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Habitat Preferences Dictate Amphibian Assemblage and Diversity in Langkawi Island, Kedah, Peninsular Malaysia

(Pemilihan Habitat Menentukan Himpunan dan Kepelbagaian Amfibia di Pulau Langkawi, Kedah, Semenanjung Malaysia)

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ABSTRACT

Various habitats found on Langkawi Island such as agricultural fields, peat swamps, lowland forests, upland forests, and riverine forests are occupied by many species of anuran fauna. These variations provide a platform to explore species diversity, distribution, and other ecological parameters to understand the distribution patterns and to facilitate the management of important species within particular areas. The objective of this study was to compare species richness of anuran species in different types of habitat on Langkawi Island, Malaysia. We surveyed seven types of habitat, namely agriculture (AG), coastal (CL), forest (FT), pond (PD), fisherman village near estuarine mangrove (FVM), riparian forest (RF), and river (RV). A total of 775 individuals were recorded, representing 23 species from 14 genera and six families known to occur on Langkawi Island. Forest (FT) and riparian forest (RF) (both forest habitats) indicated relatively high values of Shannon Index (H'), 2.60 and 2.38 respectively, compared to the other non-forest habitats, CL (1.82), RV (1.71), FVM (1.56), PD (1.54), and AG (1.53). Rank abundance curves showed that the majority of disturbed habitats displayed geometric series models and broken stick models, whereas forest habitat types (FT and RF) represented log normal models. The performance of species richness estimators varied but Chao 1 estimator performed well for many sampled habitat types and showed the tendency to coalesce with S_{obs} (Mao Tau) curves except for CL and FVM. As expected, the forested habitat (FT and RF) was more diverse in species diversity compared to those of non-forest groups. Nevertheless, non-forested species were found in abundance, highlighting the relevance of these habitats in supporting the amphibian fauna. This study highlights the importance of habitat types in structuring species diversity and community structures and suggest that the information may be useful to improve conservation practices of inland amphibian habitats.

Keywords: Abundance; anurans; commonness; distribution; rarity

ABSTRAK

Pulau Langkawi mempunyai kepelbagaian habitat, seperti ladang pertanian, paya gambut, hutan tanah rendah, hutan tanah tinggi dan aliran sungai di kawasan hutan. Kepelbagaian habitat ini menjadi perantara untuk meneroka kepelbagaian spesies, taburan dan parameter ekologi lain dalam memahami pola taburan dan memudahkan pengurusan spesies dalam sesuatu kawasan tertentu. Objektif kajian ini adalah untuk membandingkan kekayaan spesies anura dalam pelbagai jenis habitat di Pulau Langkawi, Malaysia. Tinjauan dilakukan terhadap tujuh jenis habitat iaitu pertanian (AG), pantai (CL), hutan (FT), kolam (PD), perkampungan nelayan (FVM), aliran sungai di kawasan hutan (RF) dan sungai (RV). Sejumlah 775 individu telah direkodkan, mewakili 23 spesies daripada 14 genus dan enam famili katak yang terdapat di Pulau Langkawi, semenanjung Malaysia. FT dan RF (kedua-duanya habitat hutan) masing-masing menunjukkan nilai Shannon Index (H ') yang tinggi, 2.60 dan 2.38, berbanding dengan habitat bukan hutan, CL (1.82), RV (1.71), FVM (1.56) PD (1.54) dan AG (1.53). Lengkungan kelimpahan menunjukkan sebahagian besar habitat yang terganggu mewakili model 'log geometric series' dan 'broken stick', manakala jenis habitat hutan (FT dan RF) mewakili model 'log normal'. Terdapat pelbagai pengukur kekayaan spesies, namun, Chao 1 mempunyai kecenderungan lengkung S_{obs} (Mao Tau) hampir pada kebanyakan jenis sampel habitat kecuali di CL dan FVM. Seperti yang dijangkakan, habitat hutan (FT dan RF) mempunyai kepelbagaian spesies yang tinggi berbanding kumpulan habitat bukan hutan. Walau bagaimanapun, spesies bukan hutan dijumpai dalam kelimpahan individu yang tinggi, justeru menunjukkan kepelbagaian habitat ini menyokong kelestarian amfibia. Kajian ini menonjolkan kepentingan pelbagai habitat dalam menentukan kepelbagaian dan komuniti struktur, seterusnya mencadangkan maklumat data yang diperoleh sangat berguna dalam pemuliharaan habitat amfibia.

Kata kunci: Katak; kelimpahan; kesamaan; spesies langka; taburan

Introduction

Many studies have been done on the amphibians and reptiles on Langkawi Island, Malaysia (Boulenger 1912; Daicus et al. 2005; Grismer et al. 2011; Ibrahim et al. 2006; Lim et al. 2010; Manthey & Grossmann 1997; Zimmerer 2004), but these studies mainly generated species checklists and new species descriptions. Understanding the various types of habitats and amphibian assemblages are essential to facilitate developmental planning and management, as well as conservation of important species or areas. Since amphibians are potential bioindicators of the health of aquatic systems (Dorcas & Gibbons 2011), identifying species abundance and distribution is key to recognising possible important areas for conservation.

Many environmental factors influence the quality of amphibians' habitat, such as amount and type of vegetation in the water body, wetland or stream and surrounding terrestrial habitat, hydro-period, water quality, presence of predators and competitors, the prevalence of diseases, and the nature and frequency of human disturbance (Hamer & McDonnell 2008). Poor quality habitats may not support viable populations, and these marginal habitats could potentially become species sinks depleting the larger-scale meta-population (Mckinney 2002). Beard et al. (2003) stated that understanding amphibians' habitat or knowledge of habitat preference could be used to assign ecological roles of certain species and predict the effect of habitat change.

Habitat structure plays a vital role in determining species diversity, with more physically complex habitats containing more species (Bell et al. 2012). There has been some controversy over what factors characterise complex versus simple habitats and affect the number of coexisting species (Hart & Horwitz 1991; Tokeshi 2009). By combining data from different habitat types, it should be possible to infer the distribution pattern of anuran species across various habitat types and compare it across the region. Therefore, the objectives of this study were to compare the population abundance of anuran species in different types of habitat on Langkawi Island and to characterise the patterns and the processes underlying it.

Materials and Methods

Habitat Sampling

Field surveys were conducted from September to November 2013 and August to December 2014. The dry season in Langkawi began in December 2013 and continued until the end of March 2014, whereas the peak of the rainy season started in July and lasted until the end of October 2014. The reproductive periods of anurans were profoundly affected by the rainfall distribution (Aichinger 1987). Thus, sampling covered most of the peak rainy season to maximize sampling. A total of 49 sampling sites were classified into seven habitat types: (1) AG, (2) CL, (3) FT, (4) PD, (5) FVM, (6) RF, and (7) RV (Figure 1).

Habitat Description

AG: Paddy fields along the bunds. Sampling started during the wet season when the fields were flooded and muddy. Sweep nets were useful to catch the amphibians and larvae. CL: Coastal area included relatively undisturbed coastal forests dominated by coconut palms (*Cocos nucifera*: Arecaceae) and Rhu (*Casuarina equisetifolia:* Casuarinaceae) and sandy beaches. FT: Forest refers to the lowland and hill dipterocarp forests of Gunung Raya along an existing road leading to the peak starting from 0 to above 600 m. PD: Pond refers to five pond areas, which had waterlilies (Nymphaeaceae) and *Colocasia esculenta* (Araceae) as dominant plants. FVM: Surveys included muddy ground, brackish area and nearby roads about 200-300 m from the mangroves. RF: Riparian forest refers to recreational forests along rocky streams of about 5-10 m wide with scattered waterlogged rock pools. RV: Survey areas exposed to open areas near human habitation sites.

Sampling of Anurans

Visual Encounter Surveys (VES) were employed to collect specimens. Sampling effort at each habitat was carried out by two to four people using headlights, for approximately three hours at night starting from 2000 - 2300 h. Total sampling days for each habitat type was eight nights. All frog sightings and calls heard at a distance of approximately 10 m on both sides of the centre line of the search were captured by hand, placed into individual plastic bags, identified, and labelled accordingly.

Specimen Preparations

Each specimen was measured with Mitutoyo digital calipers to the nearest 0.1 mm. All measurements were made on the left side of the body where applicable (Wood et al. 2009). Two characters examined were snout-vent length (SVL) which was measured from the tip of the snout to the tip of the vent and tibia length (TL). These measurements are essential for identification purposes and future reference. Two voucher specimens from each species were randomly selected for preservation. Selected specimens were euthanized with tricaine (ethyl 3-aminobenzoate methanesulfonate salt), fixed in 10% formalin and stored in 70% ethanol. Tissue samples were stored in 100% alcohol for future taxonomic studies. All specimens and tissues samples were deposited in the

Langkawi Research Centre of Herpetofauna Collection (LRCHC), Universiti Kebangsaan Malaysia in Langkawi, Malaysia. Other collected specimens were released near point-of-capture on the next day.

DATA ANALYSIS

Univariate measures, including species richness, Shannon index (H'), Evenness (E) and Simpson Diversity (1-D) were performed for each of the seven habitat types using the software PAST version 2.17c (Hammer et al. 2001) to compare between anuran assemblages.

Species abundance and distribution (SAD) of each habitat were visualized using rank-abundance curves, where log-abundance was plotted on the y-axis vs species rank on the x-axis to compare between relative proportion of rare, intermediate, and common species. There are four species abundance models, namely the geometric, log series, log normal, and broken stick (Magurran 1988). The geometric series model assumes that species abundance is roughly proportional to total resource use. Usually, this model portrays species-poor communities with minimal cooperation in ecosystems. Log series is closely related to the geometric series model (May 1975). Some studies have found both models fit the same community, and noted that one (geometric) or a few (log) species dominate a community. For example, Thomas and Shattock (1986) showed that both the geometric series and the log series models adequately described the species abundance patterns of filamentous fungi on the grass *Lolium perenne*. Besides, most communities fit into the log-normal, which are usually represented by large and mature communities. For the broken stick model, it is generally conceived of as the average species abundance distribution. It can be misleading to test the fit of a single sample to the theory of equal resource partitioning. The best-fitted model is selected by comparing the observed curves to the predictive model as given in Magurran (1988).

Four estimators were calculated using the programme Estimate S version 9.1.0 (Colwell 2006), namely ACE, Chao1, Jacknife1 (Jack 1) and Jacknife2 (Jack 2). These estimators can detect the missing species through extrapolation, and also evaluate and predict species richness. Individual-based abundance data refer to Chao 1 and ACE, which consider the number of individuals represented by each species in a sample. The abundance-based coverage estimator (ACE) uses additional information based on those species with 10 or fewer individuals in a sample (Chao et al. 1993). In contrast, sample-based incidence data, Jack 1 and Jack 2 occur in only one sampling unit (uniques) or exactly two sampling units (duplicates).

A cluster analysis based on the presence and absence of each anuran species was performed using Multivariate Statistical Package MVSP version 3.13b (Kovach 1999). The cluster analysis using the Jaccard's coefficient similarity index was employed to test the degree (percentage) of similarity among amphibian species assemblages represented in each study site (Jongman et al. 1995).

RESULTS

A total of 775 amphibian individuals were recorded, consisting of 23 species of anurans in 14 genus and six families (Table 1). Five species occurred across all habitat types, namely *Duttaphrynus melanostictus* (Schneider), *Fejervarya limnocharis* (Gravenhorst), *Polypedates leucomystax* (Gravenhorst), *P. discantus Rujirawan*, Stuart & Aowphol, and *Hylarana erythraea* (Schlegel). The most abundant species were *F. limnocharis* with 239 individuals or 30.8% of the total frogs, followed by F. *cancrivora* (Gravenhorst) with 172 individuals (22.2%) and *H. erythraea* with 105 individuals (13.5%). The other 18 species had between 1 and 28 individuals sampled. Species constituting a single sample were *Ingerophrynus parvus* (Boulenger), which was found at the forest habitat (FT), and *Microhyla heymonsi* Vogt, found at the coastal area (CL).

In relation to species distribution pattern, most species have strong preference towards choosing a habitat near the vicinity of a forest (FT and RF). A theoretical model of anuran species distribution showed that nine species were restricted to forested habitats and five species were restricted to non-forest habitats (Figure 2). There were nine species that can inhabit both habitats. Overall, 18 species were found in forested habitats and 14 species in non-forest habitats. In terms of the number of families, only forest habitats (FT and RF) had all six families of frogs of Peninsular Malaysia. The family Megophryidae was not found at the rest of the habitats.

FT scored the highest Shannon Index (*H'*= 2.60 ± 0.02), with high Evenness Index (E= 0.75) and low Dominance Index (*D*= 0.09 ± 0.01) (Table 2). Shannon index of RF was also relatively high (*H'*= 2.38 ± 0.05). The Shannon index values of other habitats ranged from the lowest 1.53 ± 0.03 to 1.71 ± 0.04. These values are supported by the rank abundance models, in which assemblages with high species abundance are indicated by a shallow gradient. The long tail that skews to the right and depicted as a log-normal model is represented by FT and RF (Figure 3).

The patterns of rank abundance shown by the models were determined by visual assessment followed the curve which resemble the predictive model as given in Magurran (1998). Magurran (1998) stated that, the best solution in almost all cases will be to elucidate the results of the shape or pattern of the species abundance data which is by visual pattern. Both forest habitat types (FT and RF) represent the log-normal models. Non-forest habitat types (AG and FVM) conformed to the geometric series model, CL and PD fitted the broken stick model, and RV fitted the log series pattern (Figure 3).

The performance of species richness estimators varied but the Chao 1 estimator performed well in many habitat types as assessed by its coalescence to Sobs (Mao Tau) curves except for CL and FVM (Figure 4). For AG and RF, Chao 1 estimated 14 and 17 species, compared to 11 and 16 from the S_{obs} (Mao Tau) curves, respectively. Chao 1 estimator for PD was identical to the S_{obs} (Mao Tau) curve, indicating the best fit. Chao 1 estimators of species richness at FT was 18.7, while at RV, the value was the same as the observed data. At CL and FVM habitat types, Jack 1 and ACE mean performed well, by being flatter and closer to the S_{obs} (Mao Tau) curve, with the estimated species number 11.6 and 12.4, respectively, compared to nine and 10 species from the observed data, respectively.

Based on the cluster analysis, sites with the closest species composition or high in similarity index were considered as one group, and those that were different as another group (Figure 5). The closest amphibian assemblages were between AG and RV, indicated by the Jaccard's coefficient similarity index of 83.3% (Node 1). The second highest percentage was between CL and PD, 77.8% (Node 2), followed by Node 1 and MG, 75% (Node 3). Node 4 was represented by FT and RF with 70% as Group A, whereas Node 5 was represented by Group B (Node 3 and Node 2) 62.2%. The least similarity index was between Node 5 (Group B) and Node 4 (Group A) with 37.1%.

DISCUSSION

Most of the sampled species were common and widely distributed in Peninsular Malaysia, except for two species, *Leptobrachium smithi* Matsui, Nabhitabhata & Panha, and *Limnonectes macrognathus* (Boulenger). These two species are not known from the mainland Peninsular Malaysia, but Pulau Langkawi is their southern distribution limit (Grismer et al. 2009). *Leptobrachium smithi* is also found in Peninsular Thailand (Das & Chanda 2004). Zimmerrer (2004) had reported the presence of *L. hendricksoni* in the lowland rainforests of Pulau Langkawi, but it was most probably *L. smithi*. *Limnonectes macrognathus* is also recorded in Myanmar through Thailand (Khonsue & Thirakhupt 2001; Leong et al. 2003). Langkawi Island in northern Peninsular Malaysia lies in a transition zone between the Thai-Burmese wet seasonal evergreen forest of the north extending southward down the Thai-Malay Peninsula and the evergreen rain forest of the south extending north through Peninsular Malaysia (Woodruff 2003). Thus, Langkawi Island serves as the southern distribution limit for a number of Indochinese species (Chan et al. 2009), which are *Leptobrachium smithi* and *Limnonectes macrognathus*.

Among the seven sampled habitat types on Langkawi Island, the highest abundance was at AG (156 individuals), with two species dominating the community, namely *Fejevarya limnocharis* (41.7%) and *F. cancrivora* (33.3%). The total number of individuals of these two species contributed 75% of the total individuals at AG. They also occurred at FVM, especially at the edges where the habitats were associated with grassy and open areas. These two species are considered as common to residential areas and disturbed or modified environment (Janiawati et al. 2015). *Fejervarya cancrivora* (crab eating frog) is the only species that is highly tolerant of brackish water, and it can survive well in salinity ranging between 0 and 39 ppt (Gordon & Tucker 1965).

A high dominance was reflected in the steep gradient of the rank abundance model in AG and FVM, thus, represented a geometric series pattern by visual assessment (Figure 3). AG and FVM were presented many rare species (singletons) and few species of intermediate abundance in the habitat (four and three singletons). Magurran (2004) also stated that a geometric series distribution of species abundances is predicted to occur when species arrive at an unsaturated habitat at regular intervals of time. By contrast, as a log series, RV showed the intervals between the arrival time of these species were random rather than regular. The log series produced a slightly more even distribution of species abundances than the geometric series (Magurran 2004). Nevertheless, May (1975) noted that the geometric series and log series models are closely related. RV had a high number of individuals but a low number of species, resulting in the uneven species distribution pattern. At first, RV looked like it conforms to the geometric series model, as the gradient was steep, but the gradient did not abruptly stop. Thus, the log series model is the best choice instead of the geometric series model.

FT and RF are visually represented as a log-normal distribution. The shallow gradient usually indicates a log-normal distribution and higher evenness of species number. The log-normal also describes more data sets than the log series (Magurran 1988). Hughes (1986) suggested that the model which distinguishes the log-normal from the log series model may arise from the sampling effort, species misidentification and sampling errors. Magurran (1988) showed that many data sets will be described equally well by both the log series and the log-normal models, and it may be difficult for the ecologist to decide which is more appropriate.

CL and PD are visually fitted into the broken stick model. Both assemblages had lower number of species richness, which is nine and seven species, respectively, compared to other habitats which had between 10 and 18 species. Cohen (1968) and Poole (1974) stated that the broken stick model is characterized by only one parameter, S (number of species), and strongly subjected to sample size. Moreover, there were no significantly dominant species, and the numbers of rare and dominant species were smaller in CL and PD compared to those of other habitats.

The non-parametric richness estimator performance in this study concluded that the estimator performance varied but Chao 1 estimator performed well in many sampled habitat types except for CL and FVM. According to Gotelli and Colwell (2011), four of the estimators, which are Chao1, ACE, and the two individual-based jackknife estimators, are appropriate for abundance data. Basualdo (2011) stated that ACE and Chao1 show very close scores at the family level, whereas, Chao1 is the most suitable abundance estimators at the genus level. He concluded that most of the estimators had a different performance depending on the sample under study, except Chao1, which was always the most stable. According to Basualdo (2011), the smaller the sub-sample size, the better the performance of the estimator. The constancy of the sub-sample size is also needed to estimate the total observed richness, measured as one standard deviation (SD) of the previous criterion. The lack of erratic behaviour in the curve shape is considered more stable and, therefore, a more reliable estimate. Lastly, the similarity in curve shape is important throughout the data sets. All of those criteria are important towards the goal of measuring completeness, and the most tendencies to coalesce S_{obs} (Mao Tau) curve is the best estimator among others.

More species are detected in forest habitats compared to non-forest habitats. *Leptobrachium smithi* and *Occidozyga lima* (Gravenhorst) are among the two notably rarer and endemic species in the northern peninsular, and both are restricted to forest habitats. Nine of the 23 species were exclusively found in forest habitats (FT and RF) such as *Limnonectes blythii* (Boulenger), *L. hascheanus* (Stoliczka), *L. macrognathus, Leptobrachium smithii, M. aceras* Boulenger and *Chalcorana labialis* (Peters), hence can be considered as a forest specialist group (Group A). Based on the cluster analysis, sites with the most similar species composition are clustered as one group (Figure 5). The other group forms the non-forest habitats (Group B), which are the terrestrial, generalist and commensal species (Gillespie et al. 2005; Graeme et al. 2012; Inger & Stuebing 2005). The non-forest generalists such as *F. limnocharis, F. cancrivora, P. leucomystax, P. discantus, K. pulchra Gray, D. melanostictus* and *H. erythraea* are highly adaptable and can tolerate disturbance and severe habitat alteration. For example, *D. melanostictus* is widely distributed up to 700 m a.s.l. on Gunung Raya and other disturbed lowland habitats. Additionally, many of these species such as *D. melanostictus*, *H. erythraea*, and *F. limnocharis* are listed as key species for man-made habitat. In contrast, *C. labialis* is listed as key species for forest habitat (Kiew et al. 1996). The presence of these key species can support the information to access the remediation status of a habitat (Norhayati et al. 2014).

Both FT and RF have contrasting characteristics from the non-forest habitats, and the presence of all six families of frogs was expected. Frogs from the family Megophryidae are the ground dwellers of the litter layer and have cryptic body colour to blend well in their natural habitats. Hence, they tend to be found on the forest floor and leaf litter, which is typical of forested habitats. Also, riparian sites are important for maintaining anuran populations, while forest habitats are incomparable to conserve rare amphibians (Paoletti et al. 2018). Non-forest habitats are structurally less complex and lacking many microhabitats important to tropical amphibian species. The microhabitats include leaf litter (Danielsen 1995), a diverse array of arboreal, terrestrial and aquatic microhabitats (Chung et al. 2000). These various microhabitats, however, are subject to more significant microclimatic variations (Peh et al. 2006). Factors like cryptic morphology, elusive lifestyles and the fact that some species do occur in low densities are some of the factors that may affect sampling (Duellman & Trueb 1994), and thus, influence composition, abundance and richness estimation of anuran species. These factors are difficult to separate in practice unless rigorous sampling methodologies are applied (Chan & Norhayati 2009).

TABLE 1. Anuran species composition from seven types of habitat on Langkawi Island (number in the bracket is percentage of relative abundance)

	Species	AG	CL	FT	PD	FVM	RF	RV	TOTAL
	Bufonidae (5.9%)								
1	*Duttaphrynus melanostictus*	1	11	4	5	2	1	4	28 (3.6)
2	*Ingerophrynus parvus*	0	0	1	0	0	0	0	1 (0.1)
3	*Phrynoidis asper*	0	0	5	0	1	8	3	17 (2.2)
	Dicroglossidae (61.4%)								
4	*Fejervarya cancrivora*	65	10	0	41	40	0	16	172 (22.2)
5	*Fejervarya limnocharis*	52	24	13	36	41	14	59	239 (30.8)
6	*Limnonectes blythii*	0	0	0	0	0	10	0	10 (1.3)
7	*Limnonectes hascheanus*	0	0	5	0	0	2	0	7 (0.9)
8	*Limnonectes macrognathus*	0	0	12	0	0	3	0	15 (1.9)
9	*Occidozyga laevis*	1	1	6	3	0	0	6	17 (2.2)
10	*Occidozyga lima*	0	0	2	0	0	0	0	2 (0.3)
11	*Occidozyga martensii*	6	0	0	0	0	2	6	14 (1.8)
	Megophryidae (2.6%)								
12	*Leptobrachium smithii*	0	0	15	0	0	0	0	15 (1.9)
13	*Megophrys aceras*	0	0	4	0	0	1	0	5 (0.6)
	Microhylidae (7%)								
14	*Kaloula pulchra*	1	1	2	0	1	4	3	12 (1.5)
15	*Microhyla berdmorei*	0	0	2	0	0	2	0	4 (0.5)
16	*Microhyla butleri*	6	0	7	0	5	2	0	20 (2.6)
17	*Microhyla fissipes*	12	0	0	0	1	0	4	17 (2.2)
18	*Microhyla heymonsi*	0	1	0	0	0	0	0	1 (0.1)
	Rhacophoridae (7.2%)								
19	*Polypedates leucomystax*	1	8	2	5	3	1	2	22 (2.8)
20	*Polypedates discantus*	2	9	10	6	3	2	2	34 (4.4)
	Ranidae (15.9%)								
21	*Hylarana erythraea*	9	19	2	39	23	1	12	105 (13.5)
22	*Pulchrana glandulosa*	0	0	3	0	0	3	0	6 (0.8)
23	*Chalcorana labialis*	0	0	1	0	0	11	0	12 (1.5)
	Total	156 (20.1)	84 (10.8)	96 (12.4)	135 (17.4)	120 (15.5)	67 (8.6)	117 (15.1)	775 (100)

TABLE 2. Diversity indices measured of anurans from seven types of habitat on Langkawi Island

	AG	CL	FT	PD	FVM	RF	RV
No. of species (S_{obs})	11	9	18	7	10	16	11
No. of family	5	5	6	5	5	6	5
Individuals	156	84	96	135	120	67	117
Shannon (*H'*)	1.53 ± 0.03	1.82 ± 0.03	2.60 ± 0.02	1.54 ± 0.03	1.56 ± 0.04	2.38 ± 0.05	1.71 ± 0.04
Evenness (*E*)	0.42	0.68	0.75	0.67	0.47	0.68	0.50
Dominance (*D*)	0.30 ± 0.01	0.19 ± 0.02	0.09 ± 0.01	0.25 ± 0.01	0.27 ± 0.02	0.12 ± 0.02	0.29 ± 0.02

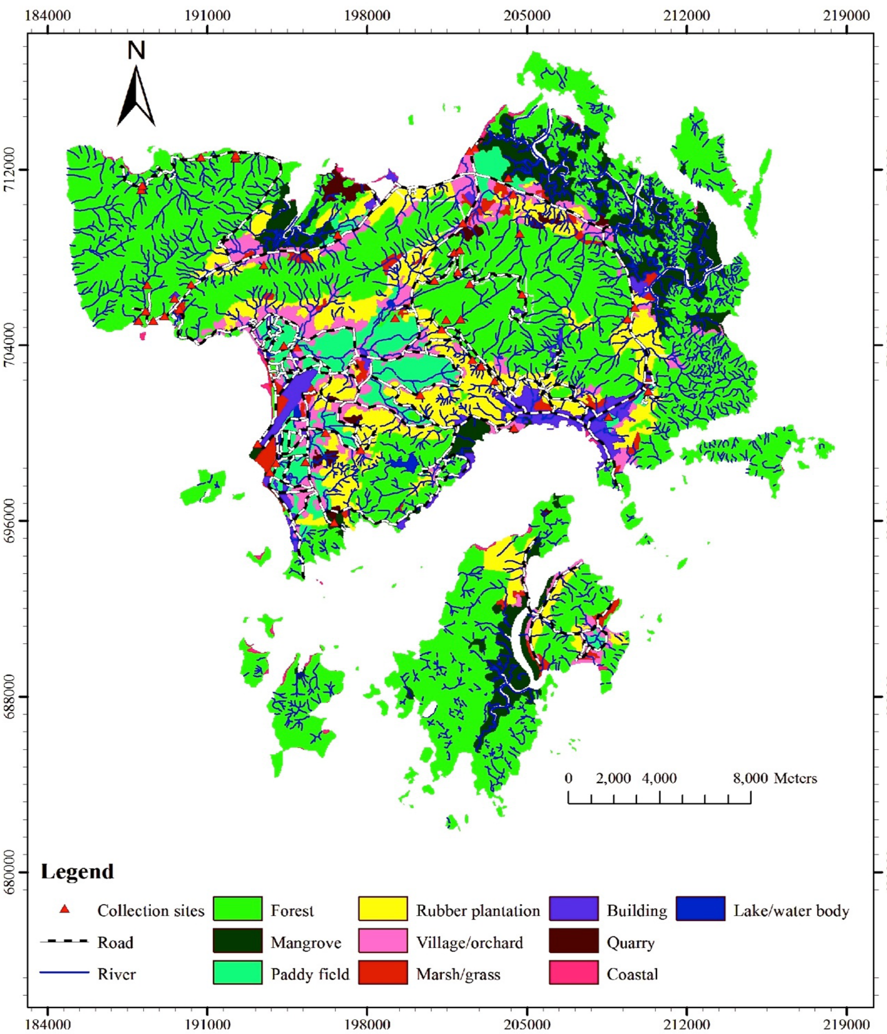

FIGURE 1. Land use map of Langkawi Island showing the 49 collection sites as indicated by red triangles

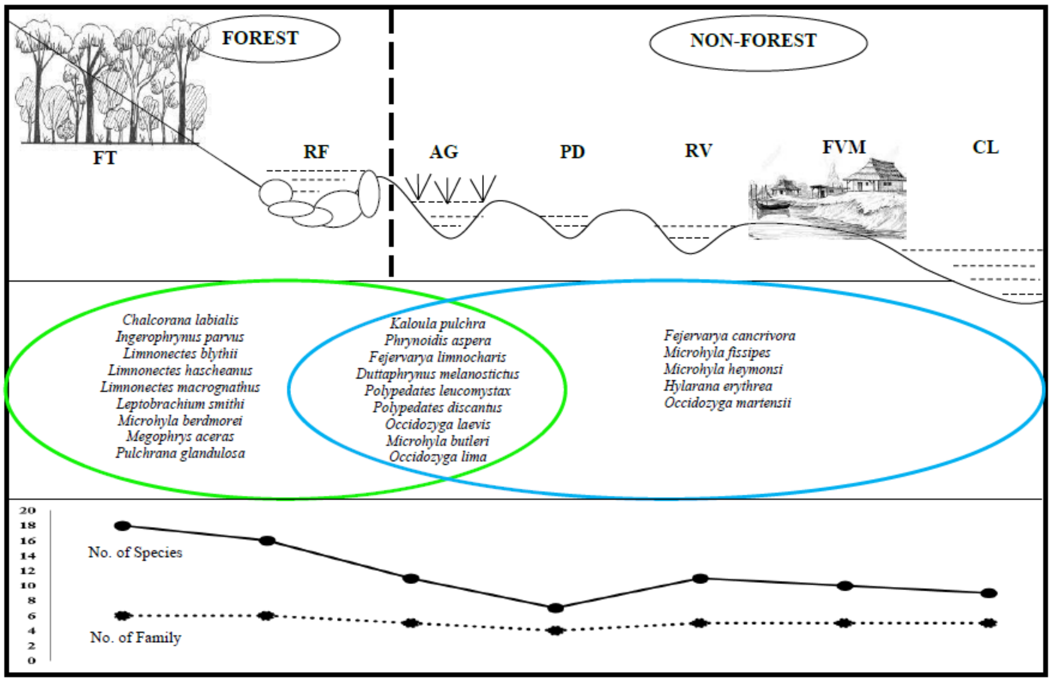

FIGURE 2. Theoretical model of anuran species distribution on Langkawi Island

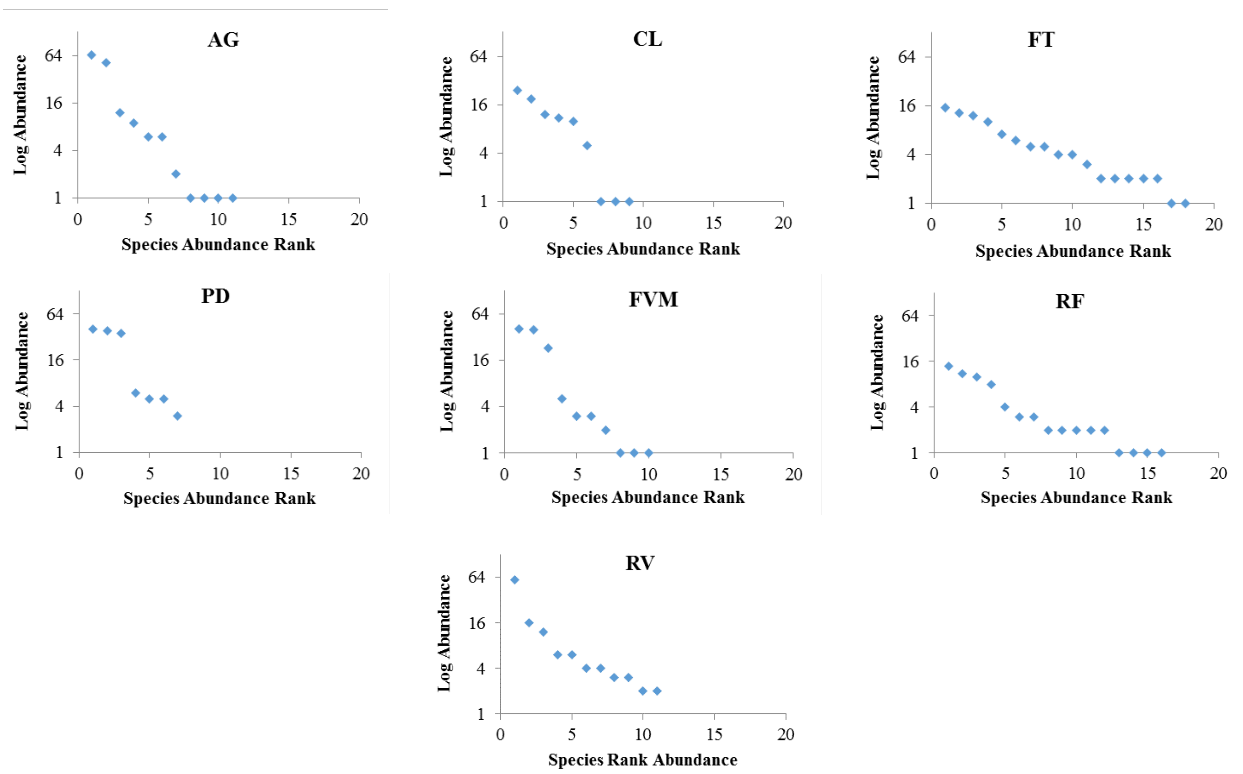

FIGURE 3. Rank abundance diagrams derived from seven habitat types. AG and FVM are represented geometric series models; FT and RF conform to log normal models; CL and PD fitted broken stick models; RV is represented log series model

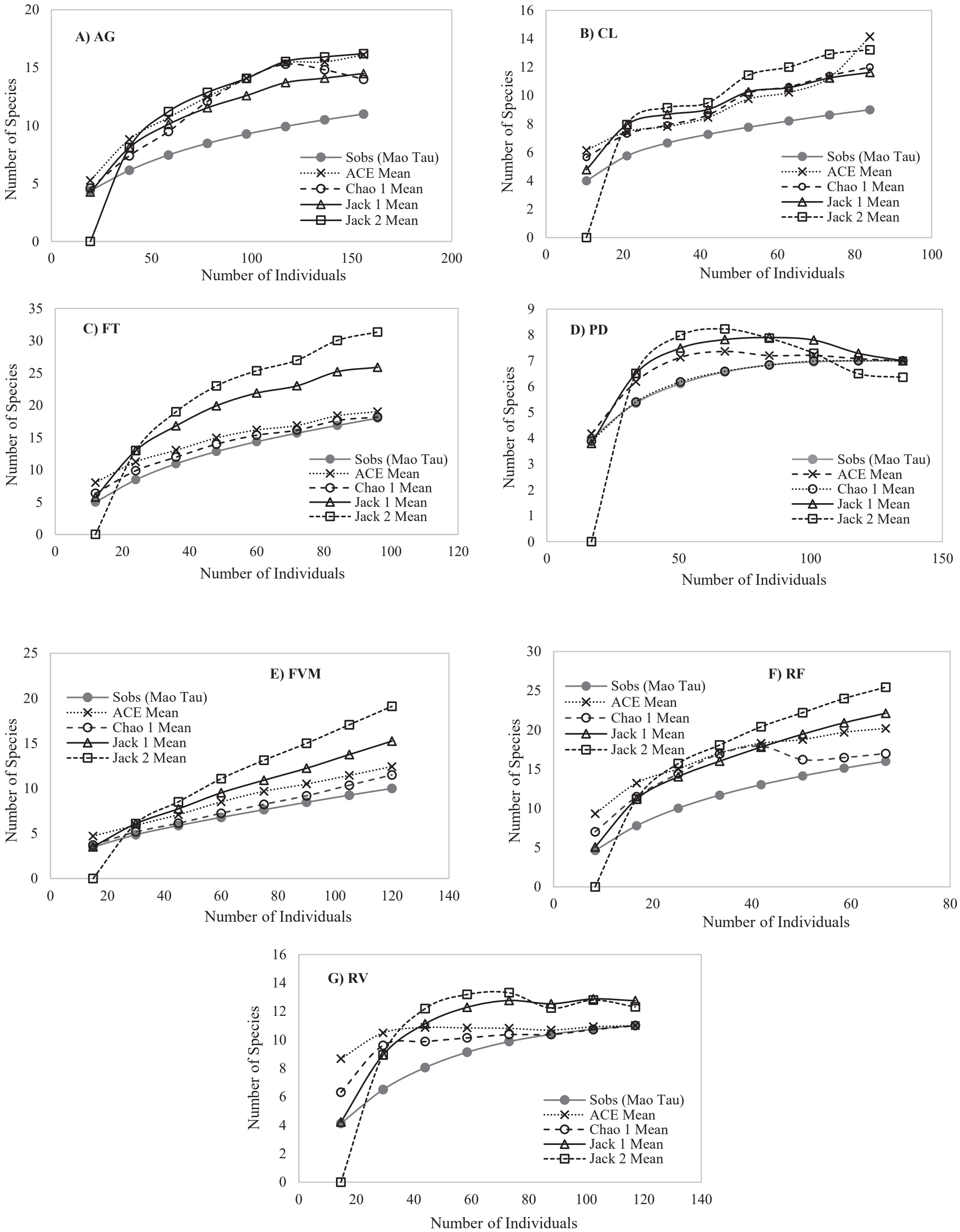

FIGURE 4. Performance of richness estimators in relation to anuran species in seven habitat types on Langkawi Island. The estimator performed varies, but Chao 1 estimator performed better in many habitat types except for CL and FVM, where Jack 1 and ACE mean estimators performed well to fit S_{obs} (Mao Tau), respectively: (a) AG=14, (b) CL=11.6, (c) FT=18.7, (d) PD=7, (e) FVM=12.4, (f) RF=17, and (g) RV=11

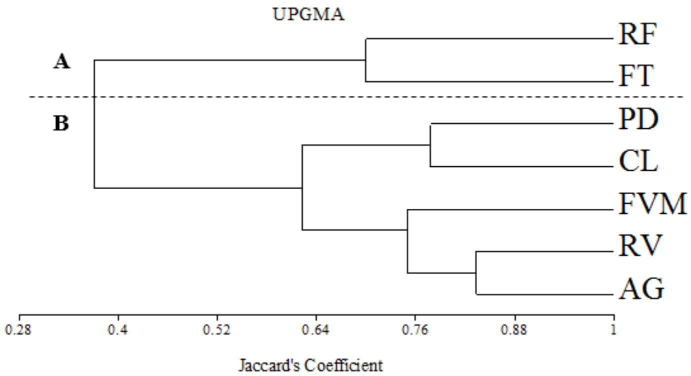

FIGURE 5. Dendrogram of Jaccard's Coefficient resulting from average linkage clustering using UPGMA method on data based on presence and absence of frog species associated with habitats

CONCLUSION

Variation in species composition and richness between these two groups of habitats were caused by differences in habitat structure. Forest species tend to live in a highly heterogeneous environment compared to other communities. This heterogeneity, in turn, enables higher biodiversity of flora and fauna. This study shows that forest habitat had quantitatively more diverse amphibian abundance compared to those of non-forest habitats. These findings are important for habitat and land use management to help conserve amphibian biodiversity on Langkawi Island, especially those rare, threatened, and specialist species.

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