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THE "EMPTY FOREST SYNDROME" AND THE HERPETOFAUNAL COMMUNITIES IN LAOS (SOUTH-EASTERN ASIA)

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Nowadays, Laos remains one of the scientifically least known countries of Asia in terms of herpetological knowledge. Here, we evaluate composition of species in freshwater ecosystems (main river courses) and terrestrial ecosystems (forests) in two distinct regions using Visual Encounter Surveys along designed transects, examination of fishers' catches and standardized interviews. In Northern Laos, we recorded only 18 reptile individuals (2 turtle and 1 snake species). Interview surveys demonstrated that in Nam Xam River, fishers are more likely to hunt turtles and we identified one potential site where the world's rarest turtle, Rafetus swinhoei, could be still present in the wild. In Nam Et Phou Louey National Park, we found 19 reptile species (8 lizard, 10 snake, 1 turtle species) in the different study sites, demonstrating a low species density in all different surveyed habitats. In Central/Southern Laos, we observed 30 species of reptiles (14 snake, 16 lizard, 35 amphibian species). Our study offers preliminary insights into the composition of amphibians and reptiles in Laos. The great majority of the species were non-threatened or not evaluated, and a few were threatened, suggesting that more research is needed to proper understand the conservation status of Laos' herpetofauna. We highlighted, indirectly by interviews with local fishers, the possible presence of the turtle Rafetus swinhoei, thus providing a new hope for avoiding the extinction of this species. Finally, we observed a relatively low number of species in each habitat type, which is remarkably lower than in tropical forests of other continents or of nearby south-east Asian countries, indicating that the herpetofauna communities in Laos are depleted, reflecting an 'empty forest syndrome'.

Keywords: Amphibia; community ecology; conservation; habitat types; Laos; Reptilia.

INTRODUCTION

Situated in south-eastern Asia, the Lao People's Democratic Republic (hereafter Laos) remains one of the scientifically least known countries of the continent in terms of herpetological knowledge (see, e.g., Stuart and Heatwole, 2008; David and Ineich, 2009; Ziegler, 2016). Until recently, new country records (e.g., Teynié and Da-

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vid, 2007; Luu et al., 2013; Nazarov et al., 2014) and even new species (e.g., Stuart and Chan-ard, 2005; Grismer, 2010; Schneider et al., 2011; Nguyen et al., 2010; Nazarov et al., 2014; Teynié et al., 2015; Luu et al., 2016, 2017, 2018; Nazarov et al., 2018; Phimmachak et al., 2018, 2019; Eliades et al., 2019; Sitthivong et al., 2019; Nguyen et al., 2020; Schneider et al., 2020) have been described from field researches, especially in the forested and poorly explored regions (Das and Van Dijk, 2013). Despite being little known in terms of its biological diversity, Laos has been exploited intensively for human development reasons (e.g., Poulsen and Luanglath, 2005; Singh, 2008; K. Hemmavanh et al., 2010). Due to rampant deforestation (Lamb, 2011) and bushmeat consumption, forests of Laos are becoming increasingly empty (Long et al., 2017; Pruvot et al., 2019) and many noteworthy vertebrate species highly threatened (e.g., Ruggeri and Timmins, 1996; Timmins and Duckworth, 1999; Brickle et al., 2008). Thus, describing biological diversity and determining patterns of community ecology and species richness variation across the various habitat types of Laos is urgently required to define better conservation programs and strategies in this biodiversity-rich Asian country (Harrison et al., 2016).

Here, we present the results of baseline surveys conducted in two distinct regions of Laos through a suite of different field methodologies. These field methodologies would include (i) Visual Encounter Surveys (VES) along designed transects (Heyer et al., 1994), and (ii) examination of fishers' catches and standardized interviews with fishers (Le Duc et al., 2020a). VES was used in order to inventory terrestrial herpetofauna species and to provide preliminary data on their assemblage structure and variation by habitat type and altitude, ambient temperature and humidity, and sampling effort. Examination of fishers' catches and standardized interviews with fishers were used to obtain data on freshwater turtles that otherwise would have been almost impossible to observe because of the duration of surveys. Here, we also provide some conservation considerations on the encountered taxa.

MATERIAL AND METHODS

Study area

Northern Laos survey. The field surveys were carried out in the Houa Phan Province (i) along three main rivers system, Nam Xam, Nam Ma, and Nam Et Rivers, and (ii) in Nam Et Phou Louey National Park.

Nam Xam River (19.987 °N 104.632 °E) flows from the Xamneua district to the Xam Tay district of Laos, changing its name to Song Chu river upon entering Vietnam and flowing through Nghe An and Thanh Hoa provinces. The Nam Xam River is about 165 km long in Laos with the main catchment being in Xam Tay district. It also runs through Nam Xam Biodiversity Conservation Area at the border of Vietnam. The Ma River (20.7199 °N 104.3687 °E) has its origin in the Dien Bien province in Vietnam, then flows through Nam Et, Xieng Khor, and Sobbao districts of Laos and then returns to Vietnam's Thanh Hoa province (see http://thanhhoa.gov.vn/portal/pages/dieu-kien-tu-nhien.aspx). The Ma River has a total length of 528 km, with about 80 km in the Houa Phan province (Laos). The Et River is a tributary of the Ma River in Et district, Houa Phan Province, Laos. The field surveys were carried out in the Houa Phan province in northern Laos, along the Ma River, Nam Xam River (Chu River in Vietnam) and Et River. Typical habitat features of the surveyed areas are given in Fig. 1.

Nam Et Phou Louey National Park (20.136 °E 103.649 °N) is among the largest protected areas in Laos (5959 km^2), with altitude ranging from 400 – 2280 m a.s.l. The protected area consists of mixed evergreen-deciduous forest <1500 m a.s.l., with a transition to an evergreen forest at 1500 – 1800 m a.s.l., and with beech and rhododendron species above 1800 m (Davidson, 1998; Johnson et al., 2009).

Central-Southern Laos survey. The field surveys were made in the Phou Hin Boun Takek area, situated in the Khammouane province. It is a karst environment constituted by limestone and dry forests. This protected area mostly consists of secondary forest which is still being exploited to some degree. The landscape is hilly-montane. The additional surveyed area were the forests in the Champasak province of southern Laos, mainly the Boloven Plateau (730 – 1400 m a.s.l.). The general habitat consisted of mature and secondary forest patches (under exploitation), and coffee plantations interspersed around the forest patches. Typical habitat features of the surveyed areas are given in Fig. 2.

Protocol

Northern Laos survey. The surveys in northern Laos consisted of distinct phases in order to evaluate the species' compositions in freshwater ecosystems (main river courses) and terrestrial ecosystems (forests; see below for the description of the surveyed forest types).

Surveys along the main river courses were conducted from 29th November to 5th December 2019. Sites for surveys were reached by motorbike using dirty roads (about 730 km in total). Because of the short time available to make the surveys, and due to the target habitat being the large rivers, the focus was put on surveying the villages

Fig. 1. Typical habitat features of the surveyed areas in northern Laos. All photos by T. Pham Van and O. Le Duc.

Fig. 2. Typical habitat features of the surveyed areas in central-southern Laos. All photos by N. Maury.

in order to examine hunters' and fishers' catches, and also to perform interviews with fishers to learn more about the turtles within the study area. A total of 35 interviews were conducted during the field survey with fishers on three rivers — Et/Ma rivers (20 interviews) and Xam River (15 interviews) in Houa Phan Province of eastern Laos. We used the same standard set of 31 questions as described in Le Duc et al. (2020a). Respondents were selected randomly and all were active fishers at the time of the interview. Aside from collecting basic statistical data, special emphasis was given to understanding whether there were any recent sightings for large softshell turtles (incl. *Rafetus swinhoei*, the most threatened chelonian species in the world) (Stanford et al., 2018, 2020).

Surveys of the terrestrial ecosystems were carried out from 19th to 30th of March 2020, in Nam Et Phou Louey National Park (500 – 1300 m a.s.l.). The team spent a total of 58 man-hours in the field and conducted 64.5 km of transects. The survey followed a non-linear transect inside a mature forest with three researchers being involved. Reptiles were captured by hand or by snake stick in the case of venomous species. The habitat type, ground temperature (measured by the infrared thermometer Etekcity), humidity, and GPS coordinate (GPS Garmin 60 CSX) of each captured/observed individual were recorded. The following habitat types were explored:

a) limestone forest is essentially dry forest growing on limestone terrain This forest was situated at about 1 km from the village, the habitat contained several small

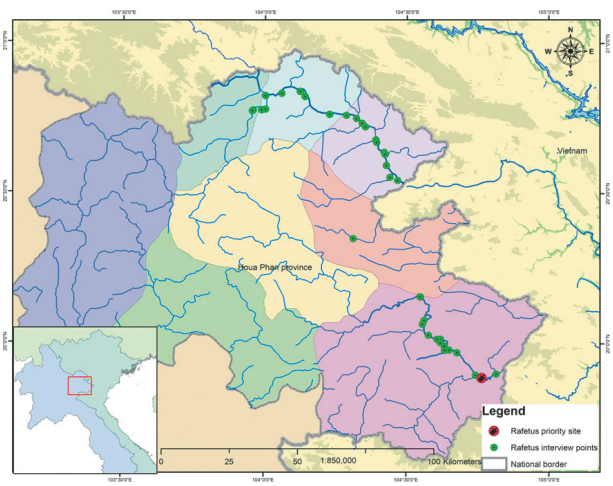

Fig. 3. Map of northern Laos showing the surveyed area (both by motorbike, boat and by walked transects) during the present study.

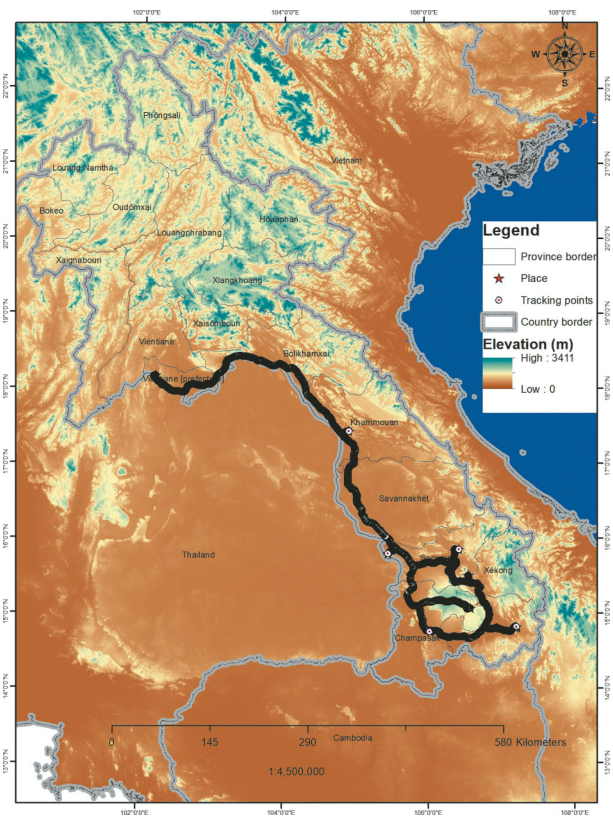

Fig. 4. Map of central-southern Laos showing the surveyed area (both by motorbike and by walked transects) during the present study.

caves and rocky cliffs covered by pioneer trees and vines. The caves along the limestone mountains were our main target for searching the unique species of genera *Cyrtodactylus* and *Hemidactylus*, as well as some snakes species.

b) mature forest included a mix of bamboo forest and evergreen forest far away from any human settlement. This mixed bamboo and rainforest habitat is typical of this region due to the monsoon weather in Northern Laos.

c) disturbed habitats around the human settlement, including small farmlands and rocky areas and piles of rotten wood, including also abandoned houses, old bricks, and dilapidated stone walls.

d) upland field, basically a bare land due to burning and clear-cutting the forest for rice/corn/cassava cultivation. This land is no longer used for agricultural practices, then the forest is starting to recover although still with lots of sun reaching the ground.

e) stream banks. These are evergreen forested banks of a slow-moving stream. The riverbed was mainly rocky and stony, with elevation 500 – 1300 m a.s.l. The habitat contains secondary forest with thick evergreen monsoon dense forest. Along the stream bank, the wet habitat also contains bamboo, banana, and fern trees.

Central-Southern Laos survey. The survey in southern Laos, conducted by three researchers, consisted of (i) exploration by motorbike along dirt roads, and (ii) walked transects (31 km) for quantitative estimates of species richness across different habitats. The whole surveyed area is given in Fig. 4. The surveys were conducted in October 2019. We traveled by off-road motorbikes in order to access remote areas that would have been otherwise very hard to reach. All transect surveys were made at night (twilight until midnight) except for one day-time survey. We explored the appropriate microhabitat for amphibians and reptiles using headlights, and we captured (by hand or by a hook in case of some snake species) and photographed all encountered individuals. Specifically, we searched for animals from the floor to the canopy — several reptile individuals were captured in trees up to 10 m height, some in the water of small rivers, some on the ground or low vegetation, and a few also below leaf litter. Only one individual, a *Lycodon fasciatus*, was captured on the road. We used Exarmor gloves and a titanium hook for handling the venomous snakes.

The following habitat types were explored (see Table 1 for the relative effort made in each of them in terms of both walked distance [km], time [number of hours spent in the field], and altitude difference [m]):

1) karst habitat — an environment constituted by limestone and dry forest, with a slow river flowing through and with small caves situated along the rock formations;

2) dry forest — a semi-deciduous secondary forest with mostly short trees (<10 m height). Most of the trees lost their leaves during the dry season. In this habitat,

TABLE 1. Synopsis of the Reptile Species Observed in the Various Habitats of the Nam Et Phou Louey National Park, Northern Laos

Species	Coordinates	Mean altitude, m	Habitat type	Ground temperature, °C	Humidity, %
	Agamidae				
Physignathus cocincinus (Cuvier, 1829)	20.09511°N 103.10495°E	694	Mature forest	23.4	44
Acanthosaura lepidogaster (Cuvier, 1829)	20.18358°N 103.21357°E	1016	Mature forest	29.7	46
Calotes emma Gray, 1845	20.18358°N 103.21357°E	1016	Mature forest	29.7	46
	Gekkonidae				
Hemiphyllodactylus sp.	20.10454°N 103.10395°E	789	Limestone forest	25.5	47
Gekko reevesii (Linnaeus, 1758)	20.10454°N 103.10395°E	758	Limestone forest	24.7	45
Hemidactylus frenatus (Schlegel, 1836)	20.10038°N 103.10409°E	627	Human settlement	24.2	44
	Scincidae				
Eutropis longicaudata (Hallowell, 1857)	20.18354°N 103.21585°E	997	Human settlement	29	46
Eutropis multifasciata (Kuhl, 1820)	20.18315°N 103.21302°E	1014	Upland field	30	46
	Colubridae				
Ahaetulla prasina (Boie, 1827)	20.11105°N 103.13061°E	1026	Mature forest	26	49
Boiga multimaculata (Boie, 1827)	20.10009°N 103.10363°E	638	Upland field	21.7	43
Cyclophiops multicinctus (Roux, 1907)	20.09269°N 103.15250°E	1051	Mature forest	24.6	45
Ptyas korros (Schlegel, 1837)	20.08548°N 103.16110°E	840	Mature forest	25.2	46
Sinonatrix percarinata (Boulenger, 1899)	20.08548°N 103.16111°E	840	Mature forest	25.2	46
Orthiophis taeniurus (Cope, 1861)	20.10454°N 103.10395°E	758	Limestone forest	23.5	45
Xenochrophis flavipunctatus (Hallowell, 1860)	20.22010°N 103.19289°E	516	Stream edge	24.6	54
	Elapidae				
Ophiophagus hannah (Cantor, 1836)	20.10173°N 103.14263°E	1316	Mature forest	25.6	47
	Viperidae				
Trimeresurus albolabris Gray, 1842	22.21464°N 103.22351°E	982	Mature forest	24.4	43
Trimeresurus vogeli David, Vidal et Pauwels, 2001	20.20452°N 103.22086°E	964	Mature forest	23.5	44
	Testudinidae				
Manouria impressa (Günther, 1882)	20.18354°N 103.21585°E	997	Human settlement		

TABLE 2. Synopsis of the reptile individuals observed in northern Laos during the present surveys

Species	No. individuals	Size, g	Latitude, °N	Longitude, °E
	Turtles			
Palea steindachneri	1	154	20.69977	104.38529
Palea steindachneri	1	15,000	20.41352	104.04995
Manouria impressa	1	2000	20.34965	104.31226
Manouria impressa	1		20.06491	104.55585
Manouria impressa	1		20.73349	104.34268
Manouria impressa	1		20.75986	104.28688
Manouria impressa	11		19.97942	104.65008
	Snakes			
Bungarus multicinctus	1		20.29407	104.53364

there was also thick bushland with plants of about 2 m tall. The forest floor was almost bare or covered with a tiny stratum of leaf litter;

3) fast current streams/rivers — heavily supplied by water all year round, these rivers flow through big rocks and were often characterized by waterfalls;

4) rocky streams with bamboo forest along the banks — slow-moving watercourses situated inside bamboo forests with some big trees. The substrate was mostly rocky and sandy;

5) rocky streams without bamboo forest along the banks — the riverbed mostly constituted of rocks and stones, the banks covered with secondary forest with thick leaf litter on the ground.

6) secondary wet forests — an evergreen forest supplied by heavy rainfall throughout the year. These forest patches were characterized by big old trees that create large shaded areas, and with small trees growing up in sunnier spots. Leaf litter was thick throughout all of this habitat type.

The geographic coordinates of the sites of capture for all individuals were recorded by a Garmin 64 GPS de-

TABLE 3. List of the species of reptiles and amphibians observed in central-southern Laos, during the surveys described in this paper

Reptilia	IUCN status	Amphibia	IUCN status
Snakes		**Anurans**	
Ahaetulla prasina	LC	*Amolops* sp.	NE
Coelognathus radiatus	LC	*Chiromantis* (*Chirixalus*) *doriae*	LC
Dendrelaphis pictus	LC	*Duttaphrynus melanostictus*	LC
Hebius (*Amphiesma*) *khasiense*	NE	*Kaloula* sp. 1	NE
Lycodon fasciatus	NE	*Kaloula* sp. 2	NE
Pareas hamptoni	LC	*Hoplobatrachus rugulosus*	LC
Pareas macularius	LC	*Hylarana attigua*	LC
Pseudoxenodon macrops	LC	*Hylarana erythraea*	LC
Rhabdophis subminiatus	LC	*Hylarana* sp. 1	NE
Xenopeltis unicolor	LC	*Hylarana taipehensis*	LC
Bungarus candidus	LC	*Kalophrynus interlineatus*	LC
Trimeresurus cardamonensis	NE	*Kurixalus odontotarsus*	LC
Trimeresurus (*Cryptelytrops*) *macrops*	LC	*Leptobrachium buchardi*	DD
Trimeresurus vogeli	LC	*Leptolalax* sp. 1	NE
Lizards		*Limnonectes coffeatus*	NE
Calotes emma	NE	*Limnonectes* sp. 1	NE
Calotes versicolor	NE	*Limnonectes* sp. 2	NE
Cyrtodactylus sp. 1	NE	*Megophrys major*	LC
Cyrtodactylus sp. 2	NE	*Micryletta inornata*	LC
Dixonius siamensis	LC	*Microhyla berdmorei*	LC
Eutropis macularia	NE	*Microhyla butleri*	LC
Eutropis longicaudata	LC	*Microhyla heymonsi*	LC
Gekko petricolus	LC	*Microhyla pulchra*	LC
Gekko cf. *scientiadventura*	NE	*Occidozyga sumatrana*	LC
Hemidactylus frenatus	LC	*Odorrana bolavensis*	DD
Hemidactylus platyurus	LC	*Odorrana banaorum*	LC
Lygosoma sp.	NE	*Odorrana* sp.	NE
Pseudocalotes poilani	NE	*Ophryophryne* sp.	NE
Scincella doriae	LC	*Polypedates leucomystax*	LC
Scincella sp.	NE	*Polypedates* sp.	NE
Tropidophorus microlepis	LC	*Rhacophorus bipuncatus*	LC
		Sylvirana nigrivittata	NE
		Sylvirana sp.	NE
		Caecilians	
		Ichthyophis sp. 1	NE
		Ichthyophis sp. 2	NE

The IUCN (2020) red list status is also presented. Abbreviations: NE, not evaluated; DD, data deficient; LC, least concern.

vice, as well as the altitude (m a.s.l.), humidity and ambient temperature (recorded by 610 Testo thermometer).

Species' identification

Captured individuals were identified by consulting appropriate bibliographic references: Nguyen et al. (2009), Teynié and David (2010), Visser (2015), Vassilieva et al. (2016), as well as the recently published new species descriptions (e.g., Nazarov et al., 2014; Teynié et al., 2015; Luu et al., 2016), Amphibia Web (last accessed 24 April 2020) and http://reptile-database.reptarium.cz/search (last accessed 30 April 2020). Identification was problematic for some species: in such cases, we reported the genus name followed by "sp.," or by "sp. 1, sp. 2" when there were more than one problematic species recorded for the same genus. In one case, we determined that some individuals identified as *Gecko* cf. *sceintiadventura* were also morphologically very similar to *Gecko aaronbaueri* and that further identification would require further investigation.

Fig. 5. Turtle species observed in northern Laos: *a*, *b*, *Palea steindachneri*; *c*, *Manouria impressa*; *d*, set of fish hook line used on Nam Xam River, also to catch freshwater turtles. Photos by O. Le Duc and T. Pham Van.

Statistical analyses

A multiple regression model (Pearson's moment product correlation coefficient) was used to correlate the number of species of amphibians and reptiles at each surveyed site with the transect length, the time effort the altitude of the site, the walked altitude difference, the ambient temperature, and the ambient humidity. All statistical analyses were made with SigmaPlot 14.0 version, with alpha set at 5%.

RESULTS

Northern Laos

Overall, we recorded only 18 reptile individuals, belonging to three different species (two chelonians and one snake) (Table 2), thus suggesting a heavily depleted reptile fauna within the study areas. While the encountered snake species is not of conservation value (*Bungarus multicinctus*, Least Concern), the two turtles species are marked as threatened by IUCN Red List (2020): *Palea steindachneri* is Endangered, and *Manouria impressa* is Vulnerable (Fig. 5).

The synthesis of the answers provided by the interviewees is as follows: the average age of fishers was 50 years, the majority of which received only primary education. Becoming a fisher in Laos is very often a hereditary occupation and very often by necessity, as fishing provides the only viable source of income for a family. 97.2% of all interviewed fishers never fished in other areas, thus they possess knowledge of turtles only in their particular local fishing grounds. Fishers overwhelmingly reported conditions of fish stock in their areas as depleted (94.4%) and 61.1% reported their fishing grounds not to be in a good state. The depletion of fish stock was believed to be predominantly due to an increased number of fishers and due to use of illegal or destructive fishing methods such as electric fishing. As for the turtle hunting situation in eastern Laos, there was a clear distinction between responses from fishers at Ma/Et rivers and Nam Xam River. In total, 38.8% or 14 fishers target turtles

Fig. 6. Some of the observed reptiles at the Nam Et Phou Louey National Park, northern Laos: *a*, *Elaphe taeniura*; *b*, *Hemiphyllodactylus* sp.; *c*, *Ptyas multicinctus*; *d*, *Manouria impressa*. All photos by O. Van Lo.

(three or 15% at Et/Ma rivers, 10 or 66.6% at Nam Xam River, and 1 at Et River). Therefore, Nam Xam River fishers are more likely to hunt turtles, and their knowledge about the various turtle species might be greater than their Et/Ma counterparts. 70% (14) fishers of Et/Ma rivers also reported that large softshell turtles are not present, which correlates with low turtle-fishers' density and possibly lower knowledge of other fishers about the presence of large softshell turtles due to low interest. However, we identified one potential site where *Rafetus swinhoei* can still be present: Nam Xam River, near the border of Vietnam (Fig. 3). Interestingly, one interviewed fisher claimed that in October 2019 a large softshell turtle escaped from inside of his fishing net. Two additional villagers from the same village confirmed the sighting, stating that it was a very large softshell turtle. All of them positively identified *Rafetus swinhoei* among the presented photographs. Majority of fishers who specialize in turtle hunting use bamboo/maze funnel trap or catch by hand. Longlines and hooks were used only in 16.7% of cases. Interestingly, it was reported that funnel traps and hooks for hunting turtles were introduced to Laotian fishers by Vietnamese traders who were interested to purchase larger quantities of turtles. Our interviewees also stated that the majority of fishers targeting turtles sell their catch to traders, very often engaging in cross-border trade to Vietnam. Interestingly, interviewees at both locations reported little or no interest in turtle eggs among the local population.

Concerning the terrestrial habitats at Nam Et Phou Louey National Park, the synopsis of the observed data is given in Table 2. Overall, 19 reptile species (8 lizards, 10 snakes and 1 turtle) were observed (Fig. 6). A total of 10 species were observed in mature forest, 3 in limestone forest, 3 at human settlements, 2 at upland field and 1 at stream edges. Thus, the overall number of observed species was low in all the habitat types. All the observed species were not of conservation concern (Least Concern) for IUCN (2020), apart from *Ophiophagus hannah* (Vulnerable) and *Manouria impressa* (Vulnerable).

Central-Southern Laos

Overall, we recorded 30 species of reptiles (14 snake species out of which were four of venomous taxa and 16 lizard species) and 35 amphibian species (33 anurans and two caecilians) (Table 3). Some of the observed species of reptiles and amphibians are respectively presented in

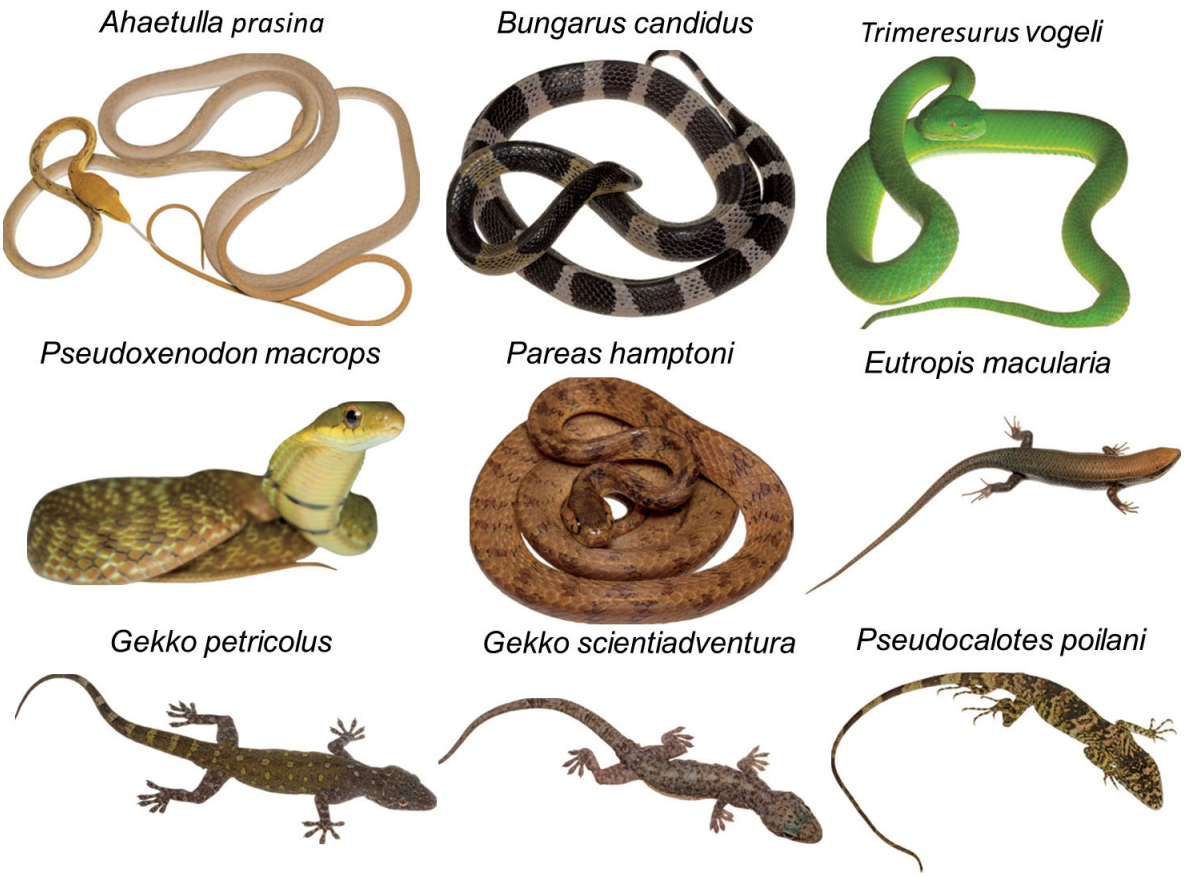

Fig. 7. Selected reptile species observed in central-southern Laos. All photos by N. Maury.

Figs. 7 and 8. All the observed reptile species were either Least Concern (60%) or Not Evaluated (40%) according to IUCN (2020) (Table 3). Regarding amphibians, 51.4% of the recorded species were Least Concern, 5.7% were Data Deficient, and 42.9% were Not Evaluated according to IUCN (2020) (Table 3).

The synopsis of the data on the species richness of amphibians and reptiles observed along the walked transects is given in Table 4. The number of sympatric species (pooling together reptiles and amphibians due to the small sample sizes) ranged from 5 – 14, with the lowest richness being observed in dry forest patches and highest in secondary wet forest patches (Table 4). A multiple regression model revealed that the number of species detected at each site was positively correlated with the transect length (i.e., km walked) ($r = 0.886$, $r^2 = = 0.785$, $P = 0.027$) and with the environmental humidity ($r = 0.775$, $r^2 = 0.603$, $P = 0.028$), whereas the other variables were not statistically significant (e.g., temperature versus number of species: $r = –0.67$, $r^2 = 0.45$, $P = 0.065$; at least $P > 0.05$ in all other cases).

DISCUSSION

General considerations on species diversity and community ecology

Although our study was carried out in two distinct regions of Laos and using a suite of field methods, nonetheless our data should be considered just a preliminary insight into the assemblages of amphibians and reptiles of this mega-diverse country of south-eastern Asia. Indeed, we were able to make only a qualitative assessment and not any quantitative measurements of the species' community metrics. Nonetheless, some clear evidence did emerge from our study (see below).

First, the great majority of the species were either non-threatened or not evaluated/data deficient according to the IUCN Red List (2020) criteria. Although most of the latter will presumably be considered as non-threatened after a proper assessment, it remains a fact that much more effort should be put into properly defining the conservation status of several herpetofaunal taxa in this area of south-east Asia. Only three threatened species

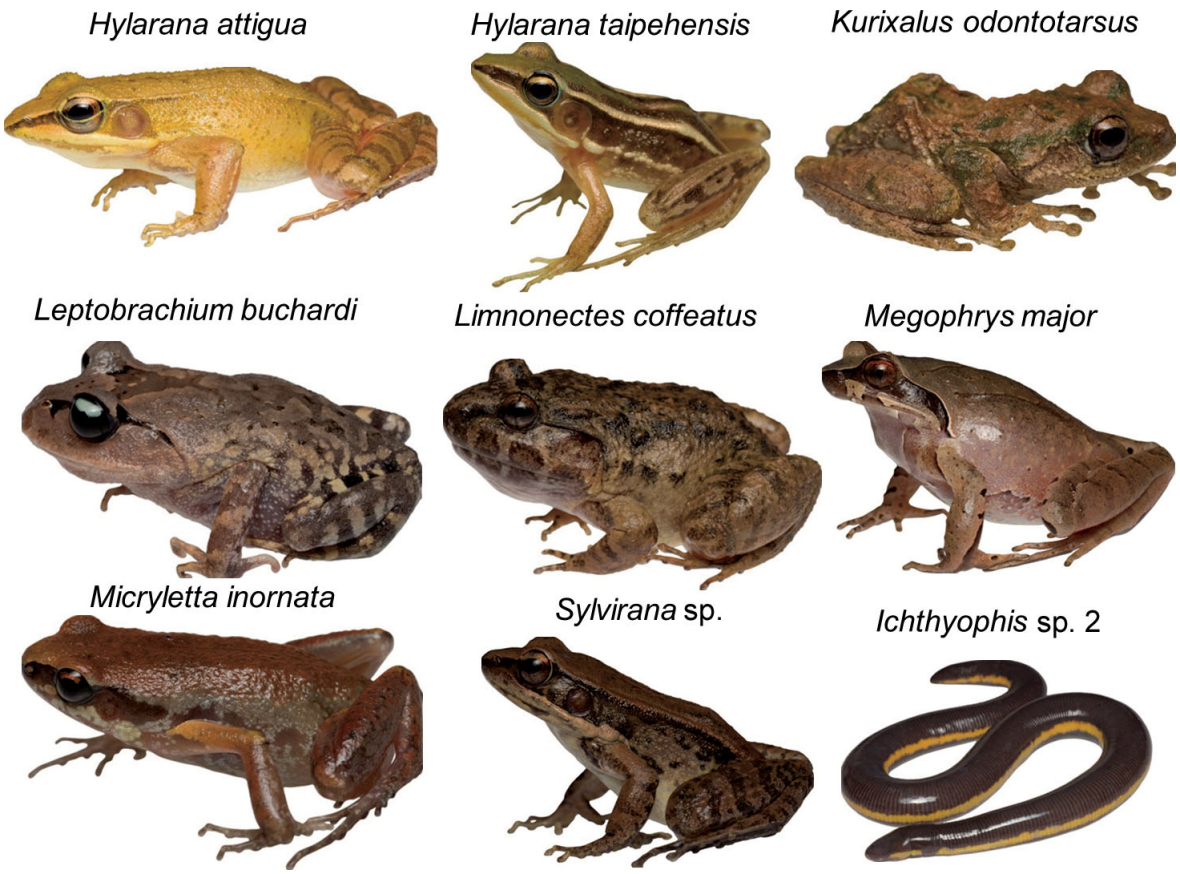

Fig. 8. Selected amphibian species observed in central-southern Laos. All photos by N. Maury.

were observed, two being chelonians and one being a snake (see below for the conservation implications of the present study). For one of these turtles, *Palea steindachneri*, our records are the second and the third one for Laos, where this species was observed just once at about 500 km distance from our records, in the Oudomxai Province (Auer, 2011). Therefore, we anticipate that the true range of this turtle is much wider in Laos than previously thought.

Second, in general we observed a relatively low number of species in each habitat type, ranging 5 – 14 in general, including both reptiles and amphibians, or even less when we count only reptiles at the Nam Et Phou Louey National Park. This number of species is remarkably

TABLE 4. Synopsis of the Results Obtained on the Species Richness of Amphibians and Reptiles Along Transects in Central-Southern Laos, in Relation to the Habitat Type and to Other Environmental Variables that Were Collected in the Field

Habitat type	Number of species	Transect length, km	Time effort, h	Altitude difference, m	Temperature, °C	Humidity, %	Mean altitude, m a.s.l.
Karst	9	5	3	0	27.5	65	290
Dry forest	5	2	3	0	28	60	250
Fast current streams	8	4	2	500	25.1	73	800
Streams with bamboo forest	12	8	5	1100	24	65	800
Secondary forest (site 1)	14	4	3	300	19.2	85	1550
Secondary forest (site 2)	12	3	2	200	19.4	85	1380
Secondary forest (site 3)	12	3	3.5	200	19	81	1380
Rocky streams	13	2	3.5	100	26.5	85	380
Total	70	31	25				

lower than observed in tropical forests at other continents or of south-east Asia where a similar methodology and field effort were carried out, for instance in Uganda (4 – 14 amphibians + 5 – 16 reptiles in each site; Behangana et al. [2019], or even up to 24 – 29 species per site considering only the amphibians in the less altered sites [Behangana and Luiselli, 2008; Behangana et al., 2009]). The species richness in Laos was even lower for amphibian species comparing to those observed in the relatively arid savannahs of South Sudan (5 – 11 species per habitat, see Demaya et al., 2019). If we compare the species richness observed in our Laos surveys with that observed in the neighboring Vietnam and Cambodia, the figures are even more striking. In Vietnam, 76 species were observed in the bamboo forest or mixed forest of bamboo and secondary forest of the Tay Yen Tu Nature Reserve (Hecht et al., 2013), 62 species in the lowland evergreen forests of the Chu Mom Ray National Park (Jestrzemski et al., 2013), 52 species in the isolated mountain forests of the of Ha Giang Province (Bain and Truong, 2004), and 132 species were recorded for Phong Nha Ke Bang national park, Quang Binh province, Central Vietnam (Ziegler et al., 2004). In Cambodia, 86 species were observed in the forests of the Phnom Kulen National Park (Geissler et al., 2019), and 43 species in the mountain evergreen forests of the Phnom Aural Wildlife Sanctuary (Grismer et al., 2007). These comparisons suggest that the herpetofaunal communities are extremely depleted in Laos (even in comparison with elsewhere sites, for instance on mountains, with similar ecological characteristics), thus indicating that an "empty forest syndrome" is clearly visible (Long et al., 2017). Differential field efforts across studies may in part explain the observed pattern, as in our surveys increasing the transect length positively affected the number of uncovered species. However, the differences were so striking that it is likely the "empty forest syndrome" did truly affect the collected data. The syndrome in this part of the world can be mainly caused by overhunting for subsistence, as local populations consume almost anything that comes from the wild (Bennett and Rao, 2002; Johnson et al., 2012). Obvioulsy, the concept of "empty forest" refers mainly to secondary forests along the banks of rivers but not to the isolated mountain mature (primary) forests which are still existing in some parts of Indochina and are characterized by higher species diversity.

Third, the main variable that positively influenced species richness per habitat (apart from transect length that we commented above) was environmental humidity, while all other variables (including temperature and altitude) were not significant. The relevance of ambient humidity in enhancing the probability of encountering herpetofauna species in tropical and subtropical forests mirrors the evidence of the most species and higher number of individuals being usually observed in the wet season (e.g., Eterovic et al., 2001; Oliveira and Martins, 2001; Prado et al., 2005; Akani et al., 2013). However, relative humidity and rainfall, although certainly influencing species' above-ground activity, may explain relatively little of the variation in activity levels, suggesting that activity levels may be determined also by other unmeasured factors (Brown and Shine, 2002).

Implications for conservation on the threatened species

Two threatened turtle species were observed, and the status of the wild populations of these taxa in Laos should be urgently evaluated, as consumption of turtle meat in central parts of Asia is widespread. It is believed by local populations, that eating turtle meat can either prolong life or heal illnesses (van Dijk et al., 2000; Cheung and Dudgeon, 2006; Pham et al., 2018). In northern Laos, the responses of the interviewed persons significantly differed depending on the watershed: Whereas in Et/Ma rivers, only 5% of respondents believe in life-extending properties of turtle meat, in the Xam river it reached 20%. A similar disparity was about healing properties of turtle meat — at Et/Ma rivers 25% of respondents believe turtle meat can heal ailments, and 66.6% at the Xam River. Thus, our results suggest that awareness campaigns for the conservation of turtles should be targeted at the local community scale, and should be necessarily adapted to the varying local cultural backgrounds. Our study also highlighted the possible presence of the world rarest turtle, *Rafetus swinhoei* (Stanford et al., 2018, 2020), at a single site of northern Laos, at the border with Vietnam. This potential site of presence should be further investigated, and careful turtle trapping should be conducted in order to ascertain the eventual survival of this exceedingly threatened species. In this regard, it should be noted that several potential sites of presence have been recently uncovered in Vietnam (Le Duc et al., 2020a, 2020b; Pham et al., 2020), thus providing new hope for avoiding the extinction of this giant freshwater turtle.

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