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Amphibians in the natural and human-modified ecosystems at the Center for Ecological Development and Recreation (CEDAR), Bukidnon, the Philippines

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Abstract

The Center for Ecological Development and Recreation (CEDAR) is an ecotourism site comprised of natural and human-modified ecosystems in Bukidnon, Philippines. With very little existing research on the influence of human-modified ecosystems on amphibian assemblages in the Philippines, we designed this study to evaluate amphibian assemblages in CEDAR. Using a combination of transects sampling, active searching, and auditory samplings, amphibian samplings were conducted at three sites: a human-modified area, a dipterocarp forest, and the Dila River System. A total of 425 individuals of 18 species from 13 genera and 7 families were documented. The family Ceratobatrachidae was the most represented group, with four species. Out of 18 species, 14 (78%) were Philippine endemics, indicating a high rate of amphibian endemism at CEDAR. In terms of IUCN conservation status, 14 out of 18 species were classified as Least Concern and two as Near Threatened, while two have undetermined conservation status. The Shannon-Weiner and Gini-Simpsons Diversity values revealed that the Human-modified area had the highest diversity compared to the Dila River System and dipterocarp forest. Surprisingly, the human-modified area in CEDAR was found to be the habitat of many anuran species, in particular, a number of generalist species, whilst some specialist species were restricted to natural habitats like the dipterocarp forest and Dila River System. The high amphibian diversity in the human-modified area requires further field studies; hence, additional amphibian samplings are recommended. Long-term wildlife evaluation and monitoring should be carried-out in CEDAR to facilitate the conservation of amphibian populations and their natural habitats in this area.

Key words: Conservation, diversity, endemics, habitat modification, microhabitat, Mindanao

Introduction

Biodiversity loss is drastically increasing worldwide, and amphibians represent the most threatened vertebrate class in terms of population and species declines (Collins and Storfer, 2003; Collins, 2010; Luedtke et al., 2023). These declines are mainly due to human-influenced activities such as habitat loss and degradation, as well as disease epidemics, and climate change (Brook et al., 2003; Stuart, 2004; Gallant et al., 2007; Alcala et al., 2012; Luedtke et al., 2023). In the Philippines, amphibian population declines are largely attributed to over-exploitation, habitat fragmentation, and habitat destruction (Stuart, 2004; Alcala et al., 2012). These human-induced ecosystem changes place wild populations of amphibians at high risk of extinction (Brearley et al., 2012).

Although habitat loss is a widespread problem around the world (Hansen et al., 2013), several forest biomes are undergoing forest transitions, or shifts from net forest loss to forest gains (Rudel et al., 2005; Ramalho et al., 2021). Rural exodus, abandonment of farmed lands, and the creation and imposition of environmental laws have caused the shifts to forest gains (Rudel et al., 2005; Lira et al., 2012). Forest transitions may also positively affect the conservation and survival of forest-dependent species, such as amphibians, as they respond more dynamically to forest coverage than generalist species (Ramalho et al., 2021). An example of such ecosystems that have undergone forest transition is at the Center for Ecological Development and Recreation or CEDAR in Mindanao, Philippines. This ecotourism site in the province of Bukidnon in the Philippines is rich in flora and has diverse habitats covering a land area of about 1,703 hectares. In 1912, CEDAR becomes a locally protected reforestation project of the Department of Environment and Natural Resources (DENR) and the Municipality of Impasug-ong, province of Bukidnon, Philippines.

However, illegal hunting and harvesting of wildlife still exist in CEDAR despite the protection provided by the local government. Moreover, infrastructure development for ecotourism such as the creation of food establishments, function halls, parking areas, covered courts, cottages, and other man-made structures has profoundly modified the ecosystems of CEDAR. These types of modifications in the natural habitats of amphibians have been shown to negatively impact their health, development, conservation, and persistence (Parris, 2006; Ceríaco, 2012; Plaza and Lambertucci, 2017).

Yet, information on diversity of amphibians and potential impacts of human-altered habitat types on the amphibian assemblage in CEDAR is still lacking. Hence, our research aimed to provide a first-hand account of the microhabitat preferences, endemism, conservation status, and species diversity of amphibians in the natural and human-modified ecosystems in CEDAR, Philippines.

Material and Methods

Ethical considerations

Prior to the fieldwork, a Wildlife Gratuitous Permit No. R10 2023-07 was secured from the Department of Environment and Natural Resources (DENR) Region 10, Cagayan de Oro City, Philippines, for the authorized collection of wildlife specimens. The amphibians collected in this study were handled in accordance with the "Guidelines for Live Amphibians and Reptiles in Field and Laboratory Research" (ASIH, HL, and SSAR, 2004). This research was also approved by the Institutional Animal Care and Use Committee (IACUC) of Central Mindanao University, Philippines with IACUC protocol no 2023-275B.

Sampling stations

CEDAR is located in Barangay Impalutao, Municipality of Impasug-ong, Province of Bukidnon, Philippines. It covers a total land area of about 1,703 hectares, located around 8.249, 125.031 with a maximum elevation of 792 meters above sea level (m asl.). It is surrounded mainly of residential areas and agricultural lands. Herpetological surveys were done from December 2022 to April 2023, spanning both the wet and the dry seasons. To increase species sampling completeness, the samplings were done in morning (07:00–12:00) and early night time (18:00–23:00) to cover amphibians' peak hours of activity.

Three sampling stations were examined in CEDAR based on habitat type:

Station 1 – Human-modified area

Station 1 (Fig. 1) is characterized by man-made infrastructure and introduced plant species from the family Araceae, Asparagaceae, Euphorbiaceae and Rubiaceae (e.g., *Coffea* sp., *Codiaeum* sp., *Cordyline fruticosa*, *Dieffenbachia* sp., *Dracaena* sp.) as well as young dipterocarp trees (*Shorea* spp.). Streams, puddles, and swimming pools are also present in the area. Its elevation ranges from 781 to 796 m asl. Transects were located at (1) 8.251333, 125.030667, (2) 8.250806, 125.031500, and (3) 8.252500, 125.034750.

Station 2 – Dipterocarp Forest

Station 2 (Fig. 2) is characterized by the dominance of dipterocarp trees, primarily *Shorea* species (e.g., *S. almon*, *S. contorta*, and *S. polysperma*). This area is surrounded by tributaries of the Dila River System with an elevation ranging from 738 to 761 m asl. Transects were established at (1) 8.251667, 125.036444, (2) 8.253194, 125.036639, and (3) 8.255444, 125.036806.

Station 3 – Dila River System

Station 3 (Fig. 3) is characterized by streams and puddles, rock mounds, and steep riparian areas dominated by dipterocarps (*Shorea* spp.), vines, and grass species (i.e., *Bambusa* sp.). Its elevation ranges from 738 to 786 m asl. Transects were established at (1) 8.252028, 125.032917, (2) 8.251944, 125.036278, and (3) 8.255417, 125.037139.

Microhabitat characterization

Microhabitat preferences of amphibians were determined following the categories of Ates and Delima (2008) with the addition of scansorial and human-modified areas (Table 1):

Table 1: Microhabitat types and descriptions modified from Ates and Delima (2008).

Microhabitat Type	Description
Arboreal	Microhabitats high above the ground (5 m-10 m), including branches and stems of plants, leaves and leaf axils.
Ground or Terrestrial	Microhabitats directly on the ground.
Scansorial	Microhabitats between ground level and 5 m above ground.
Aquatic	Streams, rivers, creeks, as well as standing bodies of water.
Human-modified Area	Microhabitats within 5 m of built infrastructure such as roads, cottages, concrete structures, etc.

Figure 1: Transects at Station 1. (A) Transect 1 located near the entrance pathway, (B) Transect 2 at the back of the covered court, (C) Transect 3 near the swimming pool.

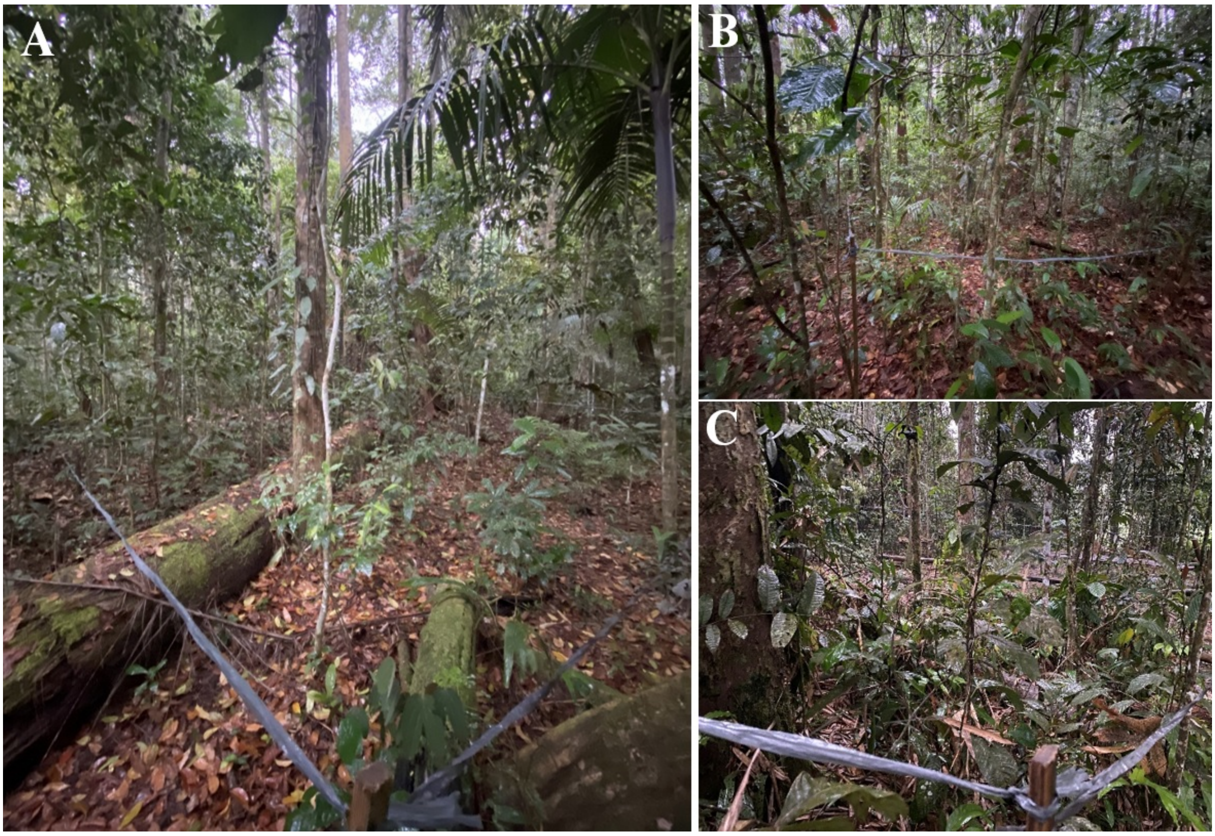

Figure 2: Transects at Station 2. (A) Transect 1, (B) Transect 2, (C) Transect 3.

Figure 3: Transects at Station 3. (A) Transect 1, (B) Transect 2, (C) Transect 3.

Sampling techniques

Amphibian sampling across habitat types was carried out using the following methods:

a. Transect Sampling – A total of nine standardized 10 m X 100 m straw-rope-fenced strip transects were placed arbitrarily across the habitat types present in the study area (Supsup et al., 2016). To maximize sampling independence, the distance between strip transects was a minimum of 200 meters (Fig. 2). Accessible microhabitats within each strip transect were thoroughly searched and sampled.

b. Active Searching – The nine standardized strip transects were surveyed thoroughly for amphibians by flipping over rocks and logs, rummaging through leaf litters and plants, inspecting tree trunks including its holes, and looking for frogs on rocks or underneath mosses within the water bodies for nine hours (one hour each): five hours during daytime (07:00–12:00) and five hours in the night (18:00–23:00).

c. Auditory Sampling – Aural searches were used to maximize sampling efforts (Ndriantsoa et al., 2017). Calling amphibians were tracked, caught, and then recorded.

Capture, Mark, and Release

Five colors of nontoxic indelible ink or food-grade ink were used for marking captured amphibians, with a different color used for every recapture. Amphibians were collected, measured, and then marked in a designated working area in the field. Ink was applied with a small, pointed brush on the arms and legs of each amphibian. Thereafter, they were immediately released back to where they were found.

Species identification

Morphometric data such as snout-to-vent length (SVL), head length (HL), head breadth (HB), snout length (SL), tympanum diameter (TD), eye diameter (ED), tibia length (TL), and hind leg length (HLL) of all individuals encountered per species. Both live and euthanized specimens were taken using digital callipers for smaller species and a measuring tape for larger species. Specimens were identified using relevant taxonomic literature and illustrated keys (Inger, 1954; Alcala and Brown, 1998; Sanguila et al., 2016; Sy, 2022). For the nomenclature and taxonomic classification of amphibians, we followed McGuire et al. (2022) and Frost (2021). Species identifications were verified by Professor Elsa May Delima-Baron (San Pedro College, Davao City, Philippines), and Mr. Kier Mitchel E. Pitogo (University of Kansas, U.S.A.)

Assessment of conservation status

The conservation status of each species was checked against the IUCN Red List of Threatened Species (IUCN 2021) and CITES Appendices (2021). Depending on the data available, the species we recorded were classified as not evaluated (NE), data deficient (DD), least concern (LC), near threatened (NT), vulnerable (VU), endangered (EN), and critically endangered (CR).

Rarefaction and extrapolation of diversity

In evaluating sampling effort and sampling adequacy, rarefaction and extrapolation curves (R/E) for each sampling station were generated with 95% confidence intervals using the iNext Online Software. The diversity of the amphibians across habitat types at CEDAR were analyzed using non-asymptotic analysis based on Hill numbers on the order of q= 0 (species richness, Chao 1), q= 1 (Shannon Diversity, H), and q= 2 (Chao Gini-Simpsons diversity) with the aid of the iNext Online Software (Chao et al., 2014; Chao et al., 2016). Shannon's Diversity index was scaled using the classification scheme of Priambodo et al. (2019).

Table 2: Classification scheme for Shannon's Diversity Index (Priambodo et al., 2019).

Shannon's Diversity Index (*H'*)	Relative Values
$H' < 1.50$	Low diversity
$1.50 \leq H' \geq 3.50$	Moderate diversity
$H' > 3.50$	High diversity

Results

Species composition

A total of 425 frogs was recorded at CEDAR, comprising 18 species from 13 genera and seven families (Table 3). The family Ceratobatrachidae had the greatest diversity, with four species, followed by the families Dicroglossidae, Ranidae, and Rhacophoridae, with three species each. Bufonidae and Microhylidae contained two species each, and Megophryidae had a single species (Fig. 4). One of the two bufonids (*Rhinella marina*) is a human introduction not native to the Philippines (Rabor, 1952).

Species accounts

***Ansonia muelleri* (Boulenger, 1887)** (Fig. 5A)

Ecology: The Mueller's Toad is endemic to the Philippines. *Ansonia muelleri* individuals were only observed in the Dila River System on mossy rocks along the streams. This species was only active from 2200 onwards. *Ansonia muelleri* has been recorded within the mountains and other forested ecosystems of central and western Mindanao, and the Dinagat Islands (Diesmos et al., 2015; Delima-Baron et al., 2021).

***Rhinella marina* (Linnaeus, 1758)** (Fig. 5B)

Ecology: The Cane Toad is an alien invasive species that is present in the human-modified area and Dila River System. *Rhinella marina* is native to South and Central America (Bessa-Silva et al., 2020), and was introduced elsewhere. *R. marina* individuals were found mostly in damp terrestrial spaces within the human-modified area, as well as in moist zones along riparian areas of the Dila River System. These observations are typical for this species as they use these damp areas to reduce water loss especially during daytime (Schwarzkopf and Alford, 1996; Seebacher and Alford, 2002).

***Platymantis* cf. *dorsalis* (Duméril, 1853)** (Fig. 5C)

Ecology: *Platymantis* cf. *dorsalis* or the Common Forest Frog is abundantly found in the northern and central regions of the Philippines, but sightings in Mt. Hilong-hilong, Eastern Mindanao have also been recorded (Plaza and Sanguila, 2015). This species was found in the human-modified area and dipterocarp forest in CEDAR.

***Platymantis* cf. *guentheri* (Boulenger, 1882)** (Fig. 5D)

Ecology: *Platymantis* cf. *guentheri* or the Guenther's Forest Frog is a small to moderately sized terrestrial frog species with individuals found only in the dipterocarp forest. *Platymantis guentheri* is distributed throughout the Mindanao Pleistocene Aggregate Island Complex (PAIC) (Sanguila et al., 2016).

***Platymantis* cf. *rabori* Brown, Alcala, Diesmos and Alcala, 1997** (Fig. 5E)

Table 3: Species composition of amphibians at CEDAR.

Family name	Species name	Human-modifiedarea	Dipterocarp Forest	Dila River System
Bufonidae	*Ansonia muelleri*			11
	Rhinella marina	11		3
Ceratobatrachidae	*Platymantis* cf. *dorsalis*	6	17	
	Platymantis cf. *guentheri*		2	
	Platymantis cf. *rabori*	2	5	
	Platymantis sp. 1		1	
Dicroglossidae	*Limnonectes leytensis*	18		
	Limnonectes magnus	7		11
	Phrynoglossus laevis			4
Megophryidae	*Pelobatrachus stejnegeri*	16		3
Microhylidae	*Kalophrynus sinensis*	11	16	6
	Kaloula conjuncta meridionalis		3	
Ranidae	*Pulchrana grandocula*	2		
	Sanguirana everetti		2	1
	Sanguirana mearnsi	14	2	4
Rhacophoridae	*Nyctixalus spinosus*	9	16	
	Philautus surdus	74	120	
	Polypedates leucomystax	24		4

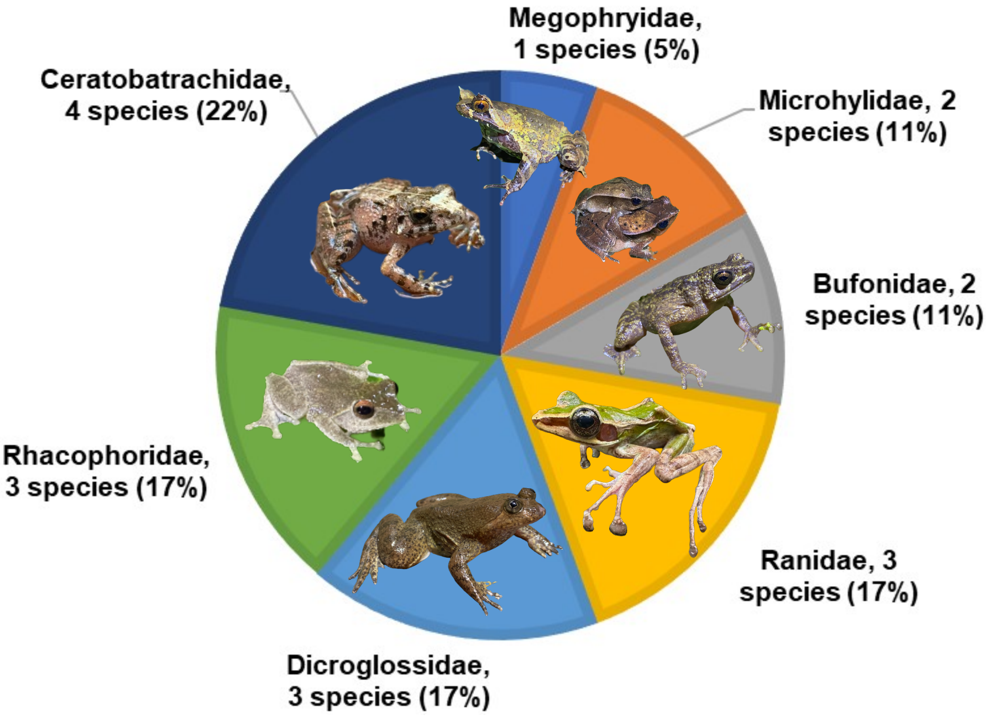

Figure 4: Species composition of amphibians by family at CEDAR.

Figure 5: Amphibians of CEDAR. (A) *Ansonia muelleri*, (B) *Rhinella marina*, (C) *Platymantis* cf. *dorsalis*, (D) *Platymantis* cf. *guentheri*, (E) *Platymantis* cf. *rabori*, (F) *Platymantis* sp. 1, (G) *Limnonectes leytensis*, (H) *Limnonectes magnus*, (I) *Phrynoglossus laevis*, (J) *Pelobatrachus stejnegeri*.

Ecology: *Platymantis* cf. *rabori* or the Rabor's Forest Frog is a platymantine species widely distributed to Mindanao PAIC (Diesmos et al., 2014). This species was mostly found in the dipterocarp forest because it is dependent on forest canopy (Sanguila et al., 2016).

***Platymantis* sp. 1 Günther, 1858** (Fig. 5F)

Ecology: *Platymantis* sp. 1 was documented in the dipterocarp forest, on top of the leaf of a young dipterocarp tree. A voucher specimen of the species was deposited in the University Museum of Central Mindanao University.

***Limnonectes leytensis* (Boettger, 1893)** (Fig. 5G)

Ecology: *Limnonectes leytensis* or the Leyte Wart Frog is widely distributed in the Mindanao Faunal Region (Plaza and Sanguila, 2015). This species was observed only in the human-modified area of CEDAR laying eggs and breeding in puddles alongside introduced plant species present in the area, which were mostly *Cordyline fruticosa*, *Codiaeum* sp., and *Dieffenbachia* sp.

***Limnonectes magnus* (Stejneger, 1910)** (Fig. 5H)

Ecology: *Limnonectes magnus* or the Mindanao Fanged Frog is found in the human-modified area and Dila River System of CEDAR. Polymorphism was also observed in recorded individuals of *L. magnus* with a total of three morphs observed. *Limnonectes magnus* individuals found within leaf litter and tree trunks have brownish dorsal coloration with black markings at the back, with some having yellow spots laterally behind the tympani. Individuals found nearby or within water bodies have either plain black dorsal coloration or green dorsal coloration with dark-green dorsal and lateral mottling. It is widely distributed in the Mindanao PAIC (Sanguila et al., 2016).

***Phrynoglossus laevis* (Günther, 1858)** (Fig. 5I)

Ecology: *Phrynoglossus laevis* or the Common Puddle Frog is a primarily aquatic found across Southeast Asia (Alcala and Brown, 1998). It is only found in puddles with sandy substrates near the Dila River System. Its coloration is ground-like to grayish-brown dorsally, and it is dark gray in coloration ventrally with yellow speckles up to its limb regions which matches the sandy microhabitat where individuals of the species were found.

***Pelobatrachus stejnegeri* (Taylor, 1920)** (Fig. 5J)

Ecology: *Pelobatrachus stejnegeri* or the Mindanao Horned Frog is the only Megophryidae species observed by the researchers in CEDAR. Individuals of *P. stejnegeri* were observed in both the human-modified area and the Dila River System. Polymorphism was observed in individuals of the species in CEDAR: *P. stejnegeri* in the human-modified area are plain dark brown to hazel brown in coloration, whereas individuals in the Dila River System have a mottled appearance and are yellowish in coloration, which matches the substrate and fallen leaves in stagnant areas of the river system. This species is widely distributed in the Mindanao PAIC (Diesmos et al., 2014).

***Kalophrynus sinensis* Peters, 1867** (Fig. 6A)

Ecology: *Kalophrynus sinensis* or the Philippine Sticky Frog is a microhylid native to the Philippines. Individuals of this species were observed in all habitat types of CEDAR. They were mostly found breeding in puddles, and calling for mates on rocks or on aroids near shallow water bodies within CEDAR.

***Kaloula conjuncta meridionalis* Inger, 1954** (Fig. 6B)

Ecology: *Kaloula conjuncta meridionalis* or the Truncate-Toed Chorus Frog is a subspecies of *K. conjuncta* restricted to Mindanao (Solania and Gamalinda, 2018). In CEDAR, it is only found in the dipterocarp forest, with two individuals found breeding within a damp tree-trunk hole.

***Pulchrana grandocula* (Taylor, 1920)** (Fig. 6C)

Ecology: *Pulchrana grandocula* or the Big-Eyed Frog is documented only in the human-modified Area along the trails, on damp dead bamboo culms and mossy rocks. It is endemic to the Philippines and is widely distributed in the Mindanao PAIC (Diesmos et al., 2014).

***Sanguirana everetti* (Boulenger, 1882)** (Fig. 6D)

Ecology: *Sanguirana everetti* or the Everett's Frog is endemic to Mindanao, the Philippines (Plaza and Sanguila, 2015). Individuals of the species were found in the dipterocarp forest and the Dila River System mostly perching above bamboo culms, as well as on rocks nearby or within streams in the area.

***Sanguirana mearnsi* (Stejneger, 1905)** (Fig. 6E)

Ecology: *Sanguirana mearnsi* or the Cabilian Frog is widely distributed in the Mindanao PAIC (Diesmos et al., 2014). Individuals of the species were found in all habitat types in CEDAR commonly by the swimming pool.

***Nyctixalus spinosus* (Taylor, 1920)** (Fig. 6F)

Ecology: *Nyctixalus spinosus* or the Spiny Tree Frog is a small and slender bodied tree frog of the family Rhacophoridae. It is commonly found in the dipterocarp forest and the Human-modified area in CEDAR. *Nyctixalus spinosus* is endemic to the Philippines and is native to the Mindanao, Leyte, Bohol, and Basilan Islands (Alcala and Brown, 1998; Stuart et al., 2008).

***Philautus surdus* (Peters, 1863)** (Fig. 6G)

Ecology: *Philautus surdus* or the Common Forest Tree Frog is the most commonly encountered frog species in the human-modified area and dipterocarp forest of CEDAR. It is the most polymorphic species in the collection, with five different coloration patterns. Variable appearance and color polymorphism of this species were also noted by Sanguila et al. (2016), which may need molecular assessments to verify if they are multiple different species hence their variability in morphology.

Figure 6: Amphibians of CEDAR. (A) *Kalophrynus sinensis*, (B) *Kaloula conjuncta meridionalis*, (C) *Pulchrana grandocula*, (D) *Sanguirana everetti*, (E) *Sanguirana mearnsi*, (F) *Nyctixalus spinosus*, (G) *Philautus surdus*, (H) *Polypedates leucomystax*

***Polypedates leucomystax* (Gravenhorst, 1829)** (Fig. 6H)

Ecology: The Four-lined Tree Frog is native to Southeast Asian countries and introduced in Papua New Guinea, Indonesia, and Japan (IUCN, 2023).

Species richness

The species richness of amphibians slightly varied between habitat types (Fig 7; Table 4). The Human-modified area had the highest species richness with 12 species; *Limnonectes leytensis* and *Pulchrana granducola* were restricted in this habitat. This is followed by the dipterocarp forest with 10 species; *Platymantis* cf. *guentheri*, *Platymantis* sp. 1, and *Kaloula conjuncta meridionalis* were unique to this habitat. On the other hand, the Dila River System had the lowest species richness, with only 9 species; *Ansonia muelleri* and *Phrynoglossus laevis* were restricted to this area.

This reveals the ecological importance of the remaining forest and river systems of CEDAR, which harbor a wide variety of amphibian species specifically the *Platymantis* complex that are usually found in pristine mountain ecosystems in the Philippines like Mt. Kitanglad, Bukidnon with 26 species recorded from multiple extensive surveys done in the mountain range (Beukema, 2011; Baron et al., 2021). Regardless, with this preliminary study done in CEDAR, its species richness is almost comparable to the Mt. Kalatungan Range, Bukidnon (20 species) which indicates that more surveys may result to additional species recorded (Warguez et al., 2013; Toledo-Bruno et al., 2017; Dela Torre and Nuñeza, 2021).

Microhabitat preferences of amphibians

Ten anuran species were observed in aquatic microhabitats such as puddles, torrents, and mossy rocks within the streams, as well as in scansorial microhabitats, especially on leaf axils of epiphytic and hemi-epiphytic Araceae species, and Asparagaceae species as well as in tree trunk holes and crevices of both dead and live trees. On the other hand, eight anuran species were observed in arboreal microhabitats such as fern fronds (mainly *Asplenium nidus*), tree trunks and branches, and bamboo culms. Eight anuran species were also observed in microhabitats within anthropogenic areas such as garbage piles, swimming pools, cottages, bridges, and toilets. Lastly, seven anuran species were observed on terrestrial microhabitats such as rock piles, fallen logs and bamboo culms, grasses, and within leaf litters (Fig. 8 and Table 5).

Table 4: Amphibian assemblage in different habitat types based on the Venn diagram.

Study sites	Species present
HA DF DRS	*Sanguirana mearnsi*, *Kalophrynus sinensis*
HA DF	*Philautus surdus*, *Platymantis* cf. *dorsalis*, *Platymantis* cf. *rabori*, *Nyctixalus spinosus*
HA DRS	*Polypedates leucomystax*, *Rhinella marina*, *Limnonectes magnus*, *Pelobatrachus stejnegeri*
DF DRS	*Sanguirana everetti*
HA	*Pulchrana granducola*, *Limnonectes leytensis*
DF	*Kaloula conjuncta meridionalis*, *Platymantis* cf. *guentheri*, *Platymantis* sp. 1
DRS	*Ansonia muelleri*, *Phrynoglossus laevis*

Table 5: Microhabitat preferences of amphibians in CEDAR.

Family	Species	Arboreal	Terrestrial	Scansorial	Aquatic	Human-modified Area
Bufonidae	*Ansonia muelleri*				X	
	Rhinella marina		X		X	X
Ceratobatrachidae	*Platymantis* cf. *dorsalis*	X		X		
	Platymantis cf. *guentheri*	X		X		
	Platymantis cf. *rabori*	X		X		
	Platymantis sp. 1	X				
Dicroglossidae	*Limnonectes leytensis*		X		X	X
	Limnonectes magnus		X	X	X	X
	Phrynoglossus laevis				X	
Megophryidae	*Pelobatrachus stejnegeri*		X		X	
Microhylidae	*Kalophrynus sinensis*		X	X	X	
	Kaloula conjuncta meridionalis		X	X		
Ranidae	*Pulchrana grandocula*			X		X
	Sanguirana everetti	X			X	
	Sanguirana mearnsi	X			X	X
Rhacophoridae	*Nyctixalus spinosus*			X		X
	Philautus surdus	X		X		X
	Polypedates leucomystax	X	X	X	X	X
Total		8	7	10	10	8

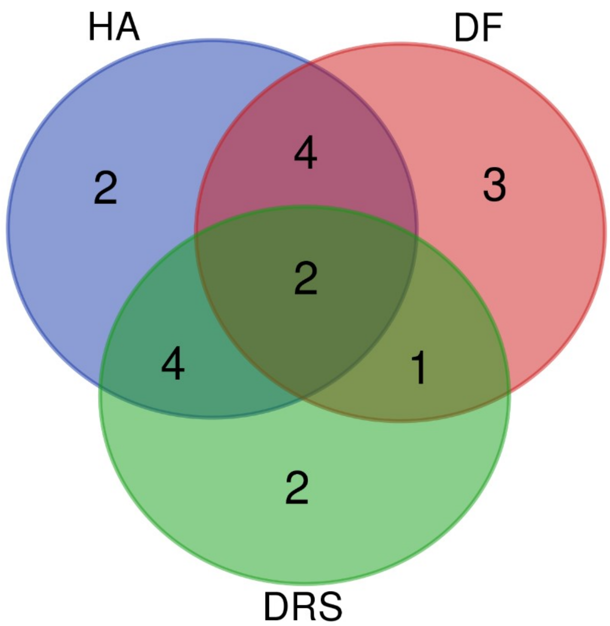

Figure 7: Patterns in species composition of the three habitat types: HA-Human-modified Area; DF-dipterocarp forest; DRS-Dila River System.

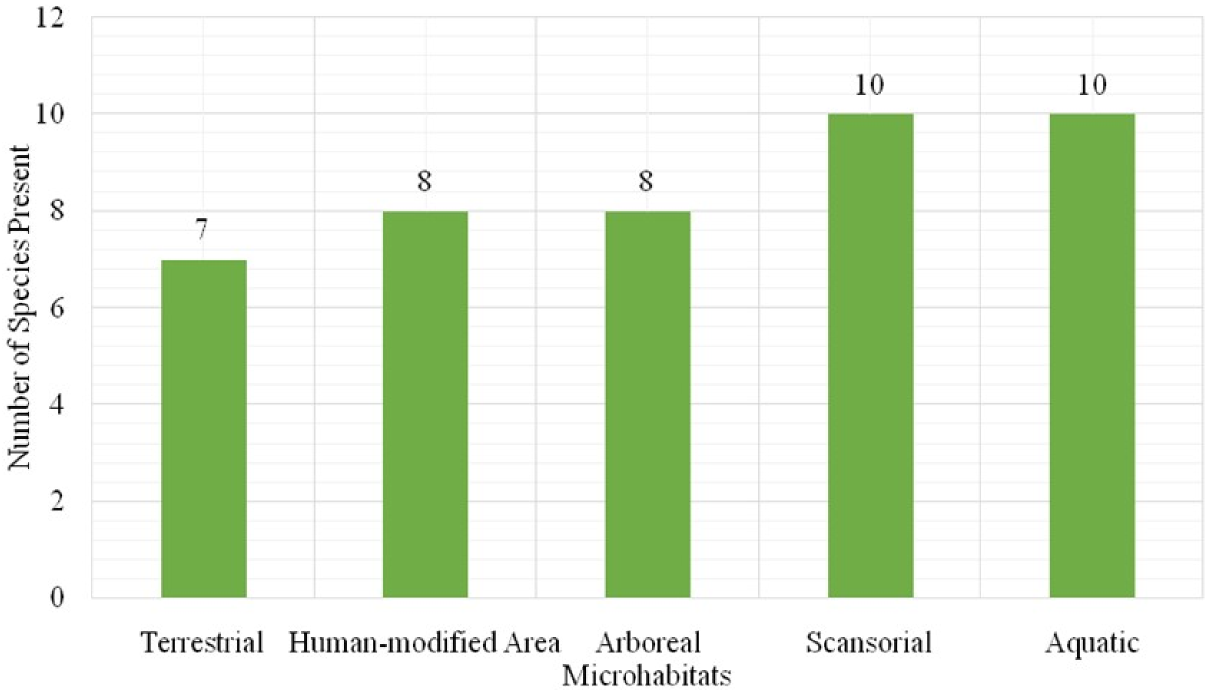

Figure 8: Microhabitat preferences of amphibians in CEDAR.

Endemism, and conservation status of amphibians

Seventy-eight percent (14 out of 18 species) observed in CEDAR were Philippine endemics, and seventeen percent (3 species) were widespread species, and only *Rhinella marina* is an invasive alien species. According to the IUCN Red List, 14 species are Least Concern (78%), of which, eight have decreasing population trends, four species have stable population trends, and one (*Pelobatrachus stejnegeri*) has an unknown population trend, while *Rhinella marina* is the only species that has an increasing population trend. Moreover, *Limnonectes magnus* and *Sanguirana everetti* are considered Near Threatened (11%) with decreasing population trends, and *Platymantis* sp. 1 and *Kalophrynus sinensis* have undetermined conservation status (11%) (Table 6). Lastly, all species documented were not listed in either one of the three CITES Appendices (McGuire et al., 2022).

Rarefaction and extrapolation of diversity across habitat types

The rarefaction and extrapolation curves suggest that all habitat types tend to an asymptote; hence, sampling effort was enough for detecting differences in amphibian assemblages between the habitat types (Fig. 9). Each habitat type varies in terms of estimated species diversity. Based on the diversity classification scheme (Table 2), the Human-modified area and Dila River System has a moderate level of diversity with H'= 2.032 and H'= 2.005, respectively, whereas, the dipterocarp forest has a low level of diversity with H'= 1.264. However, the Gini-Simpson's Diversity index showed that the Dila River System had the highest level of diversity D= 0.862, followed by the Human- modified area D= 0.812, then the dipterocarp forest with a low level of diversity D= 0.553.

Discussion

Habitat modification by humans leading to habitat destruction and fragmentation is a common threat to biodiversity (Scanes, 2018). However, man-made infrastructures such as artificial water bodies (e.g., water tanks, artificial ponds, cattle troughs, and swimming pools) can represent suitable reproductive habitats for some amphibians (Le Viol et al., 2012; Caballero-Díaz et al., 2020; Jehle et al., 2023). In the case of CEDAR, the highest species richness and diversity were observed in the human-modified area that includes an open area with a swimming pool surrounded by many cottages that are well-lit at night. A number of studies have shown that artificial sites are preferentially used by amphibians as breeding sites compared to natural aquatic habitats, providing key habitat for the species and hosting much larger numbers and densities of larvae than natural sites (Brand and Snodgrass, 2010; Le Viol et al., 2012; Caballero-Díaz et al., 2022). Interestingly, high species richness was recorded in these artificial sites comparable to the natural habitats (Brand and Snodgrass, 2010; Le Violet al., 2012; Caballero-Díaz et al., 2022). Whilst several amphibian species evidently utilized the created or modified waterbodies and infrastructures, the concentration of adults in a small habitat range, however, may imply high vulnerability to habitat fragmentation and poaching. The dipterocarp forest ranked second in terms of species richness in our study as forest habitats are structurally diverse, which provides abundant resources and microhabitats for many species.

Table 6: Endemism and conservation status of amphibians documented in CEDAR, Impalutao, Impasug-ong, Bukidnon.

Family name	Species name	Endemism	Conservation Status and Population Trend
Bufonidae	*Ansonia muelleri*	PE	LC ↓
	Rhinella marina	A	LC ↑
Ceratobatrachidae	*Platymantis* cf. *dorsalis*	PE	LC ↓
	Platymantis cf. *guentheri*	PE	LC ↓
	Platymantis cf. *rabori*	PE	LC ↓
	Platymantis sp. 1	PE	Undetermined
Dicroglossidae	*Limnonectes leytensis*	PE	LC ↓
	Limnonectes magnus	PE	NT ↓
	Phrynoglossus laevis	W	LC ↓
Megophryidae	*Pelobatrachus stejnegeri*	PE	LC ?
Microhylidae	*Kalophrynus sinensis*	W	Undetermined
	Kaloula conjuncta meridionalis	PE	LC -
Ranidae	*Pulchrana grandocula*	PE	LC -
	Sanguirana everetti	PE	NT ↓
	Sanguirana mearnsi	PE	LC ↓
Rhacophoridae	*Nyctixalus spinosus*	PE	LC ↓
	Philautus surdus	PE	LC -
	Polypedates leucomystax	W	LC -

Legends: Endemism = PE - Philippine Endemic, W - Widespread, A - Alien; Conservation Status = LC – Least Concern, NT – Near Threatened; Population Trend = ↑ - Increasing, ↓ - Decreasing, - - Stable, ? – Unknown

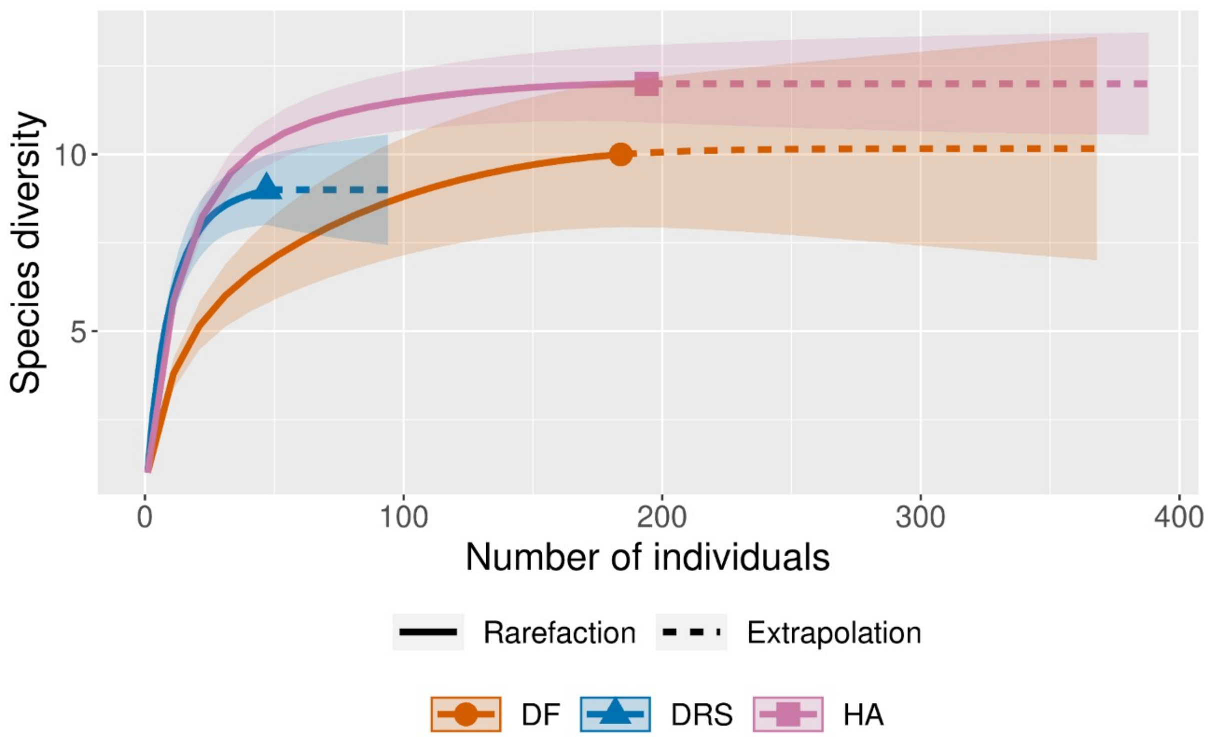

Figure 9: Individual-based rarefaction and extrapolation (R/E) curves for the amphibian assemblage among habitat types in CEDAR. Solid lines are interpolated and dashed lines are estimated; shading indicates with 95% confidence intervals around estimated species diversity.

Moreover, the differences in species richness between habitat types may be also attributed to the habitat specialization of some species (Thompson et al., 2016; Ferrante et al., 2017).

Generalist species like *Polypedates leucomystax* occurred in all microhabitats, such as on wooden chairs of built infrastructures, tree trunks and branches, petioles of Araceae and Asparagaceae species, grasses, ground, puddles, and rocks within streams. Other generalist species, including *Kalophrynus sinensis*, *Sanguirana mearnsi,* and *Rhinella marina*, occurred in multiple microhabitats. On the other hand, specialist species like *Kaloula conjuncta meridionalis* and some *Platymantis* were only recorded in the dipterocarp forest. *Platymantis* cf. *guentheri* and *Platymantis* sp. 1 exhibit habitat specificity as they were mainly observed in arboreal and scansorial microhabitats, specifically on dipterocarp tree trunks, holes, crevices, branches, and leaves of various plants within the dipterocarp forest. Although the aforementioned *Platymantis* species were primarily ground dwelling, these frogs also use arboreal habitats during calling (Alcala et al., 1999), and reproduction since they deposit their eggs on vegetation like the leaf axils and foliage of large aroid leaves (Alcala et al., 1998), hence their sightings in arboreal and scansorial microhabitats.

Other specialist species such as *Ansonia muelleri* and *Phrynoglossus laevis* were observed exclusively in aquatic microhabitats, as observed elsewhere (Sanguila et al., 2016).

The high amphibian endemism (78%) in the area may have been influenced by the island of Mindanao's highly dynamic geological history and processes of diversification as predicted by the Pleistocene Aggregate Island Complex (PAIC) paradigm (Brown et al., 2013; Sanguila et al., 2016). It is assumed that when sea levels were low during the Pleistocene, the emergence of land bridges allowed faunal exchanges between connected landmasses. These land bridges were temporary connections during the Pleistocene. After this period, the land bridges disappear and many Philippine islands become isolated for millions of years, producing highly endemic faunas within PAICs (Brown et al., 2013; Sanguila et al., 2016). As predicted, a number of Mindanao endemic amphibians were recorded in CEDAR, including *Pelobatrachus stejnegeri*, *Limnonectes magnus*, and *Kaloula conjuncta meridionalis*.

Unfortunately, environmental threats exist in CEDAR. These include habitat loss, unregulated harvesting, and the presence of invasive alien species. These threats exist as results of mismanagement and over-tolerance of such practices. Accordingly, habitat loss due to man-made infrastructures in the area may contribute to the reduction of amphibians in the area that are forest-canopy reliant (Li et al., 2022).

Overharvesting due to the frog meat trade has been considered one of the major causes of population declines of *Limnonectes magnus* and 89 other amphibian species around the world (Gratwicke et al., 2010). As observed in CEDAR, locally harvested frogs are included in the menu of a restaurant within the park. The locals living near CEDAR were also observed to harvest frogs within the park for subsistence. The edible frogs harvested by locals included species from the family Dicroglossidae (*L. leytensis*, *L. magnus*, *P. laevis*), as well as the cryptic *Platymantis* species. The establishment of invasive alien species (IAS) is also a major threat to biodiversity (Falaschi et al., 2020). For amphibians, IAS caused one-third of the group's extinctions (Blackburn et al., 2019).

Conclusions

The study found high species richness and endemism of amphibians in CEDAR, Impasug-ong, Bukidnon which makes it an important site in need of proper conservation management. Although the ecotourism park has an intact dipterocarp forest and extensive river system, amphibian diversity in the site was higher in the human-modified areas which suggests that the man-made structures in the site became suitable reproductive sites for most amphibians in CEDAR. Although several amphibian species evidently utilized the man-made infrastructures and modified ecosystems at CEDAR, the concentration of adults in a small habitat range, however, may imply high vulnerability to population fragmentation and poaching. Unfortunately, information on the high amphibian diversity in the human-modified area needs further field studies since extensive portions of the site which may hold unique species were not surveyed yet; hence, additional field sampling is recommended. Moreover, information on the species tolerance and sensitivity of amphibian communities to different disturbances may be further explored. It is also highly recommended to conduct long-term wildlife evaluation and monitoring in CEDAR to determine species at risk in the area, also to address malpractices and threats to amphibians in CEDAR, as well as the expansion of invasive alien species.

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Author contributions

The writing of the first version of this paper was done by K.H.S. Acuevas. Both authors (K.H.S. Acuevas and D.P. Buenavista) contributed in the research design, data collection, analysis, and editing of the manuscript. The research project was supervised by D.P. Buenavista.

Conflict of interest

I declare that there are no conflicting issues related to this research article.

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