diversity within this genus, in which focus was put on a combined phylogenetic and morphological analysis of the *C. laticeps*-like species group (unpublished data). This indicated the presence of four disparate lineages, corresponding to earlier records of *C. rostralis*, *C. chac*, *C. laticeps*, and *C. charadra*, in addition to the more readily distinguishable *C. milesi*, *C. laevissimus*, and *C. coffeus*. However, as McCranie (2018b) indicated, the presence of nominal *C. chac* in Northwest Honduras might be restricted to lower elevations, and hence we provisionally term this species lineage *C.* cf. *chac*, warranting further studies on its status. An ongoing molecular assessment highlighted a disparate lineage from the *Craugastor campbelli* complex in the park, provisionally termed *C.* aff. *nefrens*, and is awaiting further studies on its status (M. Jocque, pers. comm.). Additionally, *Cryptotriton nasalis* was previously considered a CNP and Honduran endemic, but after having recently been discovered just across the border in Guatemala (McCranie and Rovito 2014), it is now designated as being endemic to nuclear Central America. However, similar to *Nototriton brodiei*, it likely resides in a highly confined distribution range, is therefore still of particular conservation concern, and is still listed as Endangered by the IUCN.

For the reptiles, taxonomic changes include the recognition of the species *Anolis mccranie*, following its subdivision from the *Anolis tropidonotus* species complex (Köhler et al. 2016). We furthermore include *Diploglossus montanus* following paraphyletic relationships recovered with respect to the genus *Celestus* (Pyron et al. 2013) and recognize *Abronia moreletii* as synonymous with the genus *Mesaspis* (Gutiérrez-Rodríguez et al. 2020). *Sceloporus schmidti* was included in our list as a valid species in northwest Honduras in place of *S. malachiticus* following McCranie (2015), while the designations of *Scincella cherriei* and *S. incerta* follow generic revisions of the genus *Sphenomorphus* (see Linkem et al. 2011). *Lampropeltis abnorma* was included in our list after its split from *L. triangulum* (Ruane et al. 2014), while *Metlapilcoatlus mexicanus* was revised after polyphyletic relationships within the genus *Atropoides* (Campbell et al. 2019). *Geophis sartorii* is included following the revision of *Tropidodipsas* (Grünwald et al. 2021). *Siderolamprus montanus* is now included following generic revisions of *Diploglossus* (Schools and Hedges 2021). In addition, *Leptophis praestans* was included following taxonomic revisions in the *L. ahaetulla* complex (DE Albuquerque and Fernandez 2022). While a recent analysis showed that Honduran members of the *Micrurus diastema* complex might comprise a different lineage corresponding to *M. aglaeope*, it was concluded that this species designation needs additional study (Reyes-Velasco et al. 2020). Comparable to the amphibian genus *Craugastor* as described above, members of the reptile genus *Anolis* include various cryptic taxa and species complexes, making field identification of anoles highly challenging. We therefore first referenced our observations to the comprehensive overview of known species localities provided by McCranie and Köhler (2015), which corroborated the presence of 12 species in the reserve's core and buffer zone. Initial genetic findings in combination with field identifications also confirmed the presence of *A. uniformis* in the park (Suppl. material 2: plate 4), of which the closest known localities were noted to occur around El Paraìso, northeast of CNP (McCranie and Köhler 2015). However, an ongoing DNA barcoding study has highlighted that several more species might be present in the park, including potential candidate species (O'Brien et al., unpublished). Hence, the current species list presents a conservative estimate of anole diversity in the park. Note that here we adhere to the genus name *Anolis* as opposed to *Norops*, following recent controversy about this generic revision coined for the clade composed of "beta anoles" (see Poe 2013), in which all species in CNP are classified.

Discussion

More than 400 species of amphibians and reptiles are currently reported to occur in Honduras (Solís et al. 2014; McCranie 2015). Within the core and buffer zones of CNP, at least 105 species have been recorded thus far, amounting to around 26% of recorded Honduran herpetofaunal diversity. This highlights CNP as an exceptionally diverse national park in Honduras and as a hotspot of Mesoamerican herpetofaunal diversity and endemicity. Its location at the northern edge of the biogeographically isolated Sierra del Merendón partially explains the relatively high number of micro-endemics (four amphibians and four reptiles). These observations are echoed by inventories of other species communities in CNP, where, for instance, birds (Martin et al. 2016), bats (Medina-van Berkum et al. 2020), and non-volant mammals (Hoskins et al. 2018) were also found to exhibit remarkable species diversity across its extensive elevational range. However, it is important to note that the park has received an exceptional amount of research effort over more than 15 years, which is much more than other Honduran cloud forest regions. There are several other protected zones in Honduras that exceed CNP in both land area and habitat diversity and show a similar elevational range (CNP reaching 2,243 m/asl). For instance, Pico Bonito National Park covers an area of 565 km^2 and ranges up to an elevation of 2,480 m/asl. Across a limited number of surveys, already 82 species of amphibians and reptiles were recorded in Pico Bonito National Park (McCranie and Solís 2013). Another example is the protected yet highly imperilled area of Texiguat, where 39 species of amphibians and reptiles have thus far been observed across a similar elevational gradient (Townsend et al. 2010). Hence, biodiversity assessments are urgently warranted in other extant cloud forest ecosystems in order to refine species distribution patterns across Honduras and the wider Mesoamerican biodiversity hotspot.

Early herpetofaunal surveys in CNP were largely focused on the eastern sections of the present-day core zone (Wilson and McCranie 2004; Townsend et al. 2006). Since then, the monitoring focus has been expanded to cover both the west side of the mountain as well as lower elevations, including transects situated in the warmer and drier habitats in the designated buffer zone of CNP (see Fig. 2C). Many additions to our updated species list, and in particular many reptile species, are a result of extended monitoring efforts in these previously underexplored habitats. This is reflected by a surge in new species records in the period 2007–2008 following the start of research activities in these field sites (Fig. 3). During the course of the study period, the rate of reptile and amphibian species detections slowed down considerably (Fig. 3), and we expect the large majority of the amphibian diversity inhabiting CNP to now be recorded. However, additional reptile species continued to be observed in recent field seasons in the period 2015–2023. In addition to observations of relatively thermophilic species at lower elevations, we expect that novel records in the reserve's core zone might still arise from lesser studied microhabitats such as the forest canopy and in the form of cryptic leaf-litter dwelling or (semi) fossorial species. Further molecular studies may further highlight additional taxonomic diversity among the various species groups, which is likely to increase the known species diversity within the park. Thus, although we included 105 species in our updated species list, this figure is likely a conservative estimate.

While the herpetofauna diversity in CNP is unquestionably high, several species have been sighted only once during the study period, and records of several others are sporadically dispersed across many years. This pattern is particularly evident in snake species, which compose around 43% of the known herpetofauna in CNP. The resulting variability highlights the challenge of accurately determining seasonal species occurrence because detection can be subject to various environmental constraints. Consequently, assessing the true abundance, loss, or replacement rate of species in CNP becomes a considerable conservation challenge.

Furthermore, there remain potential additional records for several other snake species in the long-term database, such as *Oxyrhopus petolarius* (Linnaeus 1758), *Ninia pavimentata* (Bocourt 1883), and *Rhadinella anachoreta* (Smith and Campbell 1994). However, for the present study, we were unable to confirm them with certainty due to a lack of sufficient evidence, such as being identified by an expert or unambiguous photographic evidence. Additionally, *Xenodon rabdocephalus* (Wied-Neuwied 1824) is likely present in CNP, as indicated by photographs of two specimens (one roadkill) taken near the core and buffer zone in 2023 (Brown TW, pers. obs.), albeit recorded outside the annual survey season.

As a more comprehensive picture of the amphibian and reptile diversity in CNP is starting to take shape, continued monitoring efforts are becoming essential to assess the response of its herpetofaunal community to the combined effects of ongoing environmental change. With the solidification of a long-term dataset, future analyses can start shifting their focus to changes in relative species abundance and species distributions within the reserve. This is especially prudent given the notion that cloud forests are highly vulnerable to climatic change, with shifting temperature and precipitation regimes causing upslope elevational shifts in vegetation patterns and animal distribution ranges (Foster 2001; Laurance et al. 2011). As many specialised cloud forest species inhabit narrow microclimatic niches and, thus, highly specific elevational ranges, these changes have the potential to cause near-term extinctions (the "escalator to extinction" e.g., Freeman et al. 2018) and a shift in community composition. Such patterns have already started to form in CNP's bird community (Neate-Clegg et al. 2018). As ectothermic vertebrate communities include relatively more high-elevation specialists (Laurance et al. 2011), these effects might be even more pronounced among herpetofauna.

Habitat destruction has been accelerating at an alarming pace and threatens all wildlife and habitats in CNP. Being a relatively small reserve with a core zone of 7,690 ha, which is largely isolated from other high-elevation habitats, this region is highly sensitive to disturbances. Despite its protected status as a national park, CNP has no permanent forest guards, and a growing population around the mountain, together with a challenging economic situation over the past decade, increases pressure on the remaining ecosystem. Deforestation for coffee plantations and livestock led to 7% of the park's forested area being lost between 2000 and 2017 (Hoskins 2019). This deforestation is increasingly encroaching within the reserve's core zone, posing an immediate threat to this vulnerable cloud forest ecosystem and its endemic species. As such, the combined effects of habitat degradation and climate change are likely to strongly exacerbate biodiversity loss within a short timeframe (Ponce-Reyes et al. 2012). The reserve's buffer zone accommodates limited settlement and licenced farming practices and has little primary habitat left. Nevertheless, our findings across transects in the buffer zone indicate that the existing mosaic of disturbed forest fragments and anthropogenic landscape features still supports a wide variety of reptiles and amphibians. Besides the paramount importance of safeguarding the remaining pristine cloud forest in the core zone, sustained efforts are therefore also needed to preserve extant forest patches in the buffer zone. The protection of cloud forests such as CNP thus becomes increasingly dependent on successful community-based conservation schemes that incorporate sustainable socio-economic benefits to nearby livelihoods (Hostettler 2002; Bubb et al. 2004). For instance, payment for ecosystem services (PES) programmes might aid in the participatory protection of cloud forests. Nevertheless, this only becomes possible once the environmental value of cloud forests is adequately recognised and exceeds the short-term gains of habitat conversion (Martínez et al. 2009).

The persistence of many amphibian species in CNP is particularly jeopardised. Of the 13 species in the reserve that are listed as Critically Endangered or Endangered by the IUCN Red List, 11 are stated to be in continued decline, and in the other two, the population trend is unknown. In addition to other environmental stressors, the amphibian diversity in CNP is imperilled by the spread of emerging infectious diseases, most notably the amphibian chytrid fungus *Batrachochytrium dendrobatidis* (*Bd*) (Longcore et al. 1999). This pathogen causes the lethal disease chytridiomycosis, which has been linked to global amphibian population declines and extinctions and has had especially devastating effects on Neotropical amphibian communities (Scheele et al. 2019). Reports of declines of Critically Endangered amphibian species in CNP prompted an investigation in 2007, revealing widespread *Bd* presence in the park with a high prevalence of infection in Endangered and Critically Endangered species, such as the endemic *Plectrohyla dasypus* McCranie & Wilson, 1981 and *P. exquisita* McCranie & Wilson, 1998; Kolby et al. 2010). An array of *Bd* dispersal mechanisms were identified in CNP, including detection not only in stream water and bromeliad reservoirs but also potential aerial dispersion by rainwater, waterfall spray, and residues on leaves resulting from contact with amphibian skin (Kolby et al. 2015 a, b). Stream-associated amphibians in CNP were found to be five times more susceptible to *Bd* infection than bromeliad-dependent species (Blooi et al. 2017). Yet, even strictly canopy-dwelling species can be infected; for example, *Bd* was detected in 100% (n=4) of the sampled *E. salvaje* during 2017–2018 (Thorp et al. 2021). Further investigation and continued disease monitoring in CNP are therefore crucial to detecting long-term changes in host-pathogen dynamics. The recently established Honduras Amphibian Rescue and Conservation Centre (HARCC) is actively researching methods to protect vulnerable species within habitats where this pathogen is present. On the upside, *Craugastor milesi*, a species previously listed as Extinct and now listed as Critically Endangered, was rediscovered in CNP in 2008 after last being seen in the 1980s when it was still locally abundant (see Kolby and McCranie 2009), thus providing prospects for its persistence in the park. A second observation of *C. milesi* (Kolby, Brown, Solis, pers. obs.) was registered in 2013, but subsequent monitoring efforts have failed to detect the species again, and it is possible the species might have disappeared from CNP in recent years (Solís et al. 2017). Its continued presence in the park thus remains to be reaffirmed. If the species has indeed disappeared from CNP, this would constitute the first local extinction among all previously documented herpetofaunal diversity (Wilson and McCranie 2004; Townsend et al. 2006; the present study).

Less information is available on the conservation status of reptile species present in CNP, with several remaining to be evaluated by the IUCN. However, an extended conservation assessment by García-Padilla et al. (2020) recently highlighted 11 amphibian and 12 reptile species in CNP as being among the most threatened 'priority level' species in Mesoamerica based on their combined endemic distribution range and high EVS scores. Their present IUCN status is therefore not an indication of lower conservation status than the amphibians, but rather indicates the absence of data sufficient to designate a particular level of concern, and thus many species urgently warrant further research and conservation attention. Furthermore, it can be expected that amphibian declines have cascading effects on reptile diversity, with reptile declines following the decline and extirpation of their amphibian prey (Zipkin et al. 2020). All the CNP endemic reptiles have been assessed by the IUCN Red List, including *Anolis amplisquamosus* (McCranie et al. 1993), which is listed as Critically Endangered and the three endemic snake species *Geophis nephodrymus* Townsend & Wilson, 2006, *Omoadiphas aurula* Köhler et al., 2001, and *Rhadinella pegosalyta* (McCranie, 2006), which are presently considered Vulnerable.

Much of the herpetofaunal diversity in Mesoamerica likely remains undescribed, with high rates of species discoveries taking place in concert with high rates of habitat destruction (Johnson et al. 2015; García-Padilla et al. 2020). Besides the Wallacean shortfall, uncertainty about the actual species diversity existing in areas (the Linnean shortfall) is, therefore, another factor hindering conservation efforts in biodiversity hotspots (Whittaker et al. 2005). Additional field surveys are therefore not only necessary to fill crucial knowledge gaps in species occurrences but also to gather the molecular, morphological, and ecological data necessary to disentangle undescribed diversity. DNA barcoding studies based on a standardised set of loci could, in this way, provide an increasingly affordable and scalable means to facilitate species delimitation in understudied tropical assemblages (Vences et al. 2005; Menegon et al. 2017). In CNP, an assessment of the cryptic species diversity within *Anolis* is presently underway, and further studies are assessing the status of several candidate species. Moreover, by gathering comparative genetic data across time, it could be evaluated to what extent populations retain their genetic diversity and connectivity within and between increasingly fragmented and imperilled forest regions (Dixo et al. 2009). While the present paper is directed at providing a renewed overview of herpetofaunal species richness in CNP, such complementary studies in the park, the broader Sierra de Omoa, and other forest regions across Honduras would therefore strongly benefit our understanding of regional biodiversity patterns and dynamics.

Conclusion

CNP is an irreplaceable hotspot of Mesoamerican biodiversity, providing habitat to a remarkable 105 species of reptiles and amphibians, including a high number of local, national, and regional endemics. Ongoing threats to CNP, in particular its high deforestation rates, place strong conservation urgency on this unique ecosystem and its biodiversity. A detailed understanding of the importance of CNP's herpetofaunal community has only been possible due to our long-running monitoring program. Increased surveys in other extant forest regions are thus necessary to provide essential baseline biodiversity data and inform the timely and targeted conservation efforts necessary to safeguard the future of Mesoamerica's irreplaceable herpetofaunal diversity.

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Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

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Author contributions

Conceptualization: MJ JEK. Methodology: All authors helped in collecting data. Formal analysis (taxonomic decisions): JMS, TB. Investigation: AEL, JMS, TB, GL, SEWG, TEM, JRG, JEK, JE, MJ. Data Curation: SEWG. Writing - Original draft: JE, AEL. Writing - Review and Editing: All authors. Visualization: AEL, JE, OB. Project administration: AEL, JE.

Author ORCIDs

Alexandra E. Lakin https://orcid.org/0000-0003-4410-7195
José M. Solís https://orcid.org/0000-0002-5808-7386

Tom Brown https://orcid.org/0000-0003-2333-7127
Stephen E. W. Green https://orcid.org/0000-0002-3979-0578
Thomas E. Martin https://orcid.org/0000-0003-2347-982X
Josue R. Galdamez https://orcid.org/0009-0001-2858-180X
Jonathan E. Kolby https://orcid.org/0000-0002-8241-4711
Jesse Erens https://orcid.org/0000-0001-8503-4610

Data availability

All of the data that support the findings of this study are available in the main text or Supplementary Information.

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Supplementary material 1

Photographic vouchers of amphibian species recorded in Cusuco National Park during the research period 2007–2023

Authors: Alexandra E. Laking, José M. Solís, Tom Brown, Simon T. Maddock, Oliver Burdekin, Peter Taylor, George Lonsdale, Stephen E. W. Green, Thomas E. Martin, Josue R. Galdamez, Jonathan E. Kolby, Jesse Erens, Merlijn Jocque

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Supplementary material 2

Photographic vouchers of reptile species recorded in Cusuco National Park during the research period 2007–2023

Authors: Alexandra E. Laking, José M. Solís, Tom Brown, Simon T. Maddock, Oliver Burdekin, Peter Taylor, George Lonsdale, Stephen E. W. Green, Thomas E. Martin, Josue R. Galdamez, Jonathan E. Kolby, Jesse Erens, Merlijn Jocque

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