

## Temporal variation of amphibians on Gunung Raya, Pulau Langkawi, Kedah, Peninsular Malaysia

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**Abstract:** Seasonal factors have been shown to affect the abundance and diversity of amphibians. However, an intensive study on the interactions of seasonal factors, such as precipitation, temperature, relative humidity, and solar radiation, is lacking in an insular island habitat. Therefore, this study was conducted to investigate temporal habitat use based on relative abundance and identify the monthly variation of habitat parameters governing species richness. A passive sampling technique was used to record the presence of amphibians by using two types of traps: the drift-fenced pitfall trap and the PVC pipe trap. Samplings were conducted from February 2014 until January 2015 on Gunung Raya, Pulau Langkawi, Kedah. A total of 100 individuals from six species were recorded. Correlation analysis revealed that the average monthly rainfall and relative humidity were positively correlated with amphibian richness, while temperature showed a negative correlation. High abundance and species richness were recorded during the rainy season between May and December 2014. The results showed that amphibians favoured rainy season over the dry season.

**Keywords:** Anura, mountain, island, species diversity, tropical rainforest

### INTRODUCTION

Ecological changes that occur within a particular time, such as daily, monthly, and yearly, can dynamically change the abundance of a specific population in a habitat. The population will eventually be stabilised by the life cycle, niches, dispersion, and persistence that drive them in high-density areas (Ackerly 2003). The sharp decline in biodiversity caused by habitat loss calls for increased efforts to manage habitats to keep them suitable for wildlife (Fahrig 2003). In order to assist conservation managers, scientists need to understand the spatio-temporal variation of habitat availability and use for the animals of interest.

Proper management of habitats should sustain local populations. However, it is often impossible to delineate habitat patches that might support independent demographic populations. There are many other factors at play, including colonisation-extinction events of individual habitat patches (Baguette and Mennechez 2004), size of habitat patches (Franken and Hik 2004), or patchiness of distribution between different species (Harrison 1991). Moreover, the temporal relationship between species in a community is affected by the natural variability inherent in many amphibian populations (Kevin 2000; Peterken and Game 1984).

Temperature and rainfall are two significant factors in climatic variability in determining the presence of amphibian species in a particular habitat (Owen 1989). The rainy season can influence the abiotic and biotic factors in the environment (Pereira *et al.* 2020; van de Sande *et al.* 2017), which subsequently provide a suitable microclimate to

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encourage the presence and emergence of amphibians in the habitat. There is a distinct dry season, particularly along the Thai-Malay Peninsula. As a result of the same climatic patterns, the type of plants in the forests of Peninsular Malaysia are similar to those in the Southern Thai and Burmese forests (Raffae 2003). During the dry season, most of the dipterocarp leaves will turn yellowish or reddish before shedding within a few weeks in January and February. The total rainfall collected during this period is usually less than 100 mm per month. Many small intermittent streams and ponds will dry out, and the soil dries up and hardens. Water becomes scarce, resulting in the congregation of amphibians at the few remaining water bodies.

Water is vital to amphibians, as they spend various stages of their life cycles living in or near water. According to Crump (1989), water is essential for breeding and larval development processes. Most of the water sources at high elevations comes from precipitation. Bickford *et al.* (2010) stated that water scarcity could have adverse effects on the amphibians' breeding and life cycle. It is known that low rainfall and extended drought can cause high mortality of tadpoles and eggs (Donnelly and Crump 1998). Common prolonged breeders, such as *Microhyla heymonsi*, are negatively affected by extended droughts due to the uncertainty of hydroperiod, which affects their metamorphosis process (Bickford *et al.* 2010). In other words, humidity plays a significant role for amphibians. A study by Giaretta *et al.* (1997) on frog distribution on forest floors revealed that humidity and litter depth were the most important parameters. However, some of the studies did not show strong evidence of humidity in influencing the distribution of amphibians (Allmon 1991; Sluys *et al.* 2007).

Amphibians react positively to wet and rainy seasons compared to dry seasons. Thus, their abundance is higher during wet season due to the massive emergence of individuals. This emergence occurs because of the optimization of environmental conditions, which fulfill each species' environmental preferences (Eterovick and Kopp 2006; Gardner *et al.* 2006). However, there is a lack of information regarding the temporal variation of amphibians in Langkawi, which would complicate any conservation effort. An understanding of the relationship between the amphibian communities and their environment on a temporal scale may provide a clear overview of the ecology of these animals. Therefore, this study was conducted to investigate habitat use in terms of relative abundance according to the months and to identify the monthly variation of habitat parameters governing species richness.

## METHODS AND MATERIAL

### Sampling site

The study was conducted on Gunung Raya, Pulau Langkawi (Figure 1). Seven trails were identified in this study (Table 1), each of which represented the elevation of Gunung Raya at every 100 m. The first trail was at 68 m a.s.l., while the last was at 650 m a.s.l.

**Table 1.** The coordinate of the sampling points at different elevations of Gunung Raya, Langkawi.

No.	No. Trail	Coordinate	Elevation
1	T1	06° 21.979' N 099° 47.463'E	68
2	T2	06° 22.982' N 099°47.187'E	103
3	T3	06° 23.628' N 099° 47.698'E	237
4	T4	06° 23.739' N 099° 47.791'E	307
5	T5	06° 23.198' N 099° 47.811'E	408
6	T6	06° 22.905' N 099° 48.030'E	503
7	T7	06° 22.665' N 099° 49.278'E	657



**Figure 1.** Location of sampling sites at Gunung Raya, Langkawi.

### Sampling methods

Amphibians were surveyed passively every month along an elevational gradient of Gunung Raya for 12 months, starting from February 2014 until January 2016. Two trapping methods used, namely the drift-fenced pit-fall trap (DPT) (Figure 2a) and the PVC pipe trap (PPT) (Figure 2b). All DPTs were examined every day for ten days during the monthly survey. The days to check the traps were chosen randomly by using a random number table. Meanwhile, all PPTs were examined twice a month, on the 1<sup>st</sup> and the 15<sup>th</sup> day of the month.



**Figure 2.** Drift-fenced Pitfall Trap (DPT) **a)** and PVC Pipe Trap (PPT) **b)** that used to trap amphibians during the sampling at Gunung Raya, Pulau Langkawi.

Amphibians caught in the traps were placed into individual cotton or plastic bags to prevent injury and desiccation. Amphibian taxonomy followed Frost et al. (2021), Che *et al.* (2007) and the Amphibian Species of the World 5.3 by the American Museum of Natural History (<http://research.amnh.org/herpetology/amphibia/>), last accessed on 5 June 2009. Specimens were deposited at Universiti Kebangsaan Malaysia Herpetological Collection, Faculty of Science and Technology, UKM at Bangi, Selangor and at the Zoological Museum, Langkawi Research Centre (PPL LESTARI), UKM at Langkawi, Kedah.

### Data analysis

PAST software (version 3.06) was used to calculate diversity measures, including the Dominance index (D), Shannon diversity index ( $H'$ ), and the Evenness index (E). Species accumulation curves were generated by the software EstimateS (version 9.1.0). To identify the similarity composition in two different habitats, Jaccard's Similarity index, J, was chosen because it stands out as one of the most useful and widely used indices of the 60 or so similarity indices for binary data (Ludwig and Reynolds, 1988; Real, 1999). Moreover, this coefficient is the most reliable because it can be interpreted quickly and logically in clustering habitat similarity compared to other coefficients. Pearson Correlation was used to test and project the relationship between abundance and species richness with a climatic parameter, such as rainfall, temperature, relative humidity, and solar radiation. The outcome of the relationship is either a positive linear or a negative one. The value of  $-1$  and  $+1$  is a perfect relationship, while 0 correlation or approaching 0 is considered as having no relationship between variables (Rodgers and Nicewander, 1988).

## RESULTS

Four environmental parameters were tested to see if there was any relationship with the abundance of amphibians: (i) average monthly rainfall (AMR), (ii) mean monthly temperature (Temp), (iii) mean monthly 24-hour relative humidity (RH), and (iv) average monthly solar radiation (SR). These four parameters were chosen to represent the temporal effects on the amphibian abundance. The correlation analysis using Pearson Correlation showed that three out of four parameters were significant ( $p < 0.05$ ), which were AMR, RH, and SR. The correlation between species abundance and AMR was positive ( $r = 0.545$ ,  $p = 0.034$ ). Meanwhile, the correlation between amphibian species abundance and temperature showed a negative correlation ( $r = -0.462$ ,  $p = 0.06$ ). The amphibians reacted inversely to temperature, as indicated by the negative correlation value. A strong positive correlation was detected between species abundance and relative humidity ( $r = 0.707$ ,  $p = 0.005$ ). SR showed a strong negative correlation with amphibian species abundance ( $r = -0.827$ ,  $p = 0.000$ ).

The variation of the abundance of amphibian species and relative humidity (RH) was shown in Table 2. The RH can be divided into two phases: a low percentage of less than 80% to indicate the dry season, and a high percentage of more than 80% to indicate the wet season. Each species has its own specific seasonal pattern. High amphibian abundance was recorded during high RH from May to December 2014. The most dominant species, *Leptobrachium smithii* ( $n = 37$ ), was recorded only from May to December 2014, following a high RH of more than 80%. *Xenophrys aceras* also occurred during these months. Rare amphibian species ranging in sample size from one to two individuals, such as *Fejervarya limnocharis*, *Ichthyophis* sp., *Ingerophrynus parvus*, and *Phrynoidis asper*, did not show any pattern or preference. Species that emerged abundantly during the rainy season were *Leptobrachium smithii*, *Limnonectes macrognathus*, *Xenophrys aceras*, *Occidozyga laevis*, and *Limnonectes hascheanus*.

**Table 2.** The relative abundance of the amphibians in Gunung Raya through the study period.

<b>Family/Species</b>	<b>Feb -14</b>	<b>Mar -14</b>	<b>Apr -14</b>	<b>May -14</b>	<b>Jun -14</b>	<b>Jul -14</b>	<b>Aug -14</b>	<b>Sept -14</b>	<b>Oct -14</b>	<b>Nov -14</b>	<b>Dec -14</b>	<b>Jan -15</b>	<b>Total</b>
<b>Ichthyophiidae</b>													
<i>Ichthyophis</i> sp.							1						1
<b>Bufo</b>													
<i>Ingerophrynus parvus</i>					1								1
<i>Phryno</i>			1	1									2
<b>Dicroglossidae</b>													
<i>Fejervarya limnocharis</i>				1									1
<i>Limnonectes macrognathus</i>					2	1			3	1	3	2	12
<i>Limnonectes hascheanus</i>				1			1	1		1	2		6
<i>Occidozyga laevis</i>					1	1	1	1		1			5
<b>Megophryidae</b>													
<i>Leptobrachium smithii</i>				2	8	6	4	3	7	5	2		37
<i>Xenophrys aceras</i>					4	5	4	4	4	1	6		28
<b>Rhacophoridae</b>													
<i>Polypedates leucomystax</i>	2		1								3	1	7
<b>Number of Individual</b>	2	0	2	5	13	15	12	9	14	9	16	3	100
<b>% Relative Abundance</b>	2	0	2	5	13	15	12	9	14	9	16	3	100
<b>Number of Species</b>	1	0	2	4	3	5	6	4	3	5	5	2	10
<b>Average Monthly Rainfall (mm)</b>	0.00	6.56	8.33	11.19	9.11	5.01	14.27	12.64	21.83	8.54	11.22	0.19	
<b>% Relative Humidity</b>	65.1	66.0	79.5	83.6	83.0	80.8	84.3	85.6	87.2	83.0	80.3	68.9	

**Table 3.** The diversity measurement of the amphibian at Gunung Raya through the study period.

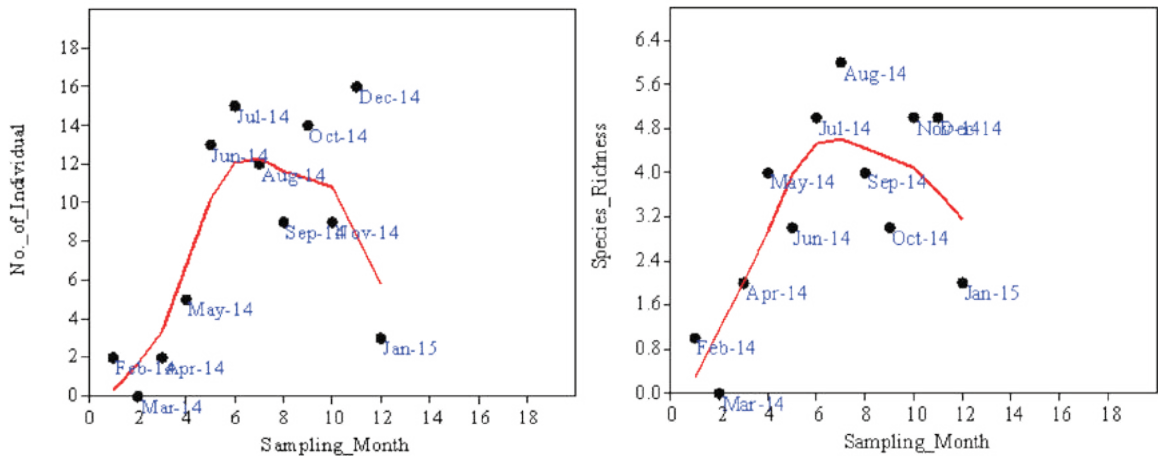
<b>Diversity Parameter</b>	<b>Feb -14</b>	<b>Mar -14</b>	<b>Apr -14</b>	<b>May -14</b>	<b>Jun -14</b>	<b>Jul -14</b>	<b>Aug -14</b>	<b>Sep -14</b>	<b>Oct -14</b>	<b>Nov -14</b>	<b>Dec -14</b>	<b>Jan -15</b>	<b>Total</b>
No. of Individual	2	0	2	5	13	15	12	9	14	9	16	3	<b>100</b>
No. of Species	1	0	2	4	3	5	6	4	3	5	5	2	<b>10</b>
Avg. Sp. Richness	1	0	2	1.91	1.58	1.75	1.83	1.76	1.67	1.75	1.83	1.68	<b>1.76</b>
Variance	0	0	0	0.08	0.25	0.19	0.14	0.18	0.22	0.19	0.14	0.22	<b>0.18</b>
Standard Error	0	0	0	0.29	0.50	0.43	0.38	0.43	0.47	0.43	0.38	0.47	<b>0.43</b>
Shannon Index (H')	0	0	0	0	0.82	1.307	1.49	1.14	1.00	1.11	1.49	0	<b>1.70</b>
Variance H'	0	0	0	0	0.02	0.01	0.02	0.03	0.01	0.07	0.00	0	<b>0.00</b>
Standard Error	0	0	0	0	0.13	0.12	0.14	0.16	0.08	0.27	0.05	0	<b>0.03</b>
95% Conf. Limit (t)	0	0	0	0	0.61	1.03	1.19	0.68	0.80	0.45	1.40	0	<b>1.62</b>
95% Conf. Limit (+)	0	0	0	0	0.94	1.45	1.64	1.28	1.09	1.56	1.57	0	<b>1.75</b>
Dominance Index, D	0	0	0	0	0.62	0.42	0.38	0.47	0.51	0.55	0.37	0	<b>0.37</b>
Variance D'	0	0	0	0	0.01	0.00	0.00	0.00	0.01	0.02	0.00	0	<b>0</b>
Species Diversity, 1/D	-	-	-	-	1.61	2.38	2.63	2.12	1.96	1.81	2.70	-	
95% Conf. Limit (-)	0	0	0	0	0.50	0.333	0.30	0.429	0.40	0.333	0.286	0	<b>0.341</b>
95% Conf. Limit (+)	0	0	0	0	0.80	0.50	0.40	0.571	0.70	0.833	0.429	0	<b>0.395</b>
<b>Average Monthly Rainfall (mm)</b>	0.00	6.56	8.33	11.19	9.11	5.01	14.27	12.64	21.83	8.54	11.22	0.19	
<b>Relative Humidity (%)</b>	65.1	66.0	79.5	83.6	83.0	80.8	84.3	85.6	87.2	83.0	80.3	68.9	-

The Shannon index of species diversity for all observations was modest, ranging from the lowest of  $0.82 \pm 0.13$  to the highest of  $1.49 \pm 0.14$  (Table 3), reflecting some degree of unevenness among species abundances. The Shannon diversity index was available for June to December 2014, during the wet season when relative humidity was more than 80%, although the onset of the rainy season was in April 2014 (RH = 79.5). However, the sample size was insufficient to calculate the Shannon index in April (n = 2) and May (n = 5). The Shannon Index values were consistent with the Dominance Index, D and Species Diversity, 1/D. Low values of the Shannon index were also consistent with high values of the Dominance Index, caused by the high abundance of *Leptobrachium smithii* in June, October, and November 2014 (Table 2).

The distributional pattern of amphibian abundance and species richness throughout the sampling period showed a ‘hump’ distribution pattern (Figure 3). At the beginning of the sampling period (dry season), the abundance of amphibians was low from February 14 to April 14. Henceforth, the abundance increased tremendously until July 14, when it decreased from August 14 until January 15.

On the other hand, the species richness was inclined at the start of the sampling period (February 14), then increased from April 14 to July 14 to form a peak, before decreasing from August 14 to January 15.

The formation of a humped-shaped pattern for amphibians was mainly influenced by seasonal changes. It was statistically proven that amphibian species are influenced by humidity which is induced by the presence of rainfall. This means that immediately after rain, the humidity will increase and stimulate the amphibians to activate their breeding mode. Thus, as breeding increases, the individual increases and more genera can be detected.



**Figure 3.** The distribution pattern of amphibian abundance (left) and species richness (right) during the sampling period at Gunung Raya by using LOESS Smoothing Analysis (smoothing parameter,  $\alpha = 0.5$ ).

## DISCUSSIONS

### Temporal variation of amphibian abundance

The Pearson Correlation test showed that three out of four parameters were significant ( $p < 0.05$ ), which were AMR, RH, and SR. The positive correlations were between species abundance and AMR ( $r = 0.545$ ,  $p = 0.034$ ) and relative humidity ( $r = 0.707$ ,  $p = 0.005$ ), while the negative correlation was with temperature ( $r = -0.462$ ,  $p = 0.06$ ).

The amphibian species were abundant primarily during the rainy season (May until December) and were less abundant during the dry season (January until April) as shown in Table 2. However, *Polypedates leucomystax* was trapped three out of the four dry months and was only trapped in once out of eight wet months. Being the only arboreal and vegetation-dwelling frog in the area may explain the occurrence of this species inside the PVC pipe traps during the dry months. Myers *et al.* (2007) reported that a PVC pipe trap was more efficient at trapping the Pacific tree frogs (*Pseudacris regilla*) in northwestern California than a ground-based trap. Vegetation-dwelling frogs are difficult to sample, but the use of PVC pipe traps mimics the natural features that frogs use for water source and in extension, shelter and breeding space (Boughton and Staiger 2000; Pittman *et al.* 2008; Trimble and van Aarde 2014). PVC pipe traps can facilitate data collection outside the breeding season as well as reduce observer and detection bias (Willson and Gibbons 2010). In this case, although capture success was low (7% of the total amphibians), *P. leucomystax* was present and was presumed to persist throughout the year, even during the dry spell.

Temperature and solar radiation were inversely correlated to the abundance of amphibians. During the dry spell, the air was warm and dry, which could cause problems with dehydration for most amphibians. Most amphibians will hide behind rocks, fallen trees, and decaying wood under leaf litter to reduce water loss from their bodies. Hence, the amphibians respond negatively to temperature and solar radiation. However, relative humidity seemed to induce a more significant response in the abundance of certain amphibian species compared with other environmental factors, such as average monthly rainfall, temperature and solar radiation. This was demonstrated by *Limnonectes macrognathus*, *Leptobrachium smithii* and *Xenophrys aceras*.

The Pearson Correlation analysis showed a strong positive relationship ( $r = 0.707$ ,  $p = 0.005$ ) between abundance and RH percentage but a weak relationship for rainfall ( $r = 0.545$ ,  $p = 0.034$ ). According to Andreone (1996), some species – especially those with direct egg development, need only high air humidity to breed at Andohalela, Madagascar. Nurulhuda *et al.* (2015) also concluded that relative humidity was the main factor related to the emergence of amphibians at Kuala Gandah, Pahang.

The results of the current study suggested that rainfall has affected the abundance of amphibians. Rainfall activates the amphibians' breeding mode and increases the abundance of adults, juveniles, tadpoles, and eggs. Studies by Shahriza *et al.* (2012a, 2012b) found a positive relationship between the amount of rain with the calling, mating activity, and egg production activities of *Ingerophrynus parvus* and *Chalcorana labialis* in Kedah. The increases in these activities indicated high amphibian abundance, which increased the probability of breeding activities during the rainy season. A study by Jensen *et al.* (2003) on the relationship between reproduction modes of the Gopher frogs (*Rana capito*) and rain in Alabama, found that the number of eggs produced was significantly related to the rainy season. A large number of eggs being mass-produced showed that the abundance of *Rana capito* was high during the rainy season as this species breeds during this season. Rainfall causes the formation of puddles and irrigates streams and ditches that become the breeding grounds for frogs (Zina and Haddad 2005).

However, a study conducted by Marsh (2000) in Barro Colorado Island, Panama, concluded that Tungara frogs (*Physalaemus pustulosus*) did not interact significantly with rainfall to begin their reproduction processes. Female Tungara frogs were not affected by changes in rainfall (precipitation rate) but were affected by other environmental cues, such as night humidity. Henzi *et al.* (1995) found that rainfall was not the main factor that led to the breeding process of Painted-reed frogs (*Hyperolius marmoratus*) in Zululand, South Africa, but rather, other environmental factors which induced the process of reproduction, such as the number of females and moisture. Other studies have shown the importance of

humidity on the abundance of amphibians. According to Fredericksen and Fredericksen (2004), many adult frogs in moist forests in Bolivia were concentrated in areas with high humidity. Similarly, Burrowes *et al.* (2004) in Puerto Rico also noted that amphibians were found in high-humidity areas, but with a shortage of water resources. The importance of these findings was related to the spread of the infectious chytrid fungus (*Batrachochytrium dendrobatidis*) which causes chytridiomycosis. According to Bosch *et al.* (2007), the fungus spread optimally during the reproductive process that occurred when relative humidity was high. Thus, management and monitoring of the environment and health status of amphibians should be intensified during the high humidity period.

### **Temporal distributional pattern of amphibians at Gunung Raya**

In this study, the physical factors that influence the temporal variation were assumed to be the same at different elevations because Gunung Raya was only 880 m a.s.l. Meanwhile, the highest study area was only 600 m a.s.l. The sampling trails did not extend up to the highest point due to several limitations, such as extreme slope (steep slope and dominated by large granite boulders) and human disturbance (the open area of highland resorts and telecommunication towers).

This study found that the species richness of amphibians was high during the rainy season (Table 3). Meanwhile, the number of individuals were significantly lower during the dry season in the current study (see Table 2 and Table 3). As described previously, the amphibians reacted positively to humidity and rainfall. This relationship was supported by the presence of a high number of species in the middle of the rainy season. The amphibian species are greatly affected by the presence of rainfall and are most abundant during the rainy season (Duellman, 1995; Schlaepfer and Gavin 2001). Watling and Donnelly (2002) studied litter frogs in Central America came to the same conclusion that amphibian abundance was highest during the rainy season (Prado *et al.* 2005). In a study conducted in Costa Rica, Schlaepfer and Gavin (2001) reported an increase in the number of amphibians during the wet season. The rain altered humidity, creating a perfect environment to seek their partner to breed and activate reproductive modes, which subsequently activated the emergence of amphibians (da Silva *et al.* 2012).

Even though amphibian abundance can be high during the rainy season, the increasing pattern do not necessarily indicate the beginning of the rainy season since the increase is not immediate. The increase in abundance only starts a month after the rainy season due to optimal relative humidity. Nurul Huda (2012) reported that the increase in several amphibians was caused by humidity, which stimulated the breeding mode of amphibians. This transitional period allowed humidity to reach the optimal stage, providing an ideal environment for the amphibians to breed. At the same time, reestablishment of intermittent water bodies occurred, which is essential to provide a suitable breeding site for the amphibians (Shahriza *et al.* 2010).

The abundance of the species also can be related to the reproduction behaviour of amphibians, which is triggered by the presence of water bodies and humidity. The needs of the species drive the amphibian to seek breeding partners during the rainy season. The mating calls, which are the breeding interaction mechanisms, become loud and heavy when the environment is humid and during a heavy rainfall (Shahriza *et al.* 2010). Thus, this is considered a suitable time to breed. In a few months, the abundance of amphibians will reach the optimum number before it decreases in the middle of the rainy season.

The decrease in abundance can also be caused by the ending of the breeding season and the beginning of tadpole development (Aichinger 1987). The adult amphibians do not nurture and watch their tadpoles. Thus, the fused egg will be developed in the nests that their parents have built. After hatching, the tadpoles will undergo metamorphoses on their

own without any help from their parents. Thus, the abundance number decreased before the end of the rainy season. Furthermore, the decrease in abundance during the rainy season could be due to flooding at the breeding habitat, causing the amphibians to avoid the area and preventing the tadpoles from being eaten by fish (Prado *et al.* 2005). Khan (1982) suggested that the breeding of amphibians in monsoon tropical forest with the presence of water was lesser during the dry season and is limited during the rainy season due to the conditions at the selected breeding sites. These implied that specific breeding phenology was related to breeding habitat, seasonal changes, or the presence of potential prey or predator.

Bufonid (e.g., *Phrynoidis asper*) and racophorid (e.g., *Polypedates leucomystax*) species were recorded during the dry season. There are several rationales to the presence of this species during the dry season. *Phrynoidis asper* is a species with warty and dry skin that has high adaptability to the dry conditions. Their affinities for the dry environment are higher compared to the other amphibian species. Furthermore, this species is less dependent on water and is usually found far from water body. Meanwhile, *Polypedates leucomystax* is a tree frog that inhabits bushes and twigs. The adult male of this species will congregate near stagnant water body and build foamy nest above the water during the breeding session (Ibrahim *et al.* 2008). This species were recorded in the water contained in one of the PVC pipe traps in this study, which described its presence during the dry season. Table 4 describes the presence of most amphibian species during the rainy season instead of the dry season.

## CONCLUSION

The results of this study showed positive correlations between species abundance with average monthly rainfall ( $r = 0.545$ ,  $p = 0.034$ ) and relative humidity ( $r = 0.707$ ,  $p = 0.005$ ), while species abundance showed negative correlation with temperature ( $r = -0.462$ ,  $p = 0.06$ ). The diversity index showed a high value during the rainy season in July, August and December, which was supported by the dominance index, which showed low values. The highest number of species was recorded in August, with six species. Amphibian abundance spiked during the rainy season – specifically during high air humidity, due to the optimum environment for breeding. Amphibians on Langkawi had to time their breeding activity to coincide with the brief periods when there is enough rain to create water bodies because of the distinctive and prolonged dry season in the island. Thus, environmental conditions of high humidity and precipitation during a specific time of the year allowed for wide niche segregation. This included not only periods of breeding activity, but also in terms of amphibian species abundance throughout the wet and dry seasons. Many terrestrial species are strictly confined to leaf litter substrate (e.g., *Xenophrys aceras* and *Leptobrachium smithii*). Other species (e.g., *Phrynoidis asper* and *Ingerophrynus parvus*) occur in permanent riparian habitat, while some (e.g., *Fejervarya limnocharis*) can be found in altered to degraded parcels as well.

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**Table 4.** The presence of amphibian species at Gunung Raya during the rainy season (May-14 until Nov-14) and dry season (Feb-14 until April-14 and Dec-14 until Jan-15).

Season / Month	Dry Season			Rainy Season			Dry Season					
	Feb -14	Mar -14	Apr -14	May -14	Jun -14	Jul -14	Aug -14	Sep -14	Oct -14	Nov -14	Dec -14	Jan -15
<b>Species</b>												
<b>Family: Ichthyopiidae</b>												
<i>Ichthyophis</i> sp.				*****			*****					
<b>Family: Bufonidae</b>												
<i>Phrynoidis asper</i>				*****								
<i>Ingerophrynus parvus</i>												
<b>Family: Dicroglossidae</b>												
<i>Fejervarya limnocharis</i>				*****	*****	*****	*****	*****	*****	*****	*****	*****
<i>Limnonectes</i>				*****	*****	*****	*****	*****	*****	*****	*****	*****
<i>macrogathus</i>				*****	*****	*****	*****	*****	*****	*****	*****	*****
<i>Limnonectes hascheanus</i>				*****	*****	*****	*****	*****	*****	*****	*****	*****
<i>Occidozyga laevis</i>				*****	*****	*****	*****	*****	*****	*****	*****	*****
<b>Family: Megophryidae</b>												
<i>Leptobrachium smithii</i>				*****	*****	*****	*****	*****	*****	*****	*****	*****
<i>Xenophrys aceras</i>				*****	*****	*****	*****	*****	*****	*****	*****	*****
<b>Family: Racophoridae</b>												
<i>Polypedates leucomystax</i>				*****	*****	*****	*****	*****	*****	*****	*****	*****
<b>Total</b>	1	0	2	4	3	5	6	4	3	5	5	2

Note: \*\*\*\*\* = presence of species

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