Annals of Tropical Research 45 (2):1-26(2023)
https://doi.org/10.32945/atr4521.2023

Effects of habitat disturbance and elevation on the diversity and endemicity of Herpetofauna in Northeastern Leyte, Philippines

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ABSTRACT

Received: 19 April 2022 | Accepted: 6 June 2023

The effect of anthropogenic habitat disturbance and elevational gradient on herpetofaunal diversity and endemicity was investigated in the present study. The habitat disturbance types considered were primary forest, selectively logged primary forest, agroecosystem (coconut plantation), and pasture, with varying elevational distributions (21–1101m asl). The herpetofaunal diversity and endemicity were compared between habitat disturbance types with habitat types (stream and terrestrial), and their relationships with elevation were further explored. A total of 489 herpetofauna belonging to 44 species (22 amphibians and 22 reptiles) were documented. The habitat disturbance significantly lowers the reptile species richness and diversity, and overall herpetofaunal endemicity is low in highly disturbed habitats (pasture). It was found that stream habitats harbor the greatest herpetofaunal diversity and endemicity. Herpetofaunal diversity and endemicity responded differently relative to the elevation, where the former decreased and the latter increased with increasing elevation. Moreover, the highly disturbed habitat (pasture) was strongly associated with widespread and disturbance-tolerant species, while the more pristine habitat (primary forest) was strongly associated with intolerant species. Lastly, this study highlights the need to conserve and protect remaining critical primary habitats especially stream habitats to ensure high herpetofaunal diversity and endemicity in the study area.

Keywords: Amphibians, indicator species, lowland dipterocarp forest

INTRODUCTION

The Philippine Archipelago which is situated at the interface between the Oriental and Australian faunal zones is home to a spectacular and diverse assemblage of

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amphibians and reptiles (herpetofauna) (Diesmos et al 2002). Currently, at least 110 amphibians (84% endemic) and 250 reptile species (66% endemic) are known to occur in the country (Diesmos et al 2015, Diesmos et al 2002) and more new species are being described each year as result of more extensive field surveys (Siler et al 2012, Siler et al 2010, Diesmos et al 2020). However, considering that the Philippines is known to be one of the most important biodiversity hotspots on the Earth (Langenberger et al 2006), the diversity of amphibians and reptiles is being threatened mainly by deforestation as a consequence of logging, urbanization, and agricultural expansion (Liu et al 1993, Lasco et al 2013, Diesmos et al 2015). Eventually, these anthropogenic activities are expected to result in species decline and an increase in species extirpation/extinction (Sodhi et al 2010).

Habitat disturbance (eg, deforestation) is considered to be the primary culprit of biodiversity loss worldwide (Palmeirim et al 2017), and the most important anthropogenic factor influencing ecosystems at a very high-speed rate (Berriozabal-Islas et al 2017). The herpetofauna are very good indicators of ecosystem health where their absence or decrease in number and endemicity indicates a disturbance in their natural habitat (Nuñeza et al 2010). Prior studies have investigated some of the effects of disturbance on herpetofaunal communities, such as the study by Cruz-Elizalde et al (2016) which found a reduced number of species in disturbed habitats versus preserved habitats. Nuñeza et al (2010) indicated that herpetofaunal endemism in the tropics can be negatively affected by habitat disturbance (eg, agricultural conversion), especially in the lowlands. Also, the study by Decena et al (2020) has revealed that forest habitats are dominated by forest specialist species whereas open or more disturbed habitats are dominated by open-habitat specialist species. The significant reduction in herpetofaunal diversity, endemism and shifting community compositions due to habitat disturbance can be specifically attributed to the loss of forest structure, and the reduced availability and quality of microhabitats (Gonthier et al 2014, Palmeirim et al 2017, Decena et al 2020).

Furthermore, elevation can be another factor influencing the pattern of herpetofaunal diversity and endemism. As expected, species diversity tends to vary with elevation (Khatiwada et al 2019, Chen et al 2020). Several studies in other parts of the world have demonstrated a decreasing pattern of herpetofaunal diversity with increasing elevation (Khatiwada et al 2019, Chen et al 2020, Malonza 2015). This herpetofaunal elevational diversity gradient (EDG) is strongly linked to various climatic factors such as temperature and precipitation, making the study of these factors essential in order to understand the patterns of species diversity (Tang et al 2004). Likewise, the said variation can also be attributed to the differences in species distribution and composition, and the availability of suitable microhabitats (Khatiwada et al 2019). In addition, species endemism can vary with elevation as influenced by disturbance and species characteristics (Kessler 2002). For example, the study of Nuñeza et al (2010) showed that higher endemism is distributed in higher-elevationn habitats compared to disturbed lowland habitats.

The Leyte Island belongs to a large biogeographic region of the country called the Mindanao Pleistocene Aggregate Island Complex (Mindanao PAIC), with Mindanao proper as well as other islands such as Dinagat, Siargao, Bohol, Samar and other neighboring small islands (Supsup et al 2017). Wherein, all these islands were joined together by land bridges during the Pleistocene period, which allowed for the possible exchange of faunas (Denzer et al 1994). This biogeographic region is exceptional as it harbors many unique and globally threatened endemic species, especially herpetofauna (Supsup et al 2017). However, on Leyte Island this high diversity and endemicity are being threatened by the continued shrinkage of natural habitats caused by anthropogenic disturbances including deforestation and agricultural conversion. Previously, the majority of the studies on the Philippine herpetofauna have dealt more with the taxonomic aspect, but studies regarding the influence of habitat disturbance and elevational variation on herpetofaunal diversity and endemicity have been rarely conducted (Nuñeza et al 2010, Relox et al 2011, Supsup et al 2020, Decena et al 2020). Therefore, this present study was conducted (a) to determine any difference in abundance, species richness, diversity (Shannon-Wiener), and endemism of amphibians and reptiles among habitat types (stream and terrestrial) in a variety of habitats (eg, primary forest, selectively logged primary forest, agro-ecosystem/coconut plantation, and pasture), (b) to determine the relationship between abundance, species richness, diversity (Shannon-Wiener) and endemism of herpetofauna with elevation, and (c) to determine the indicator species in each habitat disturbance type.

MATERIALS AND METHODS

Study Area

The study was conducted in the two localities of northern Leyte specifically on the eastern side of the Leyte Cordillera and Babatngon Range (specific municipalities include San Miguel, Jaro, and Javier) (Figure 1). The Leyte Cordillera represents the rugged and mountainous sections of the island with a maximum elevation of about 1300m asl. It is part of the Philippine fault line extending from north to south over the whole length of the island (Langenberger & Belonias 2011). The geomorphology of the mountain range is closely associated with the way the island was formed, which was brought about by the tectonic movement and plate convergence in the Tertiary and Quaternary periods (Japan International Cooperation Agency 1990, Maranguit & Asio 2013). The Babatngon Range is located in the northeastern portion of Leyte. The core of the mountain range is represented by ultramafic outcrops called the Tacloban Ophiolite Complex (TOC), as a NW-SE trending massif in the northeastern portion of the island. The mountain range is overlain by sedimentary sequences dated to Late Miocene-Pliocene and Pleistocene volcaniclastic deposits on its eastern and western flanks, respectively (Suerte et al 2005). The maximum elevation of the area reaches up to 600m asl.

The natural vegetation of both study sites particularly at the lower elevations is tropical rainforest of the dipterocarp type. As in many tropical forest ecosystems, the predominant cause of forest degradation in the hilly portions of the study area is slash-and-burn agriculture ("*kaingin*") which involves clearing and burning of the forest and later planting with cultivated crops (eg, coconut, banana and corn). The climate of the study area is characterized as equatorial rainforest-fully humid (Kottek et al 2006). The study area has no dry season and has more or less evenly distributed rainfall throughout the year. The warmest month is April with a mean annual temperature of 27ºC and pronounced wetness occurring in the months of November, December and January with an annual total precipitation of 2293mm (Quiñones & Asio 2015, Marteleira 2019).

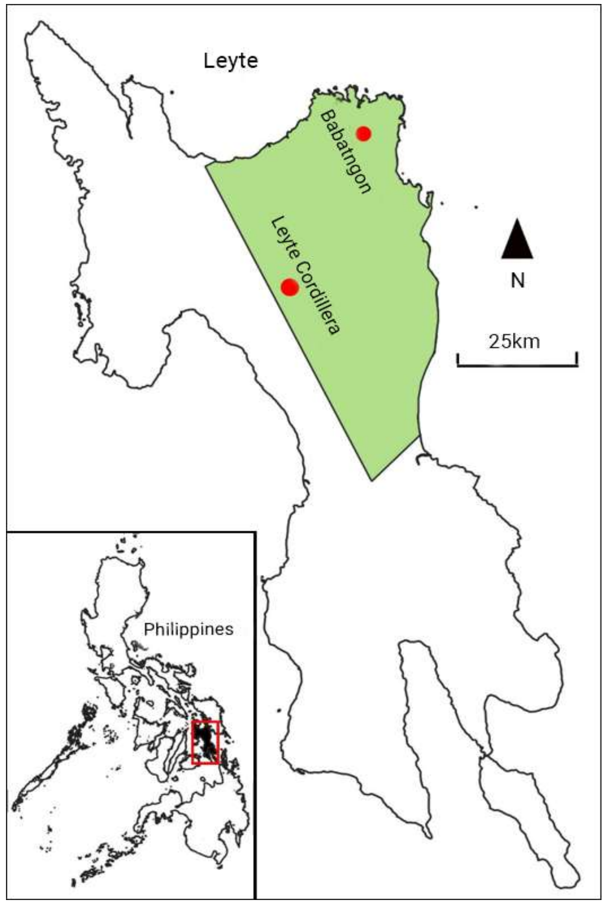

Figure 1. Location of the study area with Leyte Cordillera Mountain Range and Babatngon Range in northeastern Leyte, Philippines. Utilized with permission from the publisher and exclusive copyright holder: the Department of Science and Technology through the Philippine Journal of Science Editorial Office

Sampling Sites

Prior to the sampling, preliminary surveys were conducted to identify possible sampling areas. The habitats that were selected for amphibian and reptile sampling were primary forest, selectively logged primary forest, agroecosystem, and pasture (Figure 2).

Figure 2. The habitat disturbance types sampled from the mountain ranges of Leyte Cordillera and Babatngon in northeastern Leyte, Philippines. (A) Primary Forest; (B) Selectively Logged Primary Forest; (C) Agroecosystem (coconut plantation); and (D) Pasture

The primary forests that were considered in this study were generally undisturbed or slightly disturbed dipterocarp forests and montane forests. Undisturbed primary forest had no significant human disturbance although there were some traces of rattan harvesting and wildlife poaching. The forests were located in protected watersheds and in areas with very steep terrain that is too difficult for illegal loggers to access. These primary forests are still characterized by unlogged and intact dipterocarp forests with a canopy reaching 30-50m high. In the case of montane forests, these were in the Leyte Cordillera Mountain Range at an elevation of 900-1300m asl. However, fewer sampling efforts were devoted to the montane forest as this forest type was situated on very steep slopes and the sampling was only possible on the ridges or along the trail. The montane forests were characterized by smaller or stunted trees and the trunks were usually covered with moss, tree ferns were also commonly observed.

The selectively logged primary forests (dipterocarp forests) were characterized by traces of old and newly cut trees, where discarded lumber was commonly observed along the streams. These selectively logged forests have very few remaining dipterocarps as a consequence of selective logging. This forest type is the most common since lowland primary forests are easily accessible and often selectively logged.

The agroecosystem chosen for sampling was coconut plantation. These plantations were usually located at lower elevations. The coconut plantations were located closer to communities and were characterized by understorey vegetation composed of ferns, shrubs (*Melastoma malabatricum*) and early successional tree species (*Commersonia bartramia*, *Ficus* spp. and *Piper aduncum*). Temporary pools created by water buffalos and puddles were present in the area, which may serve as temporary breeding areas especially for amphibians.

Pasture areas sampled in this study were permanently grazed by cattle or water buffalos. These areas were marked by the sparse presence of trees or bushes, with a thin layer of grasses. The pasture areas were usually adjacent to secondary forests or agroecosystems.

Herpetofaunal Sampling

In this study, as well as the four types of disturbed habitats, additional habitat types (stream and terrestrial) were identified for sampling. To sample the amphibian and reptile species, a total of 40 unique 5mx100m strip plots were laid with 15 in primary forest (6 stream and 9 terrestrial), 11 in selectively logged primary forest (8 stream and 3 terrestrial), 8 in agroecosystem (3 stream and 5 terrestrial), and 6 in pasture (3 stream and 3 terrestrial). For the stream habitat, in order to sample stream breeding and dwelling amphibians and reptiles, 2.5m wide riparian vegetation on both banks of the stream including the water body was searched. In some cases, the 5m wide non-riparian strip plots were laid along the trail, especially in montane forests where strip plot establishments were only possible along the trails or ridges. The strip plots were generally straight linear however some deviated whenever there were obstacles or where they were constrained by topography and/or stream patterns. As much as possible, each of the strip plots was established away from habitat edges, however, sometimes this could not be avoided, especially in pasture areas, where the habitats being sampled were narrow. To maximize the sampling independence, the distance between strip plots was kept at a minimum of 200m, and only one strip plot was established in each patch of non-forest habitat (agroecosystem and pasture) which was usually separated by secondary vegetation or matrix habitat. Whenever possible, different combinations of strip plots from the different habitat types were sampled throughout the sampling period to reduce the potential of seasonal confounding effects (Gillespie et al 2015). All the strip plots were positioned and the elevation was determined in meters using a handheld GPS (Garmin etrex).

This study mainly used the active search method whereby each strip plot was thoroughly searched for amphibians and reptiles twice on the same day, first in the morning at 8am to 11am and then at the night at 7pm to 10pm, this was done to sample both diurnal and nocturnal species. In this study, a total of 80 sampling sessions were performed which corresponded to 240 person-hours. Three people (with the head torch for night sampling) slowly walked and thoroughly searched and recorded every herpetofauna species that they encountered and captured. This included searching in all kinds of substrates or surfaces such as leaf litter, rocks, soil, fallen or rotten logs, shrubs, tree trunks, tree holes, branches, and leaves. In addition to the active search method, we employed auditory sampling techniques to increase the chances of species' encounters particularly for arboreal amphibians or individuals calling in hidden places. However, only those species heard calling that were successfully located and captured were recorded to minimize the chances of misidentifying species (Ficetola 2015). Also, to be consistent, only calling individuals within or near the strip plot was considered for sampling. The speed of the sampling per plot was approximately 3m min^{-1} except during handling and recording. The time allotted for sampling was constrained to 1h only to avoid pseudo replication. In addition, species that were not encountered inside the strip plots but were encountered upon approaching or leaving the strip plots were also documented and recorded, but not included in the analysis of the data. All individuals captured were photographed and were measured for snout-vent length (SVL) or tail length in mm. The individuals sampled were released unharmed at the point of the collection after taking measurements and photographs. Marking individuals was not employed for captured individuals since previously the study of Decena et al (2020) in the same location/region showed very few or insignificant recaptures for amphibians. In addition, this was also due to time and resource constraints, and the difficulty of capturing the animals, especially frogs and reptiles (Paoletti et al 2018). So, to reduce the risk of recounting the same individuals, photos or measurements were double-checked, and if possible, all the persons searching for amphibians and reptiles traversed the strip plots only once.

The research was conducted in accordance with the Institutional Animal Care and Use Committee (IACUC) protocol (no. 2021-005-005) from the University of San Carlos, Cebu, and Gratuitous Permit (no. 2021-11) from the Department of Environment and Natural Resources, Region VIII, Tacloban City, Philippines.

Species Identification and Photo-voucher Deposition

Herpetofauna species were identified following the nomenclature of Sanguila et al (2016), Brown et al (2013), and Weinell et al (2019). Identification of species was confirmed by an expert at Kansas University, USA, and the photo-vouchers were also cataloged and deposited in the said institution.

Data Analyses

To assess the adequacy of survey efforts and samples, individual rarefaction curves were generated for amphibians and reptiles in all the habitat types. The abundance (total number of individuals encountered/recorded), species richness, and diversity of amphibians and reptiles were determined for each strip plot across habitat disturbance types. The individual rarefaction curves and the diversity indices were calculated using PAST 3.22 (Hammer et al 2001). For endemism, the number of endemic amphibians and reptiles was determined for each of the strip plots.

For spatial data, the presence of autocorrelation is a common issue that indicates dependence between observations (Gaspard et al 2019), therefore, spatial autocorrelation analysis (Moran's I) was performed in the *R* package *ape* (Paradis et al 2019). The Moran's I test was performed for the data on the abundance, species richness, diversity, and endemicity by using the midpoint geographical coordinates of each strip plot. Moran's I with a value of 0 suggests the absence of spatial autocorrelation (Ranjitkar et al 2014).

All the data were tested for normality using the Kolmogorov-Smirnov test. As the data were generally normal and with no or minimal spatial autocorrelation, the two-way ANOVA was performed to assess the effects of habitat disturbance types (primary forest to pasture) and habitat types (stream and terrestrial) including their interactions with amphibian and reptile abundance, richness, diversity, and endemism. Tukey's post-hoc tests were performed whenever there were significant differences at $p \leq 0.05$. In addition, to explore the relationship between diversity indices and endemism with elevation, regression analysis was performed. The analyses such as the Kolmogorov-Smirnov test, two-way ANOVA, and regression analysis were performed using SPSS 20 for Windows.

Indicator species analysis (Dufrêne & Legendre 1997) was performed to identify species that were associated with or indicator of certain habitat types. Indicator species analysis has been previously used in earlier studies in identifying amphibians and reptile species especially associated with habitats or sites (Jongsma et al 2014, Amarasinghe et al 2021). The analysis used the *multipatt* function of the *R* package *indicspecies* (De Caceres et al 2020). Then, the statistical significance of this relationship was tested using a permutation test (De Caceres 2020). Both the spatial autocorrelation analysis and indicator species analysis were carried out in *R* 4.1.0 (R Core Team 2021).

RESULTS AND DISCUSSION

Sampling Adequacy and Spatial Autocorrelation

To assess the adequacy of the sampling efforts or the samples in this study, the individual rarefaction curves were generated for both amphibians and reptiles in the different habitat disturbance types. For amphibians, individual rarefaction curves were closer to asymptote indicating that most species likely to occur in all the habitats sampled were actually detected (Figure 3A). On the other hand, individual rarefaction curves for reptiles were farther from the asymptote suggesting that there was a likelihood of unseen species (Figure 3B).

Spatial autocorrelation is frequently encountered in ecological data suggesting dependence between samples, and eventually, this becomes a problem for classical statistics tests such as ANOVA (Lichstein et al 2002). The spatial autocorrelation analysis indicated that the data on amphibian communities (abundance, species richness, Shannon-Wiener, and endemicity) were not influenced by the spatial distance (p=>0.05; Moran's I=-0.026–0.084) (Table 1). Though the analysis for almost all the data for reptiles, and amphibians and reptiles combined were significant ($p<0.05$) (Table 1), the Moran's I values were closer to 0 suggesting the lack of spatial autocorrelation.

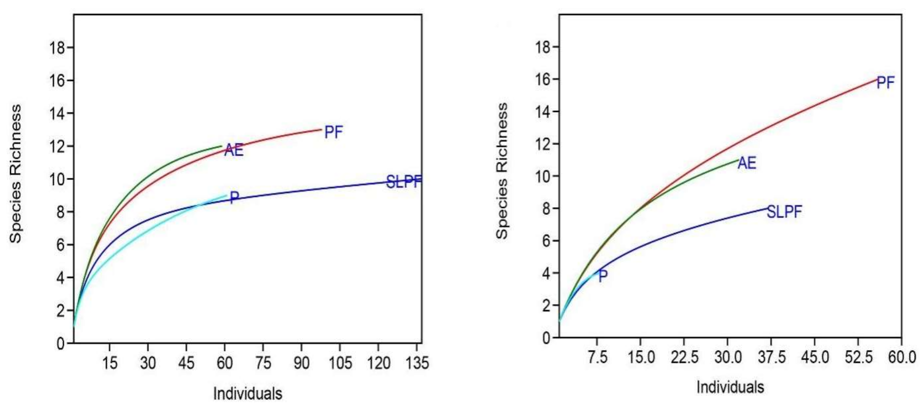

Figure 3. Individual rarefaction curves displaying sample-based species richness among habitat disturbance types for (A) amphibians and (B) reptiles. PF=primary forest, SLPF=selectively logged primary forest, AE=agroecosystem, P=pasture.

Table 1. Results of the spatial autocorrelation analysis (Moran's I) on diversity indices and endemism

Variables	Moran's I	*p*-value
Amphibians		
Abundance	0.084	0.113
Species Richness	0.060	0.240
Shannon-Weiner	-0.026	0.993
Number of endemic species	0.082	0.139
Reptiles		
Abundance	0.256	<0.001
Species Richness	0.252	<0.001
Shannon-Weiner	0.195	0.003
Number of endemic species	0.319	<0.001
All Species		
Abundance	0.153	0.012
Species Richness	0.175	0.006
Shannon-Weiner	0.098	0.085
Number of endemic species	0.252	<0.001

Herpetofaunal Diversity

In the present study, a total of 489 herpetofauna belonging to 44 species (22 amphibians and 22 reptiles) and 14 different families were documented inside the strip plots from the various habitat disturbance types from the two mountain ranges (Leyte Cordillera and Babatngon) in northeastern Leyte, Philippines (Table 2 and Table 3). Most of the individuals observed were amphibians with a total number of 355 wherein the most abundant species was the Near Threatened (NT) frog *Limnonectes magnus* (International Union for Conservation of Nature [IUCN] 2021) from the Dicroglossidae family with 79 individuals, followed by *Pulchrana grandocula* and *Occidozyga laevis* with 52 and 40 individuals, respectively. When compared to a previous study, the 15 amphibian species from this recent study were previously documented by Decena et al (2020) on the Babatngon Range in Leyte, who documented 18 species, where the same species (*L. magnus*) was also found to be the most abundant. On the other hand, a total of 142 individuals were reptiles with the most abundant species being a semi-aquatic lizard *Pinoyscincus llanosi* with 32 individuals, followed by *Cyrtodactilus annulatus* and *Pinoyscincus jagori jagori* with 26 and 17 individuals, respectively. Based on the IUCN Red List of Threatened Species (IUCN 2021), one reptile species (*Hydrosaurus pustulatus*) is considered vulnerable (VU), two (*Pinoyscincus llanosi* and *Stegonotus muelleri*) as near threatened, and the rest are of least concern, data deficient (DD) or not evaluated (NE). Also, other species of herpetofauna (1 amphibian and 8 reptiles) encountered outside the strip plots were noted but not included in the analysis. These species were *Nyctixalus spinosus*, *Gekko gecko*, *Hemidactylus frenatus*, *Pseudogekko pungkaypinit*, *Boiga cynodon*, *Coelognathus erythrurus erythrurus*, *Tropidonophis dendrophiops*, *Trimeresurus* cf. *flavomaculatus* and *Cuora amboinensis*.

Table 2. List of amphibians recorded in the different habitats with varying disturbance in northeastern Leyte, Philippines. Habitat disturbance, PF-primary forest, SLPF-selectively logged primary forest, AE-agroecosystem, P-pasture; Threat status according to The IUCN Red List of Threatened Species (IUCN, 2021), DD-data deficient, LC-least concern, NT-near threatened

Species	Species Occurrence	Endemism	IUCN Status	Photo voucher
AMPHIBIA				
Bufonidae				
Pelophryne lighti (Taylor 1920)	PF, AE	Endemic	LC	KUDA 013395
Rhinella marina (Linnaeus 1758)	AE, P	Non-endemic	LC	KUDA 013407
Ceratobatrachidae				
Platymantis corrugatus (Dumeríl 1853)	PF, SLPF, AE	Endemic	LC	KUDA 013399
Platymantis guentheri (Boulenger 1884)	PF	Endemic	LC	KUDA 013400
Platymantis sp.1	SLPF			KUDA 013401
Platymantis sp.2	PF			KUDA 013402
Platymantis sp.3	PF			KUDA 013403
Dicroglossidae				
Fejervarya moodiei (Taylor 1920)	P	Non-endemic	DD	KUDA 013385
Fejervarya vittigera (Weigmann 1834)	AE, P	Endemic	LC	KUDA 013386
Limnonectes leytensis (Boetger 1893)	SLPF, AE, P	Endemic	LC	KUDA 013390
Limnonectes magnus (Stejneger 1910)	PF, SLPF, AE, P	Endemic	NT	KUDA 013392
Occidozyga laevis (Günther 1859)	PF, SLPF, AE	Non-endemic	LC	KUDA 013394
Megophryidae				
Megophrys stejnegeri (Stejneger 1905)	PF, SLPF, AE, P	Endemic	LC	KUDA 013393
Microhylidae				
Kalophrynus sinensis (Peters 1867)	PF, SLPF, AE	Endemic	LC	KUDA 013388
Kaloula picta (Duméril and Bibron 1841)	P	Endemic	LC	KUDA 013389
Ranidae				
Hylarana erythraea (Schlegel 1837)	P	Non-endemic	LC	KUDA 013387
Pulchrana grandocula (Taylor 1920)	PF, SLPF, AE	Endemic	LC	KUDA 013405
Sanguirana mearnsi (Stejneger 1905)	AE	Endemic	LC	KUDA 013408
Staurois natator (Günther 1858)	PF, SLPF	Endemic	LC	KUDA 013409
Rhacophoridae				
Philautus leitensis (Boulenger 1897)	PF	Endemic	LC	KUDA 013396
Polypedates leucomystax (Gravenhorst 1829)	AE, P	Non-endemic	LC	KUDA 013404
Rhacophorus bimaculatus (Peters 1867)	PF, SLPF	Endemic	LC	KUDA 013406

The two-way ANOVA analysis revealed that amphibian, reptile, and overall abundance did not differ significantly between habitat disturbance types (Figure 4 A-C, Table 4). Although the majority of previous studies showed that habitat disturbance significantly reduced the abundance of herpetofauna in tropical regions (Gallmetzer & Schulze 2015, Roach et al 2020, Paoletti et al 2018, Folt & Reider 2013), it turns out that it may not always be the case as in this study. Such a finding was also reflected in the study of Ndriantsoa et al (2017) where amphibian abundance in some severely modified or disturbed habitats (eg, banana plantations and rice fields) was similar to non-riparian forest habitats.

Table 3. List of reptiles recorded in the different habitats in northeastern Leyte, Philippines. Habitat disturbance, PF-primary forest, SLPF-selectively logged primary forest, AE-agroecosystem, P-pasture; Threat status according to The IUCN Red List of Threatened Species (IUCN 2021), NE-not evaluated, DD-data deficient, LC-least concern, NT-near threatened, VU-vulnerable, EN-endangered

Species	Species Occurrence	Endemism	IUCN Status	Photo voucher
LIZARDS				
Agamidae				
Bronchocela marmorata (Gray 1845)	PF, AE	Endemic	DD	KUDA 013412
Draco bimaculatus (Günther 1864)	SLPF	Endemic	LC	KUDA 013418
Draco ornatus (Gray 1845)	AE	Endemic	LC	KUDA 013419
Gonocephalus interruptus (Boulenger 1885)	PF	Endemic	DD	KUDA 013424
Hydrosaurus pustulatus (Eschsholtz 1829)	AE, P	Endemic	VU	KUDA 013426
Gekkonidae				
Cyrtodactilus annulatus (Taylor 1915)	PF, SLPF, AE	Endemic	LC	KUDA 013416
Cyrtodactilus gubaot (Welton *et al* 2010)	PF	Endemic		KUDA 013417
Scincidae				
Eutropis multicarinata (Gray 1845)	PF, SLPF, AE, P	Non-endemic	LC	KUDA 013420
Eutropis multifasciata (Kuhl 1820)	P	Non-endemic	LC	KUDA 013421
Lamprolepis smaragdina philippinica (Mertens 1928)	AE, P	Endemic	LC	KUDA 013427
Lipinia pulchella pulchella (Gray 1845)	PF	Endemic	LC	KUDA 013428
Pinoyscincus coxi coxi (Taylor 1915)	PF	Endemic	LC	KUDA 013429
Pinoyscincus jagori jagori (Peters 1864)	PF, SLPF, AE	Endemic	LC	KUDA 013432
Pinoyscincus llanosi (Taylor 1919)	PF, SLPF, AE	Endemic	NT	KUDA 013436
Tropidophorus grayi (Günther 1861)	PF, SLPF	Endemic	LC	KUDA 013441
SNAKES				
Colubridae				
Calamaria lumbricoidea (H. Boie in F. Boie 1827)	PF	Non-endemic	LC	KUDA 013413
Lycodon dumerilii (Boulenger 1893)	PF	Endemic	LC	KUDA 013430
Stegonotus muelleri (Duméril, Bibron and Duméril 1854)	PF	Endemic	NT	KUDA 013437
Lamprophiidae				
Oxyrhabdium modestum (Duméril 1853)	PF, AE	Endemic	LC	KUDA 013431
Psammodynastes pulverulentus (Boie 1827)	PF	Non-endemic	LC	KUDA 013433
Natricidae				
Rhabdophis auriculatus auriculatus (Günther 1858)	PF, SLPF, AE	Endemic	LC	KUDA 013435
Viperidae				
Tropidolaemus philippensis (Gray 1842)	PF, SLPF, AE	Endemic	NE	KUDA 013439

Even if habitat disturbance will result in the disappearance of some species, particularly forest specialist species, they can be replaced by disturbance-tolerant or open-habitat specialist species in high abundance (Cruz-Elizalde et al 2016). However, disturbance-tolerant and non-native species are considered to have low conservation importance with negative impacts on habitat quality and subsequently ecosystem services (Platenberg 2007, Gutierrez 2017). The ability of these herpetofauna species to thrive in high abundance in disturbed habitats can probably be attributed to their generalized habits, environments, or the microhabitats they occupy (ie, tropical forests, pastures, man-made or temporary habitats, etc.) and periods of activity for foraging or reproductive behavior

(Cruz-Elizalde et al 2016, Jongsma et al 2014). In the study area, high abundances of amphibians (*Fejervarya moodiei* and *Fejervarya vittigera*) and reptiles (*Pj jagori* and *Eutropis multifasciata*) were observed in disturbed habitats, especially in the pasture as well as in the agroecosystem. The above-mentioned herpetofauna species are considered to be tolerant species, for example, *F. vittigera* and *E. multifasciata* are known to inhabit other highly modified habitats either in drainage ditches, rice fields, or residential areas and gardens (Devan-Song & Brown 2012, Sanguila et al 2016).

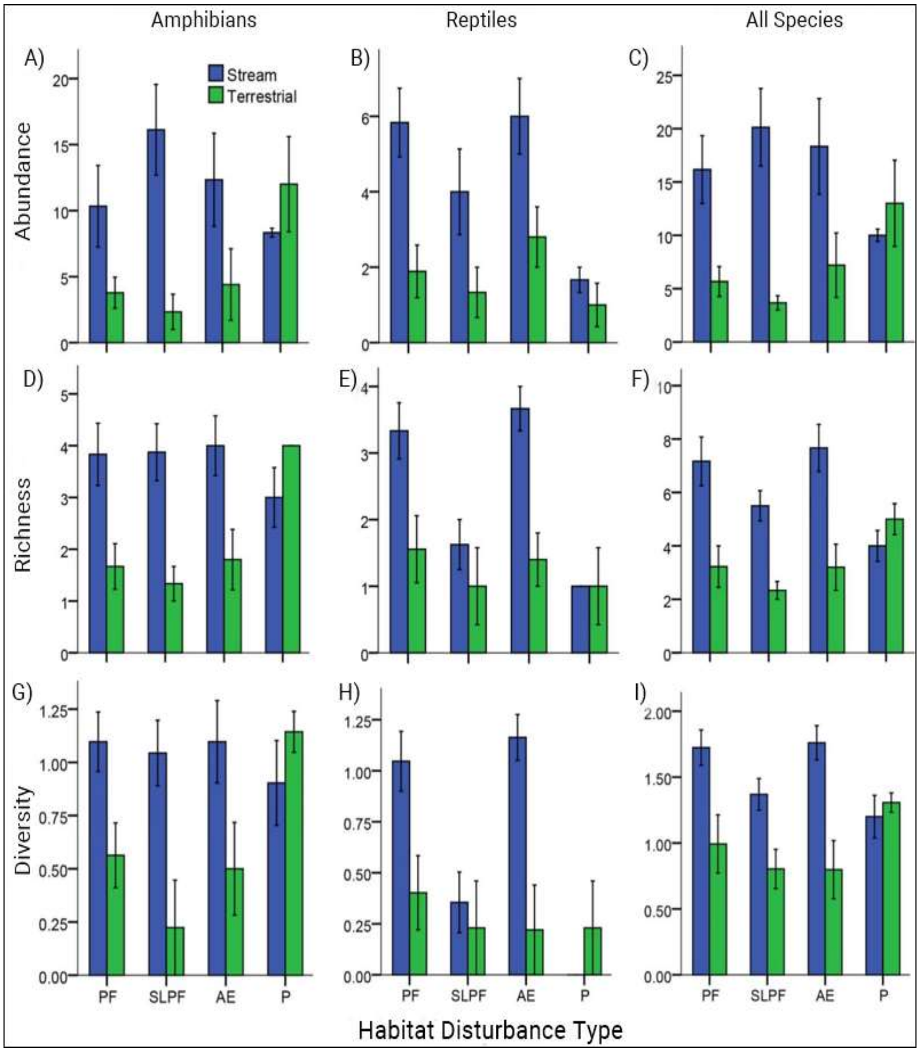

Figure 4. The difference in abundance, richness, and diversity of (A-C) amphibians, D-F) reptiles, and G-I) all species in the different habitat disturbance types. PF=primary forest, SLPF=selectively logged primary forest, AE=agroecosystem, P=pasture

On the other hand, habitat disturbance resulted in a significant reduction in species richness and diversity of reptiles only, primarily in pasture areas (Figure 4 E & H, Table 4). According to Palmeirim et al (2017), human-induced disturbance induces considerable decreases in the number of reptile species, with, in fact, nearly one in five reptilian species threatened with extinction (Böhm et al 2013). Prior studies have also reported a similar pattern with decreasing reptile species richness and/or diversity in disturbed or converted tropical forests (Urbina-Cardona et al 2006, Gardner et al 2007, Gallmetzer and Schulze 2015, Maynard et al 2016, Berriozabal-Islas et al 2017). This response can be attributed to several factors, for example, the lower availability and quality of microhabitats in disturbed sites (Gonthier et al 2014). Urbina-Cardona et al (2006) showed that microhabitat structures that can strongly affect the distribution of reptiles in the tropical forest include canopy cover, leaf litter cover, understorey density, and temperature. Specifically, reduction in forest or canopy cover in altered or degraded forests is often incompatible with the energetic ecology and behavior of shade-tolerant species, thereby aggravating stressors that lead to their local extinction (Palmeirim et al 2017). In contrast, heliothermic reptiles favor disturbed sites with reduced canopy cover for foraging and basking in direct sunlight to maintain their high body temperature as these areas have larger and numerous canopy openings resulting in higher temperatures (Vitt et al 1998, Pike et al 2011). In addition to lost canopy cover, the removal of large trees, buttresses and lianas also have a negative effect on species richness (Nuñeza et al 2010, Palmeirim et al 2017), as these habitat structures are important, especially for arboreal reptile species. Therefore, the low quality or absence of the abovementioned microhabitat or habitat structures in the pasture areas in this study likely explains the reduction in species richness or diversity. In fact, very few reptile species were encountered in the pasture areas, except for primarily disturbance tolerant lizards *E. multifasciata*. Only one arboreal species (*Lamprolepis smaragdina philippinica*) was found in pastures, whereas the rest of the arboreal species were strictly found in forests or agroecosystem habitats. However, the species richness and diversity in agroecosystem was comparable to forest habitats suggesting that the former could still significantly support herpetofauna communities. As observed, the agroecosystem (coconut plantations) still retained a very heterogeneous habitat, characterized by the presence of large trees, higher canopy cover, dense understorey vegetation and a variety of aquatic habitats.

Moreover, habitat type consistently influenced not only herpetofaunal abundance but also richness and diversity that was significantly higher in the stream compared to the terrestrial habitat (Figure 4 A-I, Table 4). Other studies have also reported similar results with higher herpetofaunal abundance and diversity in the stream habitat in rainforest ecosystems (Ficetola et al 2008, Jongsma et al 2014, Ndriantsoa et al 2017, Paoletti et al 2018). For ectothermic animals like amphibians, stream or riparian habitats are very important as these areas maintain cool moist conditions that are utilized for various life history functions such as breeding and foraging (Semlitsch 1998, Olson et al 2007, Jongsma et al 2014). In the case of reptiles such as lizards and snakes, riparian areas are vital to them for foraging activities due to the presence of many prey items (frogs and insects) (Gojo Cruz et al 2018). In addition, higher abundance and diversity of herpetofauna in stream habitats are associated with habitat complexity and quality (Bateman & Merritt 2020). For example, the study of Keller et al (2009) demonstrated that habitat heterogeneity in terms of environmental factors such as stream turbidity, river size, and understorey density drive herpetofaunal diversity and community structure. Bateman and Merritt (2020) revealed in their study that riparian areas with native stands of forest provide higher quality habitat for reptiles and amphibians compared to non-native stands. In this study, the majority (73%) of the amphibian species recorded occurred in the stream habitats that were mainly dominated by *L. magnus* and *P. grandocula,* which are strictly stream-breeding species (IUCN 2021). Similarly, 82% of the reptiles documented occurred in riparian habitats with the semi-aquatic lizard *P. llanosi* as the most abundant species. This higher herpetofaunal diversity in stream habitats suggests that these areas should be made a priority for conservation (Jongsma et al 2014).

Herpetofaunal Endemism

Overall, the endemism of herpetofauna was significantly influenced by both habitat disturbance and habitat type with a greater number of endemic species in the forest and agroecosystem, and in the stream habitat, respectively (Figure 5A-C, Table 4). Reduction in the number of endemic species due to disturbance and conversion of tropical forests in the Philippines was likewise observed for the herpetofauna of Victoria-Anepahan Mountain Range (VAMR), Palawan (Supsup et al 2020) and Mt. Malindang, Mindanao (Nuñeza et al 2010), and even for small mammals in the Central Cordillera of northern Luzon (Rickart et al 2011). Such response can be attributed to the view that endemic species are less tolerant of disturbance than widespread species, presumably because of greater ecological specialization (Brown 1995). In addition, the endemic species lost due to disturbance can be replaced by non-endemic species including invasives (Irwin et al 2010).

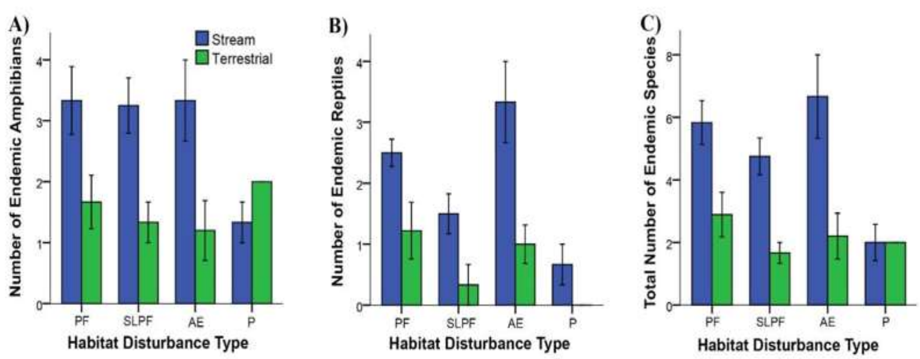

Figure 5. The difference in endemic (A) amphibians, (B) reptiles, and (C) amphibians and reptiles in the different habitat disturbance types. PF=primary forest, SLPF=selectively logged primary forest, AE=agroecosystem, P=pasture

Effects of habitat disturbance and elevation on the diversity and endemicity

Table 4. Results of the two-way ANOVA analysis on diversity indices and endemism

Variable	df	F	*p*-value
Amphibian Abundance			
Habitat Disturbance Type	3	0.40	0.755
Habitat Type	1	7.39	0.011
Interaction	3	2.15	0.113
Reptile Abundance			
Habitat Disturbance Type	3	2.76	0.058
Habitat Type	1	11.64	0.002
Interaction	3	0.80	0.504
Overall Abundance			
Habitat Disturbance Type	3	0.12	0.948
Habitat Type	1	12.77	0.001
Interaction	3	2.33	0.093
Amphibian Species Richness			
Habitat Disturbance Type	3	0.64	0.592
Habitat Type	1	10.85	0.002
Interaction	3	2.75	0.059
Reptile Species Richness			
Habitat Disturbance Type	3	4.08	0.015
Habitat Type	1	9.17	0.005
Interaction	3	1.66	0.196
Overall Richness			
Habitat Disturbance Type	3	1.21	0.321
Habitat Type	1	16.73	<0.001
Interaction	3	3.02	0.044
Amphibian Diversity (Shannon-Weiner)			
Habitat Disturbance Type	3	1.10	0.363
Habitat Type	1	9.05	0.005
Interaction	3	2.13	0.116
Reptile Diversity (Shannon-Weiner)			
Habitat Disturbance Type	3	4.06	0.015
Habitat Type	1	6.13	0.019
Interaction	3	2.73	0.060
Overall Diversity (Shannon-Weiner)			
Habitat Disturbance Type	3	0.69	0.565
Habitat Type	1	12.24	0.001
Interaction	3	1.81	0.166
Endemic Amphibians			
Habitat Disturbance Type	3	0.72	0.547
Habitat Type	1	9.66	0.004
Interaction	3	2.01	0.132
Endemic Reptiles			
Habitat Disturbance Type	3	6.36	0.002
Habitat Type	1	13.29	<0.001
Interaction	3	0.88	0.426
Overall Endemic Species			
Habitat Disturbance Type	3	3.59	0.032
Habitat Type	1	16.98	<0.001
Interaction	3	2.06	0.145

The Philippines is known for its exceptionally high endemicity, especially for herpetofauna, which can be strongly attributed to the island's complex geological settings and biogeographical affinities (Supsup et al 2020). Previous investigations of the country's herpetofauna showed relatively high to very high endemicity, for example, Nuñeza et al (2010) found 42% and 48% endemicity for amphibians and reptiles, respectively in Mt. Malindang, Mindanao, Supsup et al (2020) found 50% and 33.3% of amphibians and reptile species respectively, were endemic to VAMR or Palawan Island, while Relox et al (2011) documented up to 77.8% and 93.3% amphibian and reptilian endemicity, respectively in Mt. Hamiguitan, also in Mindanao. In line with the above previous findings, very high endemicity relative to the total number of captured species was also observed in the present study with 14 species (64%) and 18 species (82%) of the documented amphibians and reptiles, respectively, were endemic to Leyte or Philippines. This high endemicity of herpetofauna is largely attributed to the presence of pristine or less disturbed habitats such as lowland dipterocarp or montane forests (Relox et al 2011). Specifically, the highest number of endemic species was found in the primary forest (dipterocarp forest) of the study area with 10 species (46%) and 13 species (59%) of amphibians and reptiles, respectively, while pasture possessed only about 5 species (23%) and 2 species (9%) of endemic amphibians and reptiles, respectively. Moreover, there was a higher endemicity in the stream habitat as many of the herpetofauna sampled were considered to be stream breeders or inhabitants, of which the overall endemicity was 75% (12 species) and 78% (14 species) for amphibians and reptiles, respectively. In the studied mountain ranges, the communities of endemic herpetofauna that inhabit forests with stream habitats were dominated by the threatened amphibian *L. magnus* followed by *O. laevis*, and the semi-aquatic lizard *P. llanosi*. Finally, the results of this study highlight the importance of the conservation of pristine forests with streams particularly lowland dipterocarp forests for supporting the populations of endemic as well as threatened herpetofauna (Nuñeza et al 2010, Supsup et al 2020).

Herpetofaunal Elevational Diversity and Endemism Gradient

The results of the regression analysis showed that amphibian richness and the overall herpetofaunal diversity linearly decreased with increasing elevation (Figure 6A & B). This negative response of herpetofauna to elevation was also found in prior studies in the Philippines (Supsup et al 2020) and in other parts of the world (Malonza 2015, Khatiwada et al 2019, Chen et al 2020). The lower species richness and diversity of herpetofauna in higher elevations are likely to be due to increasing environmental constraints (Körner 2007). Malonza (2015) indicated that climatic variables in terms of precipitation and temperature can influence regional herpetofaunal species richness as well as diversity, wherein precipitation increases and temperature decreases with increasing elevation. Heliothermic reptiles prefer warmer and drier lower-elevation habitats where they are found in greater abundance, compared to the colder and moist higher-elevation habitats (Nuñeza et al 2010, Relox et al 2011). This possibly explains why there were a lower abundance and number of reptile species encountered in some of the study areas particularly in the montane primary forests (>800m asl), the species identified include *Gonocephalus interruptus*, *C. annulatus*, *E. multicarinata*, *Rhabdophis auriculatus auriculatus*, *Oxyrhabdium modestum*, and *Psammodynastes pulverulentus*. Another possible factor explaining the higher diversity of herpetofauna in lower-elevation habitats is the presence of more and diverse microhabitats (Khatiwada et al 2019). For amphibian communities, permanent aquatic microhabitats (eg, lentic and lotic water bodies) that are often present at lower elevations are vital for their reproduction. In higher-elevation habitats like mossy or montane forests with steep terrain most breeding habitats formed by rainfall are shallow and swift, and diminish quickly in volume because of rapid runoff (Nuñeza et al 2010). This condition favors only the existence of species that do not require the said aquatic microhabitats (Inger & Stuebing 1989) and usually breed by direct development. It is worth noting that the majority of the amphibian species encountered in the study area were stream-breeding or stream-dependent species inhabiting particularly the lowland dipterocarp forests, which attract more predatory lizards and snakes.

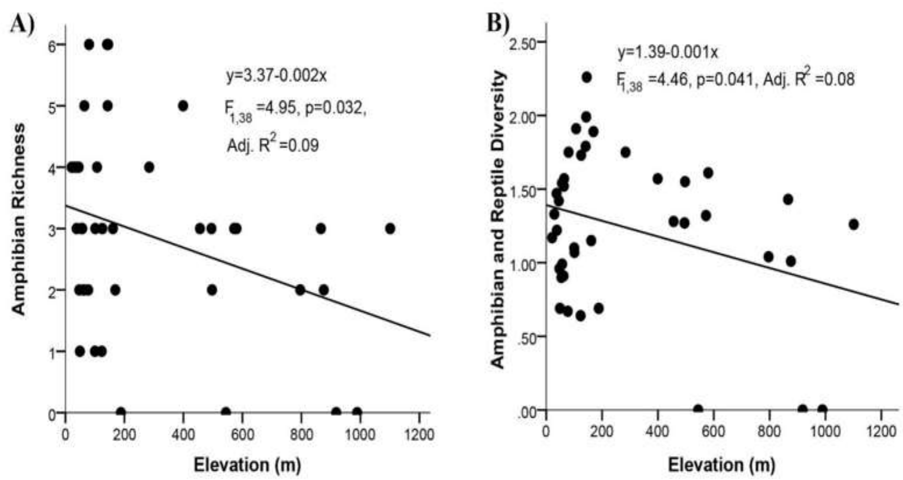

Figure 6. The relationship between (A) elevation and amphibian richness, and (B) elevation and amphibian and reptile diversity. The significant regression lines and their equations, R^2, F and *p*-values are presented

Conversely, a positive relationship was found between the elevation and the number of endemic reptiles, and herpetofauna (Figures 7A & B). The relationship was only detected for stream-dwelling herpetofauna, where the endemicity increased with increasing elevation. Prior studies in the Philippines have reported higher herpetofaunal endemicity at higher elevations specifically in montane and mossy forests compared to lower-elevation forest habitats (Nuñeza et al 2010, Relox et al 2011). On the other hand, the reduction in herpetofaunal endemicity at lower-elevation habitats is strongly attributed to disturbance (Malonza 2015). It is also reported that endemic species have a lower tolerance to anthropogenic habitat disturbanceresulting in disturbed habitats being dominated by widespread and non-endemic or introduced species (Gojo Cruz et al 2018). In the Philippines, dipterocarp forests that were the dominant original and pristine lowland habitats for herpetofauna have been more prone to anthropogenic disturbance and frequently transformed into highly disturbed habitats (eg, secondary vegetation, pastures, & croplands) that likely support a far smaller number of endemic species. In the study area, pasture was one of the commonly disturbed habitats along streams and was found to host very few endemic herpetofauna. Notable species from this habitat were the widespread Philippine endemic frogs *Fejervarya vittigera* and the vulnerable Philippine sailfin lizard *H. pustulatus*. Although the agroecosystem (coconut plantation) is also considered to be a disturbed habitat, unlike pasture, it has retained some of the habitat structural complexity that enables it to still support more endemic species. Lastly, the results of the study further imply that the remaining lowland dipterocarp and montane forests are of high priority for conservation as these habitats support high herpetofaunal endemicity (Nuñeza et al 2010).

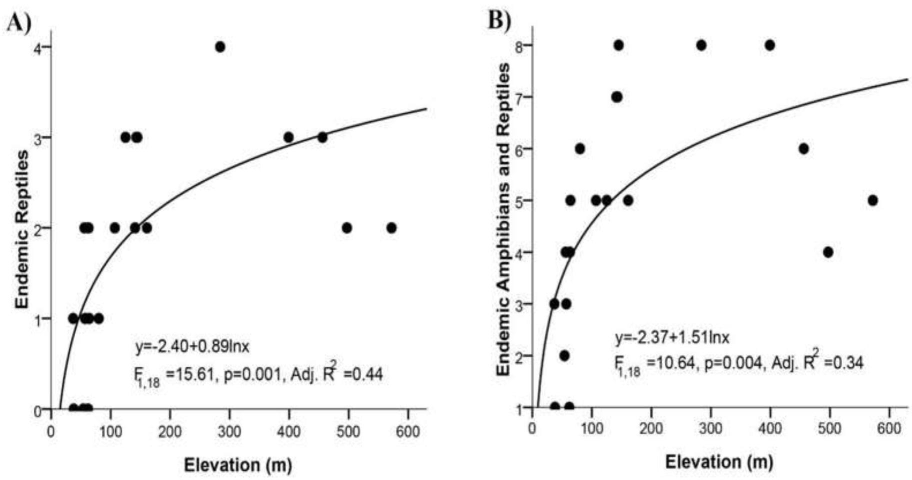

Figure 7. The relationship between (A) elevation and number of endemic reptiles, and (B) elevation and endemic amphibians and reptiles in stream habitat. The significant regression lines and their equations, R^2, F and *p*-values are presented

Indicator Species

The indicator species analysis identified a total of 8 out of 44 herpetofaunal species analyzed, consisting of 6 amphibians and 2 reptile fauna (Figure 8, Table 5). Almost all of the species were indicators of a single habitat disturbance type, except for 1 species that was an indicator of a combination of two habitats. More than half of these identified species were an indicator of pasture habitat, with 4 amphibians such as *F. moodiei*, *F. vittigera*, *Hylarana erythraea* and *Kaloula picta* (Figure 8A-D), and 1 reptile species *E. multifasciata* (Figure 8G). The non-endemic amphibian *Polypedates leucomystax* (Figure 8F) was strongly associated with both pasture and agroecosystem. The arboreal frog *Platymantis guentheri* (Figure 8E) and snake *Psammodynastes pulverulentus* (Figure 8H) were strongly associated with primary forests (dipterocarp or montane forests). Whereas, no species was found to be an indicator for the selectively logged primary forest.

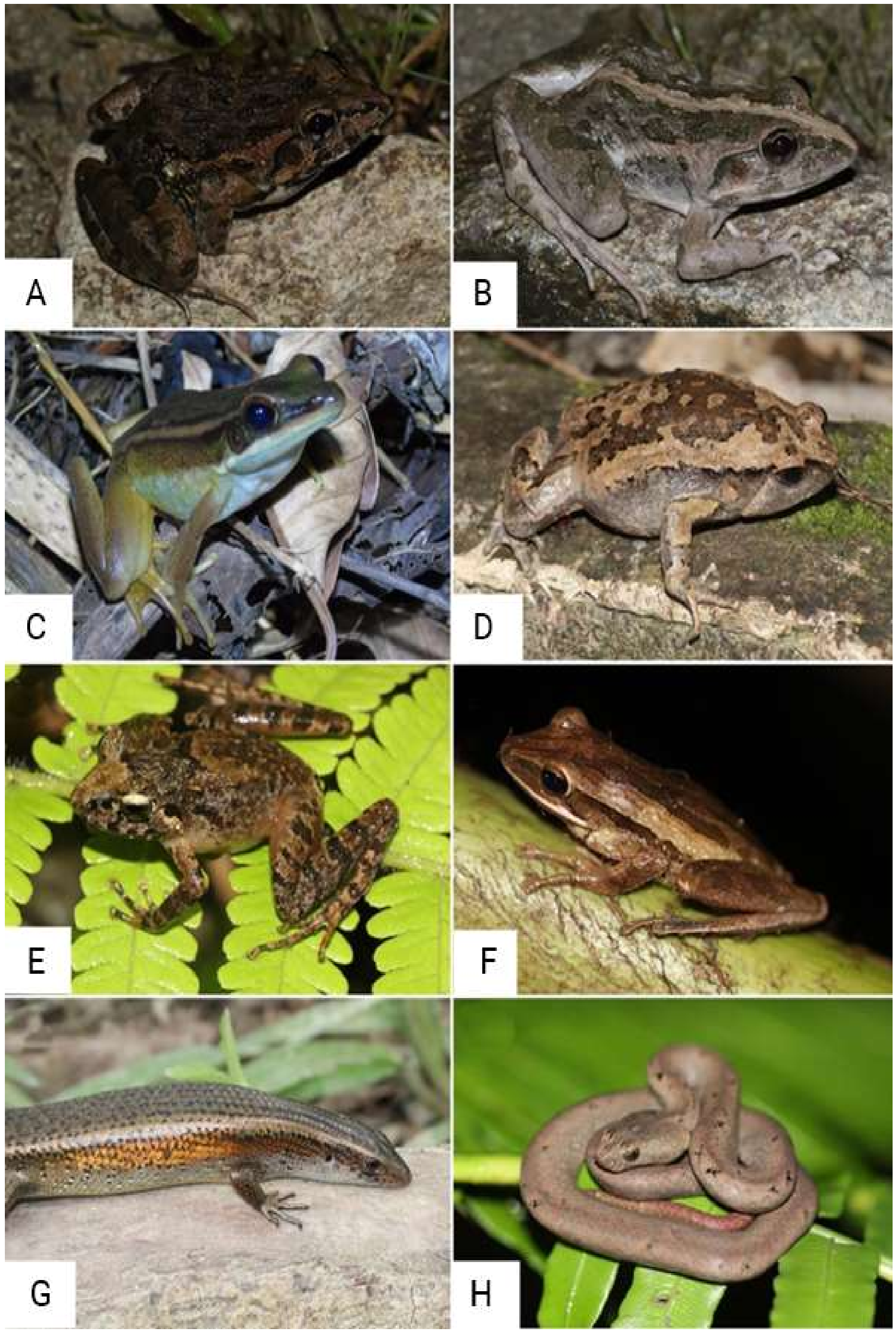

Figure 8. Indicator species identified from the different habitat disturbance types. (A) *Fejervarya moodiei*, (B) *Fejervarya vittigera*, (C) *Hylarana erythraea*, (D) *Kaloula picta*, (E) *Platymantis guentheri*, (F) *Polypedates leucomystax*, (G) *Eutropis multifasciata*, and (H) *Psammodynastes pulverulentus*

Table 5. The results of Indicator Species Analysis with 8 indicator species out of 44 species analysed based on indicator value (*IndVal*)

Habitat	Indicator species	Test statistic	*p*-value
Pasture	*Fejervarya moodiei*	0.913	<0.001
	Fejervarya vittigera	0.870	<0.001
	Hylarana erythraea	0.707	0.003
	Kaloula picta	0.577	0.022
	Eutropis multifasciata	0.775	0.002
Agroecosystem/Coconut Plantation + Pasture	*Polypedates leucomystax*	0.555	0.042
Primary Forest	*Platymantis guentheri*	0.707	0.002
	Psammodynastes pulverulentus	0.555	0.036

Some species or groups of species are intolerant to factors such as pollution, environmental disturbance and habitat modifications. Their presence is an indicator of a healthy ecosystem, while their absence can indicate environmental or habitat disturbance (Amarasinghe et al 2021). Among these organisms, amphibians and reptiles are generally good indicator species due to their sensitivity to habitat alteration and environmental change (Welsh & Ollivier 1998). Historically, herpetofauna (especially amphibians) have been widely used as indicators of environmental pollution by various contaminants (eg, fertilizers, chemical pesticides, heavy metals, and pharmaceutical compounds) (de Wijer et al 2003, Schmutzer et al 2008, Bókony et al 2020). More importantly, herpetofauna have also been used as important indicators of habitat disturbance and alteration in tropical forest ecosystems (Jongsma et al 2014, Gillespie et al 2015, Decena et al 2020, Amarasinghe et al 2021). In addition to environmental sensitivity, herpetofauna are further considered useful indicator species because they are easily sampled (Dale and Beyeler 2001). Unlike larger-bodied taxa-like birdsthat need high-cost mist-net trapping and ringing techniques with associated high labor costs, herpetofauna sampling and monitoring usually just requires double observer – visual encounter – belt transect surveys at night (Amarasinghe et al 2021). Therefore, it is more advantageous to use herpetofauna as indicator species to monitor habitat disturbance or alteration, not only because of their sensitivity but also for cost efficiency.

In the present study, indicator analysis showed that some herpetofauna can be considered indicator species for certain habitats with varying levels of disturbance. The pasture habitat is regarded to be the most disturbed among all and has the greatest number of indicator species (5 species). These indicator species include 4 amphibians, however, only 3 of these (*F. moodiei*, *F. vittigera* and *H. erythraea*) can be considered excellent indicator species considering their higher abundance. Almost all the said amphibians were restricted to pasture only, except for a few individuals of *F. vittigera* that were also found in the agroecosystems, and these species were completely absent in forest habitats (primary and selectively logged forests). All these species are known to be widespread in the Philippines and tolerant of habitat disturbance. For example, *H. erythraea* is an introduced and open-habitat specialist species also preferring to inhabit other disturbed environments like residential areas and edges of secondary forests (Siler et al 2012, Devan-Song & Brown 2012). Though *F. vittigera* is a Philippine endemic, it is known to inhabit very disturbed low-elevation habitats such as rice fields (Siler et al 2012).

In addition, the lizard species *E. multifasciata* was found to be an indicator species where the individuals were encountered exclusively in pastures. The presence of this lizard indicates that this habitat is already disturbed since it prefers to be active in open areas not only in pasture but also in secondary vegetation or abandoned farmland. The non-endemic arboreal frog *P. leucomystax* serves as an indicator species for both pasture and agroecosystem, wherein this amphibian species is also widespread and disturbance tolerant (Sanguila et al 2016).

The less disturbed primary forest was represented by 2 indicator species *P. guentheri* and *P. pulverulentus*. The endemic *P. guentheri* was exclusively encountered in lowland dipterocarp and montane forests indicating that the species is a good indicator of less disturbed forest habitats. This arboreal species prefers to inhabit non-riparian forests and breeds by direct development as its life history adaptation strategy (AmphibiaWeb 2021, IUCN 2021). The absence of this species can strongly signal disturbance of old-growth forests as these forest types are its main habitats based on observation. Finally, the non-endemic snake *P. pulverulentus* served also as a good indicator species for forests as the species was exclusively encountered in such habitats. Often, this reptile species was observed in the healthy understorey vegetation characterized by an abundance of large ferns (*Angiopteris palmiformis* and *Sphaeropteris* sp.) in lowland dipterocarp and montane forests.

CONCLUSIONS

The results of the study indicated that the diversity and endemism of herpetofauna could be influenced by habitat disturbance and elevation. The habitat disturbance significantly reduced the reptile richness and diversity, and herpetofaunal endemicity particularly in highly disturbed habitats (pasture). Meanwhile, stream habitats host the greatest diversity and endemicity of herpetofauna compared to terrestrial habitats. The herpetofaunal diversity and endemicity had a contrasting response with the elevation where the diversity decreased but endemicity increased with increasing elevation. In addition, habitat disturbance types are strongly associated with specific indicator species, indicating that less disturbed habitats (primary forests) are associated with intolerant species, while highly disturbed habitats (pasture) are dominated by disturbance-tolerant and widespread species. Overall, the present study highlights the need to implement conservation actions towards the remaining critical primary habitat (dipterocarp and montane forests), especially with stream habitats, to ensure the persistence of high herpetofaunal diversity and endemicity. Further, herpetofauna appeared to be good indicator species that can potentially be utilized to monitor habitat quality in the study area.

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