DISTRIBUTION MODELING OF THE *Lamproptera* SPECIES (PAPILIONIDAE: LEPTOCIRCINI) IN BORNEO

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ABSTRACT

Conservation planning and ecological research aimed to understand patterns of biological diversity have focused on determining threatened and rare species. Species distribution modelling had been increasingly used to understand the rare and endangered species distribution and their relationship with environmental factors. The aim of this study was to predict the potential distribution of *Lamproptera* butterflies across Borneo, and determine the conservation status and potential threats to their survival. Subsequent to this, species occurrence data obtained from voucher specimens of *Lamproptera* butterflies deposited in Universiti Malaysia Sarawak Insects Reference Collection (UIRC), Research Development and Innovation Division (RDID) of the Sarawak Forest Department, and Centre of Insects Systematics (CIS), Universiti Kebangsaan Malaysia, an extensive literature reviews and field sampling were documented. The occurrence data were later analyzed using Maxent software to obtain the potential distribution of the *Lamproptera* species. Majority of the high suitability area for the *Lamproptera* butterflies lie in the northwest part of Borneo. Environmental variables that affects the species distributions are temperature of annual range (Bio7), precipitation of driest month (Bio14), temperature seasonality (Bio4) and precipitation of wettest quarter (Bio16). Increasing knowledge on the status and distribution range regarding *Lamproptera* species will provided more understanding on their population dynamics and increase the effectiveness of their conservation planning.

Keywords: *Lamproptera meges, Lamproptera curius,* Species Distribution Modelling (SDM).

ABSTRAK

Perancangan pemuliharaan dan penyelidikan ekologi yang bertujuan untuk memahami corak kepelbagaian biologi sering tertumpu kepada penentuan spesies yang terancam dan langka. Model penyebaran spesies telah digunakan secara meluas bagi menentukan taburan spesies yang langka serta faktor-faktor persekitaran yang mempengaruhi mereka. Sehubungan dengan itu, kajian ini dijalankan untuk meramalkan kawasan yang berpotensi untuk didiami oleh spesies Lamproptera, menentukan status pemuliharaannya sekaligus menentukan ancaman yang menggugat kelangsungan spesies ini di Borneo. Data lokaliti spesimen diperoleh dari

Bahagian Rujukan Serangga Universiti Malaysia Sarawak (UIRC), Bahagian Pembangunan dan Inovasi Penyelidikan (RDID) Jabatan Hutan Sarawak dan Pusat Serangga Sistematik (CIS), Universiti Kebangsaan Malaysia, kajian literatur yang menyeluruh dan kajian lapangan telah didokumentasi. Data tersebut kemudiannya dianalisis di dalam perisian MaxEnt bagi memperoleh kawasaan yang berpotensi didiami oleh spesies Lamproptera. Kebanyakan kawasan yang mempunyai kesesuaian yang tinggi dan berpotensi untuk didiami oleh spesies *Lamproptera* terletak di bahagian barat laut Borneo. Pembolehubah persekitaran yang mempengaruhi distribusi spesies adalah suhu tahunan (Bio7), bulan paling kering (Bio14), suhu musim panas (Bio4) dan kadar hujan pada musim paling lembap (Bio16). Peningkatan pengetahuan tentang status dan jarak taburan spesies *Lamproptera* dapat meningkatkan kefahaman tentang dinamik populasi spesies ini serta meningkatkan keberkesanan perancangan pemuliharaannya.

Kata Kunci: *Lamproptera meges*, *Lamproptera curius*, Model Taburan Spesies (SDM).

INTRODUCTION

One of the greatest concerns in biodiversity management and conservation is the scarcity of comprehensive information regarding a species distribution (Nazeri et al. 2012). Besides detailed knowledge on species natural history and biology, understanding and distinguishing their habitat preference as well as their basic habitat requirements had become the top priority in any decision-making and action plan (Nazeri et al. 2012; Papeş & Gaubert 2007). Hence, scientists had established a suitable model known as species distribution model (SDM), to be used in the determination of suitable habitat for the threatened species.

The knowledge of potential distribution is relevance to many disciplines and has been applied in various fields including biodiversity, conservation and ecology studies (Boria et al. 2014; Warren & Seifert 2011). Although species-environmental relationship analysis has always received a spotlight in ecology and biogeography (Guisan & Zimmerman 2000), its usage for rare species usually represented by species with small distribution range size and higher habitat specificity has seldom been assayed especially for most insects (Tsoar et al. 2007). Accurate incidence data are rarely available especially for rare species and species with inaccessible locations (Navarro-Cerrillo et al. 2011).

Ecological niche modeling (ENM) or SDM methods, practically used the presence-only records (Anderson et al. 2003; Elith et al. 2006) while the major source of the occurrence data is a networking of museum collections (Graham et al. 2004). There is a vast amount of information in museums, natural history collections as well as in the literature could be gathered for species distribution study. Unfortunately, the reliability of those information in distribution modelling has often been questioned due to several limitations associated with data from these resources such as vague description of the specimen locality which results in poor locational accuracy when geocoded (Newbold 2010).

On the other hand, records of observed species occurrence only provide information on a subset of sites occupied by a species (Rondinini et al. 2006) without information on sites that may be colonized in the future (Hoegh- Guldberg et al. 2008). However, both museums and observed records are important for making robust conservation management decision especially for poorly known species because for some species, these are the only available data. Usually, poorly known species are represented by low numbers of museum records (Papeş & Gaubert 2007). Robust conservation management can be achieved by incorporating prediction of species occurrences from environmental suitability models that combine biological records from various resources with spatial environment data.

The members genus *Lamproptera* are among fascinating butterflies in the family Papilionidae as they are much smaller in size and possess a unique distinctive characteristic, such as transparent forewings and a very long tail in the hindwings (Hoskins 2002). This genus comprised of only two recognized species, which are *Lamproptera curius* Fabricus (1787) (White Dragontail) and *Lamproptera meges* Zinken (1831) (Green Dragontail) (Otsuka 2001). They are also known as dragontails butterflies due to their flying habits that resemble dragonflies when circling low for a drinking spot (Larsen 2004). Currently, our knowledge on distributions, area of occupancy and population trends of *Lamproptera* species in Borneo are still lacking and insufficient. In order to guarantee the sustainability of the *Lamproptera* butterflies as well as to overcome the Wallacean shortfall, an adequate information on their habitat preferences are required. The current identified distribution range of the *Lamproptera* butterflies are South Asia and Southeast Asia. Despite being known to exist in Borneo, available literature on their distribution within this region are still lacking. The only reference for *Lamproptera* distribution in Borneo was by Otsuka (2001). Thus, this study aimed identifying the possible potential distribution of *Lamproptera* butterflies in Borneo, being one of the uncommon and rarely encountered species within the family Papilionidae with a very low representation as voucher specimens in museum collections.

MATERIALS AND METHODS

Historical Distribution

Voucher specimens of *Lamproptera* species deposited at the UNIMAS Insect Reference Collection (UIRC), Universiti Malaysia Sarawak, Research Development and Innovation Division (RDID) of the Sarawak Forest Department, and Centre of Insects Systematics (CIS), Universiti Kebangsaan Malaysia were studied where the locality data and ecological habitats gathered from the specimen collectors label were documented. The locality data of specimens collected were reviewed and geocoded using Google Earth in order to obtain geographic coordinate. Specimens without adequate information of georeferenced localities were excluded from the analysis and multiple specimens with similar locality were geocoded only once. The data compiled from extensive literature surveys of entomological papers, publications, unpublished species list and previous studies were also used as a mean of references of the distribution and the locality of the species studied.

Current Distribution

Current distribution data for *Lamproptera* species were obtained from field surveys at all potential locations selected based on the historical presence of the *Lamproptera* species. The presence of *Lamproptera* species foraging and puddling in the surveyed area was also recorded. In order to increase the sampling effort, two methods, which are transect counts or Pollard walk were combined with active sampling. Occasionally the species were collected for further research. Transect routes were established at each site. Sightings of *Lamproptera* species were counted during surveys along transects of approximately 100 m long and 5 m wide, following the standard protocol of Pollard & Yates (1993). A habitat plot of 10 by 10 m was established randomly along each transect. Environmental and habitat parameters such as elevation, temperature, average height of the vegetation (cm), soil and land cover were measured and recorded in the plot. The geographic coordinate for each locality was obtained using Global Positioning System (GPS) unit and by geocoding the localities using Google Earth.

Species Distribution Modeling

A habitat analysis consisting of three key environmental variables, which are elevation, precipitation and temperature were used. The worldclim dataset was developed from the data collection, and used to develop the Ecological Niche Model (ENM) describing the contemporary and historic distribution of the *Lamproptera* butterflies. A presence only modeling technique was used, in part to account for difficulty of detecting *Lamproptera* butterflies. MaxEnt software version 3.3.3k was used to accurately estimate the ENM by using species presents and environmental variables as it can effectively predict the ENM accurately from minimum five occurrence records. The presence-only methodology implemented in MaxEnt increases the possibility of comparing the historic, current and future predictions. The maximum entropy ENM technique was used to analyse historic and current data in order to describe the past, present and future distribution of *Lamproptera* species and next model the distribution of the environmental variables (Table 1) as extracted from occurrence localities over geographic space. The approach then compared the distribution to a null distribution of those environmental variables over the same geographic space using a set of background points, referred to as pseudo-absence. Models significance and validation estimates can be approximated. The Habitat Suitability Index (HSI) per pixel was calculated in MaxEnt, where a value of '0' represent unsuitable habitat and a value of '1' represented completely suitable habitat. The results were projected into QGIS software to determine the potential distribution of the species.

Table 1. A list of environmental variables used in the study

Code	Environmental variables	Unit
Bio1	Annual Mean Temperature	°C
Bio2	Mean Diurnal Range (Mean of monthly (max. temp. – min. temp.))	°C
Bio3	Isothermality ((Bio2/Bio7)x 100)	-
Bio4	Temperature Seasonality (standard deviation x100)	°C
Bio5	Max. Temperature of Warmest Month	°C
Bio6	Min. Temperature of Coldest Month	°C
Bio7	Temperature Annual Range (Bio5-Bio6)	°C
Bio8	Mean Temperature of Wettest Quarter	°C
Bio9	Mean Temperature of Driest Quarter	°C
Bio10	Mean Temperature of Warmest Quarter	°C
Bio11	Mean Temperature of Coldest Quarter	°C
Bio12	Annual Precipitation	mm
Bio13	Precipitation of Wettest Month	mm
Bio14	Precipitation of Driest Month	mm
Bio15	Precipitation Seasonality (Coefficient of Variation)	-
Bio16	Precipitation of Wettest Quarter	mm
Bio17	Precipitation of Driest Quarter	mm
Bio18	Precipitation of Warmest Quarter	mm
Bio19	Precipitation of Coldest Quarter	mm
Borneo alt.	Altitude or elevation of Borneo island	m

RESULTS AND DISCUSSIONS

A total of 223 occurrence was successfully recorded for two *Lamproptera* species representing 80 unique locations were compiled where the occurrence of these butterflies are not overlap in each location. Out of that, 42 occurrences were represented by the White Dragontail (*Lamproptera curius*) and the remaining 38 occurrences were represented by the Green Dragontail (*Lamproptera meges*).

The models of both species in this study, reveal that *L. curius* and *L. meges* have different potential areas of distributions, which are coastline areas (Figure 1) and highland areas (Figure 2), respectively despite both having a high probability to occur in the northwest part of Borneo. The different potential distribution areas of the *Lamproptera* species is due to species preference and requirements, as Hernandez et al. (2006) stated that every species has its own habitat requirement and occurs in a specific place. The range of environmental conditions tolerated by a species might be the limitation factor in modelling the distribution of a rare species with a narrow range of habitat specificity (Buechling & Tobalske 2011). As these species are often habitat specialist, there is only limited number of sites of known occurrence. The paucity of known occurrence data of rare species, available for model calibration and fitting will become the limiting factor in the distribution modelling (Manel et al. 2001).

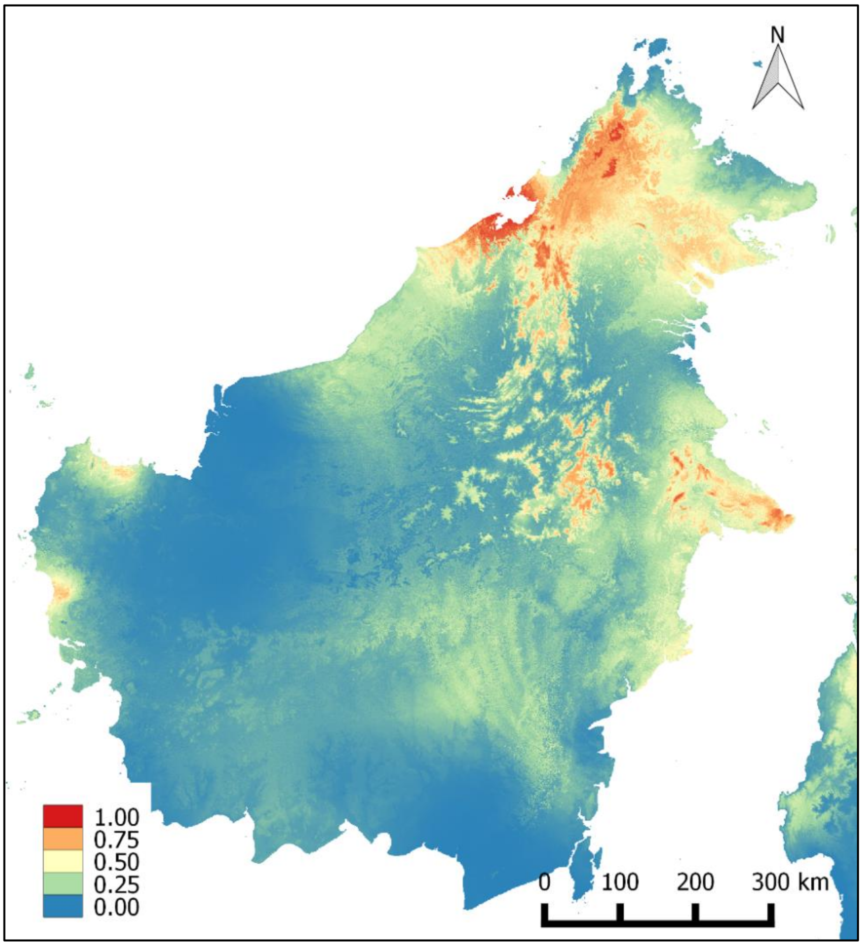

Figure 1. Predictive distribution map for *Lamproptera curius*

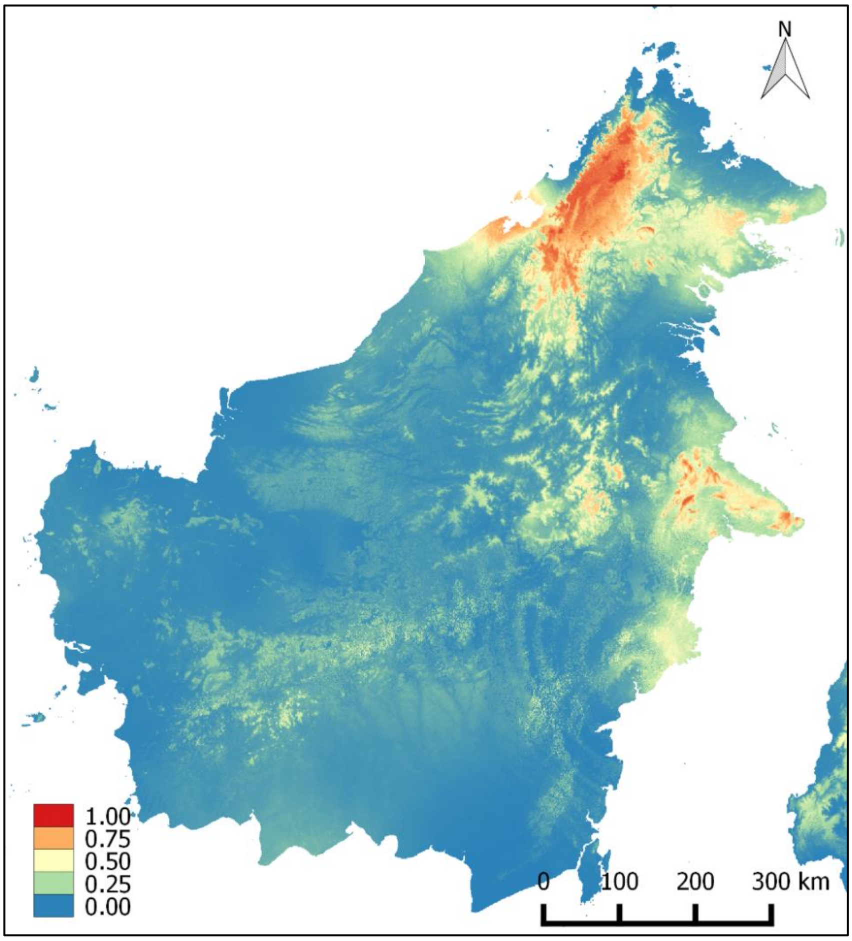

Figure 2. Predictive distribution map for *Lamproptera meges*

Ecological and evolutionary history of a species often affect its area of distribution (Brown et al. 1996; Gaston 2003). The most significant factors affecting distributional areas of a species include: 1) the limits of species tolerances, 2) the suite of other species with which it interacts and 3) the potential for dispersal and colonization within a given time period (Pulliam, 2000; Soberón & Peterson 2005). Ferrer-Sánchez and Rodríguez-Estrella (2015) suggested that the pattern of species distribution are the results of historical and ecological factors at both temporal and spatial scale. Since the northwest part of Borneo produce a high habitat suitability index (HSI) scores for both species (Figure 1 & 2), it indicates that the northwest region presents favourable conditions for both species, which is referred to as 'potential niche' of the species by Jackson and Overpeck (2000) and 'existing fundamental niche' by Peterson et al. (2012).

In order to determine which variables are important, the increase in gain in the model provided by each variable is heuristically defined (Baldwin 2009; Phillips et al. 2009). This study reveals that out of 20 environmental variables used, only fourteen variables contribute to the *L. curius* model and thirteen variables contribute to the *L. meges* model. Figure 3 shows that the highest influences were made by the precipitation of driest month (Bio14), temperature annual range (Bio7), temperature seasonality (Bio4) with their proportional weights 40.9%, 28.7% and 8.3% respectively for *L. curius* model. The top three predictors for *L. meges* portrayed in Figure 4 were precipitation of the driest month (Bio14) (47.4%), temperature annual range (Bio7) (20%) and precipitation of the wettest quarter (Bio16) (13.7%).

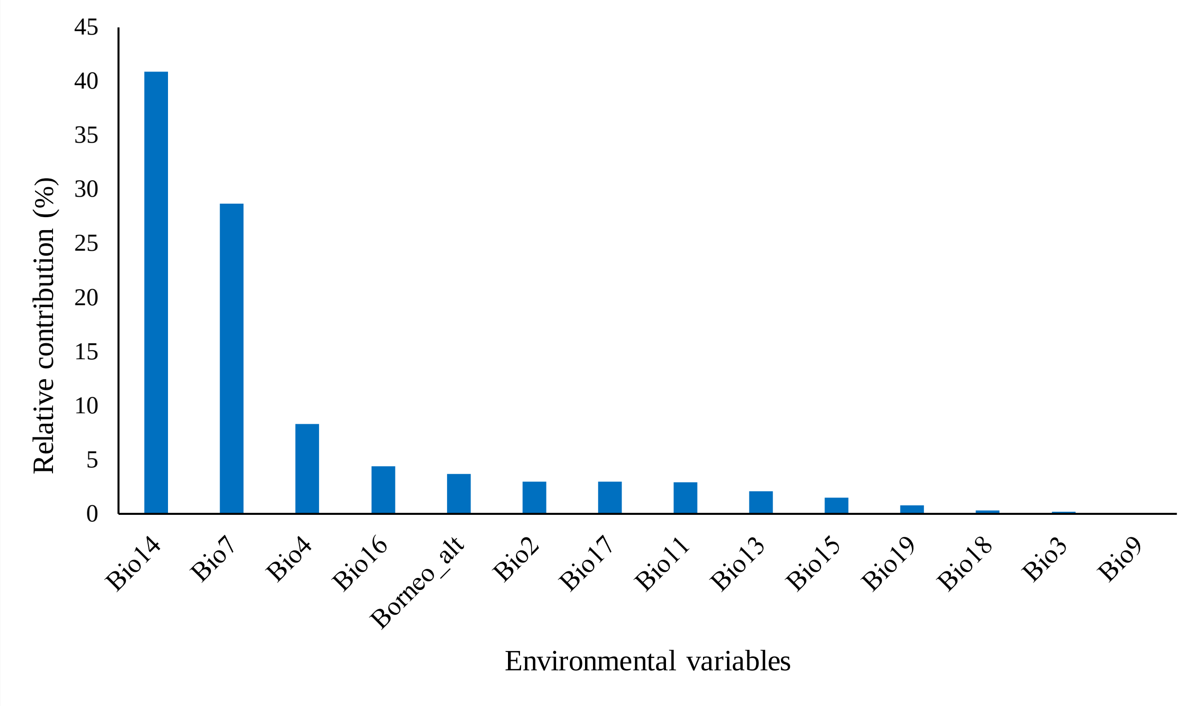

Figure 3. Relative contribution of the environmental variables for *L. curius*

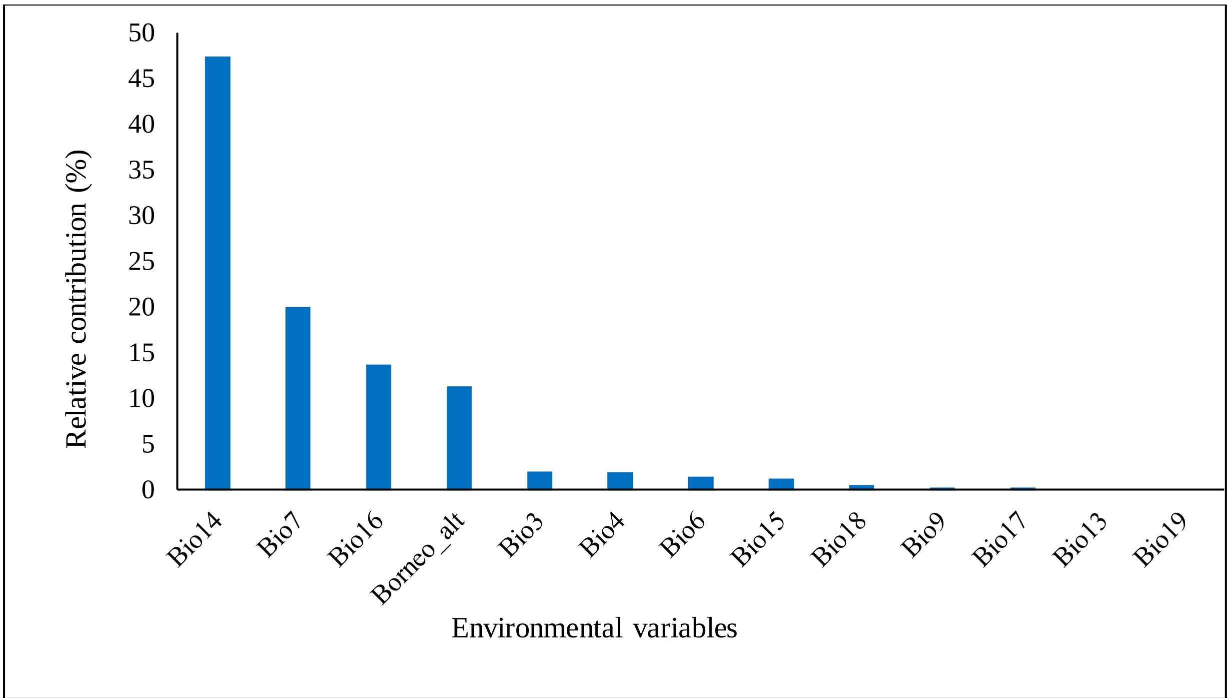

Figure 4. Relative contribution of the environmental variables for *L. meges*

Apparently, the models show a strong dependency of the potential habitat of *L. meges* and *L. curius* on climatology conditions. As both species are strongly affected by temperature and precipitation, consequently, a climate change scenario of one-degree increment could greatly diminish the survival possibility of the species. Results highlighted that both temperature and precipitation had affected *Lamproptera* species particularly in 1) distributional range; 2) daily activities and 3) food and host plant availability.

Recent shifts of species geographical distribution ranges across taxonomic groups, from invertebrates to birds are believed to be the effects of major changes in global climate on biodiversity (Abang et al. 2016; Zografou et al. 2014). Generally, latitude and longitude marked impacts on insect's life history and frequently utilize the phenotypic flexibility and genotypic adaptability of many species (Foin et al. 1998). Temperature had affected insect's development rates and voltinism which are reflected in changes in their geographical ranges. This is because most insects tracked climate changes and shifted their ranges rather than adapted to it (Coope 1978). Temperature is obviously an important environmental factor, especially for ectothermic organism such as the butterflies (Brehm et al. 2007). Species with lower dispersal ability appear to be more sensitive to temperature than species with greater dispersal ability (Kharouba et al. 2013). *Lamproptera* species clearly demonstrate that not all insects prefer the warmest climate by having suitable range of suitable temperature, even between species.

Result of our study indicated that both of the *Lamproptera* butterflies have been affected by climate changes. *L. curius* shows a northward shift in latitudinal ranges (Figure 1) while *L. meges* shows an upward shift in elevational ranges (Figure 2). Many species extend their distribution in response to climate change. Eventually, upwards extension will contract their ranges making them more vulnerable as most butterflies have narrow elevational ranges (Acharya & Chettri 2012). The upwards range shift pattern, contraction of elevational and latitudinal range of butterflies have also been observed in different parts of the world, including Europe (Parmesan et al. 1999), Canada (White & Kerr 2006) and central Spain (Wilson et al. 2007).

Temperature and rainfall are two variables that are mostly studied in butterfly's population (Pollard 1988). Climate change had induced an increase in extremes rainfall and snowfall across the globe (Tollefson 2016). Rainfall plays a key role in providing wet, sandy and rocky surface for male butterflies (Otis et al. 2006) where they puddle to get important salts, protein and minerals. Thacker et al. (1997) stated that an intense precipitation will only enhance the mortality factor of butterflies. The results of this study strongly support this theory as *L. meges* portray an increasing number of occurrences during the dry season. Rainfalls will prohibit their daily activities, including foraging and mating as they take refuge under the leaves (Pellet 2007).

Besides, both temperature and rainfall are a crucial factor in regulating nectar availability for nectar feeding butterflies. More plants will be flowering with a suitable climate conditions which eventually promote a range expansion of the butterfly to forage on the newly abundant resources (Thompson 2016). Compared to the adult, butterfly larvae including the dragon tail butterflies might encounter severe difficulties in foraging for their food as some of the species are highly associated with their larval host plants. Usually, the host plants are highly localized to specific climate, soil and other condition which are immobile and cannot migrate along the dispersing of the butterflies' population (Peterson, 2001). This interaction becomes a major disadvantage, particularly for butterfly species with single larval food plant. This situation might also influence the occurrence of *Lamproptera* species as they are known to feed on a specific host plants namely *Illigera* sp. Plant growths form and seasonal availability strongly influence the life history of insects associated with them (Foin et al. 1998). A close synchrony with host plant phenology is required to ensure a successful life-cycle completion in many host specific herbivores insect.

CONCLUSION

Effective conservation planning for the *Lamproptera* butterflies needs to address issues of habitat prediction through model analysis. In this study, the majority of the high suitability area for the *Lamproptera* butterflies lies in northwestern part of Borneo, within which area of high suitability index (HSI) for *L. curius* is in the coastline area and for *L. meges*, is in the highland area. It also revealed that environmental factors that highly affect the distribution of both species are the annual temperature range, precipitation of the driest month, temperature seasonality and precipitation of the wettest quarter. Due to climate irregularity, both *Lamproptera* species portray a shift in their geographical distribution ranges. *L. curius* had shown a northward shift in latitudinal ranges while *L. meges* showed an upward shift in elevation ranges. This study has shown that spatial predictions generated from habitat models developed from compiled ecological data are sufficiently accurate for use in conservation planning of rare species. Using occurrence data to estimate species ecological tolerances opens up the possibility of conducting studies in both conservation and basic science that are difficult or sometimes impossible to be achieved.

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