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Microhabitat and Microclimate Preferences of Anuran Species Inhabiting Restoration and Adjacent Forest of Cameron Highlands, Pahang Darul Makmur, Malaysia

(Keutamaan Mikrohabitat dan Mikroklimat Spesies Anuran yang Mendiami Pemulihan dan Hutan Bersebelahan Tanah Tinggi Cameron, Pahang Darul Makmur, Malaysia)

Nadia Simon[1], Marina Mohd. Top[1,2,*], Mohd. Zaki Hamzah[3], Nor Azwady Abdul Aziz[1], Mohamad Azani Alias[3], Mohd. Ridza Awang[4], Zahari Ibrahim[4], Ahmad Fadzil Abd. Majid[4], Mohd. Syahrir Azrin Salleh[4] & Azhar Anuar[4]

[1]*Department of Biology, Faculty of Science, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor Darul Ehsan, Malaysia*
[2]*Centre of Foundation Studies for Agricultural Sciences, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor Darul Ehsan, Malaysia*
[3]*Department of Forestry Science and Biodiversity, Faculty of Forestry and Environment, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor Darul Ehsan, Malaysia*
[4]*Forestry Department of Peninsular Malaysia, Jalan Sultan Salahuddin, 50660 Kuala Lumpur, Federal Territory, Malaysia*

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ABSTRACT

The conversion of forests to agricultural farmland modifies lands into small patches, making amphibians more susceptible to external environmental changes. It is important to restore the forest ecosystem so that fauna species, especially anurans, could gradually recover and help create a balanced ecosystem in the restoration process. The aims of this study are to determine diversity, richness, and evenness of the anuran species, and to investigate the relationship of the anuran species with environmental variables of restoration areas and adjacent forests of Terla Forest Reserve (FR), Cameron Highlands, Pahang. The study recorded 14 species belonging to six families with higher species diversity, whereby the Shannon Wiener (H') value in the adjacent forest (H' = 1.71) was higher as compared to the restoration area (H' = 0.77). The anuran species in the restoration area showed an adaptation to bare soil, herbs, and shrubs. Meanwhile, in the forest, forest litter was favoured by the anuran species. Species abundance demonstrated correlation towards microclimate. The adaption of two species to the restoration area showed that temperature had a significant and negative correlation with *Duttaphrynus melanostictus*; relative humidity was significant and positively correlated with *Polypedates leucomystax*; while relative humidity had a significant and negative correlation with *Microhyla annectens*, a forest specialist. A deeper understanding of environmental factors that affect the presence of anurans, especially in restoration areas, can facilitate forest management in evaluating the effectiveness of forest restoration in this region.

Keywords: Agriculture; amphibian; biodiversity; highland; species richness

ABSTRAK

Penukaran hutan menjadi ladang pertanian mengubah tanah kepada kawasan kecil mengakibatkan amfibia lebih bergantung pada perubahan persekitaran luaran. Pemulihan ekosistem hutan adalah penting supaya spesies fauna, terutamanya spesies anura, akan pulih secara beransur-ansur, menggalakkan kawasan restorasi dan membantu mewujudkan ekosistem yang seimbang dalam proses pemulihan. Tujuan kajian ini adalah untuk menentukan kepelbagaian, kekayaan dan keserataan spesies serta menyelidiki hubungan spesies anura dengan pemboleh ubah persekitaran di kawasan restorasi dan hutan berhampiran iaitu di Hutan Simpan Terla, Tanah Tinggi Cameron, Pahang. Kajian merekodkan 14 spesies anura yang terdiri daripada enam famili dengan kepelbagaian spesies, Shannon-Wiener (H') yang lebih tinggi di kawasan hutan berdekatan (H' = 1.71) berbanding kawasan restorasi (H' = 0.77). Spesies anura di kawasan restorasi menunjukkan adaptasi terhadap kawasan tanah kosong dan tumbuhan semak sementara di hutan, sesampah hutan disukai oleh spesies anura. Kelimpahan spesies menunjukkan korelasi terhadap mikroiklim. Dua spesies yang beradaptasi terhadap kawasan restorasi menunjukkan suhu berkorelasi negatif dan signifikan terhadap *Duttaphrynus melanostictus*; kelembapan relatif berkolerasi positif dan signifikan terhadap *Polypedates leucomystax*; sementara kelembapan relatif berkolerasi negatif yang signifikan terhadap spesies hutan, *Microhyla annectens*. Pemahaman yang lebih mendalam mengenai faktor persekitaran yang mempengaruhi kehadiran spesies anura, terutama di kawasan restorasi akan memudahkan pengurusan hutan dalam menilai keberkesanan pemulihan hutan di wilayah ini.

Kata kunci: Amfibia; kekayaan spesies; kepelbagaian biologi; pertanian; tanah tinggi

Introduction

The mountainous regions in Peninsular Malaysia are composed of jagged, hilly, and steep slopes. This complex topography has added a compelling component to the upland system, making this region high in herpetofaunal diversity and endemism (Chan & Grismer 2021; Chan et al. 2019, 2014, 2009; Grismer et al. 2010, 2004; Matsui et al. 2009; Norhayati et al. 2011; Sumarli et al. 2015). The variety of topography also contributes to different kinds of environment, such as water bodies that serve as essential habitats and breeding sites for amphibians (Shahriza et al. 2011). Early checklists by Butler (1902) and Robinson (1905) accounted for 63 amphibian species in Cameron Highlands (Lim et al. 2002). This was followed by Boulenger (1912) with a detailed monograph on the Malay Peninsula's herpetofauna, which was later revised by Smith (1930) with an addition of 21 more species of amphibians. Discoveries and revisions in taxonomy have rendered the earlier compilations of Peninsular Malaysia's amphibian fauna by Berry (1975), Chanard et al. (1999), and Manthey and Grossmann (1997) obsolete. Das and Norsham (2007) identified 93 amphibian species in their checklist (90 anurans; three caecilians). The amphibian composition of Peninsular Malaysia has been substantially altered in a revised and modified checklist, due to a number of errors and multiple discoveries, raising the total number of amphibian species in Peninsular Malaysia from 93 to 107 (Chan et al. 2010). Recently, Norhayati (2017) reported that 111 species of anurans comprising six families were recorded in Peninsular Malaysia. The six families are Bufonidae, Dicroglossidae, Megophryidae, Microhylidae, Ranidae, and Rhacophoridae.

The issue of illegal forest conversion to agricultural farmland has become a serious matter, especially in Cameron Highlands, Pahang. Land clearing is cultivated on hill gradients and isolated forests, contributing to several damages such as mudslides and landslides and leading to water pollution (Khoo 2016; Razali et al. 2018). Consequently, the soil's chemical run-off erodes into the river (Saadati et al. 2012) and threatens the faunas inhabiting the hill gradients (Barrow et al. 2005). According to Blaustein et al. (1994), nearly all amphibians and reptiles have limited home range and exist within a small landscape patch. Lands are modified into small patches due to uncontrolled agriculture, logging, and urbanisation, making the amphibians more susceptible to external environmental changes and higher exposure to extinction as compared to birds and mammals (Blaustein et al. 1994).

Anurans are significant faunas to study as direct human disturbances greatly impact them. Being a bioindicator organism, anurans play a substantial part in maintaining balance between humans and ecosystem health (Hayes et al. 2002). Anurans feed on invertebrates, so they are an important link affecting the transfer of energy between insects and other invertebrates. Moreover, anurans are sensitive to the external environment due to skin permeability and being ectothermic, meaning that they are unable to thermoregulate accurately and are susceptible to temperature and environmental humidity (Rios-López & Mitchell Aide 2007).

Several studies on anuran diversity and inventories and elevation gradients have been conducted in montane regions of Peninsular Malaysia (Chan et al. 2019; Dring 1979; Ehwan 2017; Grandison 1972; Grismer et al. 2010; Ibrahim et al. 2012; Lim et al. 2002; Norhayati et al. 2011 & Sumarli et al. 2015). Other studies focused on amphibian species composition and richness in logged forests and regenerating logged forests (Izam et al. 2016), a green corridor in oil palm plantations to nearby oil palm plantations without a green corridor (Ehwan 2011), and anuran species diversity in non-forest and forest sites (Noor Bahiah et al. 2019). However, monitoring anuran diversity after restoration in Cameron Highlands is yet to be explored. Therefore, the study on anuran assemblage inhabiting restoration sites and adjacent forests was initiated. The first objective of this study was to compare the species richness and diversity of anurans between the restoration site and adjacent forest. The second objective was to investigate the relationship between the environmental characteristics with abundance of anurans in the restoration site and adjacent forest.

Materials and Methods

Study Area

Cameron Highlands is a district situated in the northwest of Pahang Darul Makmur, Malaysia, encompassing an area of 712.18 km^2 and is located on the mountainous range of Titiwangsa between 4°20'N to 4°37'N and 101°20'E to 101°36'E. The average temperature recorded in Tanah Rata, Cameron Highlands is 18 °C with a mean minimum temperature of 15 °C and a mean maximum temperature of 22 °C. Total annual rainfall in Cameron Highlands ranges from 2000 mm to more than 3000 mm (Chan et al. 2006; Kumaran & Ainuddin 2006; Leong 2006).

Study Site

Terla Forest Reserve (FR) is one of the restoration areas listed under the 'Restoration, Rehabilitation, and Reclamation (3RSM)' programme in Cameron Highlands. Cameron Highlands is among the focused areas affected by floods in 2014. Therefore, the Forestry Department of Peninsular Malaysia initiated a restoration programme, which was included in the Eleventh Malaysia Plan 2016 - 2020 with an estimated area of 1800 ha. Tree planting activities in these study sites have been steadfastly conducted from October 2017 until 2019, marking two successful years of the programme. Anuran surveys were carried out in the lower montane forest between the elevation of 1200-1500 m. a.s.l near Terla Forest Reserve, which was divided into Terla A (04°35'36.6" N, 101°22'54.7" E) and Terla B (04°34'42.1" N, 101°22'30.5" E) blocks (Figure 1). Each

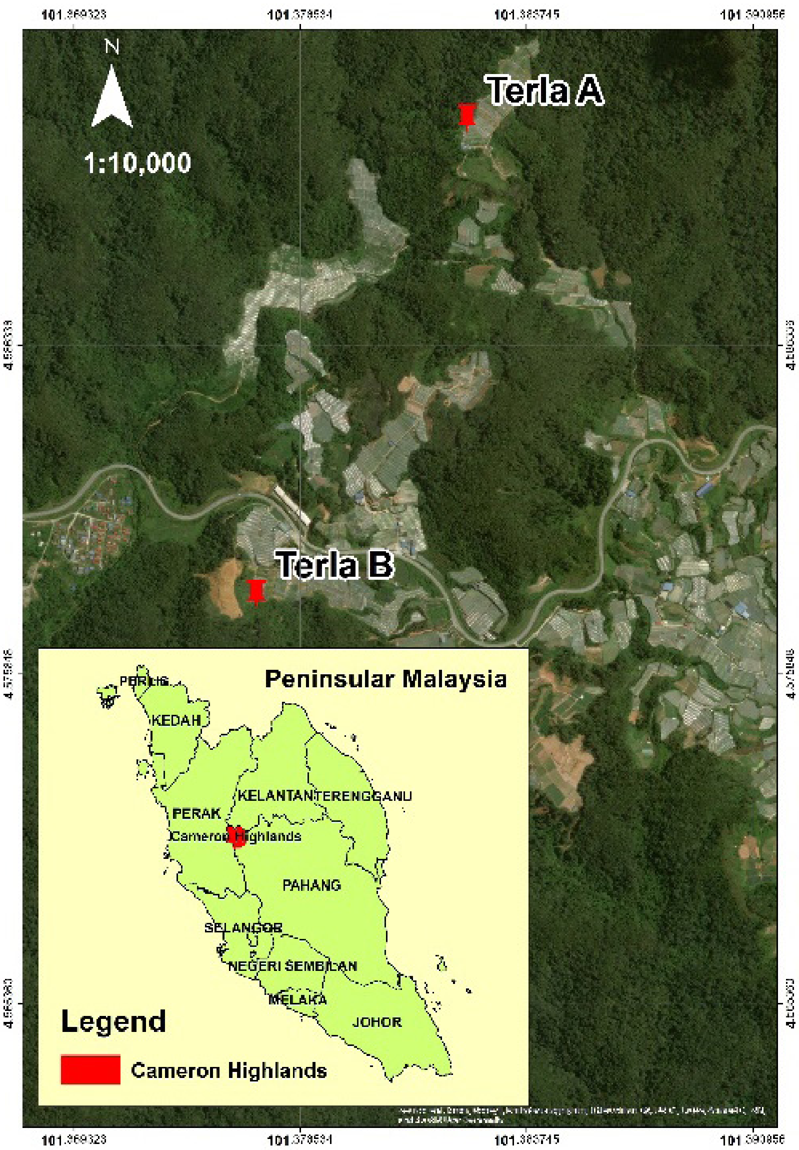


FIGURE 1. The location of study area, Cameron Highlands, Pahang Darul Makmur, Malaysia

study site included two types of habitats: Restoration area and adjacent forest. The Forestry Department reclaimed the encroached area and planted indigenous tree species, such as *Shorea platiclados* (Meranti Bukit), *S. acuminata* (Meranti Rambai Daun), *Hopea odorata* (Merawan Siput Jantan), *Exbucklandia populnea* (Gerok), *Casuarina* sp. (Rhu Bukit), and *Michelia champaca* (Cempaka). The adjacent forest, which is a secondary forest, serves as a reference ecosystem for model planning of ecological restoration projects, thus accommodating the evaluation of the project later (SER 2004). Terla FR is located at an altitudinal range of 1200-1500 m. a.s.l with an area of 1,926.70 ha (Haziq Syahmi 2018). The forest is dominated by Dipterocarpaceae, Lauraceae, and Myrtaceae. According to Haziq Syahmi (2018), trees from families of Clusiaceae and Lauraceae were commonly found in the forest of Cameron Highlands. The sampling site was chosen according to the availability of water bodies observed in the area since water sources are an important factor required by anurans to complete their life cycle (Heard et al. 2008). Therefore, availability of water bodies in the sampling sites directly contributed to the presence of anurans within the plots and transect boundaries.

ANURAN SAMPLING

The surveys were carried out in two study sites for four nights per month, starting from June 2018 till February 2019. The duration of the study was three to four hours per day from 2000 h until 0000 h. Each census was carried out at night as most anurans are nocturnal and reportedly seen more at night than during the day (Marsh & Pearman 1997). This nocturnal sampling required a five man-effort assisted with a handheld torchlight to increase anuran detection during sampling. The sampling methods included permanent quadrats, transects, Visual Encounter Survey (VES), and Call Survey. A total of ten permanent quadrats measuring 25 m × 25 m were set up at the restoration area. Besides, 400 m nocturnal transects were used to survey anurans in the forest streams and forest trails. Some transects were unconnected due to safety precautions and restricted access. Visual Encounter Survey (VES) (Crump & Scott 1994) and Call Survey (Zimmerman 1994) aided the sampling search to be conducted in high potential areas within quadrats and transects. The search was also deferred while a specimen was being captured. Each ecological data, such as locality, time and date of capture, microhabitat, and microclimate, were documented in a survey form. Every anuran species was kept till the next morning for species identification. Identification included physical measurement of the anuran, snout-vent length (SVL), which was the line from the tip of the snout to the vent, and tibia length (TL), i.e. the distance from the outer surface of the knee to the heel (Watters et al. 2016) by using a vernier calliper. The anuran samples were weighed with a weighing scale (PESOLA Weighing Scale). The photographs of each anuran including dorsal, ventral, and side views were taken using Sony Cyber-Shot Camera model DSC-W810 for identification. Subsequently, confirmation of identification was referred to Berry (1975) and Norhayati (2017). Captured anurans were marked using a paint mark or a nail polish at their tibia and released at the point of capture of each recorded transect or plot. The paint mark is a temporary dye commonly used in mark-recapture studies because the dye does not affect or harm behaviour of the studied organism (Faruk et al. 2013; Muhammad Faris et al. 2016; Nietfeld et al. 1994).

ENVIRONMENTAL VARIABLES

The microhabitats are categorised into three groups, which are horizontal position, vertical position, and substrate position. Horizontal position (H) was defined as the distance of anurans captured from the water body; 0.0 - 0.5 m; 0.6 - 1.0 m; 1.1 - 1.5 m; 1.5 - 2.0 m; > 2.1 m. Vertical position (V) was a position occupied by anurans on a subsurface (exposed ground), such as bare soil, leaf litter, grass, rock, and shrubs at 1 - 7 m from the ground. Substrate (S) was defined as the surface area utilised by anurans by perching on at the time of capture, such as the leaf of plants, stems of herbaceous plants, stem of shrubs or trees, and banks of mud, sand, or gravel (Inger et al. 2000; Zainudin et al. 2017). The vegetation types, i.e. shrub, herb, fern, moss, exposed leaf litter, and bare ground, were assessed by estimating the percentage using six cover classes: 1 = 0% - 5%, 2 = 5% - 25%, 3 = 25% - 50%, 4 = 50% - 75%, 5 = 75% - 95%, and 6 = 95% - 100% (Coulloudon et al. 1999). Two microclimate variables, namely temperature and relative humidity were included. These variables were taken at the capture point using an anemometer (Extech Meter for Humidity, Temperature, Airflow, and Light Level 45179).

DATA ANALYSIS

To estimate the number of species expected to be present in a random sample of individuals taken from any given collection (Hsieh & Li 1998), rarefaction curve was generated by using a sample-based rarefaction method on EstimateS Win Version 8.20 (Colwell et al. 2012). All diversity indices were analysed using MVSP Version 3.22 to conduct the Shannon-Wiener Diversity Index (H’). The Shannon-Wiener analysis was used to measure the species diversity in a community, while species evenness (E) was calculated using Simpson’s Index assuming if individuals in a community were dominated by one species or evenly distributed. Additionally, Simpson’s Index (D) was employed to determine abundance of dominant species in a community. Canonical Correspondence Analysis (CCA) was conducted using Paleontological Statistics (PAST) Version 3.22 to determine the relationship between anuran species and environmental variables (horizontal position, vertical position, substrate position, and vegetation percentage cover). As for microclimate, Spearman's Correlation, a non-parametric approach, was performed to investigate microclimate variables' associations with anuran abundance. Spearman's Correlation determined the strength and direction of the monotonic relationship of two variables rather than a linear relationship. This statistical method was done using SPSS Version 22.

RESULTS AND DISCUSSION

A total of 14 species from six families were recorded in two habitats of Terla Forest Reserve, Cameron Highlands (Figure 2 & Table 1). Specifically, three species in the restoration site and 13 species in the

FIGURE 2. Anuran species recorded from six families (A) *Duttaphrynus melanostictus*, (B) *Fejervarya cancrivora*, (C) *Fejervarya limnocharis*, (D) *Limnonectes deinodon*, (E) *Limnonectes malesianus*, (F) *Limnonectes nitidus*, (G) *Pulchrana banjarana*, (H) *Microhyla annectens*, (I) *Odorrana hosii*, (J) *Xenophrys longipes*, (K) *Philautus larutensis* (L) *Polypedates leucomystax*, (M) *Rhacophorus rhodopus* and (N) *Rhacophorus prominanus*

forest area, whereby two species were shared among two habitats, and 11 species were unique to one habitat. The most abundant species among the shared habitat was *Polypedates leucomystax* (Four-lined Frog), while the unique species, *Duttaphrynus melanostictus* (Asian Toad), was the highest catch only in the restoration site. The individual-based species accumulation curve of observed species richness in the forest habitat (Figure 3) was incomplete because the curves produced did not achieve an asymptote point. An asymptote point explains total species richness in the study area (Heyer et al. 1994). Increasing pattern of the curve showed that most of anuran species had been discovered in the forest due to restoration. A complete wholesome sampling was not possible due to habitat heterogeneity in the forest, which greatly affected species distribution since different species had different habitat requirements (Loehle et al. 2005; Rosenzweig 1995). To achieve sampling completeness, an increase in individual sampling or area is needed as more new species can be obtained in a habitat (Gotelli & Colwell 2001).

The forest area of Terla FR showed a higher anuran species diversity (H' = 1.71), while species diversity was lower in the restoration area (H' = 0.77). The greater microhabitats might be a significant and important criterion on the anurans' assemblages, especially for their shelter, prey diversity, and survival (Gillespie et al. 2015). However, species evenness in the restoration site (E = 0.72) was higher than in the forest area (E = 0.42). The Simpson's Dominance Index (D) indicated a higher value in the restoration site (0.49). This situation was probably due to species dominance of anuran, namely *Duttaphrynus melanostictus* (56.0%). The species was often observed to inhabit non-forest areas (Nur Johana et al. 2016), suggesting the ability of *D. melanostictus* to withstand high disturbance in the habitat.

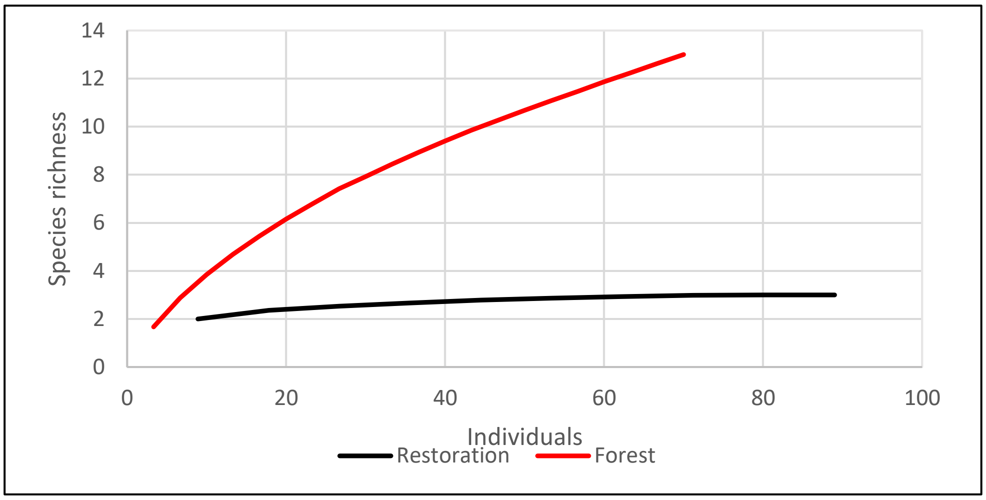


FIGURE 3. Individual-based rarefaction curve of anuran in restoration and forest of Terla Forest Reserve, Cameron Highlands, Pahang

The CCA analysis produced two sets of data components between anuran species and horizontal position. Axis 1 accounted for 76.0% of the horizontal position and was strongly associated ($p < 0.05$) with *Polypedates leucomystax* and *D. melanostictus* (Figure 4(a)). *Polypedates leucomystax* and *D. melanostictus* were associated with a distance of H = 0.0 – 0.5 m and H = 1.6 - 2.0 m from the water body, respectively. The majority of amphibians required water as a primary habitat to avoid desiccation or predation and a majority were sampled in proximity to water sources (Thorpe et al. 2018). The presence of *P. leucomystax* and *D. melanostictus* close to water bodies might be related to their breeding period. *D. melanostictus* was reported to breed in slow-moving water (Hawkeswood & Sommung 2017). This species breeds throughout the year as long as there is water nearby (Yap 2015). Ehwan (2011) stated that *P. leucomystax* selects a distance of 1.1 - 2.0 m away from the water body. This species requires water sources for its breeding phase. According to Zweifel (1998), some arboreal species will produce a foam nest while mating and builds it above water sources, so the tadpoles fall into the water once hatched (Zweifel 1998). Although these species are adaptable to disturbed habitats, water

TABLE 1. List of anurans in two habitats of Terla Forest Reserve, Cameron Highlands

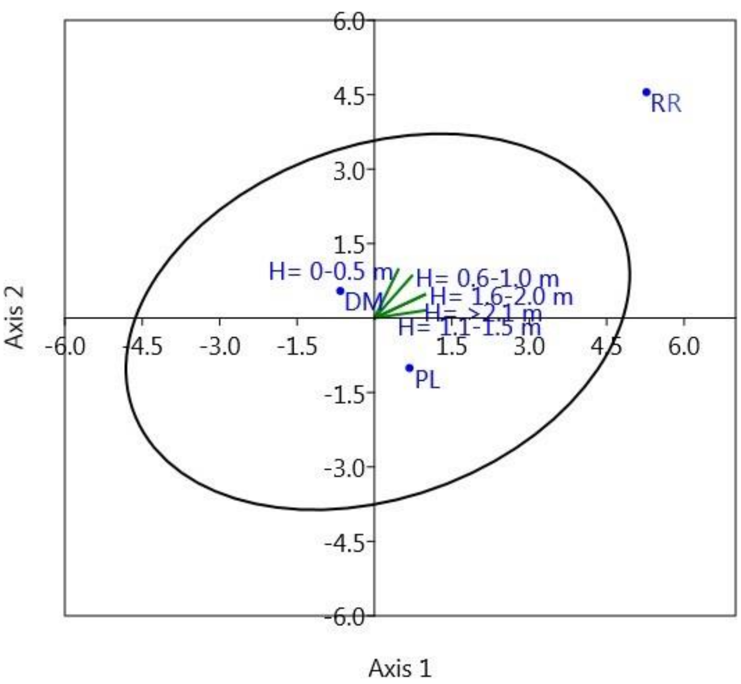
No.	Taxa	Habitat		IUCN 2020	WCA 2010
		Restoration	Forest		
	Bufonidae				
1	*Duttaphrynus melanostictus*	52		LC	NP
	Dicroglossidae				
2	*Fejervarya cancrivora*		1	LC	NP
3	*Fejervarya limnocharis*		1	LC	NP
4	*Limnonectes deinodon*		1	LC	NP
5	*Limnonectes malesianus*		1	NT	P
6	*Limnonectes nitidus*		5	EN	P
	Megophryidae				
7	*Xenophrys longipes*		5	NT	P
	Microhylidae				
8	*Microhyla annectens*		6	VU	NP
	Ranidae				
9	*Odorrana hosii*		1	LC	P
10	*Pulchrana banjarana*		9	NT	P
	Rhacophoridae				
11	*Philautus larutensis*		1	LC	NP
12	*Polypedates leucomystax*	39	1	LC	NP
13	*Rhacophorus rhodopus*	2	37	LC	NP
14	*Rhacophorus prominanus*		2	LC	P
	Total individual	93	71		
	Total species	3	13		

IUCN = International Union for Conservation of Nature; WCA = Wildlife Conservation Act 2010; LC = Least Concern; NT = Near Threatened; EN = Endangered; VU = Vulnerable; NP = Not Protected; P = Protected

is important for hydration, especially in an exposed area (Rittenhouse et al. 2008). The CCA analysis (Figure 4(c)) showed that Axis 1 accounted for about 56.0% of the variation of species diversity in the vertical position in the habitat and was strongly correlated ($p < 0.05$) with *D. melanostictus* and *P. leucomystax*. *Duttaphrynus melanostictus* and *P. leucomystax* were grouped into Vertical (V) = Grass (GR) and Vertical (V) = Bare Soil (BS), while *M. annectens* was seen towards Vertical (V) = Leaf Litter (LL). The vertical position chosen by *D. melanostictus* and *P. leucomystax*, which depicted bare soil and grass, was supported by Ehwan (2011), whereby *D. melanostictus* was recorded more at the bare soil, whereas *P. leucomystax* was reported on shrubs or seedlings and blended well with the grassy area for cover (Ehwan 2011; Malkmus 2002). Additionally, abundance of these species in bare soil and grass might be attributed to their diet. *Duttaphrynus melanostictus* was reported to feed on insects such as gnats (Cecidomyiidae) as they are constantly found on the ground (Yap 2015). On the other hand, ants, and termites were found to be a dominant diet in *P. leucomystax* (Yap 2015). Yap (2015) explained that termites consumed by *P. leucomystax* as a diet were mainly soldiers as this species usually encounters termite trails. Some anuran species tend to inhabit habitats associated with forest litter and vegetation substrate (Inger & Stuebing 2005). *Microhyla annectens* prefers a leaf litter microhabitat that may provide important habitat characteristics to the species. Similarly, plethodontid salamanders in the Blue Ridge Mountains require leaf litter for foraging activity and retaining skin moisture (Ash 1997). This suggests that leaf litter may increase soil moisture and shade, keeping *M. annectens* active especially at low temperature and high air humidity (Rittenhouse et al. 2008). The CCA analysis including substrate variables with an anuran species explained

74.0% of the species richness variation among habitats in Axis 1 (Figure 4(e)). The association between the anuran species and substrates was significant ($p < 0.05$). The study showed that only *P. leucomystax* was associated with Substrate (S) = Stems of herbaceous (STHB) and Substrate (S) = Stems of shrubs (STSR). However, the species was also found to prefer the leaf of plants as a substrate (Ehwan 2011). According to Yap (2015), the species was frequently reported in tall vegetations. Noor Bahiah et al. (2019) reported that *P. leucomystax* was abundant in non-forest habitats associated with dead vegetations and shrubs. The association between species abundance and vegetation may be related to support provided by the plants to the species. Moreover, an increase in high plant diversity is shown to affect the anuran abundance in an area. In the CCA analysis, vegetation percentage cover was explained as 69.0% with anuran species richness and was significant ($p < 0.05$) as shown in (Figure 4(g)). *Duttaphrynus melanostictus* was associated with C2 = S and C2 = H, *P. leucomystax* tended to select C5 = F, followed by *M. annectens* preferring C5 = L, and *Rhacophorus rhodopus* was reflected towards C5 = H microhabitat. The occurrence of *D. melanostictus* in 5% - 25% of shrubs and herbs coverage was consistent with the findings reported by Ehwan (2011), whereby this species was frequently reported in bare soil with lesser vegetation coverage. The association of *P. leucomystax* to 75% - 95% of fern coverage was supported by Noor Bahiah et al. (2019), whereby this species inhabited a habitat with vegetation. This study also showed that *M. annectens* preferred 75% - 95% of forest litter, which might provide this species with a conducive habitat and moisture to avoid desiccation (Nuzzo & Mierzwa 2000). Another arboreal species, *R. rhodopus*, was noticed to select 75% - 95% of herbaceous coverage. Based on the site observation, this species was regularly sighted on a leaf of the genus *Zingiber*. Iangrai (2008) supported this finding, whereby *R. rhodopus* required higher herbaceous cover for their habitat and constructed their foam nest underneath herbaceous leaves for their breeding sites.

a)



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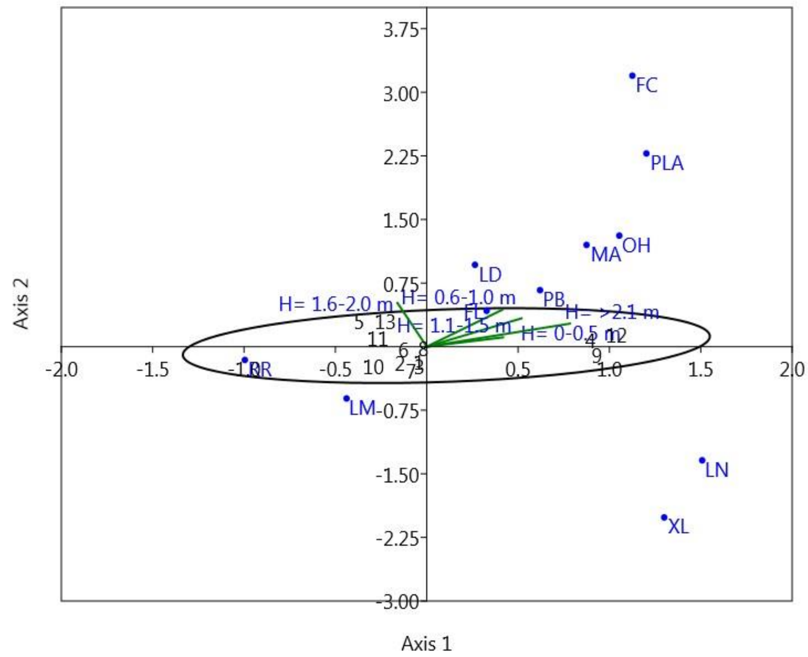
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H= 0.6-1.0 m
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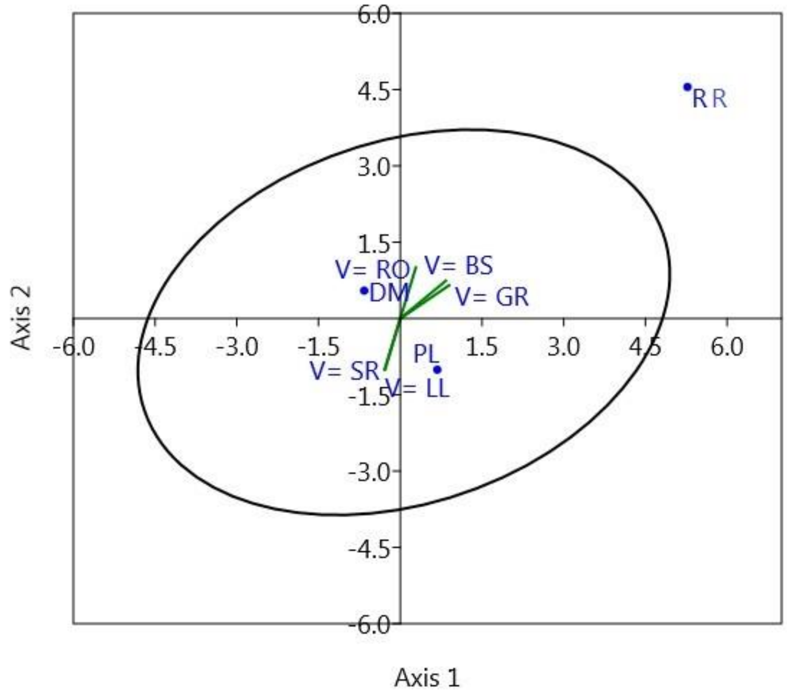
c)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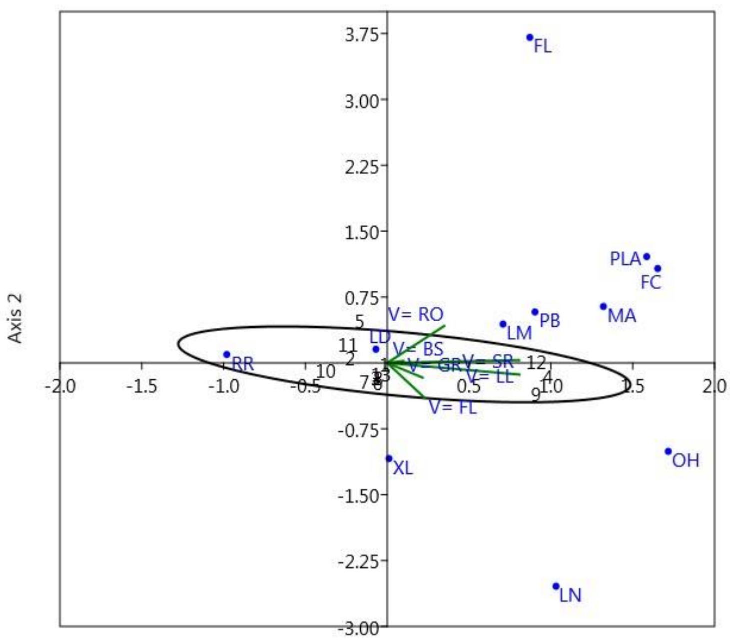
Axis 2
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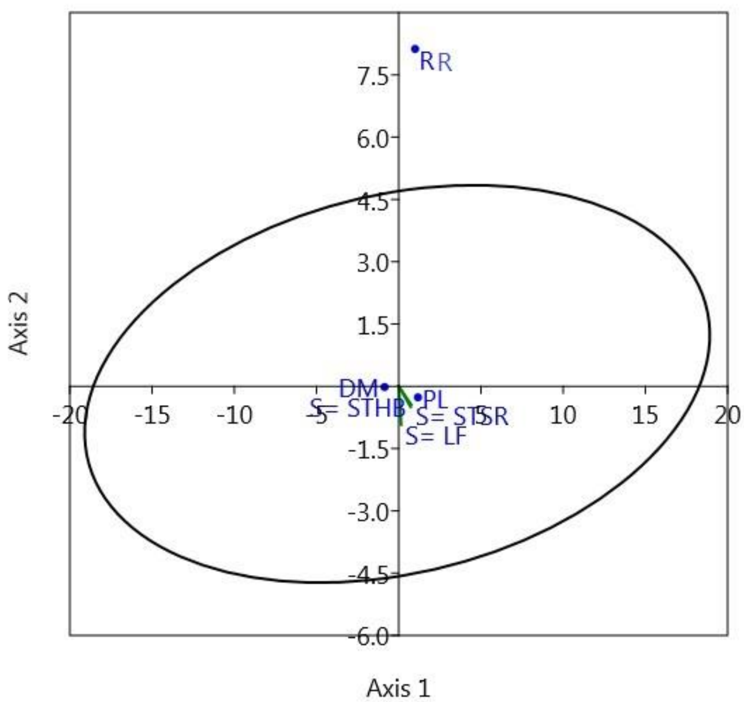
e)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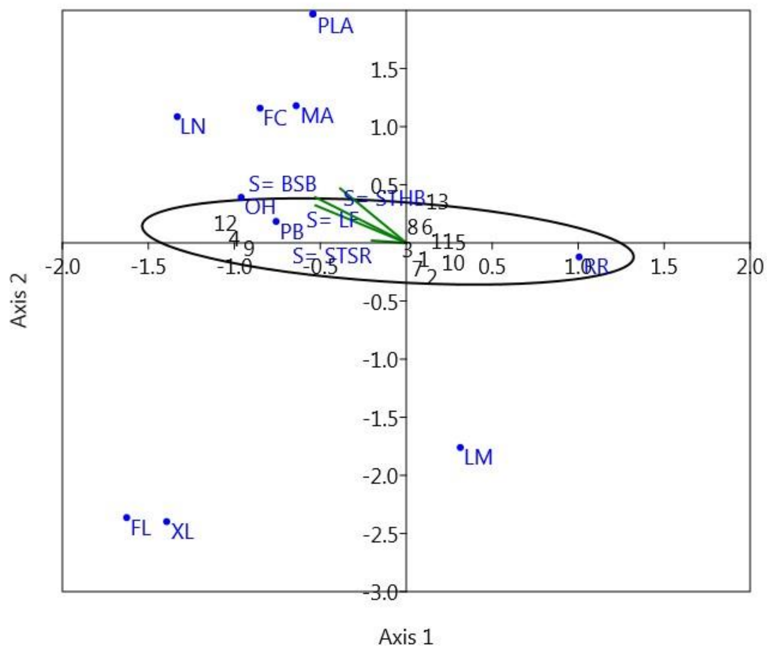
f)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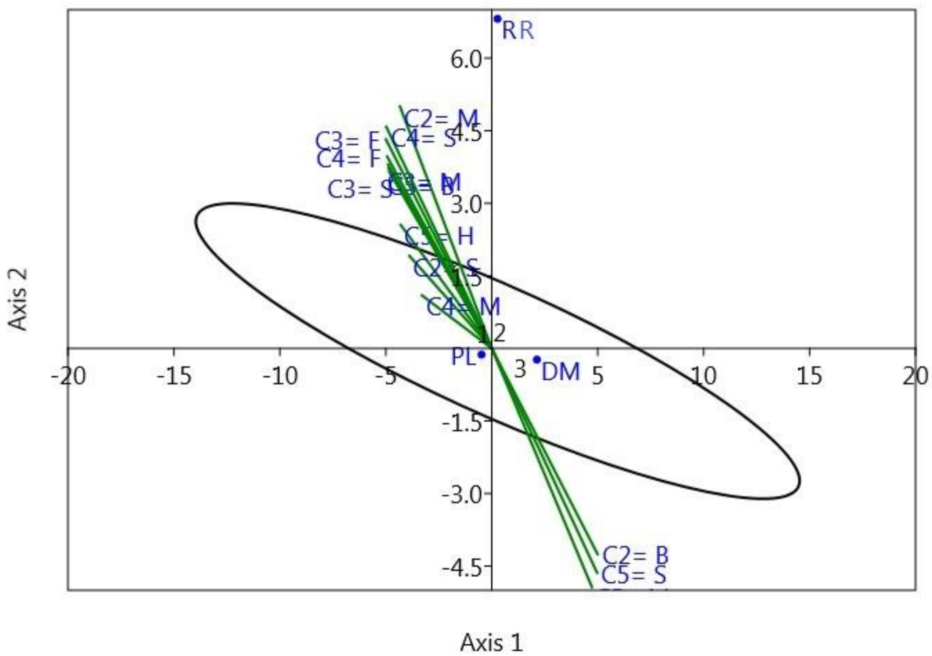
g)


RR
C2= M
C3= F
C4= S
C4= F
C3= S
C1= H
C4= M
PL
DM
C2= B
C5= S
Axis 1
Axis 2

h)

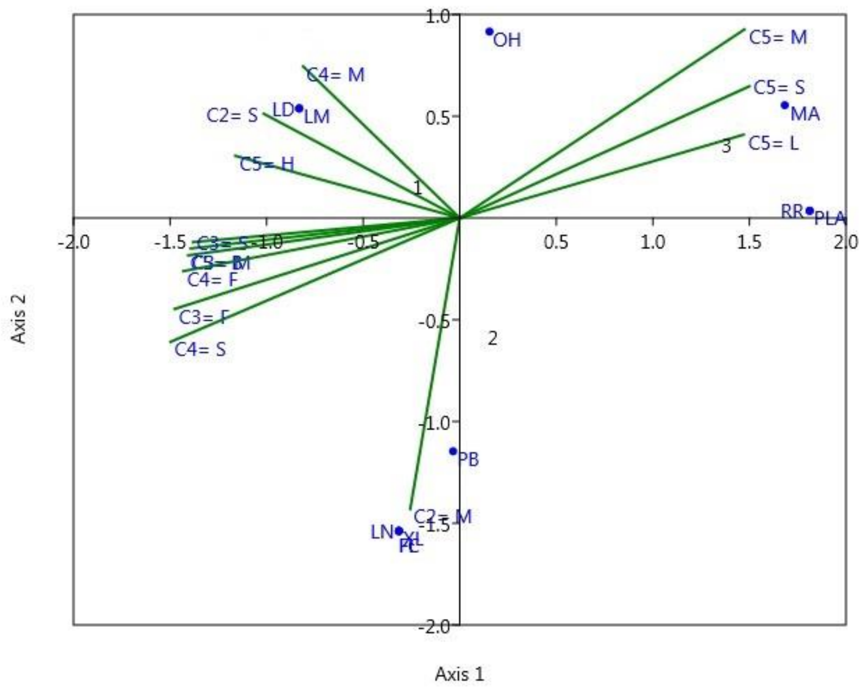


FIGURE 4. Canonical Correspondence Analysis (CCA) for microhabitats in restoration site and forest area. (a),(b) Horizontal position denote as (H); 0.0-0.5 m; 0.6-1.0 m; 1.1-1.5 m; 1.6-2.0 m; > 2.1 m; (c),(d) Vertical position denote as (V); Bare soil (BS); Leaf litter (LL); Grass (GR); On Rock (RO); On Shrub (1-7 m) (SR); (e), (f) Substrate position denote as (S); Leaf of plant (LF); Stem of herbaceous plant (STHB); Stem of shrubs/tree (STSB); Bank of mud/sand/gravel (BSB); (g),(h) Vegetation percentage cover denote in Class (C1-C6) in each of vegetation type Shrub (S); Herbaceous (H); Ferns (F); Forest litter (L); Bare ground (B); Moss (M); C1= 0-5%; C2= 5-25%; C3= 25-50%; C4= 50-75%; C5= 75-95%; C6= 95-100%; Species; *Duttaphrynus melanostictus* (DM); *Fejervarya cancrivora* (FC); *Fejervarya limnocharis* (FL); *Limnonectes deinodon* (LD); *Limnonectes malesianus* (LM); *Limnonectes nitidus* (LN); *Xenophrys longipes* (XL); *Microhyla annectens* (MA); *Odorrana hosii* (OH); *Pulchrana banjarana* (PB); *Philautus larutensis* (PLA); *Polypedates luecomystax* (PL); *Rhacophorus rhodopus* (RR); *Rhacophorus prominanus* (RP)

Microclimatic conditions for each habitat were shown to have a slight variation from June 2018 until February 2019. Two microclimates were represented by temperature and relative humidity. The mean temperature was highest in the forest area (20.9 °C) and slightly lower in the restoration site (20.7 °C). Similarly, the mean relative humidity was highest in the forest area (83.2%) and lowest in the restoration site (80.1%). Spearman's correlation analysis was conducted on anuran abundance with microclimatic variables (Table 2). The correlation showed that *D. melanostictus* (r_s (50) = -0.652, p = 0.000) and *P. leucomystax* (r_s (36) = -0.591, p = 0.000) had strong negative correlations and were statistically significant with temperature. Amphibians are ectothermic species, and their performances are greatly influenced by temperature. These species are known to tolerate some degree of habitat modification, such as in the restoration site. The restoration site observed tended to be drier and warmer in daylight due to large, exposed areas and lesser canopy shades. However, the species richness seemed higher at night to a microhabitat with water bodies such as rain puddles and man-made pools. According to Smith et al. (1999), microhabitats, climatic, and habitat combinations might serve as an ecological physiological requirement such as protection from climatic extremes. Álvarez and Nicieza (2002) reported that low temperature influenced the developmental rates of anuran.

However, only *P. leucomystax* was found to have a significantly strong positive association with relative *humidity* (r_s (36) = 0.512, p = 0.001). Besides, the endemic montane species, *M. annectens*, had a strong negative correlation to relative humidity (r_s (4) = -0.928, p = 0.008) in the forest. Kati et al. (2007) concluded that relative humidity is an important factor in anuran composition and abundance. In this study, *P. leucomystax* was classified as a generalist species because this species was found in restoration sites and forest areas (lowland to highland). *Polypedates leucomystax*, or an arboreal species, was often sighted perching on vegetation such as herbaceous and shrubs in the restoration site, suggesting that this microhabitat preference was adapted to avoid desiccation. Furthermore, this species' distribution and breeding phase coincided with rainfall, where temperature and humidity were high (Iangrai 2008). Besides, the humidity level could be a strong predictor of amphibian richness although in the same biomes or small geographical range (da Silva et al. 2012). On the other hand, *M. annectens*, a montane specialist, was only recorded in the montane forest, and thus listed as 'Vulnerable' by the International Union for Conservation of Nature (IUCN) Red List (IUCN 2019). Amphibians are less tolerant to drier climates and require higher humidity than reptiles or other vertebrates (Ludwig 1945). The inverse correlation of *M. annectens* showed that this species was adapted to relatively lower humidity. This species tended to select leaf litter or leaf of plant microhabitat in the forest. In this study, *M. annectens* was found in the forest are about 200 m from the restoration area. The habitat where *M. annectens* was collected had a sparse tree canopy structure. The microhabitat was considered near to the restoration area where the level of humidity was lower as compared to a location deep into the forest due to the canopy structure. This species was observed on the surface of leaves as this might be an adaptation to provide a longer hydration period by sitting on leaves and during foraging activities (Nuzzo & Mierza 2000). This may differ from other studies on anuran species, whereby humidity in the forest is highly correlated with the distance from the forest and forest structure. For example, *Hyla arenicolor* (Canyon Tree Frog) has a large bladder that is resistant to cutaneous evaporative water loss. The large bladder helps this species to reabsorb water and promotes *H. arenicolor* to stay moist and carry out foraging activities (Snyder & Hammerson 1993). Anurans may use specific behavioural habitat selections and physiological adaptations to lower hydration and thermoregulation (Tingley et al. 2012), making this species endemic and inhabiting only on the upland to survive.

TABLE 2. Spearman Correlation Analysis between anuran abundance to microclimate variables in restoration site and forest area where * p< 0.05. Eight species including *Fejervarya cancrivora*, *F. limnocharis*, *Limnonectes deinodon*, *L. malesianus*, *Odorrana hosii*, *Polypedates leucomystax* (one recorded in the forest), *Philautus larutensis*, and *Rhacophorus prominanus* were excluded from the analysis due to lower number of individuals

Taxa	Temperature (°C)	*p*-value	Relative humidity (%)	*p*-value	Habitat
Duttaphrynus melanostictus	-0.652*	.000	0.068	.632	Restoration
Limnonectes nitidus	0.051	.935	-0.051	.935	Forest
Microhyla annectens	0.116	.827	-0.928*	.008	Forest
Pulchrana banjarana	0.134	.730	0.067	.864	Forest
Polypedates leucomystax	-0.591*	.000	0.512*	.001	Restoration
Rhacophorus rhodopus	-0.110	.529	0.123	.481	Forest
Xenophrys longipes	-0.700	.188	0.300	.624	Forest

Conclusions

Environmental parameters are known to affect the abundance and species richness at restoration areas and adjacent forest habitats, and can be separated into three groups: microhabitat, vegetation percentage cover, and microclimate. From the study, it was shown that anurans preferred a particular microhabitat position in an area. As such, especially in the horizontal position, it was noted that anurans were highly dependent on water bodies in both habitats. The number of individuals for the vertical position was higher in bare soil at the restoration area, while leaf litter was a preferred microhabitat in the forest. The stems of shrubs or trees were greatly selected substrate spots in the restoration area. Whereas in the forest, anurans tended to choose the leaves of plants as a substrate. However, anurans were highly accommodating in 75% - 95% of herbaceous, shrubs, and forest litter coverage in both habitats. Additionally, temperature and relative humidity were important microclimatic parameters that strongly correlated towards anuran assemblage in the study. These additional factors are essential to understand the anuran species' adaptations, especially in comparatively lesser microhabitats, vegetation cover, and often drastic microclimatic changes in a habitat. In accordance with these findings, restoration areas have great potential in providing more anuran species, particularly with the help of proper restoration management to increase habitat heterogeneity and aid in recolonisation. Therefore, a deeper understanding of environmental factors that affect the presence of anurans, especially in restoration areas, will facilitate forest management in evaluating the effectiveness of forest restoration in this region.

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*Corresponding author; email: marinamohd@upm.edu.my