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Herpetological Assemblages in Tropical Forests of the Taguibo Watershed, Butuan City, Eastern Mindanao, Philippines

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Tropical watershed ecosystems support heterogeneous habitats and diverse non-human species assemblages, together providing ecosystem services to humans. Amphibians and reptiles are recognized as sensitive indicators of ecosystem "health," related to beneficial services (provisional, regulating, cultural, structural, functional) human societies receive from terrestrial watersheds. The Taguibo Watershed supplies fresh drinking water to Butuan City in the Caraga Region of northeast Mindanao Island. However, very little is known about the herpetofauna of the area. Here, we synthesize biodiversity data from historical (1971, 1979) and recent (2013, 2017) herpetological surveys from the region. We utilize specimen-associated occurrence records and natural history information to produce a species inventory, analyze their habitat utilization, and characterize diversity metrics to describe herpetological communities of the watershed – resulting in 44 species (27 new records). A number of historically-documented species persist, having partitioned riparian and terrestrial habitat types in dipterocarp and secondary-growth forests of Taguibo. Reptiles exhibit little overlap in the use of microhabitats – in contrast to amphibians, which exhibit either unique or frequently shared microhabitat substrates. In terrestrial microhabitats (not immediately associated with water), many newly-recorded reptiles and amphibians (particularly, of the genus *Platymantis*) partition space predictably – either occupying a single microhabitat or, in one species (a pit viper, *Tropidolaemus subannulatus*), two microhabitats. We anticipate that our initial characterization of Taguibo's herpetofauna may serve as a baseline to promote further research and facilitate conservation initiatives. We emphasize the importance of primary sources – field-based surveys and re-surveys – and open-access biodiversity data served *via* online platforms that provide live, transparent access to original, unaltered data. Anthropogenic threats involving economic-driven activities present a need for field-based research in support of watershed management. Periodic, survey, and re-survey studies – continuously updating earlier work – are the most reliable, repeatable, and publicly-transparent use of biodiversity survey data in support of societal benefits and ecosystem services.

Keywords: anthropogenic disturbances, biodiversity database, ecosystem services, habitat use, heterogeneity, spatial partitioning

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INTRODUCTION

Economically-important watershed ecosystems are often threatened by anthropogenic disturbances and remain important focal areas for long-term studies in support of sustained biodiversity management and conservation initiatives (Squires 2013). Such is the case of the Taguibo Watershed, formally known as the Taguibo River Watershed Forest Reserve (TRWFR) located south of Mt. Hilong-hilong massif, a key biodiversity area in Caraga Region of the Eastern Mindanao biodiversity corridor (Mallari *et al.* 2001). The Taguibo Watershed provides ecosystem services to its surrounding communities, primarily as a source of continuous supply of fresh drinking water for the entire of Butuan City and water for irrigation to the surrounding rural community; this surface catchment also serves as an environmental buffer from extreme or inclement weather conditions in the Caraga Region (Santillan *et al.* 2011; Sanguila *et al.* 2016).

Anthropogenic factors such as for-profit economic land-utilization (*e.g.* massive historical logging concession activity; Bautista 1990) have long threatened the Taguibo Watershed, resulting in the conversion of its forested habitats to grasslands and barren, non-productive areas (Santillan *et al.* 2011). In addition, the Taguibo Watershed is plagued with ongoing, active, local insurgency similar to other conflict-prone areas in the Philippines. This insurgency and its resultant logistical obstacles to field biologists' security has a negative final impact – restricting access to sampling sites and creating challenges for the field-based survey and re-survey biodiversity studies (Brown *et al.* 2002, 2012b; Siler *et al*. 2011).

Amphibians and reptiles provide ecosystem services that benefit human welfare directly, and indirectly, through food-web dynamics. These include: 1) direct provisioning and cultural services as protein sources, medicinal resources, cultural, and raw materials (Mohneke *et al*. 2011; Alves *et al*. 2013; Valencia-Aguilar *et al.* 2013); and 2) indirect regulation and support services that sustain ecosystems and biodiversity: seed dispersal, nutrient cycling, biological control, bioturbation, habitat, and community stability/resilience (Gibbons *et al*. 2000; Civantos *et al*. 2012; Hocking and Babbitt 2014; Cortés-Gomez *et al*. 2015; Àlvarez-Grzybowska *et al*. 2020).

The Taguibo Watershed constitutes an important (societally-relevant) and ideal (geographically-proximate to a major metropolitan area) focal study site for herpetological surveys, following the seminal works by A.C. Alcala (Silliman University) and W.C. Brown [California Academy of Sciences (CAS) in the Mt. Hilong-hilong Mountain Range (1971, 1979). From their surveys, a diverse suite of amphibian and reptile species have been historically-documented at varying elevations along the Taguibo River (CAS 2020). Despite the availability of these data in the public domain, very little remains known on the herpetological community composition of the Taguibo Watershed. No proper follow-up herpetofaunal "re-survey" efforts have been conducted (missing a valuable opportunity; Brown *et al*. 2012b, 2013); in fact, it is the only one of its kind in the southern Philippines (Sanguila *et al*. 2016). The apparent anthropogenic threats to the Taguibo Watershed (see above) – coupled with a lack of basic natural history information for the amphibian and reptile species native to this biodiverse, species-rich site of key importance – urgently calls for re-surveys.

Herein we provide a characterization of herpetological assemblage (a local ecological community) of the Taguibo Watershed utilizing historical and recent field-based datasets from freely-served biodiversity databases. We discuss practical points (deliverables) of conservation implications from our results and evaluate its potential use for guiding strategies of local conservation and sustainable management initiatives in Butuan City's Taguibo Watershed.

MATERIALS AND METHODS

Study Sites and Data Collection

The Taguibo Watershed is located within several political boundaries of Agusan del Norte Province, eastern Mindanao, Philippines. It has a total area of 43.67 sq. km. In this study, we identified sampling sites within the watershed (Figure 1; QGIS V 3.4.3, WGS 84) based on published information from the CAS database derived from the Alcala and Brown (1971, 1979) herpetological surveys at mid-elevation dipterocarp forests, which constituted Sites 1–3 (Site 1: M19–22: 09°02'46.6"N 125°42'3.6"E; Site 2 M-23 09°05' 43.9"N 125°42'7.2"E; Site 3: 138-A 09°08'47.0"N 125°44'38.4"E and 136-B; Area 7: no coordinates available), and from recent herpetological surveys comprised of Sites 4 and 5 (see description below) derived from the Father Saturnino Urios University (FSUU) Specify database.

Site 4: Mindanao Island, Agusan del Norte Province, Butuan City; TRWFR; Barangay Anticala; Ginubatan: 09°02'57.7"N 125°41'76.3"E; 600–700 m elevation. This site is a primary mid-montane forest characterized by a fast-flowing stream of 10–15 m wide with large boulders and moss, ferns, pitcher plants (*Nepenthes*), overhanging vegetation, and dipterocarp trees. Field surveys at Site 4 were conducted in the riparian zone by JLP and party on 26–28 Apr (with MBS), 24–30 May, 25–30 Jun, 17–21 Jul, 16–18 Aug, and 11–13 Sep 2017 – following standardized collection and specimen preservation techniques (Heyer

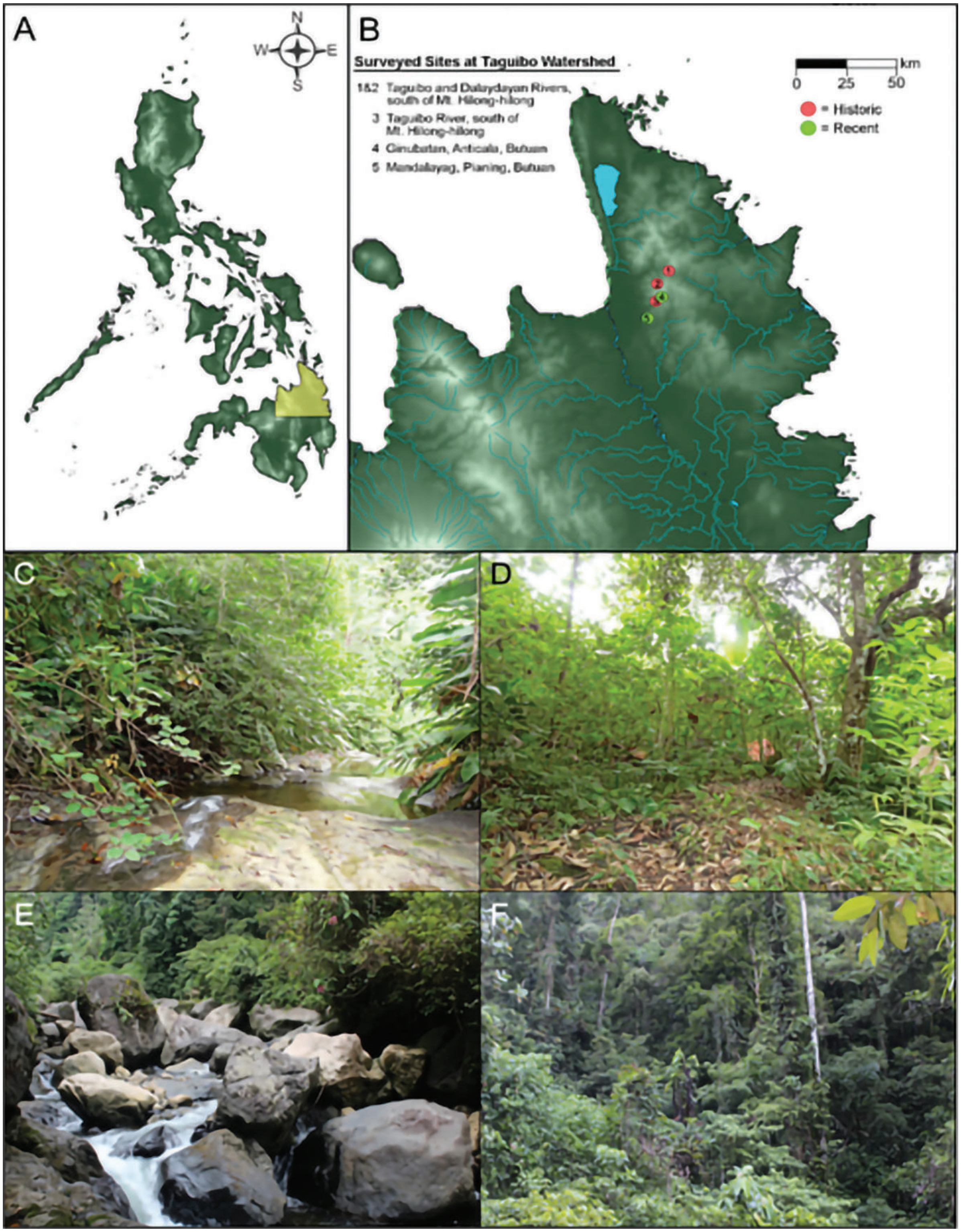

Figure 1. Map of the Philippines (A) highlighting the Northeast Mindanao Region (B) and sampling sites historically surveyed by Brown and Alcala (1971, 1979; Sites 1–3; pink dots) in dipterocarp forests at mid-elevation, versus sampling sites recently surveyed in 2013 and 2017 (Sites 4–5; green dots) in primary-mossy forests at higher elevation and secondary-growth low-elevation forests of the Taguibo Watershed. Characteristic appearance of recently surveyed sites: riparian and terrestrial zone habitats of low-elevation forests (C–D), and riparian and terrestrial zone habitats of mid-elevation forests (E–F) of the Taguibo Watershed. Map: QGIS V 3.4.3, WGS 1984. Photos: MBS and JLP.

et al. 1994; Simmons 2002). Nocturnal (1900–0000h) searches were conducted by small groups of observers (on foot), focusing on amphibians only (but resulting in incidental collection for reptiles, such as sleeping agamids and snakes). All surveys were conducted in three 100-m line transects (50 m away from each other), marked at 10 m intervals using fluorescent tagging.

Site 5: Mindanao Island, Agusan del Norte Province, Butuan City; TRWFR; Barangay Pianing; Mandalayag: 08°58'25.5"N 125°40'01.2"E; 200–300 m elevation. This site is near cultivated land and is characterized as a secondary-growth forest with a 3–5 m wide, slow-moving stream. The first field surveys at Site 5 were conducted by MBS, JLP, MYM, and RCE on 29 May–7 Jun 2013 – following the same, standardized, collection, and specimen preservation techniques (Heyer *et al.* 1994; Simmons 2002). Nocturnal (1900–0000h) and diurnal (1000–1500) searches were conducted in a variety of habitat types, along 2.0-km transects, established in each riparian and terrestrial zone. Our subsequent field surveys were conducted within the riparian zone by JLP and party on 26–28 Apr, 24–30 May, 25–30 Jun, 17–21 Jul, 16–18 Aug, and 11–13 Sep 2017. Nocturnal (1900–0000h) searches (amphibians only) were conducted in three 100-m line transects (50 m away from each other), marked at 10 m intervals using fluorescent tagging.

All specimens were identified in the field and vouchers were verified following published reference guides (Alcala and Brown 1998; Brown *et al*. 2000, 2012b; Siler *et al*. 2011; Diesmos *et al*. 2015; Sanguila *et al*. 2016; Leviton *et al*. 2018; Weinell *et al*. 2019; Uetz 2020). All voucher specimens from the recent herpetological surveys have been deposited and permanently cataloged at the FSUU Reference Natural History Collection (NHC). Species occurrence records and their specimen-associated natural history information was archived using the software Specify at FSUU, which is served *via* the Global Biodiversity Information Facility (GBIF 2020).

Data Processing

We compiled published species records and associated natural history information from the herpetological surveys by Alcala and Brown (1971, 1979; CAS 2020) and recent surveys (2013, 2017) obtained from the FSUU database. We then designated two major categories of amphibian and reptile qualitative habitat types (macro- and micro-habitat; Table 1) as follows: macrohabitats were described as species dwelling sites within forested areas of dipterocarp, primary mossy, and secondary growth vegetation. Within these macrohabitats, we adopted riparian (areas adjacent, along, or in streams and rivers) and terrestrial (areas far away from bodies of water; river

Table 1. Characterization of three microhabitat types in forested, riparian, and terrestrial zones of the Taguibo Watershed collated from museum-served, relational, specimen-associated databases of the Alcala and Brown collections [historical, 1971, 1979 (see also Brown and Alcala 1974, 1980, 1982)] and recent [2013, 2017 (see also Plaza and Sanguila 2015; Sanguila *et al*. 2016)] herpetological biodiversity surveys. Specimen-associated natural history information were extracted from the publicly-accessible [California Academy of Sciences (CAS) and Father Saturnino Urios University (FSUU)] databases.

Higher taxa	Zone	Microhabitat types		
		Aquatic	Arboreal	Ground
Amphibians	Riparian	Perched on rocks midstream, or in water of stagnant pools of flowing 2–15 m wide stream or river	On leaf, twig, or branch of shrubs, aerial ferns, in saplings or understory vegetation; or in canopy-layer trees (usually in general proximity to 2–15 m wide stream or river)	Among decomposing leaves, or other forest floor debris, on exposed soil, or gravel or other bank surface; on rocks or boulders (usually in general proximity to 2–15 m wide stream or river)
	Terrestrial	In puddles along transect; in ditches along road, ≥ 500 m from stream or river	On leaves of shrubs, saplings, or other herb-layer vegetation; on lower leaves of understory tree, or trunks, ≥ 1 m from ground; or shrubs and saplings along transect	Among decomposing leaves, or under other forest floor debris (rotting logs); or on exposed forest floor soil
Reptiles	Riparian	Perched on rocks midstream, or in water of stagnant pools, of flowing 2–15 m wide stream or river	On leaf, twig, or branch of shrubs, aerial ferns, in saplings or understory vegetation; or in canopy-layer trees (usually in general proximity to 2–15 m wide stream or river)	Among decomposing leaves, or other forest floor debris, on exposed soil, or gravel or other bank surface; on rocks or boulders (usually in general proximity to 2–15 m wide stream or river)
	Terrestrial		In pocket ferns; on coconut trees; on leaves, branches, or trunks of saplings or trees; on house walls	Among decomposing leaves, or under other forest floor debris (rotting logs); or on exposed forest floor soil or rocks along transect; under coconut husks or other debris along road; on lower (≤ 1 m from ground) tree trunks or buttresses.

systems 50–100 m or more) habitats as macrohabitat zones frequented by amphibians and reptiles (Brown and Alcala 1961; Auffenberg and Auffenberg 1988; Brown *et al*. 2012b; Sanguila *et al.* 2016; Supsup *et al*. 2017). Within riparian and terrestrial zones, we categorized microhabitats as "arboreal," "aquatic," and "ground." Each category was designated, based on our actual observation of the immediate location in which each specimen was recorded. Nevertheless, specific descriptions of microhabitats among our study and those of previous field workers may differ for some species, depending on the zone in which specimens were recorded. For example, the description of aquatic microhabitats in the riparian zone may pertain to a species' use of substrates – such as either perched on rocks or floating in water of stagnant pools or swimming in streams; or resting in ephemeral bodies of stagnant, non-flowing water along transects (in the case of *Occidozyga laevis*, a puddle frog specialized in silted, still, temporary pools). In the terrestrial zone, categorization of structural microhabitat may pertain to substrates – such as a species perched on rocks; in stream-side vegetation; in water of ephemeral forest puddles; or in flowing canals, streams, or ditches in established transects (as in the case of *Fejervarya vittigera*).

Data Analysis

We filtered the compiled dataset from the CAS and FSUU databases to derive amphibian and reptile species occurrence records and their associated habitat type descriptions. These species occurrence records were used as the basis for generating a species list (a faunal inventory). We then determined species-habitat utilization by discrete association analysis between species occurrence records (presence *vs.* absence) and described habitat types using the bipartite package in R (Dormann *et al.* 2009, 2020).

The Shannon index was used to measure amphibian species diversity following the formula: $H = -\sum_{i=1}^{S} p_i \, log_b p_i$, where p_i is the proportion of species i and S is the number of species so that $\sum_{i=1}^{S} p_i = 1$ and b is the base of the logarithm. Evenness was calculated using Pielou's evenness (1966): $J = H'/H'_{max} = -(\sum p_i \log p_i)/log\, S$, where p_i is the proportion of individuals at the site belonging to i^{th} species and S is the total number of amphibian species collected at the site. We used the non-parametric Wilcoxon signed-rank test to compare relative abundance, species richness, diversity, and evenness values across months between sites. Statistical analyses were performed (and results graphically summarized) using the Vegan package in R (Oksanen *et al.* 2019).

RESULTS

Herpetofaunal Species Occurrences in Taguibo Watershed

We documented a total of 44 herpetofaunal species (20 amphibians, 16 lizards, and eight snakes) in the Taguibo Watershed (Table 2). The herpetofauna of the Taguibo Watershed consists primarily of endemic species of the Mindanao faunal region. Moreover, according to the IUCN (2020) criteria of a species' conservation status, there were 32 species (17 amphibians, 15 reptiles) under "Least Concern," two species (one amphibian, one reptile) were under "Vulnerable," three species (one amphibian, two reptiles) were under "Near Threatened," three species (one amphibian, two reptiles) were under "Data deficient," and five (one amphibian, four reptiles) were under "Data not available." Based on the criteria by the Philippine Red List Committee (PRLC 2020) for threatened fauna, no reptile species and only three amphibians were

Table 2. Herpetological inventory species list for the herpetofauna of Taguibo Watershed, summarizing species occurrence records from the historical surveys (H[a]) of Alcala and Brown [1971, 1979; California Academy of Science (CAS) database] and recent surveys [N[b]; 2013, 2017; Father Saturnino Urios University (FSUU) database], corresponding voucher specimen catalog numbers, biogeographic distribution, and current conservation status as assessed by the International Union for the Conservation of Nature (IUCN) and PRLC (Philippine Red List Committee).

Taxa	RT		Catalog numbers	Distribution	IUCN Red List status (2020)	PRLC status (2020)
	H[a]	N[b]				
Amphibians						
Bufonidae						
Ansonia muelleri (Boulenger, 1887)	x	x	CAS 137515, CAS 133443–455, CAS 133489–93, CAS 248315–19, CAS 137509–14; MBS 514–19	Mindanao faunal region	Least Concern	Vulnerable
Ceratobrachidae						
Platymantis corrugatus (Duméril, 1853)		x	MBS 449–51	Widespread in the Philippines except in Palawan faunal region	Least Concern	Data not available

Taxa	RT		Catalog numbers	Distribution	IUCN Red List status (2020)	PRLC status (2020)
	H[a]	N[b]				
Platymantis cf. *dorsalis* (Duméril, 1853)		x	MBS 448	Widespread in the Philippines except in Palawan faunal region	Least Concern	Data not available
Platymantis rabori Brown, Alcala & Diesmos, 1998	x		CAS 197880	Mindanao faunal region	Least Concern	Vulnerable
Platymantis sp.		x	MBS 314–18, MBS 420–24	Northeast Mindanao	Data not available	Data not available
Dicroglossidae						
Fejervarya vittigera (Wiegmann, 1824)		x	MBS 360–62	Widespread in the Philippines	Least Concern	Data not available
Limnonectes diuatus (Brown & Alcala, 1977)	x		CAS 139389–93, CAS 133430–34, CAS 133500	Mindanao faunal region	Vulnerable	Vulnerable
Limnonectes leytensis (Boetger, 1893)		x	MBS 316–19, MBS 320, MBS 474	Mindanao faunal region	Least Concern	Data not available
Limnonectes magnus (Stejneger, 1910)	x	x	CAS 139396, 133429, 133433, 186128; MBS 284–94; MBS 502, 509, 510, 513	Mindanao faunal region	Near Threatened	Other Threatened Species
Occidozyga laevis (Günther, 1859)		x	MBS 287, MBS 377, MBS 402–04, MBS 427, MBS 429, MBS 457–8, MBS 471–72; JLP 080	Widespread in the Philippines except in Palawan faunal region	Least Concern	Data not available
Megophyridae						
Leptobrachium lumadorum Brown, Siler, Diesmos & Alcala, 2009		x	MBS 405, MBS 456, MBS 589, MBS 594, MBS 648, MBS 664; JLP 061, JLP 102, JLP 153–55	Mindanao faunal region	Least Concern	Data not available
Megophrys stejnegeri Taylor, 1920	x	x	CAS 133486–88; MBS 413–15, MBS 418–19, MBS 425, MBS 452–55, MBS 576; JLP 160–62	Mindanao faunal region	Least Concern	Other Threatened Species
Microhylidae						
Kaloula picta (Duméril & Bibron, 1841)		x	MBS 359	Widespread in the Philippines	Least Concern	Data not available
Kaloula meridionalis Inger, 1954		x	MBS 469	Mindanao faunal region	Least Concern	Data not available
Kalophrynus sinensis Peters, 1867		x	MBS 459, MBS 586	Mindanao faunal region	Least Concern	Data not available
Ranidae						
Pulchrana grandocula (Taylor, 1920)	x	x	CAS 137535–39, CAS 139397–98, CAS 145938, CAS 133503–04; MBS 272–78, MBS 502, 528–31	Mindanao faunal region	Least Concern	Data not available
Sanguirana mearnsi (Inger, 1954)	x	x	CAS 137533–34, CAS 139394–95, CAS 133422–23, CAS 133501; MBS 486, MBS 522-27; JLP 098–101	Mindanao faunal region	Least Concern	Data not available
Staurois natator (Günther, 1858)	x	x	CAS 137525–32, CAS 133435–42, CAS 133494; MBS 597, MBS 808–09, MBS 840, MBS 844, JLP 066	Mindanao faunal region	Least Concern	Data not available
Rhacophoridae						
Polypedates leucomystax (Gravenhorst, 1829)		x	MBS 277, MBS 279, MBS 283, MBS 308, MBS 333–37	Widespread in the Philippines	Least Concern	Data not available
Rhacophorus bimaculatus (Peters, 1867)	x		CAS 139399, CAS 133427, CAS 180678, CAS 182564	Widespread in the Luzon and Mindanao faunal region	Least Concern	Data not available

Taxa	RT		Catalog numbers	Distribution	IUCN Red List status (2020)	PRLC status (2020)
	H[a]	N[b]				
Reptiles						
Agamidae						
Draco cyanopterus Peters, 1867		x	MBS 370–75, MBS 470	Mindanao faunal region	Least Concern	Data not available
Gonocephalus cf. *interruptus* (Boulenger, 1885)		x	MBS 485	Mindanao faunal region	Data Deficient	Other Threatened Species
Hydrosaurus pustulatus (Eschsholtz, 1829)		x	MBS 363, MBS 385, MBS 389, MBS 768	Widespread in the Philippines	Vulnerable	Other Threatened Species
Colubridae						
Ahaetulla prasina Taylor, 1922		x	MBS 391, MBS 476–78	Widespread in the Philippines	Least Concern	Data not available
Dendrelaphis marenae Vogel & Van Rooijen, 2008		x	MBS 475, MBS 481	Mindanao faunal region	Least Concern	Data not available
Lamprophiidae						
Oxyrhabdium modestum (Duméril, 1853)		x	MBS 327, MBS 369, MBS 384, MBS 461–62, MBS 480	Mindanao faunal region	Least Concern	Data not available
Elapidae						
Calliophis philippinus (Peters, 1881)		x	MBS 325	Mindanao faunal region	Least Concern	Data not available
Gekkonidae						
Cyrtodactylus agusanensis (Taylor, 1915)	x		CAS 133424–26, CAS 133506–133513, CAS 139317	Mindanao faunal region	Least Concern	Data not available
Cyrtodactylus annulatus (Taylor, 1915)		x	MBS 447	Widespread in the Philippines	Data not available	Data not available
Gehyra mutilata (Wiegman, 1834)		x	MBS 460, MBS 464–67	Widespread in the Philippines	Least Concern	Data not available
Hemidactylus frenatus (Duméril & Bibron, 1836)		x	MBS 326, MBS 376	Widespread in the Philippines	Least Concern	Data not available
Natricidae						
Rhabdophis auriculata Günther, 1858	x		CAS 133499	Mindanao faunal region	Least Concern	Data not available
Rhabdophis lineatus (Peters, 1861)	x	x	CAS 133498, CAS 133502, CAS 186140, CAS 186142; MBS 390, MBS 416–17, MBS 463, MBS 479; JLP 158–59	Mindanao faunal region	Least Concern	Data not available
Scincidae						
Brachymeles hilong (Brown & Rabor, 1967)		x	MBS 430–32	Mindanao faunal region	Near Threatened	Data not available
Eutropis multifasciata (Kuhl, 1820)		x	MBS 324, MBS 328–29	Mindanao faunal region	Data Deficient	Data not available
Lipina quadrivitatta (Peters, 1867)		x	MBS 330–31	Mindanao faunal region	Least Concern	Data not available
Sphenomorphus variegatus (Peters, 1867)		x	MBS 433–36, MBS 445	Mindanao faunal region	Data not available	Data not available
Sphenomorphus acutus (Peters, 1864)	x		CAS 133496	Mindanao faunal region	Least Concern	Data not available
Pinoyscincus coxi (Taylor, 1915)	x		CAS 133495	Mindanao and Luzon faunal region	Least Concern	Data not available

Taxa	RT		Catalog numbers	Distribution	IUCN Red List status (2020)	PRLC status (2020)
	H[a]	N[b]				
Parvoscincus mindanensis Siler, Jones, Diesmos, Diesmos & Brown, 2012	x		CAS 133497	Mindanao faunal region	Near Threatened	Data not available
Tropidophorus misaminius Stejneger, 1908	x	x	CAS 133480–84; MBS 307, MBS 386, MBS 395, MBS 446, MBS 486	Mindanao faunal region	Least Concern	Data not available
Eutropis caraga Barley, Diesmos, Siler, Martinez & Brown, 2020	x		CAS 133428	Mindanao faunal region	Data not available	Data not available
Pythonidae						
Malayopython reticulatus (Schneider, 1801)		x	MBS 965	Widespread in the Philippines	Data not available	Other Threatened Species II
Viperidae						
Tropidolaemus subannulatus (Gray, 1842)		x	MBS 927; JLP 217	Widespread in the Philippines	Least Concern	Other Threatened Species

under "Vulnerable," five species (two amphibians, three reptiles) were under "Other Threatened Species," and 35 species (15 amphibians, 20 reptiles) were under "Data not available."

Herpetological Community Assemblage in Taguibo Watershed

We described the herpetological community assemblage (species composition) of the Taguibo Watershed by determining the association between species occurrence records with our designated macro- and micro-habitat types. The Taguibo's herpetofauna comprised of nine historical (H), 27 new (N), and eight historical and new (H&N) species inhabiting both historical (Alcala and Brown's sites: dipterocarp forests) and our more recent (primary, mossy, and secondary-growth montane forests) sampling sites. Moreover, 13 amphibians (two historical [H], three new [N], and eight H&N) and nine reptiles (one H, five N, three H&N) were recorded from riparian and terrestrial zones; and seven amphibians (one H, six N) and 14 reptiles (three H, 11 N) were recorded from only terrestrial zone habitats (Figure 2; see also Table 2).

Within riparian and terrestrial zones of the Taguibo Watershed, amphibians *Ansonia muelleri* (H&N), *Leptobrachium lumadorum* (N), *Megophrys stejnegeri* (H&N), and reptiles (lizards) *Cyrtodactylus agusanensis* (H), *Hydrosaurus pustulatus* (N), (skinks) *Trophidophorus misaminius* (H&N), (snakes) *Oxyrhabdium modestum* (N), *Rhabdophis lineatus* (H&N), and *R. auriculata* (H&N) utilized strictly ground microhabitats. Reptiles (snakes) *Aheatulla prasina* (N) and *Dendrelaphis marenae* (N) preferred arboreal microhabitat (no amphibians were restricted to this microhabitat). Amphibians *Kalophrynus sinensis* (N), *Limnonectes diuatus* (H), *Occidozyga laevis* (N), and the snake *Malayopython reticulatus* (N) preferred aquatic microhabitats. We found it noteworthy that only amphibians (and no reptiles) exhibited overlap in microhabitat use between these zones. The use of ground and arboreal microhabitats were typified by *L. leytensis* (N), *Rhacophorus bimaculatus* (H), and *Polypedates leucomystax* (N). In contrast, overlap in the use of ground, arboreal, and aquatic microhabitats was detected in *L. magnus* (H&N), *Pulchrana grandocula* (H&N), *Sanguirana mearnsi* (H&N), and *Staurois natator* (H&N).

In the terrestrial zone (a suite of microhabitats not immediately associated with water), amphibians *Platymantis corrugatus* (N), *P.* cf. *dorsalis*, *Platymantis* sp. (N), and reptiles (skinks) *Brachymeles hilong* (N), *Eutropis multifasciata* (N), *Pinoyscincus coxi* (H), *P. mindanensis* (H), *Sphenomorphus variegatus* (N), and the elapid snake *Calliophis philippinus* (N) utilized ground microhabitat. The only amphibian found to utilize strictly aquatic microhabitats was *Fejervarya vittigera* (N). The native amphibians *Kaluola meridionalis* (N), *K. picta* (N), *P. rabori* (H), and reptiles (lizards) *C. annulatus* (N), *Draco cyanopterus* (N), *Gehyra mutilata* (N), *Gonocephalus interruptus* (N), *Hemidactylus frenatus* (N), *Lipinia quadrivittata* (N), and *Sphenomorphus acutus* (H) utilized arboreal microhabitats. No amphibians exhibited overlap in the use of microhabitats in this zone, whereas only the reptile (pit viper snake) *Tropidolaemus subannulatus* utilized both ground and arboreal microhabitats.

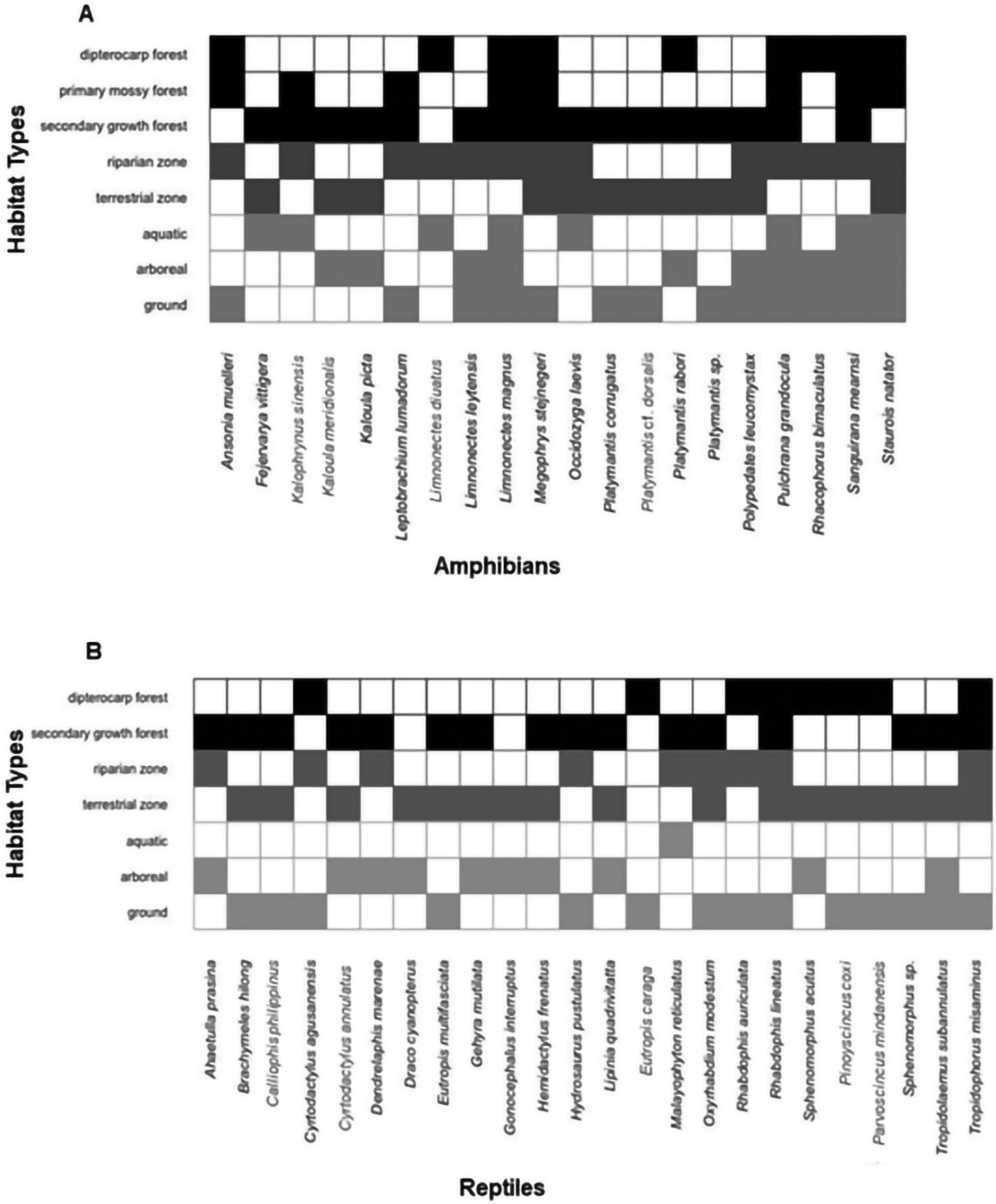

Figure 2. Habitat utilization of amphibians (A) and reptiles (B) across the heterogeneous environment making up the Taguibo Watershed. Species occurrence records used for the species-habitat association analysis were obtained from the California Academy of Sciences (CAS) and Father Saturnino Urios University (FSUU) databases.

Across six sampling months, we recorded four amphibian species (*L. magnus*, *O. laevis*, *M. stejnegeri*, and *P. grandocula*) at the low-elevation sites; and seven amphibians (*A. muelleri*, *L. magnus*, *M. stejnegeri*, *L. lumadorum*, *P. grandocula*, *S. mearnsi*, and *S. natator*) in the riparian zone of our mid-elevation site (Figure 3). Results showed that *L. magnus* (38–49%) and *P. grandocula* (25–48%) had the highest abundances on low- and mid-elevation sites. Across sampling months, *M. stejnegeri* had relatively low abundances at low- and mid-elevation sites (6–13% and 1–4%, respectively). At our mid-elevation site, *A. muelleri* had relatively high abundances (26–32%), whereas, *L. lumadorum* and the northeast Mindanao endemic *S. mearnsi* had low relative abundances (3–7% and 10–16% respectively).

The results of our comparison of amphibian species diversity (Figure 4) between low- and mid-elevation sites revealed that the four species of amphibians dominating at low-elevation had low relative abundances (36–49%) as compared to the seven species at mid-elevation, which had relatively high abundances (68–78%). Based on our Shannon diversity index (*H*) and Pielou's (*J*) evenness calculations, we found that our low-elevation site had high amphibian species diversity (H = 0.69–0.95 and J = 0.68–0.99), and the mid-elevation site had low species diversity (H = 1.35–1.55 and J = 0.79–0.84). However, this difference in amphibian species diversity between these two elevation increments were not significant (Wilcoxon signed-rank test P values for all metrics = 0.25–0.52)

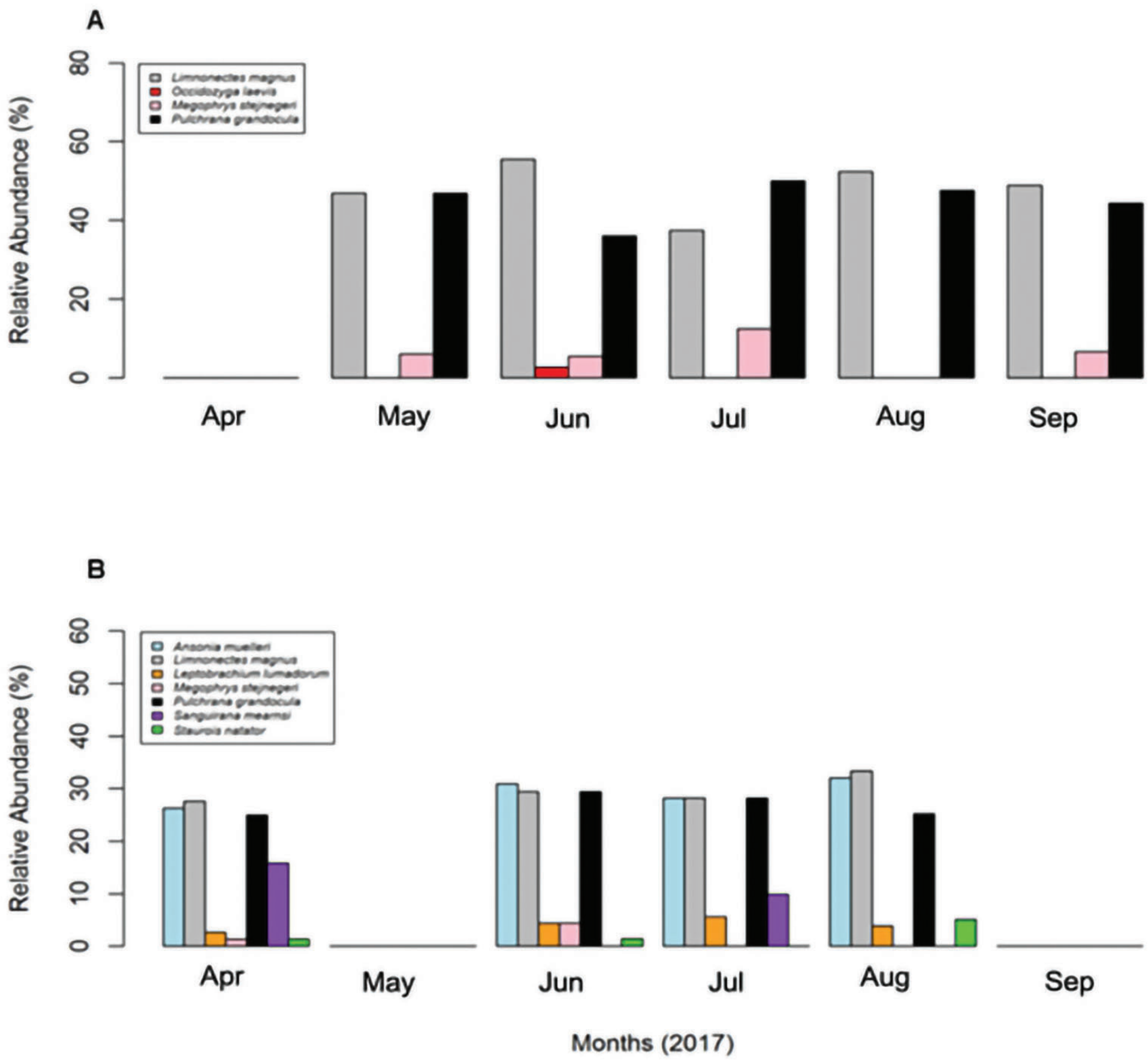

Figure 3. Relative abundances of stream amphibians in low- (A; Site 4: Pianing) and mid-elevation (B; Site 5: Anticala) forested riparian zones of the Taguibo Watershed, Agusan del Norte Province, eastern Mindanao, Philippines.

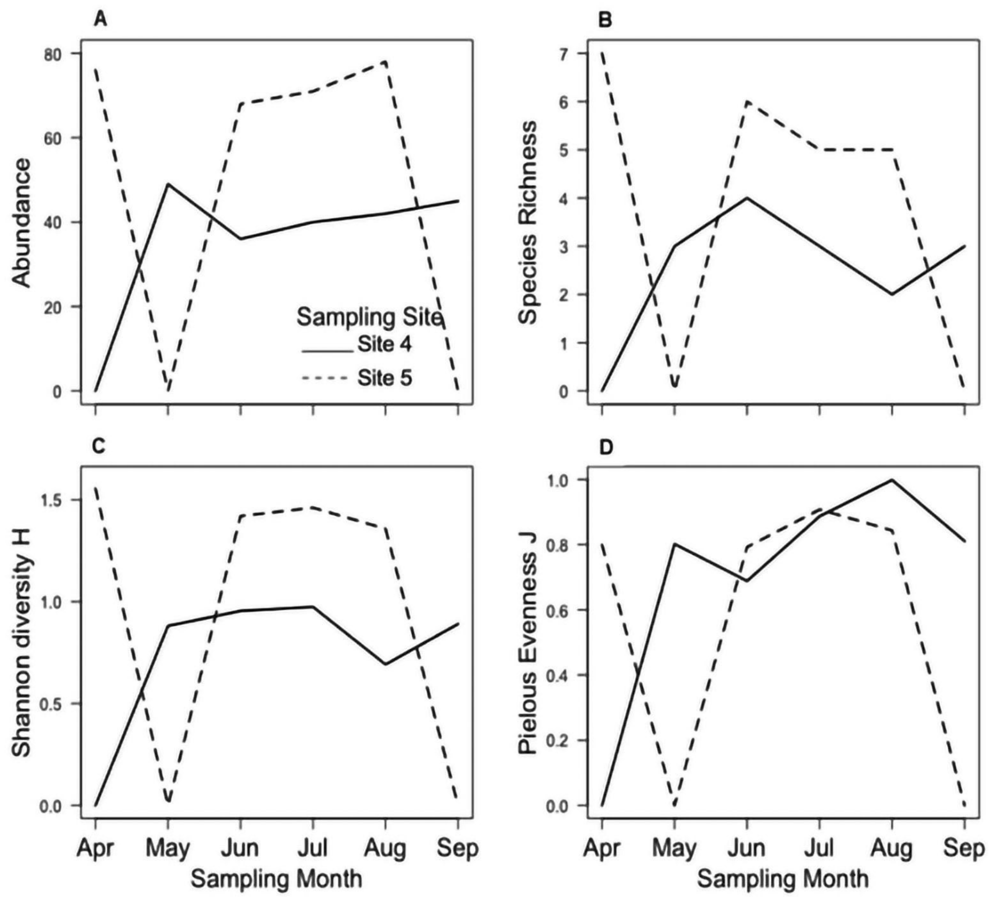

Figure 4. Species abundance, richness, diversity, and evenness (A–D) of stream amphibians recorded April–September 2017 in Site 4 (low-elevation) and Site 5 (mid-elevation) forested riparian zones of the Taguibo Watershed, Agusan del Norte Province, eastern Mindanao, Philippines.

DISCUSSION

Within Philippine faunal regions (Brown and Diesmos 2009), vertebrate communities are hierarchically structured among 5–7 distinct island banks (biogeographical sub-provinces), and across elevational gradients (Catibog-Sinha and Heaney 2006). In most elevational diversity transect studies conducted to date, herpetological species diversity peaks at mid-elevation sites (Brown *et al*. 2012b, 2013). Of the 17 herpetological species recorded by Alcala and Brown (1971, 1979), we were only able to confirm the continued persistence of eight species; however, we recorded 27 amphibian and reptile species, constituting new records for low- and mid-elevations of the Taguibo Watershed.

This study's Taguibo amphibian and reptile species inventory (an ongoing, actively-continuing checklist) represents a current snapshot of the presence of herpetological species in Caraga's Taguibo Watershed – but it is, by no means, complete (Sanguila *et al*. 2016). Extensive, continuous, regular (and seasonal) re-survey sampling efforts will be necessary to understand the caveats (location of sampling sites, elevational gradients, duration of sampling effort, inter-investigator biases and sampling techniques; Fauth *et al*. 1989; Heyer *et al.* 1994) of the current effort to synthesize and summarize all that is known of herpetological species diversity in the Taguibo Watershed and the Caraga Region in general (Sanguila *et al*. 2016). The Alcala and Brown herpetological surveys (Brown and Alcala 1974, 1980; CAS 2020) were conducted along mid-elevation sites only, whereas more recent herpetological surveys (Sanguila *et al.* 2016) were conducted at low-, mid-, and high-elevations. We are unable to provide properly-characterized, statistical, or quantitative estimates of species richness and abundances because this study's inventory methodology (Heyer *et al.* 1994) was focused on establishing baselines of species' geographic occurrence records and comparing these to the methodologically-dissimilar formative work of Alcala and Brown (CAS 2020). Moreover, recent surveys did not employ quadrats in established transects (2013) and our 2017 surveys focused on amphibians only.

Community assemblages of herpetological species (many H&N) in the Taguibo Watershed depict a diverse and locally-abundant vertebrate component in both riparian and terrestrial zones of forested areas (Plaza and Sanguila 2015; Sanguila *et al*. 2016); these endemic Mindanao taxa partition space in structurally-heterogeneous habitats in complex and, sometimes, unpredictable ways (Brown and Alcala 1961; Alcala *et al*. 2004). Our initial qualitative characterization of Taguibo's herpetofaunal community may provide invaluable information on the species assemblage's finer-scale patterns of habitat utilization (individual, species-specific microhabitat preferences, or limits), which we attempt to preliminarily enumerate below.

In riparian and terrestrial zones (habitat types) in the Taguibo Watershed, many newly-recorded amphibians (more species than reptiles) exploit singular or multiple overlapping microhabitats. This amphibian community structure may be attributed to a species' reproductive and life-history strategy (Brown and Alcala 1982; Duellman and Trueb 1994; Wells 2007), spatial effects (Parris 2004; Scheffers *et al*. 2013), and/or environmental heterogeneity (Keller *et al.* 2009). For example, in amphibians that are known to be aquatic, indirect developers – such as bufonids (*Ansonia muelleri*), dicroglossids (*Limnonectes diuatus*, *L. leytensis*, *L. magnus*, *Occidozyga laevis*), and ranids (*Pulchrana grandocula*, *Sanguirana mearnsi*, *Staurois natator*) – most taxa rely on aquatic and ground microhabitats as sites for larval development, egg-deposition, courtship, and mating (Duellman and Trueb 1994). Megophyrids like *Leptobrachium lumadorum* and *Megophrys stejnegeri* are frequently recorded at either larval or juvenile stages ≤ 3 m away from stream banks, but adults are frequently encountered on more distant, suitable ground microhabitats in the terrestrial zone substrates only (Sanguila *et al.* 2016). The arboreal group of species such as rhacophorids *Polypedates leucomystax* and *Rhacophorus bimaculatus* is frequently found perching above ephemeral pools or constructing foamy nests in vegetations along streams or above ephemeral pools (Taylor 1920; Brown and Alcala 1982). In tropical forests, riparian habitat heterogeneity influences amphibian assemblage composition; however, additional abiotic and biotic factors may influence community composition metrics in future exploration of the Taguibo Watershed (Keller *et al*. 2009); this topic holds promise for future studies of the structure and function of herpetological communities in relation to ecosystem services.

Another plausible explanation of the herpetological assemblage variation in riparian and terrestrial zones of the Taguibo Watershed may be attributed to the differential use of resources. In terrestrial vertebrates, food, space, resources, and timing of their exploitation may facilitate co-existence in similar or dissimilar species (Toft 1985; Auffenberg and Auffenberg 1988, 1989; Setiadi *et al*. 2011). However, there exist only a few herpetological studies on such topics in the Philippines, and the structure and community composition in terrestrial vertebrates are generally poorly understood in the archipelago (Brown *et al*. 2002; 2013, Oliveros *et al*. 2011; Siler *et al*. 2011; Supsup *et al*. 2020). Our prevailing knowledge of amphibian and reptile community composition only includes biogeographers' initial descriptions of co-occurring (sympatric, syntopic) herpetological species (*e.g.* Taylor 1928, Inger 1954; Brown and Alcala 1970) and their qualitative correlation of a species preference for similar structural microhabitats (substrates) in varying forest habitat types (Nuñeza *et al*. 2010; Plaza and Sanguila 2015; Supsup *et al*. 2017); these may be augmented by dietary partitioning exhibited by co-occurring amphibians on Borneo (Inger and Greenberg 1966), but such studies have yet to be undertaken in the Philippines (Brown *et al*. 2002, 2012a).

A number of newly-recorded amphibian and reptile species persist and primarily utilize a single microhabitat; in this study, only one reptile exhibited the use of two microhabitats (*Tropidolaemus subannulatus*: aquatic and terrestrial zones in secondary-growth forests of the Taguibo Watershed). We assume a species-specific microhabitat preference emphasizes its specialized need for microhabitats (*e.g.* Brown and Alcala 1982; Brown *et al*. 2020) that can provide microclimate environments, buffer temperature extremes, and provide optimal conditions for life-history stages/events which play a vital role for species persistence (Huey 1991; Duellman and Trueb 1994; Wells 2007).

For instance, the occurrence of diurnally active lizards and their use of ground substrates (species of *Sphenomorphus*, *Pinoyscincus*, *Parvoscincus*, *Brachymeles*, and *Eutropis*) and arboreal (species of *Lipinia*, *Gonocephalus*, and *Draco*) microhabitats (Sanguila *et al.* 2016) may be related to a species' thermal biology. Tropical lizards have been characterized as thermo-conformers (Huey *et al.* 2009), but this assertion has gone largely untested. In addition, unique microhabitat features such as leaf litter, beneath cover (under logs), perched low in herb- and shrub-layer vegetation, and perched high from the ground in saplings (or in semi-disturbed, agricultural areas: Site 1 in this study – commonly utilized by species of *Lamprolepis*, *Eutropis*, and *Draco*) provide optimal microclimate and perch sites for foraging or basking (Auffenberg and Auffenberg 1988; McGuire and Alcala 2000; Ord and Klomp 2014; Barley *et al.* 2020). Moreover, in the terrestrial zone, forest frogs of the genus *Platymantis* (Brown *et al*. 2015) utilize ground (*P.* cf. *dorsalis* and *P. corrugatus*; among leaf litter or under rotting logs on the forest floor) and arboreal (*P.*

rabori; typically on leaves of understory trees ≥ 3 m from the ground; *P. guentheri* typically ≤ 3 m above the ground) microhabitats. *Platymantis* are known direct developers occupying litter, humus layers, epiphytes, and aerial ferns (Brown and Alcala 1982), which may suggest that water and moisture trapped on these habitat layers provide an environment for refuge, oviposition, and mating sites (Scheffers *et al.* 2013).

The varying levels of relative abundances in co-occurring (syntopic) stream amphibians may be attributed to three factors such as a species surface microhabitat requirements, ecological tolerances, and reproductive biology (*e.g.* female *A. muelleri* samples were gravid for all sampling months] (Navas 1996; Afonso and Eterovick 2007; Frishkoff *et al.* 2015). We cannot determine which between our sites holds a higher amphibian species diversity because: 1) three (*i.e. L. magnus*, *P. grandocula*, and *A. muelleri*) of the seven amphibian species have high relative abundances, which might have contributed to the relatively equal amphibian species evenness (Scott 1976; Fauth *et al.* 1989) for both sites, and 2) low species diversity appears to be an artifact of the small sample sizes in four (*L. lumadorum*, *M. stejnegeri*, *S. mearnsi*, and *S. natator*) of the seven amphibian species on mid-elevation site.

This study utilized field-derived data characterizing Taguibo's herpetofaunal community assemblages from international (CAS) and local (FSUU) biodiversity data platforms. Our synthesized dataset supplements information on the knowledge gap on taxon-specific biotic inventories (species list) and the first attempt to fill in basic ecological information of the biodiversity (herpetofauna) of the Taguibo Watershed. Both are essential categories of information in support of conservation planning initiatives (Margules and Austin 1994; Groves *et al*. 2002).

We did not determine a direct comparison between historical and new survey records, but the available data allow us to convey insights, which may have practical value towards local conservation efforts for the Taguibo Watershed. The area embodies a typical, multi-faceted conservation challenge – which is anthropogenically threatened by association with the surrounding human population's utilization of its natural resources – specifically driven by economic development (Santillan *et al.* 2011). The current social situation is worrisome because such threats (*e.g.* mineral extraction, logging, dam constructions for water provision, road construction) modify and fragment habitats; this, if unmanaged, may contribute to a top-down or a bottom-up trophic cascade of food web collapse, resulting in species loss (Davic and Welsh 2004; Kremen 2005) – potentially disrupting predator-prey networks and destabilizing emergent properties at the community and ecosystem level (Pianka 1994).

Although this study's objectives did not include the provision of evidence for a correlation between anthropogenic activities and herpetofaunal species decline or loss, we nevertheless argue that forest removal and/or modification has been documented to significantly alter the overall structure and function of natural systems and ecosystem services (Rowley *et al*. 2009; Laurance 2013). With Butuan City reliant entirely on the Taguibo Watershed as its primary source of drinking water, we have no doubt that preservation of its forested habitats is of utmost importance.

CONCLUSION

Our results demonstrate that herpetological species persistence and community composition may be attributed to the ability of species to partition space in heterogeneous forests such as watershed ecosystems, according to structural microhabitats. Herpetological assemblage composition complexity is clearly correlated with ecosystem services: the presence of species and their specialized need for optimal environmental conditions in specific zones of forested habitats (provided by watersheds) may indicate overall ecosystem health and function (services like freshwater) in the Taguibo Watershed. Thus, we emphasize a fundamental need for local conservation efforts to preserve habitats occupied by these forest-and-water dependent vertebrate species. Efforts to preserve forested habitats of the Taguibo surface water catchment ensure the continued provisioning of fresh drinking water by the Watershed to its surrounding human population (the major metropolitan area of Butuan City). As such, we emphasize that local biodiversity repositories and online databases are invaluable, transparent, freely-available public resources, and we advocate their use in support of long-term biodiversity conservation efforts for sites of particular local importance. In particular, these especially include forested areas located in biodiversity frontiers of national significance – such as the Eastern Mindanao Biodiversity Corridor – which are major components of the globally-significant Philippine biodiversity conservation hotspot.

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