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Herpetofaunal diversity of West Bali National Park, Indonesia with identification of indicator species for long-term monitoring

A.A. Thasun Amarasinghe[a,b,c,*], Chairunas A. Putra[c], Sujan M. Henkanaththegedara[d], Asri A. Dwiyahreni[a], Nurul L. Winarni[a,b], Sunaryo[a], Chris Margules[a,b,e], Jatna Supriatna[a,b,*]

[a] Research Center for Climate Change, Multidisciplinary Lab, University of Indonesia, FMIPA Building, 7th Floor, Kampus UI, Depok 16424, Indonesia
[b] Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Indonesia, Kampus UI, Depok 16424, Indonesia
[c] Association of Asian Herpetology (Asosiasi Herpetologi Asia), Jl. BSD Bintaro No. 88, Pondok Aren, 15228 Tangerang Selatan, Indonesia
[d] Department of Biological & Environmental Sciences, Longwood University, Farmville, VA 23909, USA
[e] College of Science and Engineering, James Cook University, PO Box 785, Tolga 4882, Queensland, Australia

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ABSTRACT

We report on the results of a survey of the herpetofauna of West Bali National Park (Taman Nasional Bali Barat in Indonesian, hereafter TNBB) that was carried out in 2015. The survey also included other taxa and the motivation for it was to identify a species or group of species that could be used as indicators of management success for Protected Area Credits (PAC) under the Rainforest Standards (RFS™) system. Four major ecosystems, moist forest, deciduous monsoon forest, savanna and an abandoned Teak plantation, were sampled over a period of 10 days, using belt transects and pitfall traps. We measured species richness, abundance and density, herpetofaunal diversity (Simpson's Index of Dominance and the Shannon Weiner Index) and community similarity. We also estimated the indicator value to determine which species, if any, might be suitable as indicators of environmental conditions. The survey yielded 30 species, 12 frogs and toads, 7 snakes and 11 lizards. Out of them there is an endangered gecko, *Cyrtodactylus jatnai*, a vulnerable frog, *Microhyla orientalis*, and a vulnerable tree-skink, *Cryptoblepharus baliensis*. Diversity was highest in the moist forest, followed closely by both the deciduous forest and the savanna. The greatest abundance was found un the savanna, followed by the moist forest and then the deciduous forest. Both diversity and abundance were extremely low in the abandoned teak plantation. Eleven species were identified as potential indicators of environmental deterioration if their numbers were to decrease. Frogs and toads were the best indicators in the moist forest, while lizards were the most suitable indicators for savanna and deciduous forest. No snakes were identified as indicators. It is concluded that herpetofauna can be useful and cost-effective indicators of environmental change.

* Corresponding authors at: Research Center for Climat e Change, Multidisciplinary Lab, University of Indonesia, FMIPA Building, 7th Floor, Kampus UI, Depok 16424, Indonesia.
E-mail addresses: thasun@rccc.ui.ac.id (A.A.T. Amarasinghe), j.supriatna@sci.ui.ac.id (J. Supriatna).

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1. Introduction

Bali, one of world's most popular tourist destinations has been overlooked as a biodiverse region of Indonesia (Supriatna, 2014). The island (5780 km^2) is geologically part of a volcanic island arc that includes the Greater and Lesser Sunda Islands to the west and east respectively. It was created by submarine volcanic eruptions about 3 million years ago (McKay, 2006) and is separated from mainland Java by the 3 km wide Bali Strait and from Lombok Island by the 35 km wide Lombok Strait (Whitten et al. 1996). The northern portion of the island was created over time by the eruptions of undersea volcanoes, and it probably surfaced about 3 million years ago (McKay, 2006). Bali's fauna and flora are generally most closely allied with that of neighboring Java. Java is a much larger island (128,297 km^2) formed by an east–west series of volcanoes and sedimentary accretions, and separated from Bali only by the narrow (3 km) Bali Strait (Whitten et al. 1996). Bali Strait is shallow in its narrowest part with an average depth of about 50 m and deeper at its northern and southern ends where depths range from 100 to 800 m (Berlianty and Yanagi, 2011).

It has been suggested that for some species, the genetic difference between the Balinese populations and those of the Greater Sundas to the west may indicate that the populations on Bali have been isolated for a substantially long period of time, although, the strait between East Java and Bali is narrow and should not hinder species migration (Amarasinghe et al. 2017). The herpetofauna of this island is a combination of species associated with the humid tropical habitats of Southeast Asia and the Greater Sunda Islands, and the generally drier weather patterns along the Lesser Sunda chain. Sixteen species of frogs and toads, and 62 species of terrestrial reptiles have been recorded on Bali (McKay, 2006; Riyanto and Mumpuni, 2013; Amarasinghe, 2015; Somaweera et al. 2018; Amarasinghe et al. 2020).

West Bali National Park (Taman Nasional Bali Barat in Indonesian, hereafter TNBB) was formally established in 1995, mainly to protect the only remaining population of the critically endangered Bali starling (*Leucopsar rothschildi*), a species of a monotypic genus which is endemic to west Bali. Habitat conversion and illegal collections for the pet trade have been the main causes of the decline of the Bali starling, which are also the common threats to other wildlife in the region (van Balen et al. 2000). Additionally, TNBB has been a popular tourist destination and supports a thriving ecotourism industry with local community participation (Sunarta, 2015). In 2015, TNBB was selected for a demonstration project for the Protected Area Credit (PAC) using the Rainforest Standard™ (RFS™) developed by Warfield et al. (2014). The RFS™ is the world's first forest carbon credit standard to fully integrate requirements and protocols for carbon accounting, socio-cultural/socio-economic impacts, and biodiversity outcomes. The initiative to use TNBB as a demonstration project was developed by the University of Indonesia and Columbia University. Prior to calculating the PAC, a biodiversity benchmark survey was conducted covering several different taxa (mammals, birds, herpetofauna, butterflies, and plants) to identify a group of species or a single species (i.e. indicator species), which may serve as a predictor of habitat change for future monitoring efforts (Warfield et al. 2014; Winarni et al. 2020a, 2020b).

Indicator Species are organisms whose occurrence in a given location predicts the quality of the environment at that location (Landres et al. 1988; Burger, 2006; Siddig et al. 2016). Additionally, these species are supposed to be relatively easy to monitor and should reflect ecological shifts in the sampled environment (Siddig et al. 2016). Therefore, indicator species are a valuable tool in assessing the effectiveness of a management program and/or for use as a "warning signal" of approaching ecological danger (e.g. climate change impacts; Siddig et al. 2016). Typically, biological traits such as abundance, density, reproduction rate and growth rate are directly influenced by the environmental quality in the habitat. Therefore, ecologists have been using such traits associated with indicator species as cost-effective methods to monitor short-term and long-term environmental change (Spellerberg, 2005; Burger, 2006). Although plants and microorganisms are widely used as indicator species, some studies have utilized vertebrates (Spellerberg, 2005; Siddig et al. 2016). Among all indicator taxa, the least used are herpetofauna, which represent about 1% of taxa in published indicator species studies (Siddig et al. 2016).

Here we report the detailed findings of the biodiversity benchmark survey conducted of herpetofauna at TNBB. We report herpetofaunal diversity, abundance, and density across four major ecosystems in TNBB and compare community similarity among these four habitats. Our survey is also notable as the first comprehensive survey of herpetofauna of TNBB conducted during the dry season. We also compare our findings with the wet season survey of Riyanto and Mumpuni (2013) to gain insights on the differences or similarities of diversity and community composition of herpetofauna between dry and wet seasons. Additionally, we report on the application of the *Indicator Value* concept (Dufrêne and Legendre, 1997) to determine indicator species for long-term monitoring of habitat change at TNBB.

2. Materials and methods

2.1. Study area

TNBB belongs to two administrative districts, Buleleng and Jembrana in Bali Province. It is located in the north-west of the island of Bali (8°05'20"–8°15'25"S, 114°25'00"–114°56'30"E). Three major sites which represent four different ecosystems in TNBB were identified for sampling based on environmental stratification (Margules and Austin, 1994) (Figs. 1 and 2): (site 1) Lebak Buah, which consists mainly of abandoned Teak Plantations and deciduous monsoon forests; (site 2) Mt. Lannying, which consists of moist forests, and (site 3) Teluk Brumbun, which consists of scrublands and savanna adjacent to the beach. Weather conditions during the survey were dry and hot. The dry season prevails from May to October with monthly air temperature of

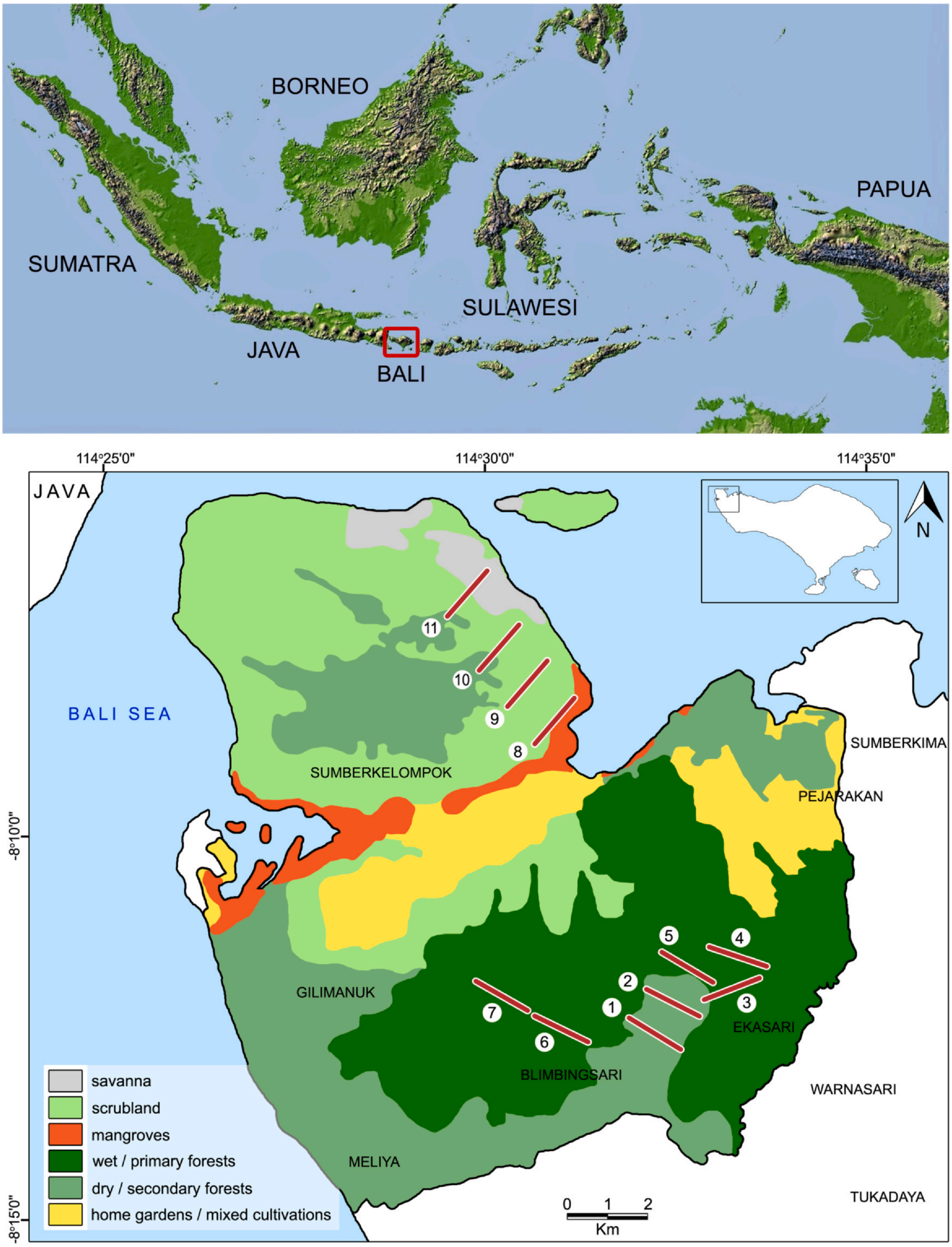

Fig. 1. The location of West Bali National Park (TNBB) in the Indonesian Archipelago and the distribution of belt transects (11) in various habitat types sampled for herpetofauna.

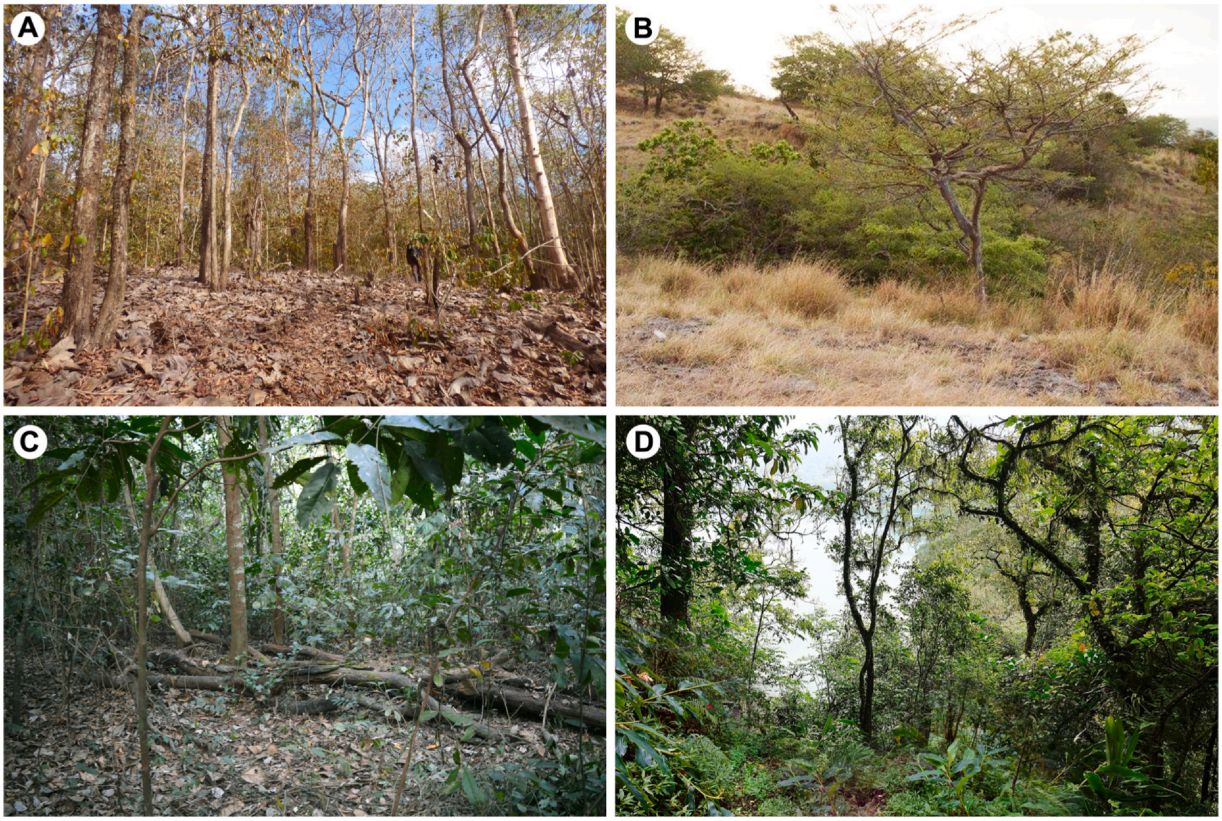

Fig. 2. Various habitat types sampled for herpetofauna, (A) Abandoned teak plantation, (B) Deciduous forest, (C) Moist forest, and (D) Savanna.

25–26 °C and monthly rainfall of 20–120 mm. However, during the months of November to April, the area receives monthly rainfall of 180–320 mm and experiences monthly air temperatures of 27–28 °C marking a clear wet season (Fig. 3; BMKG, 2015).

2.2. Data collection

The survey was carried out from 21 August 2015–4 September 2015 with a total of 10 field days (8 hrs /day). Surveys were carried out across eleven transects within the four TNBB ecosystems in order to sample the range of variation within those ecosystems. Surveys were conducted during both day and night. Flashlights were used at night. All habitats were thoroughly searched (e.g. turning over rocks and logs, stripping bark from trees, looking in to cracks and holes) for the presence of reptiles, frogs and toads. The following sampling techniques were used.

2.2.1. Belt transects

Five belt transects (5 m wide x 2 km long) were conducted at the first site (two in teak plantation and three in deciduous monsoon forest), two belt transects were conducted at the second site (moist forest), and four belt transects were conducted at the third site (savanna) (Fig. 1). Five field staff walked along transect at regular intervals (7:00–10:00 h in the morning and 16.00–19.00 h in the evening), systematically searching for reptiles, frogs and toads. Each transect was repeated only two times, morning and evening (Table 1).

2.2.2. Pitfall traps

Pitfall traps were set out at intervals of 100-meter along each 500-meter belt transect. The pitfall traps were checked frequently: at minimum, twice a day (morning and evening). Each pit was 30 cm in diameter and 45 cm deep (James, 1991). Five pits were placed in each sample site. The distance between each pit was 3 m. The pitfall traps were laid conjunct with drift fences (30 cm high) to increase the capture success (Morton et al., 1988). A continuous pitfall fence was used around breeding ponds (Heyer et al., 1994) for frogs and toads.

2.2.3. Taxonomy and species identification

All captured specimens were examined carefully and identified with relevant data recorded prior to being released at their original point of capture. For uncertain or unidentified taxa only, three specimens of each species were collected for further

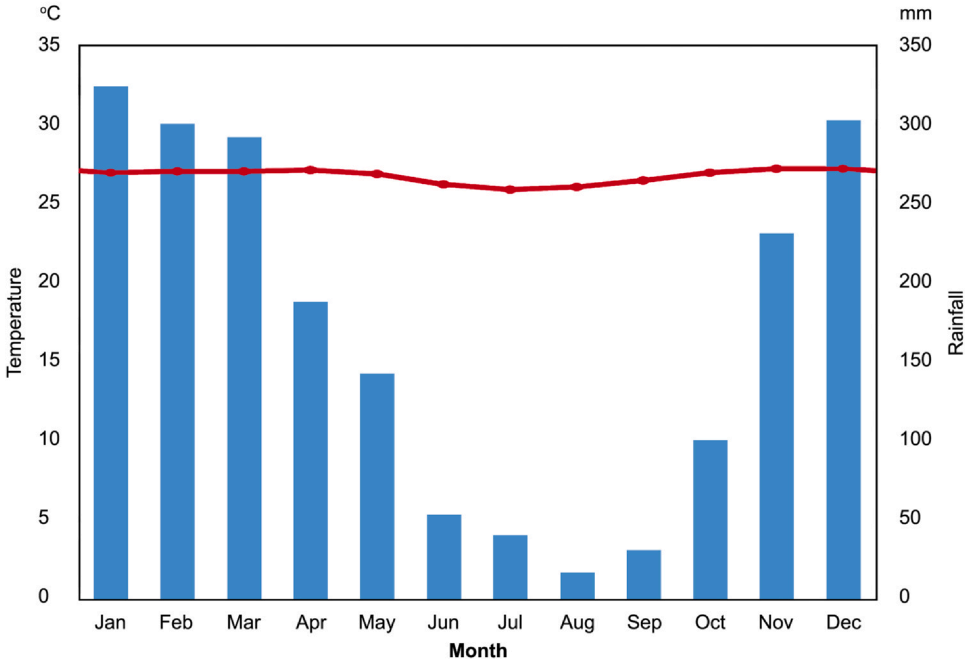

Fig. 3. Average monthly rainfall and temperature (2011–2015) recorded in West Bali region.

identification offsite. We collected the specimens by hand, except for the use of snake hooks and tongs for snakes. We euthanized the specimens with sodium pentobarbital or Trichloromethane, and fixed the specimens in 10% buffered formalin prior to storage in 70% ethanol. We preserved tissue samples for DNA analysis in 96% ethanol. We compared the specimens of uncertain or unidentified species to specimens of all the congeners found in museum collections or reference materials. When identifying species, we scored specimens for the standard morphological, meristic and morphometric characters which are used in recent descriptions of Southeast Asian congeners. All the measurements were taken with a Mitutoyo digital caliper to the nearest 0.1 mm under an AmScope microscope or a Leica Wild M3Z dissecting microscope on the right side of the body. Some of the information on character states and their distribution in other species was obtained from reliable guides such as de Rooij (1915, 1917), Iskandar and Colijn (2001), Frost et al. (2006), McKay (2006), and Somaweera (2017).

2.3. Data analysis

2.3.1. Species richness, abundance and density

We analysed the overall data set for total number of species reported, overall abundance, catch per unit effort (CPUE) and overall density. CPUE was estimated by dividing the total number of animals captured by survey time and number of people surveyed. Overall density was estimated by dividing the total number of animals by the area sampled.

2.3.2. Herpetofaunal diversity

We estimated the herpetofaunal diversity by using several biodiversity indices (Krebs, 1999). The species evenness for each habitat sampled was determined by using Simpson's Index of dominance (D) (Magurran, 1988).

$$D = \sum(pi)^2$$

Where, pi = the proportion species *i* in the community.

The heterogeneity of the sampled organisms for each habitat was determined by the Shannon-Wiener Index (H').

$$H' = -\sum[(pi) \times ln(pi)]$$

Where, pi = the proportion species *i* in the community.

A relatively higher value for Simpson's Index of dominance (D) indicates a community/sample dominated by one or a few species where the overall biodiversity is relatively low. However, a relatively higher value of the Shannon-Wiener Index (H') indicates a relatively biodiverse community/sample (Krebs, 1999).

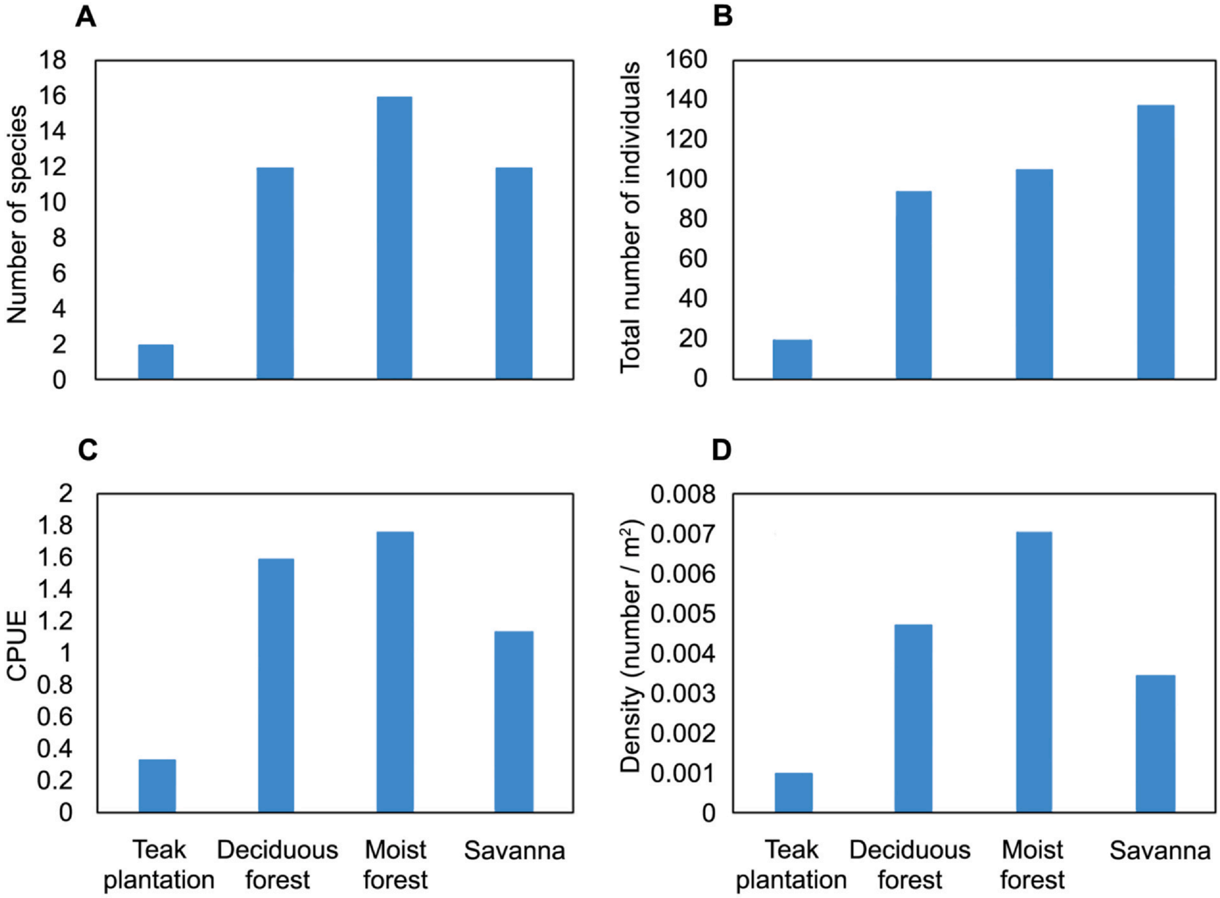

Fig. 4. Four different habitats sampled for herpetofauna show variable degrees of (A) Number of species, (B) Total number of individuals (overall abundance), (C) Catch per unit effort (CPUE), and (D) Animal density (number/m^2).

2.3.3. Community similarity

One can compare the similarity between communities using the composition of species, i.e. presence or absence of a species in a given community (Krebs, 1999). We employed Jaccard's community similarity coefficient (CCj) to measure how different the communities are from one another.

$$CCj = c / S$$

Where, c = the number of species common to both communities; S = the total number of species present in the two communities.

2.3.4. Indicator species

We estimated *Indicator Value* (IndVal) to determine which species might be used as indicators of site condition (Dufrêne and Legendre, 1997). This estimator (i.e. IndVal) is founded on the concepts of specificity and fidelity and widely used in community ecology to identify indicator species (see Borcard *et al.* 2018). We used the *multipatt* function of the R package *indicspecies* (ver. 1.7.8; de Caceres and Legendre, 2009) to conduct indicator species analysis. First, we classified the sites into four groups using non-hierarchical cluster analysis on the species data matrix (de Caceres, 2020). Then, we used function *multipatt* to determine the species that are associated with a particular group of sites/habitats. Finally, the statistical significance of this relationship was tested using a permutation test (de Caceres, 2020).

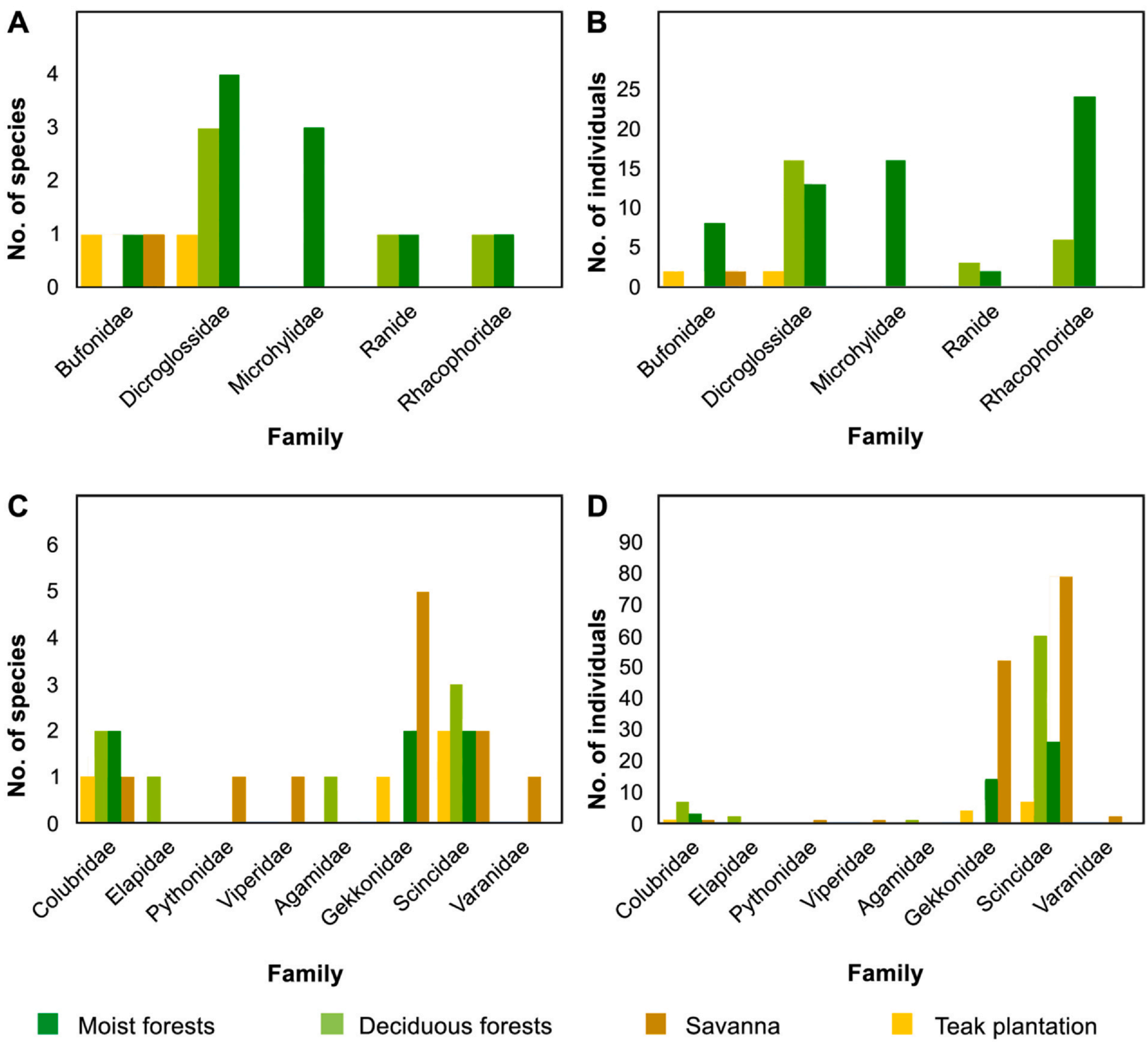

Fig. 5. (A) Species richness and (B) abundance of frogs and toads, and (C) Species richness and (D) abundance of Reptiles in each habitat type.

3. Results

3.1. Species richness, abundance and density (Figs. 4–6)

Our survey yielded 30 species of herpetofauna including 12 species of frogs and toads, 7 species of snakes and 11 species of lizards (Table 2). Out of them, *Cyrtodactylus jatnai* is an endangered gecko species, *Microhyla orientalis* and *Cryptoblepharus baliensis* are a vulnerable frog and a tree-skink respectively, and the rest of the species are Least Concern (LC) (see Table 2 for the conservation status). The highest number of species, 16, was found in the moist forest followed by 12 species each from the deciduous forest and savanna. Only two species were reported from the abandoned teak plantation (Table 2). The highest abundance of herpetofauna was reported from the savanna (138 individuals) followed by the moist forest (106 individuals) and the deciduous forest (95 individuals). The abandoned teak plantation yielded only 20 individuals (Table 2). The highest density of herpetofauna was reported from the moist forest following the deciduous forest, savanna, and teak plantation. Similarly, the highest yield for catch per unit effort was reported for the moist forest followed by the deciduous forest, savanna, and teak plantation (Fig. 4, Table 3).

Among the frogs and toads recorded during our survey, families Dicroglossidae and Microhylidae display the highest species richness; and the highest abundance is shown by tree frogs (Rhacophoridae). *Polypedates leucomystax* (Rhacophoridae) is the most abundant tree frog species, while *Fejervarya* species (Dicroglossidae) and *Microhyla palmipes* (Microhylidae), and *Bijurana*

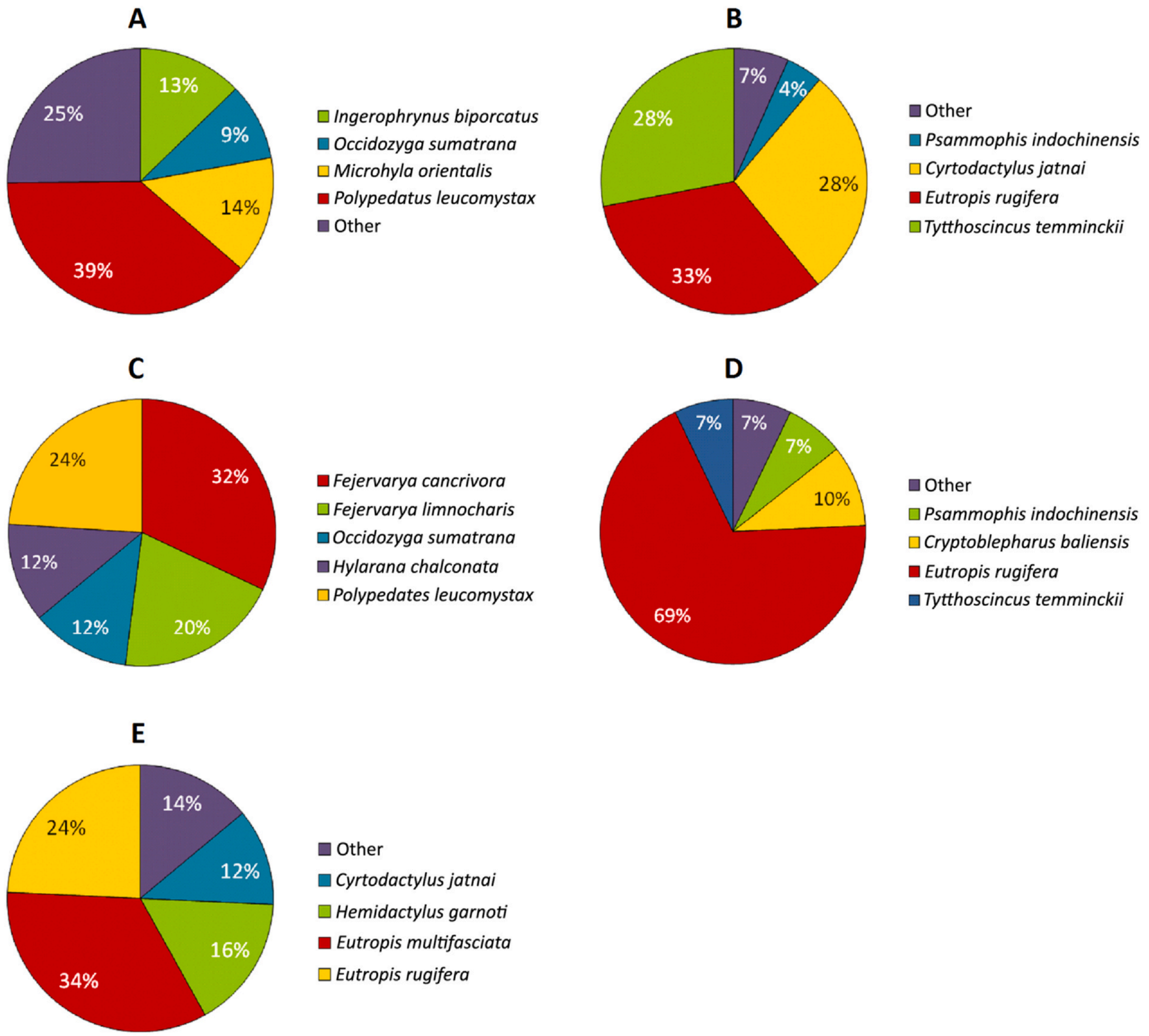

Fig. 6. Relative abundance of (A) frogs and toads, and (B) reptiles in moist forest habitat; (C) frogs and toads, and (D) reptiles in deciduous forest habitat, and (E) reptiles in savanna forest habitat.

cf. *nicobariensis* (Dicroglossidae) were found to be the least abundant. The highest species richness as well as abundance of frogs and toads was recorded in moist forests. This reflects the fact that the moist forests in TNBB provide ideal habitat for tree frogs, fork-tongued frogs, and narrow-mouthed frogs. More importantly, all the narrow-mouthed frog species (Microhylidae) were found only in moist forests, highlighting the importance of protecting the few surviving moist forest habitats in TNBB (Figs. 5 and 6).

Among the recorded reptiles, the families Gekkonidae and Scincidae have the highest species richness, as well as the highest abundance. *Eutropis rugifera* (Scincidae) is the most abundant species, while snakes as a group are the least abundant. Species richness and abundance of reptiles was highest in savanna forests. This reflects the fact that the savanna forests in TNBB are ideal habitat for geckos and skinks (Figs. 5 and 6). This unusual abundance of geckos and skinks could be due to the presence of plentiful food resources (e.g. insects) and relatively few predator species (e.g. snakes).

Among the frogs and toads in moist forests, the relative abundance of *Polypedates leucomystax* is 39% and *Microhyla orientalis* 14%. Together those two species represent the relative abundance of more than 50% of all individuals in moist forests. Among the reptiles, the highest relative abundance is represented by *Eutropis rugifera* and it is almost the same as *Polypedates leucomystax* (Fig. 6). Among the frogs and toads in deciduous forests, the relative abundance of *Fejervarya cancrivora* is 32% and *Polypedates leucomystax* 24%. Together those two species comprise more than 50% of the relative abundance of all frog and toad individuals in deciduous forests. Among the reptiles, the highest relative abundance is represented again by *Eutropis rugifera* and it is more than double that of *Fejervarya cancrivora* (Fig. 6). As there were only two individuals of *Duttaphrynus melanostictus*

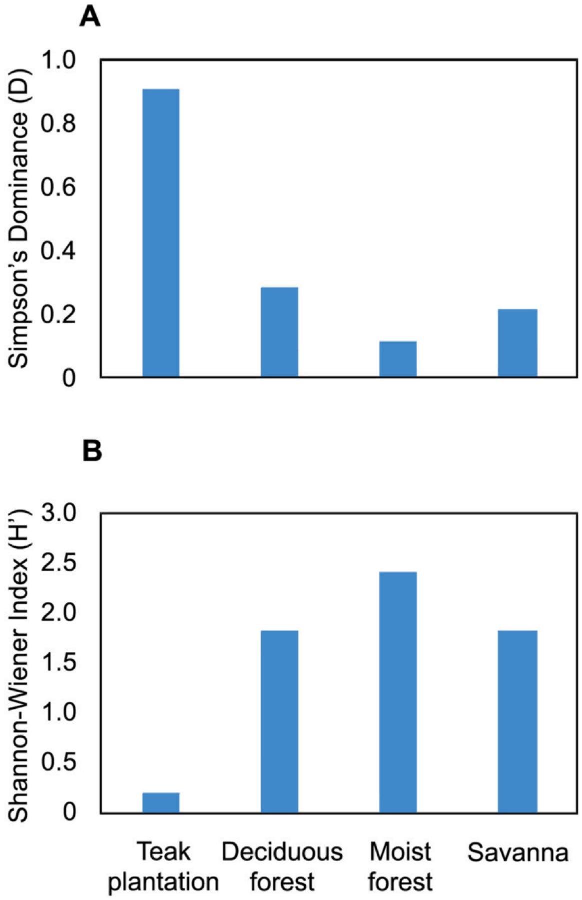

Fig. 7. Four different habitats sampled for herpetofauna show variable degrees of (A) dominance as estimated by Simpson's dominance index, D and (B) heterogeneity as estimated by Shannon-Wiener index, H' for herpetofaunal diversity.

Table 1
Summary of survey parameters for four different habitat types sampled at West Bali National Park, Indonesia.

Survey parameters	Teak plantation	Deciduous forest	Moist forest	Savanna
Size of the area surveyed (m^2)	20,000	20,000	15,000	40,000
Total time surveyed (hrs)	12	12	12	24
Number of people surveyed	5	5	5	5
Altitude range (in m)	100–300	100–300	300–600	0–100

toads recorded from savanna forests here we report the relative abundance only of reptiles. Among the reptiles, the highest relative abundance was found for the other skink species, *Eutropis multifasciata*, at 34%, while *Eutropis rugifera* still represents 24%. Interestingly these two skink species together represent more than 50% of relative abundance among the reptile fauna in savanna forests (Fig. 6).

3.2. Herpetofaunal diversity (Fig. 7)

The Shannon-Wiener Index showed that moist forests had the highest overall herpetofaunal diversity (H' = 2.41) followed by similar, though slightly lower, values for both the deciduous forest (H' = 1.81) and the savanna (H' = 1.82). The lowest overall herpetofaunal diversity was reported for the abandoned teak plantation where the species richness and the abundance of organisms was extremely low (H = 0.20). Similarly, the lowest dominance (estimated by the Simpson's Index) was reported for the moist forest (0.11) followed by the deciduous forest (0.28) and the savanna (D = 0.21). The highest dominance was reported for the abandoned teak plantation (D = 0.90) where 95% of the relative abundance was represented by *Eutropis rugifera* (Fig. 6). Overall, it shows that the highest diversity of herpetofauna was associated with the moist forest and the lowest in the abandoned teak plantation.

Table 2
A checklist of the herpetofauna reported from the West Bali National Park (TNBB), during the present study Indonesia including their global IUCN conservation status (LC, least concern; VU, vulnerable; EN, endangered; CR, critically endangered) and recorded the habitat type, and the total number of individuals.

No.	Species	Teak plantation	Deciduous forest	Moist forest	Savanna	No. of individuals
	Toads					
	Family Bufonidae					
1	*Duttaphrynus melanostictus*[LC]				+	2
2	*Ingerophrynus biporcatus*[LC]			+		8
	Frogs					
	Family Dicroglossidae					
3	*Fejervarya cancrivora*[LC]		+	+		10
4	*Fejervarya limnocharis*[LC]		+	+		8
5	*Fejervarya* sp.			+		2
6	*Occidozyga sumatrana*[LC]		+	+		9
	Family Microhylidae					
7	*Microhyla orientalis*[VU]			+		4
8	*Microhyla palmipes*[LC]			+		9
9	*Microhyla* sp.			+		3
	Family Ranidae					
10	*Chalcorana chalconota*[LC]		+			3
11	*Bijurana nicobariensis*[LC]			+		2
	Family Rhacophoridae					
12	*Polypedates leucomystax*[LC]		+	+		30
	Reptiles					
	Family Colubridae					
13	*Ahaetulla prasina*[LC]			+		1
14	*Dendrelaphis pictus*[LC]		+			2
15	*Psammophis indochinensis*[LC]		+	+		7
16	*Cerberus schneiderii*[LC]				+	1
	Family Elapidae					
17	*Bungarus candidus*[LC]		+			2
	Family Pythonidae					
18	*Malayopython reticulatus*[LC]				+	1
	Family Viperidae					
19	*Trimeresurus insularis*[LC]				+	1
	Family Agamidae					
20	*Draco volans*[LC]	+	+			2
	Family Gekkonidae					
21	*Hemidactylus platyurus*[LC]				+	4
22	*Cyrtodactylus jatnai*[EN]			+	+	28
23	*Gehyra mutilata*[LC]				+	3
24	*Gekko gecko*[LC]				+	7
25	*Hemidactylus frenatus*[LC]			+	+	24
	Family Scincidae					
26	*Cryptoblepharus baliensis*[VU]		+			7
27	*Eutropis multifasciata*[LC]				+	46
28	*Eutropis rugifera*[LC]	+	+	+	+	114
29	*Tytthoscincus temminckii*[LC]		+	+		17
	Family Varanidae					
30	*Varanus salvator*[LC]				+	2

3.3. Community similarity (Table 4)

Jaccard's community similarity coefficient (Krebs, 1999) showed the highest similarity of species composition between the moist and deciduous forests (CCj = 33.33%). This is mainly due to the wide distribution of several frogs (i.e. *Fejervarya cancrivora*, *F. limnocharis*, *Occidozyga sumatrana*, and *Polypedates leucomystax*) and very common generalist lizard, *Eutropis rugifera*. The deciduous forest and the abandoned teak plantation had a 16.67% community similarity due to the dominance of *Eutropis rugifera* in both habitats. The community similarity between the moist forest and the savanna was 12% and the other habitat comparisons have yielded less than 10% similarity indicating the uniqueness of the herpetofauna in each habitat (Table 4).

3.4. Indicator species (Table 5, Fig. 9)

Indicator species analysis identified 11 indicator species out of the 30 species analysed. Seven species were associated with single site/habitat groups, and four were associated with a combination of two site/habitat groups (Table 4). *Ingerophrynus biporcatus*, *Microhyla palmipes*, and *Microhyla orientalis* were strongly associated with moist forest habitats, while *Cryptoblepharus baliensis* was strongly association with the deciduous forest. *Cyrtodactylus jatnai*, *Eutropis rugifera*, and *Hemidactylus frenatus* were strongly associated with savanna habitats. Additionally, four species were strongly associated with both moist and

Table 3
Summary of diversity parameters for taxa sampled from four different habitats of West Bali National Park.

Category	Taxa	Habitat sampled			
		Teak plantation	Deciduous forest	Moist forest	Savanna
Number of species	Frogs and toads	0	5	10	1
	Snakes	0	3	2	3
	lizards	2	4	4	8
	Total	2	12	16	12
Total number of animals	Frogs and toads	0	25	63	2
	Snakes	0	9	3	3
	lizards	20	61	40	133
	Total	20	95	106	138
Catch per unit effort (CPUE) total/(survey time * number of people)	Frogs and toads	0	0.4167	1.0500	0.0167
	Snakes	0	0.1500	0.0500	0.0250
	lizards	0.3333	1.0167	0.6667	1.1083
	Total	0.3333	1.5833	1.7667	1.1500
Animal density (Number/m^2)	Frogs and toads	0	0.0013	0.0042	0.0001
	Snakes	0	0.0005	0.0002	0.0001
	lizards	0.001	0.0031	0.0027	0.0033
	Total	0.001	0.0048	0.0071	0.0035

deciduous forests which were *Occidozyga sumatrana*, *Polypedates leucomystax*, *Tytthoscincus temminckii* and *Fejervarya cancrivora*. No indicator species was associated with the abandoned teak plantation (Table 4).

4. Discussion

4.1. Species identifications, distributions and taxonomic updates

In addition to our general survey results, here we discuss the taxonomy of some species, and take the opportunity to correct some misidentified species listed in McKay (2006) and Riyanto and Mumpuni (2013). For example, McKay (2006) recorded the presence of *Occidozyga leavis* in Bali. According to Iskandar (1998), the population of *Occidozyga* in Bali is actually comprised of erroneously-identified *Occidozyga sumatrana*. We also recorded only *O. sumatrana* during this study, tending to support Iskandar's contention. Recent herpetofaunal checklists of Bali (e.g. McKay, 2006; Riyanto and Mumpuni, 2013) include only one species of bent-toed gecko, *Cyrtodactylus fumosus* (Müller, 1895). However, Somaweera (2017) listed it as *Cyrtodactylus* sp. A detailed re-examination of *C. fumosus* sensu stricto by Mecke et al. (2016) also revealed the *Cyrtodactylus* population in Bali may

Table 4
Percentage community similarity for habitat pairs estimated according to Jaccard's community similarity coefficient (Krebs, 1999).

Habitat	Teak plantation	Deciduous forest	Moist forest	Savanna
Teak plantation		16.67	5.88	7.69
Deciduous forest	16.67		33.33	4.55
Moist forest	5.88	33.33		12.00
Savanna	7.69	4.55	12.00	

Table 5
The results of Indicator Species Analysis showed eleven indicator species out of thirty species analysed based on indicator value (*IndVal*; Dufrene and Legendre 1997).

Sites/Habitat	Indicator species	Test statistic	P value
Moist forest	*Ingerophrynus biporcatus*	1.000	0.021
	Microhyla palmipes	1.000	0.021
	Microhyla orientalis	1.000	0.021
Savanna	*Cyrtodactylus jatnai*	1.000	0.011
	Eutropis rugifera	0.950	0.043
	Hemidactylus frenatus	0.938	0.028
Deciduous forest	*Cryptoblepharus baliensis*	0.933	0.049
Moist forest + Deciduous forest	*Occidozyga sumatrana*	1.000	0.009
	Polypedates leucomystax	0.988	0.003
	Tytthoscincus temminckii	0.978	0.005
	Fejervarya cancrivora	0.971	0.009

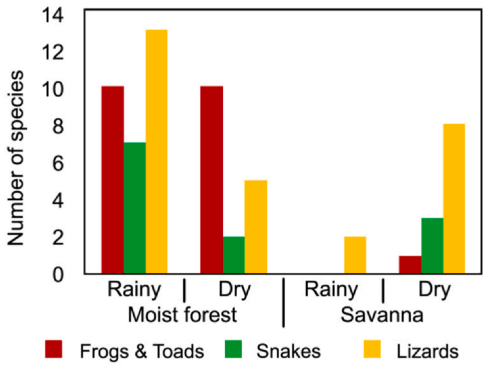

Fig. 8. Comparison of Species richness of frogs and toads, snakes and lizards during rainy season (fide Riyanto and Mumpuni, 2013) and dry season (this study) in moist forest and savanna habitat types.

represent an unnamed species. Recently, Amarasinghe et al. (2020) named the *Cyrtodactylus* population in Bali as *Cyrtodactylus jatnai* from TNBB. However, the rest of the *Cyrtodactylus* populations in Bali island may represent different species (see Mo and Mo, 2020), and further taxonomic studies are needed to resolve this matter. *Eutropis multifasciata* population in Bali was earlier considered as a distinct subspecies, *Eutropis multifasciata balinensis* Mertens, 1927. However, Amarasinghe et al. (2018) synonymised it with the typical form and invalidated the subspecies. According to Chandramouli et al. (2020), *Bijurana nicobariensis* is probably confined to the Nicobar Island (India), and the populations in Sumatra, Java, and Bali may represent one or several distinct species. Therefore, here we list the species found in Bali as *Bijurana* cf. *nicobariensis*. However, the taxonomic issues of many species in Bali are still need to be re-examined and discussed (Amarasinghe et al. work in progress).

4.2. Species richness and abundance

Our survey of herpetofauna was the first ever comprehensive study conducted at TNBB during the dry season. Overall, we reported a total of 30 herps including 12 frog and toad species, 7 snake species and 11 lizard species. The highest species richness was reported from the moist forest followed by intermediate values from both deciduous forest and savanna. The least diversity was reported from the Teak plantation. The same trend was observed for the overall abundance, density and CPUE of herpetofauna at TNBB. McKay (2006), Somaweera (2017), and Somaweera et al. (2018) compiled detailed checklists of reptiles, frogs and toads recorded from Bali Island and listed 15 species of frogs and toads, and 80 species of reptiles. Recently, Sramek and Somaweera (2020) added one more frog, *Limnonectes macrodon* (Duméril and Bibron, 1841) to the list. The first study of the herpetofauna of TNBB was conducted by Riyanto and Mumpuni (2013) over a 10 day period in 2012 during the rainy season in April. Their study recorded 10 species of frogs and toads, and 22 species of reptiles, but several rare species of herpetofauna from the area haven't been observed. Riyanto and Mumpuni (2013) conducted their survey in habitat types similar to the present study.

Their study presented a unique opportunity for us to compare and contrast the diversity and community composition of herpetofauna in the region between dry and wet seasons for deciduous forests and savanna habitats. During the present study we were able to record 12 (out of 13) species of frogs and toads, and 18 (out of 29) species of reptiles even though it was the dry season (Table 2). Based on the comparative analysis between wet season (*fide* Riyanto and Mumpuni, 2013) and dry season (this study), Riyanto and Mumpuni (2013) reported a higher number of reptile species from moist forest during the wet season compared to dry season (our study), while frog and toad species richness remained equal in both wet and dry season. In both moist forests and savanna, the rain had a significant impact on reptile species richness. In the moist forest during dry period, fewer reptile species were detected, while in savanna the number was higher (Fig. 8). Although, Riyanto and Mumpuni (2013) observed a higher number of reptile species from the moist forests (wet season), we observed a higher numbers from the savanna (dry season). It seems that the wet season in moist forests and the dry season in savanna are ideal active weather conditions for reptile fauna.

4.3. Habitat generalist vs. specialists

Among all the reptiles, only *Eutropis rugifera* is a habitat generalist distributed in all major habitat types. This species is able to thrive in a wide variety of environmental conditions; however, the relative abundance varies within each habitat (Fig. 6). The highest relative abundance of *E. rigufera* was recorded from deciduous forests (64%) and the least from savanna forests (11%), which is typical for other widespread common skinks such as *E. multifasciata* Kuhl, 1820 (personal observations).

Furthermore, Amarasinghe et al. (2017) analysed the gut contents of *E. rugifera* specimens collected from TNBB, and found evidence for a varied, heterotrophic diet. Thus, we can assume that a generalist diet would be one reason behind the successful distribution of *E. rigufera* in a wide array of ecologically distinct habitats. Although, it might that *E. rugifera* be a species complex, the wide distribution of *E. rugifera* from Nicobar Island (India) to Southern Thailand, Peninsular Malaysia, Singapore, and Indonesia could be explained by its generalist habits such as generalist diet and the adaptability to a wide array of ecologically distinct habitats. Supporting the above hypothesis, Amarasinghe et al. (2017) showed that populations of *E. rugifera* from

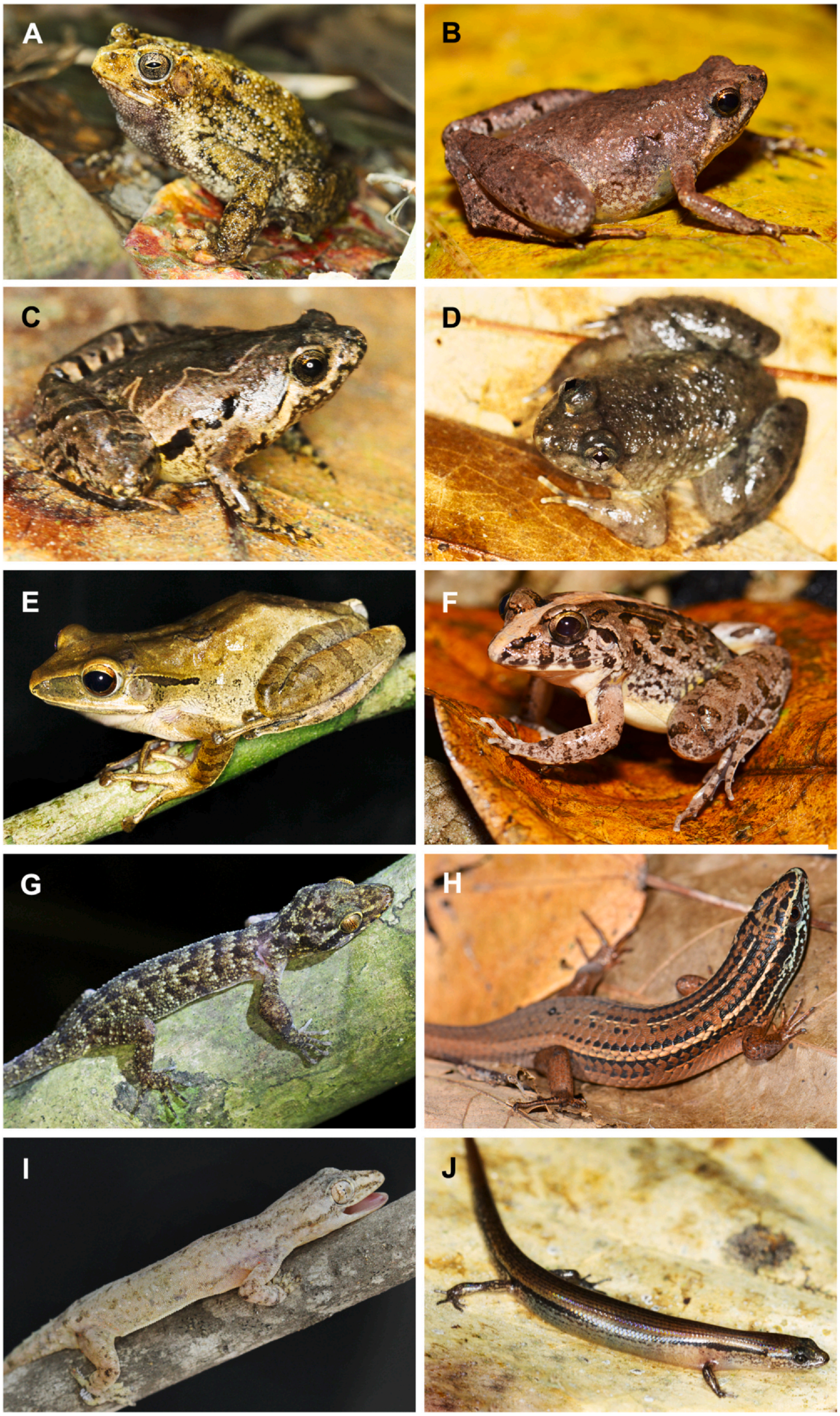

Fig. 9. Indicator species identified from TNBB (A) *Ingerophrynus biporcatus*, (B) *Microhyla orientalis*, (C) *Microhyla palmipes*, (D) *Occidozyga sumatrana*, (E) *Polypedates leucomystax*, (F) *Fejervarya cancrivora*, (G) *Cyrtodactylus jatnai*, (H) *Eutropis rugifera*, (I) *Hemidactylus frenatus*, (J) *Tytthoscincus temminckii*. © Photos: A.A.T. Amarasinghe.

Nicobar Island, Sumatra, Bawean Island (Java), and Bali Island are morphologically and genetically in close relationship, and the results confirmed that this is a widespread single species, and does not show any significant morphological variation throughout the biogeographical region.

Interestingly, based on the results of the present study, all the other species have been identified as habitat specialists who can only thrive in a narrow range of environmental conditions, perhaps due to a specialized diet, ecological interactions (i.e. competition, predation) and/or a narrow tolerance range for environmental conditions such as temperature and humidity (McPeek, 1996; Magura et al. 2020).

4.4. Indicator species for long-term monitoring at TNBB

The initial motivation for carrying out the survey reported here, was to identify a group of species or a single species that might serve as an indicator of environmental change that could be used to assess the suitability of TNBB for on-going Protected Area Credits (PAC) under the RFS™. Ecologists use a wide range of plant and animal taxa as "indicator species" to measure ecosystem health or monitor trends in condition over time (Cairns et al. 1993; Dale and Beyeler, 2001). Some species or groups of species are intolerant of factors such as pollution, environmental disturbance, and habitat modifications. Their presence is an indicator of a healthy ecosystem, while their absence can indicate environmental changes. Their presence or absence is in turn an indicator of effective management that RFS™ can use to support ongoing PAC, or not. Our results confirm that some of the herpetofauna in TNBB can indeed be used for such a purpose.

There are several general characteristics of useful indicator species, such as that they should be easily sampled, sensitive to stresses on the system, and respond to stress in a predictable manner (Dale and Beyeler, 2001). A recent study (Winarni et al. 2020a, 2020b) using data on birds, butterflies and plants collected during the benchmark surveys at TNBB suggested that birds were the best indicator species group, followed by butterflies, and plants due to their higher abundance and representation in different habitat types. Unlike mammals, birds and reptiles, the frogs and toads have semi-permeable skin sensitive for environmental changes and a biphasic life cycle still partially tied to water. These features mean that the frogs and toads are the only vertebrate indicators of changes to both aquatic and terrestrial environments in one locality. Therefore the first indication of a healthy environment is the presence of frogs and toads.

Some studies have argued that birds are the most cost-effective taxa for monitoring with the highest Indicator Value, while mammals and herpetofauna, respectively are the taxa with the highest cost (Dufrêne and Legendre, 1997; Winarni et al. 2020a, 2020b). However, frog and toad populations can be estimated long-term with low-cost standard methods such as toe-clipping (Rocha et al., 2001, Watanabe et al., 2005). In contrast larger-bodied taxa like birds need high cost mist-net trapping and ringing techniques with associated high labor costs. Usually double observer – visual encounter – belt transect surveys at night are enough for frog and toad monitoring. Therefore, most research suggests that frogs and toads are excellent indicators of environmental contamination or pollution and ecosystem health or habitat quality (see Welsh and Ollivier, 1998; Galatowitsch et al. 1999; Collins and Storfer, 2003; Sheridan and Olson, 2003; Hammer et al. 2004; Campbell et al. 2005; Waddle, 2006; Guzy et al. 2012; Sumanasekara et al. 2015). In addition, reptiles have also been identified as one of the best indicators, especially for habitat fragmentation (Hager, 1998), pollution and exotoxins (Lambert, 1987, 2004; Fossi et al. 1995; Marsili et al. 2009) and other broad assessment of environmental changes (Wilson and McCranie, 2003).

Our indicator value analysis identified a total of 11 indicator species for long-term monitoring. This represented six species of frogs and toads, and five species of reptiles (all lizards, no snakes). All indicator species for the moist forest were amphibians representing one true toad (Bufonidae) and two narrow-mouthed frogs (Microhylidae). Out of them, one narrow-mouthed frog, *Microhyla orientalis* is a vulnerable species. A single skink species, *Cryptoblepharus baliensis* (Scincidae), also a vulnerable species was selected as the indicator species for the deciduous forest. However, one species of true tree frog (Rhacophoridae), two species of fork-tongued frogs (Dicroglossidae), and single species of skink were recognized as indicator species for both moist forest and deciduous forest. All three indicator species recognized for savanna habitat were tertrapod reptiles with two gecko species (Gekkonidae) and a single skink species (Scincidae). Among them one gecko, *Cyrtodactylus jatnai* is an endangered species. This clearly indicates the tendency of selecting moist-sensitive frogs as indicator species for moist habitats while selecting lizards which are adapted for arid conditions as indicator species for drier habitats such as savanna and deciduous forest. Although we have selected a decent number of indicator species which are relatively easy to detect for long-term monitoring at TNBB, this list may be skewed given that our data only represent the herpetofaunal activity during the dry season. Therefore, we recommend conducting a similar study, probably just after the rainy season, to determine a more complete set of indicator species (specially include more frog taxa) for long-term monitoring at TNBB.

4.5. Conservation management of TNBB

Since 2012, the forest cover of TNBB lost 8.38 ha annually (Sunaryo et al. 2015) and between 2012 and 2017 the forest cover was reduced from 7557.93 ha to 7274.41 a decline of 3.75% (Dwiyahreni et al. 2021a). TNBB has been included within the Java-Bali bioregion along with 10 other national parks on Java Island as one complex sharing similar threats throughout the region such as road construction and expansion. Alarmingly, as highlighted by Wittemyer et al. (2008), human population growth continues at a rapid pace around the national parks, a trend, which is a serious threat to the remaining biodiversity isolated in these protected areas. New construction and access roads to new infrastructure, in buffer zones around the parks as well as inside them, have been identified as major growing threats (Dwiyahreni et al. 2021b). In addition to road access, TNBB is vulnerable to motorboat entree routes along the coastline. Among the national parks of the Java-Bali bioregion, TNBB should benefit from the social and cultural customs among the Balinese who value nature highly. Access by local villagers to the buffer zone surrounding the national park can provide mutual benefits and enhances the concept of coexistence with nature. Local communities use the buffer zone for tending livestock, collecting firewood, and harvesting honey. However, hunting was also evident due to the presence of snares (Purwanto et al. 2015). Ease of accessibility and more intensive harvesting of wild products are now tending towards commercial levels, abusing the concept of coexistence. Therefore, it may be time to adopt stricter policies limiting access to local communities for personal consumption. Increasing budgets for management activities, and capacity building may also have effective positive impacts on conservation of TNBB (Dwiyahreni et al. 2021a,b).

4.6. Future directions and research gaps

Further surveys and discoveries from Bali Island, which is geographically placed between Sundaland and Wallacea would fill an important gap in tracing the distribution of herpetofauna in Indonesia, perhaps revealing evolutionary links between the species of Sundaland and Wallacea. For an example, during the survey we re-discovered *Psammophis indochinensis* Smith, 1943 from TNBB 58 years after it was last record from East Java (Mertens, 1957). The herpetofauna of the Great Sundaic Islands still remain largely unstudied. The low diversity of reptiles reported in Indonesia seems to be more an artifact of low collection than anything else, and additional fieldwork focused on exploring new areas will no doubt uncover more undescribed species. On the other hand, the empty forest syndrome, which is the deterioration of forest ecosystems generally caused by lack of funding for parks, dearth of wildlife rangers, and new roads and development projects (Redford, 1992; Wilkie et al. 2011), also becoming an increasing reality in Indonesia. The challenges are therefore formidable and demand urgent national level scientific studies and the introduction of effective policies and planning. Ongoing biodiversity monitoring is needed to measure the forest cover changes, and it is relatively easy to conduct using GIS analysis. It is also important to monitor the indicator species to determine any long-term changes in environmental condition, disease outbreaks, pollution or climate change, as they may provide early warnings of changes to the natural habitats.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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