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Spatial Distribution and Range Expansion of an Exotic Butterfly *Acraea terpsicore* (Linnaeus, 1758) (Nymphalidae: Heliconiinae) in Borneo

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Abstract

Evidences provided by empirical studies indicated that species respond towards globally changing climate and most significantly butterflies attain range expansion towards climatically suitable range boundaries. The range expansion of an Indian native butterfly *Acraea terpsicore* has been documented in Borneo and can be considered as a potential case of range expansion resulting from anthropogenic induced climate change. Since its rapid southward range expansion to the Southeast Asian region during the past 30 years, this species has expanded approximately over 7000 km^2. The rate of colonisation in this region was estimated approximately 200 km/ year and as for Borneo it was calculated as 100 Km/year. The spatial distribution of *A. terpsicore* in Borneo was calculated by EOO (extent of occurrence) and the range margins of its occurrence was measured to over an area of about 322766 km^2. With the help of bioclimatic niche models, current habitable climatic range and potential future range margins until 2050 were projected by consensus forecasts. The projections for potentially promising climatic regions (until 2050) suggested that the exponential range expansion of *A. terpsicore* will likely to occur further towards the South-Eastern areas of Taiwan, Philippines and Sulawesi Island.

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In Borneo, this non-native species has also been keeping the track of its native land host plant and founded to feed on *Passiflora foetida*. Though for invasive species the distribution modelling does not provide a perfect picture of range expansion prediction in a novel range, due to landscape-climate differentiation, species biotic interactions, evolutionary adaptations and dispersal ability. So far, it is still considered a significant contributor in sketching of the climatically promising ranges for species with invasion potential.

Keywords: Spatial distribution; climate change; range expansion; invasive species; range size; dispersal.

1. Introduction

Climate change and invasive species are two of the most serious threats to biodiversity and a much more of prime concern is that these threats interact [1]. The scientific community widely accepts that anthropogenically induced climate change is occurring [2,3] and its impacts are expressed at various levels. Climate change is the major force on species distribution and species are compelled by their physiological tolerance towards temperature and humidity [4,5]. Over half of the species examined during 1970 – 2000 have experienced and responded to the modest level of global warming [6]. This includes alteration of species range limits leading to the range expansion or contraction [7]. In a wide range of taxa, the impact of climate change has been recorded by their range expansions towards higher altitudes and latitudes [8-11]. About 51 non-migrant butterfly's response to the 20th century climate warming predicted that the role of climate will potentially cause the future distributions of 35 species during a period of 2070-2099 [12].

Globally, the impact of climate change on the distribution of organisms may increase the circumstances of extinctions. For the effective protection of biodiversity, the most urgent task is to develop accurate predictions about species responses to global changes [13]. Therefore, modern research has significantly emphasized on the prediction of biodiversity in response to climate change [14].

The understanding of geographic ranges of species is an important and classical ecological challenge [15,16]. Species distributional patterns are better understood if one apprehend the ecological requirements and geographical facts which affect the structure and dynamics of the species geographical ranges [17]. To estimate species range size, the information of its distribution can be assessed either by Extent of Occurrence (EOO) or Area of Occupancy (AOO). Scrutinizing the geographic distribution of species by EOO including discontinuities in habitat or occupancy, can certainly predict information about the conservation status of species [18]. In more recent times, rare and endangered species distribution as well as environmental pressures affecting them were monitored and predicted with Species Distribution Models (SDMs) [19,20]. Theoretically, SDMs aim to determine and map (components) species ecological niche through space and time, as these models have become important tools in pure and applied ecology and evolutionary biology [21]. SDMs are widely used to forecast range shifts of organisms due to climate change, predict the eventual ranges of invasive species and infer paleoclimate from data on species occurrences [22]. Around the globe, invasive species are signified to intervene both the ecological and economic costs [23-25]. In recent approaches, many biologists and ecologists have used SDMs to forecast the future ranges of non-native or alien species. To improve the accuracy of predictions, researchers are rapidly developing tools in SDMs, forthcoming to the key biological processes needed for future concerns (policy makers and management actions) [13]. Thus, these SDMs projections assist to evaluate the risk associated with the establishment of alien or potential pest species [26] and mark the control of these species via management actions [27].

Invasive species provide unique opportunities to explore the impacts of recent range-expansion, in particular on life-history traits, making it possible to test for spatial dispersal abilities along the expanding range [28]. In Southeast Asia invasive alien species are currently outlined by ecologists and it is believed that in the coming decades, the biota of Southeast Asia will be affected far more than the impact of invasive species together with other human disturbances [29]. In Borneo, examples of biological invasion in the primary forests include the human-commensal rats, *Rattus rattus* [30]. Some invasive insects were accidentally introduced into Southeast Asia and are considered as pests to agricultural crops. For example, three species of *Liriomyza* (leaf miners) that are rapidly spreading in Malaysia, Indonesia and the Philippines [31]. In the case of butterflies, prominent invasion of the Southeastern butterfly *Papilio demoleus* (Lime/citrus Swallowtail) cannot be taken for granted [32]. This species was previously not recorded in Borneo [33] but has successfully expanded its range and invaded even the Caribbean and in the adjacent mainland near Florida [34].

The range expansion of *A. terpsicore* (Tawny Coster) (Linnaeus, 1758) and its establishment in Southeast Asia and Australia is anticipated to be as a result of both the climate change and habitat degradation. Thus it colonizes new geographical landscapes that also supplements its larval host plants. *Acraea terpsicore* is native to India and Sri Lanka [35-38] but has extended its range of distribution through the Southeast Asian countries southwards to Australia and Borneo. Until the past couple of decades it was not reported to exist in this region, but it has now become widely distributed and established as reported in Nepal, Thailand, Peninsular Malaysia and Singapore [39-43]. The most recent findings on the occurrence of *A. terpsicore* were from Indonesia [44] and also from Timor and Australia [45]. It was lately reported for the first time in the Southern foothills of Bhutan [46]. *A. terpsicore* has never been reported on Borneo Island until 2013 when it was first sighted in the areas of Kuching, Sarawak [47]. The presence of *A. terpsicore* in Mandor Landak Regency of Western Kalimantan and East Kalimantan has also been recently documented [48,49].

The aim of this study was to document the occurrence of *A. terpsicore* in Borneo and its areas of establishment across the island. The main approach was to correlate the statistically link spatial data to species distribution records and execute the range margins via maps. This study also aims to predict the potential range of *A. terpsicore* in Southeast Asia and especially in Borneo under current climatic conditions and further future climate change (2050). The Species Distribution Models (SDMs) were used for this purpose. Part of the study is focused on the events during the past couple of decades that may have contributed to its range expansion in Indo-Australian region and above all particularly, to assess its rate of colonization in Borneo as well as its possible approach of, entrance into the Island.

2. Materials and Methods

2.1 Collection of Distributional Data

The distributional data for *A. terpsicore* was obtained mainly from scientific literature and internet sites especially those with photographic proves which also provided the evidence of its presence in the Oriental and Australian region (Appendix). Most of the occurrence data for India, Bangladesh, Nepal, Bhutan, Thailand, Vietnam, Laos, Malaysia, Indonesia, Lambok, Timor and Australia were obtained from [35,39-46,50,51], respectively. The most recent record for West Kalimantan (Borneo) was gathered from [48] and [49] for Eastern and South Kalimantan. However, in Sarawak (Eastern Malaysia) multiple points of occurrence data were recorded through field observations and species collection. All the presence based records provided a total of 95 occurrence points for Southeast Asia as well as for Borneo was recorded. The spatial precision of these occurrence points varied from 10 m to more than 1km. The spatial distribution of *A. terpsicore* was executed by the method of Extent of Occurrence (EOO) through calculating the minimum convex polygon based on the Geographic Positioning System (GPS values) using the ArcGIS (ArcMap version 10.4 software).

The main interest of this study was to extract the broad pattern potential range of *A. terpsicore* in Southeast Asia. Therefore, two model outputs were generated for Southeast Asia and particularly, for Borneo, namely:

- Under current climatic conditions
- In 2050

The second model output was produced in order to predict the potential future geographic range of *A. terpsicore* in this region.

2.2 Environmental Data and Climatic Predictors

The output of species distribution modelling depends specifically on the set of climatic variables selected as a model input. The full set of 19 bioclimatic variables were selected as an input model for species niche modelling and data was obtained from WorldClim database. These bioclimatic variables are commonly used in SDMs which are derived from 1960-1990.

These represent the monthly temperature and rainfall values, annual trends (e.g., mean annual temperature, annual precipitation) seasonality (e.g., annual range in temperature and precipitation) and extreme or limiting environmental factors (e.g., temperature of the coldest and warmest month, and precipitation of the wet and dry quarters) [52; Table 1). Environmental data for these bioclimatic variables were selected at a spatial resolution of 10 arcmin (approx. 18.5×18.5 km pixel) following [1 and 45]. Future climate data for 2050 was sourced from the Fifth Assessment Report of IPCC (CMIP5= Coupled Model Intercomparison project phase 5) which was already downscaled and calibrated (bias corrected) using WorldClim 1.4 as baseline “current” climate, in order to compare the projections. For 2050 climate data six GCMs (Global Circulation Models) were selected for bioclimatic variables of 4.5 rcp (RCP; Representative Concentration Pathway). The RCPs are named after a possible range of radiative forcing values in the year 2100 relative to pre-industrial values [53].

The global warming increase (°Celsius) and projections for future climate data 2050 is averaged for year 2046-2065. With RCP4.5 the global mean temperature is likely to rise about 1.4°C (0.9 to 2.0) [54].

The six GCMs selected include;

- ACCESS1-0 (Australian Community Climate and Earth Simulator System)
- BCC-CSM1-1 (Beijing Climate System-Climate System Model)
- CCSM4 (Community Climate System Model version 4)
- HADGEM2-AO (Hadley Centre Global Environmental Model version 2-Atmosphere)
- HADGEM2-ES (Hadley Centre Global Environmental Model version 2- Earth System)
- MRI-GCM3 (Meteorological Research Institute Japan-Global Circulation Model version3).

2.3 Model Selection for Ecological Niche Modeling

To generate individual forecasts, six SDMs were selected [see also 1]. The distributional data for *A. terpsicore* was presence based only with a total 95 of occurrence points. Hence for presence based SDMs, two models were selected which are as follows:

- One-class SVM (Support Vector Machines)
- BioCLIM

For models which required pseudo-absence data, 1000 pseudo-absence points were created randomly using the environmental layer as a baseline file. Therefore, four pseudo-absence models were selected which includes:

- Two-class-SVMs (Support Vector Machines)
- BP-ANN (Back propagation-Artificial Neural Networks)
- CTree (Classification trees)
- MaxEnt (Maximum Entropy)

All the models were run using the ModEco Platform version 1.0 software. For BioCLIM and one-class SVM, user specified parameters with optimizing settings of 10% folder cross validation and Kernel= Radial basis Function (RBF) were chosen [see 55 and 1].

In case of CTree, the model algorithm was averaged for 10 iterations, windows size=10, and pruning level= 0.25 was selected. Whereas for MaxEnt, there are no parameters in ModEco.

2.4 Model Validation

Species Distribution Models are usually evaluated with the value of AUC (Area under the curve), which is a non-parametric threshold-independent measure of accuracy. For all the models the accuracy assessment was performed with 10% fold cross-validation.

AUC values that ranges from 0-1: scores between 0.5 and 0.7 are considered as low, 0.7-0.9 moderate and >0.9 high as described by [56].

Table 1: Environmental data of bioclimatic variables with respective codes

Sr. no.	Code	Description
1	BIO1	Annual Mean Temperature
2	BIO2	Mean Diurnal Range (Mean of monthly (max temp - min temp))
3	BIO3	Isothermality (BIO2/BIO7) (* 100)
4	BIO4	Temperature Seasonality (standard deviation *100)
5	BIO5	Max Temperature of Warmest Month
6	BIO6	Min Temperature of Coldest Month
7	BIO7	Temperature Annual Range (BIO5-BIO6)
8	BIO8	Mean Temperature of Wettest Quarter
9	BIO9	Mean Temperature of Driest Quarter
10	BIO10	Mean Temperature of Warmest Quarter
11	BIO11	Mean Temperature of Coldest Quarter
12	BIO12	Annual Precipitation
13	BIO13	Precipitation of Wettest Month
14	BIO14	Precipitation of Driest Month
15	BIO15	Precipitation Seasonality (Coefficient of Variation)
16	BIO16	Precipitation of Wettest Quarter
17	BIO17	Precipitation of Driest Quarter
18	BIO18	Precipitation of Warmest Quarter
19	BIO19	Precipitation of Coldest Quarter

3. Data Analysis

The limitations of this study was the total number of occurrence points of *A. terpsicore* summarized for the projections of SDMs. The larger the number of occurrence points of a species will therefore predict the most accurate distributional range margins**.**

Individual sample points of *A. terpsicore*, with the help of Geographical Positioning System (GPS) were used to calculate the rate of colonization via increase expansion rate in area over time (km^2 /year).

For the current climatic condition, six individual models were generated, from which consensus current climate map projections were constructed. Similarly, for future climate, 36 individual models forecasts were combined in one projection. The reason behind using consensus forecasts was to minimize resultant potential variation and to separate the “signal” from “noise” correlated with errors and uncertainties with individual map outputs [57]. The format for modeling techniques can be easily understood with the help of model design as shown Figure 1.

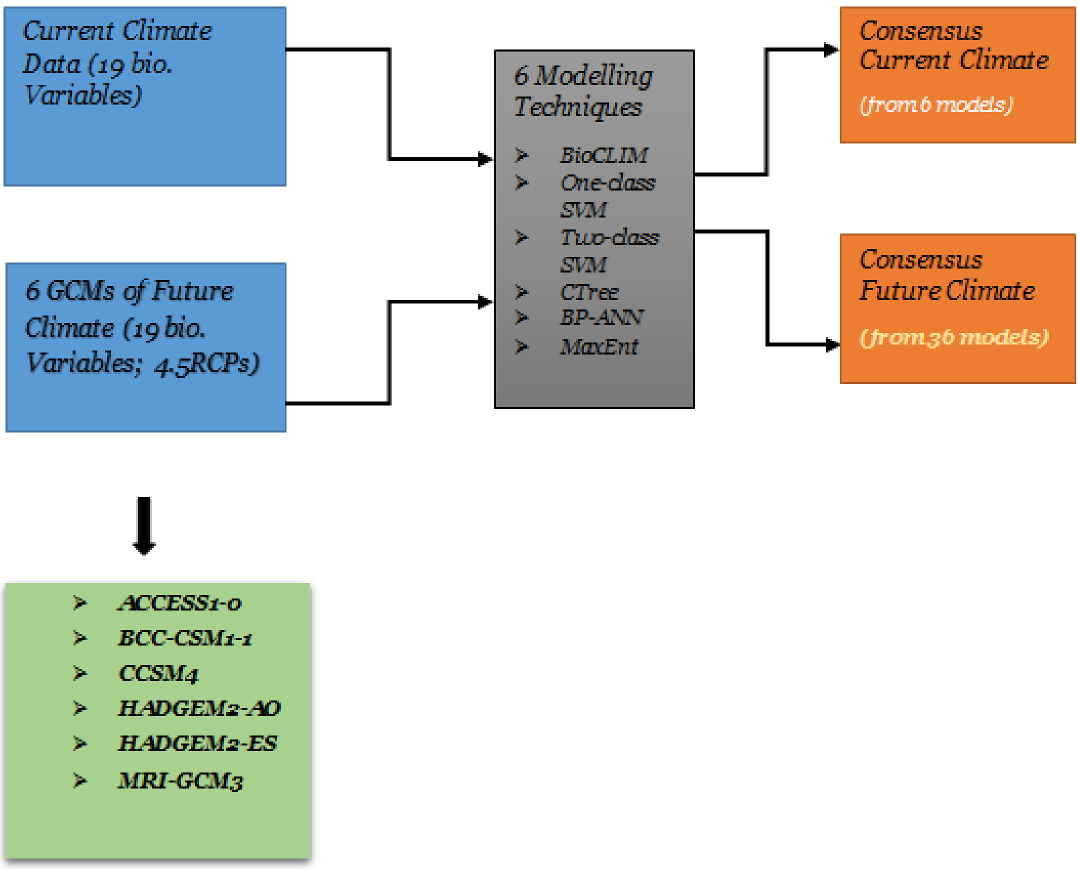


Figure 1: Model design for understanding the use of environmental data and models of current and future climate to estimate the suitable occurrence areas for *A. terpsicore*.

4. Results

4.1 Distribution Records for Southeast Asia

Records of the presence of *A. terpsicore* in Southeast Asia were gathered from information and evidences available on the internet (www.exoticinsects.com; www.ifoundbutterflies.org; lepidoptera.butterflyhouse.com/au; yukuta.it-n.jp/). These sites provide the evidence of *A. terpsicore* in Peninsular Malaysia, Singapore, Sumatra, Java, Flores and Moa Island. However the distributional records for

Thailand, Vietnam, Laos and Cambodia were obtained from [58], which describes briefly the presence of *A. terpsicore* in these regions on yearly basis (Figure 2). There was only one recent published literature of *A. terpsicore* from Lambok by [44]. Reference [45] Described the presence of *A. terpsicore's* in Timor and Australian region.

4.2 Distribution Records for Borneo

A. terpsicore was firstly recorded from Malaysian Borneo for the first time based on three specimens collected in Samarahan, southwestern Sarawak on 15th March 2013. This indicates that it probably must have arrived in 2012, and hence colonized in this region. Preliminary results of field tracking and observations of the species within the last three years indicated the establishment of *A. terpsicore* in western Borneo and expanded its area of distribution from Samarahan 200 km northwards to Sri Aman including Samariang, Kuching, Kota Samarahan, Asajaya and Serian.

Besides the sample collection from the mentioned areas, the distributional data of *A. terpsicore* was obtained from the very recent published literature of Mandor Landak Regency (West Kalimantan) and East Kalimantan by [48 and 49], respectively. From Moa Island and Mount Besar (Central Kalimantan) several individuals of *A. terpsicore* were reported (exoticinsects.com). However, the occurrence information for Banjarmasin (Central Kalimantan) was obtained from an internet site with a photographic evidence (see appendix). The summarized distributional data for Borneo is given in Table 2.

4.3 Rate of colonization

The author in [58] recorded nine individuals of *A. terpsicore* from Chang Mai. However, the presence of *A. terpsicore* from Chang Mai, reported by [40] is considered to be the earliest record for Thailand. The authors [58] mentioned the collection of one male individual from Chang Mai that supports [40] documentation. Following that it was recorded in northern Thailand (Chonburi) reported by [58,59] covering about 752 km in four years. Furthermore towards the east of Vietnam it was recorded by [58]. *Acraea terpsicore* was also traced northwards in Laos [41]. In Peninsular Malaysia, it was detected the earliest in Perlis by [42]. Subsequently it was encountered on the Islands of Langkawi and Penang (see appendix for yearly data compilation). In Singapore it was traced and recorded by [43]. Hence the migration of *A. terpsicore* all the way from Perlis to Singapore took almost 12 years (560km).

Adjacent to Singapore, *A. terpsicore* was also recorded at Jambi (about 100 km further). Migrating along the path of Greater and lesser Sunda Island it took almost four years to reach the Australian Continent, covering almost 3300 km. The above mentioned records detection of *A. terpsicore* and the rate at which it is migrating and spreading in South-East Asian region gives an estimate of its rate of colonisation in the region. The average rate of colonization from Thailand to Australia was calculated more or less 200 km/ year. The distance between Singapore and Kota Samarahan (Malaysian Borneo) is more than 720km and it took almost five years to reach the mainland. While, in Sarawak *A. terpsicore* was tracked north-west until Sri Aman (1°19'60"N, 111°40'.0"E) covering the distance of about 200km. The rate of colonisation from Singapore to Kota Samarahan was calculated about 150 km/year. While from Kota Samarahan to Sri Aman the rate of colonisation was estimated 100 km/year.

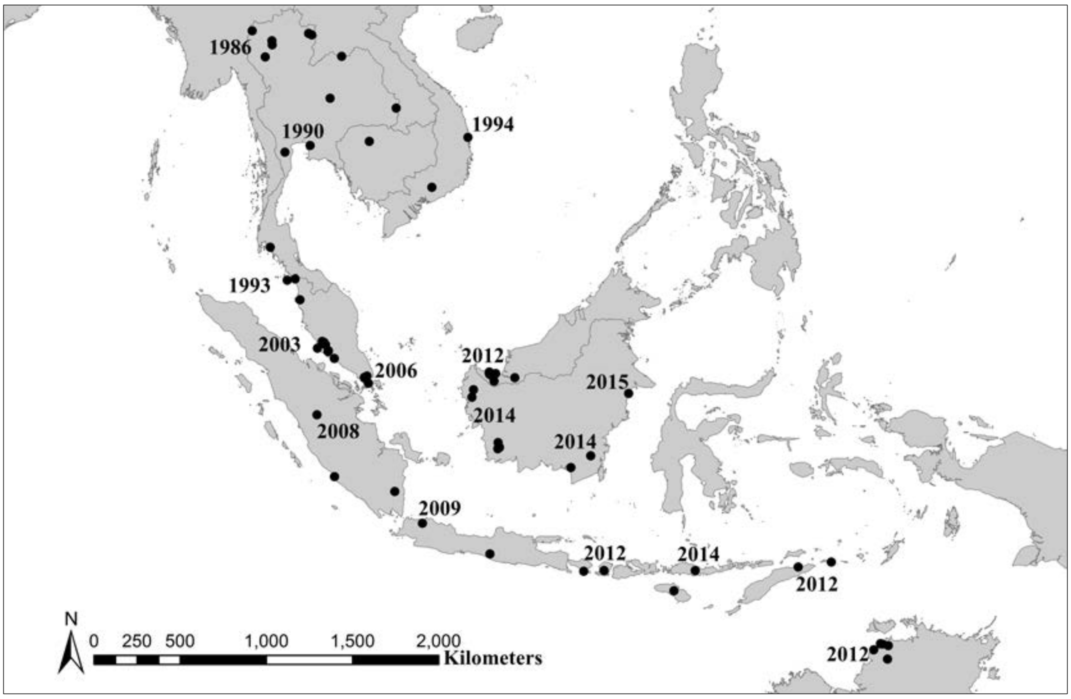


Figure 2: Distribution of *A. terpsicore* in South-East Asia (Thailand, Vietnam, Malay Peninsula, Indonesia and Australia) and particularly in Borneo, showing known locations (black circles) and years of detection (see also appendix, for the localities records and associated data)

4.4 Range size of A. terpsicore in Borneo

The range size of *A. terpsicore* was calculated by means of EOO (Extent of Occurrence) via calculating the minimum convey polygon (using IUCN toolbox in ArcGIS).

Within three years (earliest record), *A. terpsicore* has been detected at 18 locations in Borneo (10 locations in Sarawak and 8 in Kalimantan). An EOO (range size) of *A. terpsicore* was calculated that covers an area of 322766 km^2 in Borneo and is displayed in Figure 3.

4.5 Spatial modelling in South-East Asia and Borneo

Model performances (AUC) with selected parameters values for all the presence based and pseudo-absence models are given in Table 6.3. For all the six models under current climate and future climate of 2050, AUC scores ranged from 0.76-0.96, with a magnitude of moderate to excellent.

The simulation results from bioclimatic niche models under current climate conditions forecasted a much broader potential range compared to the existing geographical range of *A. terpsicore*. Outputs of SDMs projections for the world and South-East Asia are shown in Figures 4 and 5, respectively.

Table 6.2: Distribution of *Acraea terpsicore* across Borneo (presence based data)

S#	Site	Location	Latitude	Longitude	Date	Observer
1.	Desa Ilmu	K. Samarahan	1°27’10.498”N	110°27’26.83”E	March 2013	Noor Amira
2.	Taman BDC	Kuching	1°30’34.164”N	110°21’34.149”E	July 2015	Sabina Noor
3.	Jl. Stampin barat 4	Kuching	1°30’54.037”N	110°20’46.286”E	August 2015	Sabina Noor
4.	Jl. Muara Tabuan	Kuching	131’29.474”N	11023’45.249”E	August 2015	Sabina Noor
5.	Samariang Aman	Samariang	1°36’29.881”N	110°19’35.883”E	November 2013	Noor Amira
6.	Jl Cenderwasih	Petra Jaya	1°35’3.962”N	110°19’28.852”E	September 2014	Fatimah Bt. Abang
7.	Taman Cahaya Damai	Petra Jaya	1°37’44.968”N	110°20’13.827”E	November 2013	Noor Amira
8.	Kampong Semera	Asajaya	1°32’’58.031”N	110°40’14.891”E	January 2014	Noor Amira
9.	Kampung Ranchan	Serian	1°8’52.048”N	110°35’3.461”E	May 2016	Alley Majau
10.	Kerangan Petai	Sri Aman	1°19’60”N	111°40’.0”E	March 2014	Tham Vivian
11.	Banjarmasin	South Kalimantan	3°19’6.984”S	114°35’39.762”E	June 2014	Hidayati Rahima
12.	Mount Besar	South Kalimantan	02°42’39”S	115°37’32.999”E	January 2015	Exotic insects
13.	Man. Land Regency	West Kalimantan	0°19’4.778”N	109°25’33.281”E	October 2014	Florida and his colleagues
14.	Kabupaten Ketapang	West Kalimantan	02°16’35.9”S	110°52’07.6”E	April 2015	Iqbal and his colleagues
15.	Jelamu Hill	West Kalimantan	02°01’45.3”S	110°47’43.0”E	April 2015	Iqbal and his colleagues
16.	Sengkuang village	West Kalimantan	02°20’54.1”S	110°46’49.0”E	April 2015	Iqbal and his colleagues
17.	Perigi village	West Kalimantan	0°42’30.478”N	109°30’43.203”E	April 2015	Iqbal and his colleagues
18.	Bukit Pelangi	East Kalimantan	0°30’54.5”N	117°36’28.0E	June 2015	Iqbal and his colleagues

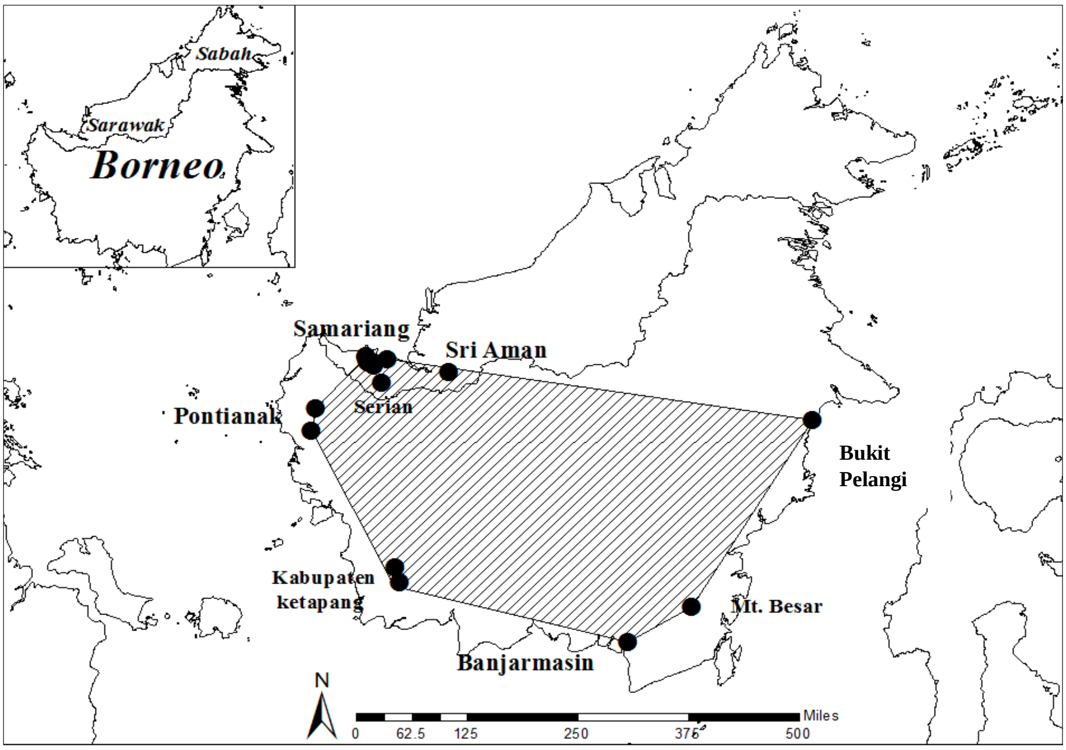


Figure 3: Distribution and range size of *A. terpsicore* in Borneo, showing known locations (black circles) and extent of occurrence (EOO) (cross-hatched area) based on the records between 2012 -2016. Inset map of Borneo is shown

Table 3: Summary of models performance and parameters range

Modelling techniques	AUC	Kappa	F-score	True positive rate
BioCLIM	0.83-0.96	-	7.41	-
One-class SVM	0.77-0.92	-	3.24-6.10	-
Two-class SVM	0.89-0.94	0.74-0.79	5.35-6.18	0.93-0.97
CTree	0.76-0.91	0.82-0.96	6.06-9.70	0.96-1.00
BP-ANN	0.91-0.96	0.45-0.86	7.09-9.07	0.76-0.98
MaxEnt	0.86-0.93	0.83-0.88	7.29-9.96	0.93

The consensus forecast of these models pointed out that besides to the well-known range of India, Sri Lanka and Thailand there were promising areas in Northern parts of Philippines, Sulawesi Island as well as in Southeastern China, Taiwan and Papua New Guinea as shown in Figure 5. In the consensus current climate forecasts climatically suitable areas of Madagascar, central Africa, Central and South of America were also indicated as shown in Figure 4. Until 2050, the consensus forecasts showed potential range will likely expand further. The expected areas of occupancy in the projections were highlighted as Central Africa and Madagascar as well as in

South America which are displayed in Figure 6. Furthermore in South-East Asia it will be probably richer in occurrence among areas of Southern Philippines, Northern part of Sulawesi Island. Whereas, moderately favorable climatic areas of Taiwan and Papua New Guinea are susceptible to be conquered by *A. terpsicore* as shown in Figure 7. Within Borneo it is predicted to occupy the areas that has been already described under current climate as displayed in Figure 8 (a). While for future climate forecast, the potential range of *A. terpsicore* was predicted to decrease in this region (Figure 8b).

4.6 Entrance into Borneo

From the bioclimatic niche models, the potential occurrence range of *A. terpsicore* was determined under current and future climate. Given that it can be proposed that *A. terpsicore* entered Borneo

- Either from Singapore via nearby islands
- Or via Sumatra /Java and nearby islands into Southern Kalimantan and then established and spread towards the western and Northern Kalimantan regions.

The second proposed mode of entry via Sumatra is more acceptable because this species was not encountered in the western tip of Eastern Malaysia (Lundu), suggesting it might have spread from western Kalimantan (Pontianak) into Sarawak via Bau and then established here.

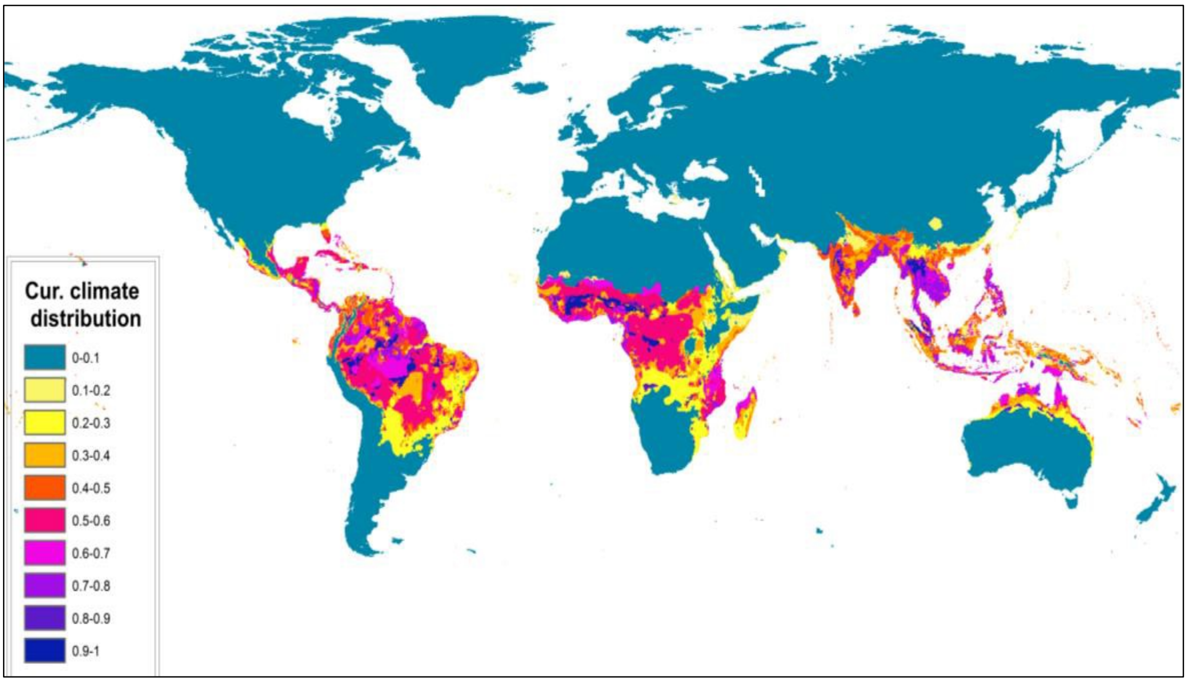


Figure 4: Potential range of distribution for *A. terpsicore* across the world, predicted under current climatic conditions are shown (blue, purple and pink shades). Likelihood of occurrence for the given pixel (from 0= unlikely to 1= very likely) is specified in the legend. The consensus forecast for current climatic conditions is based on six individual models

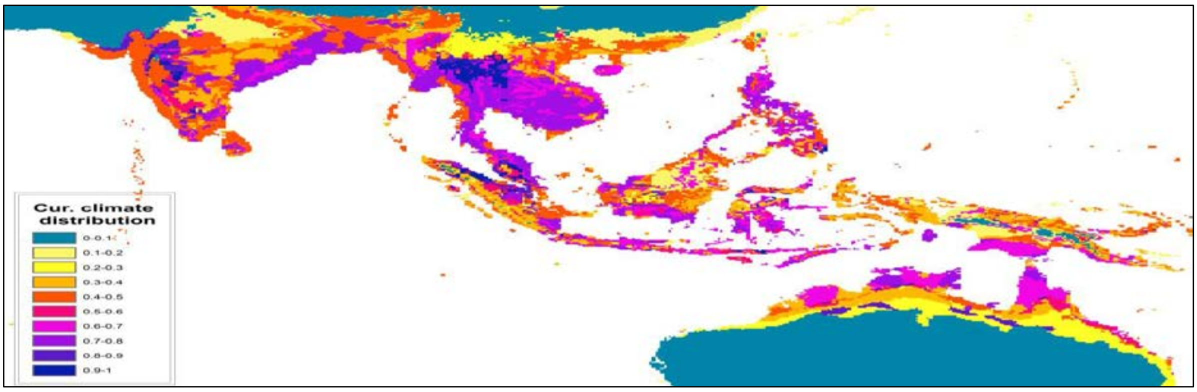


Figure 5: Potential range of distribution for *A. terpsicore* in South-East Asia, predicted under current climatic conditions are shown (blue, purple and pink shades). Likelihood of occurrence for the given pixel (from 0= unlikely to 1= very likely) is specified in the legend. The consensus forecast for current climatic conditions is based on six individual models

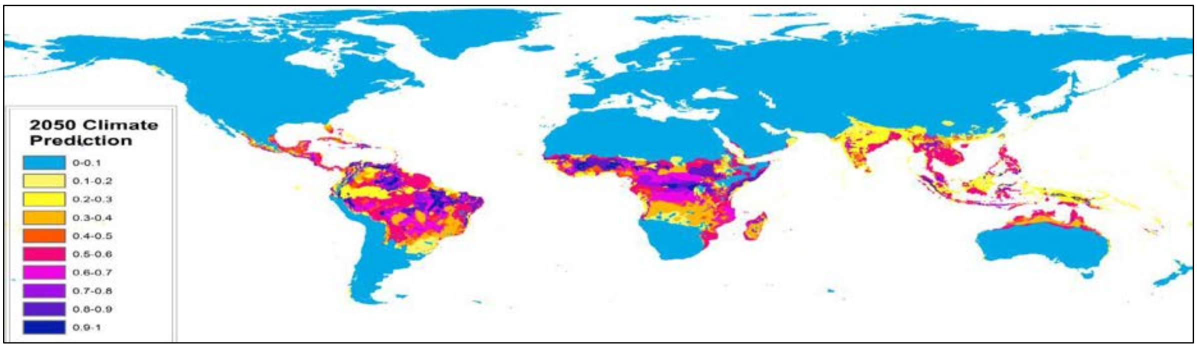


Figure 6: Potential range of distribution for *A. terpsicore* across the world, predicted for future 2050, climatic conditions are shown (blue, purple and pink shades). Likelihood of occurrence for the given pixel (from 0= unlikely to 1= very likely) is specified in the legend. The consensus forecast for future 2050, climatic conditions is based on 36 individual models

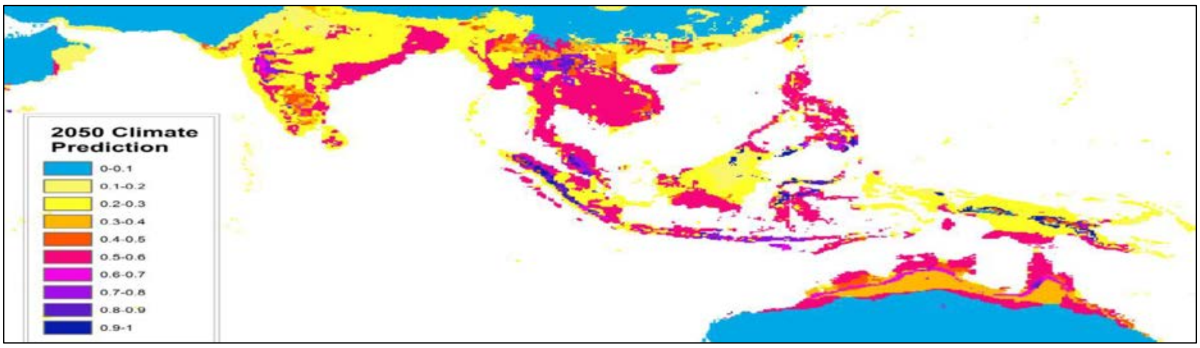
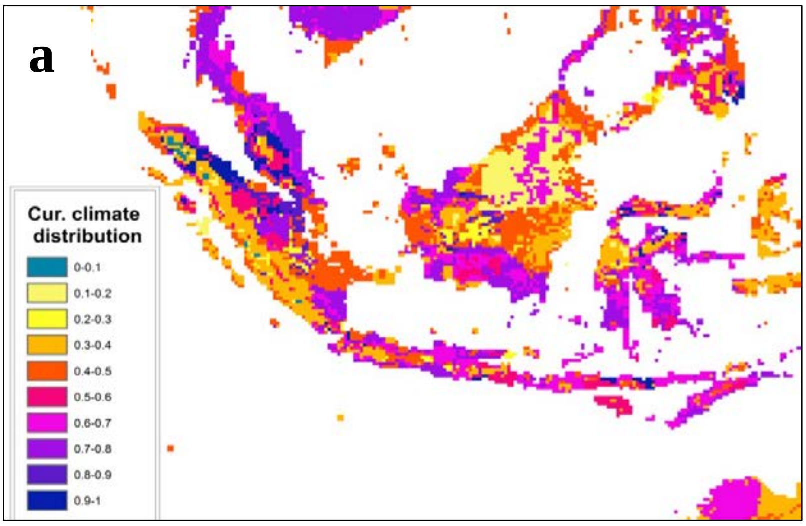


Figure 7: Potential range of distribution for *A. terpsicore* in South-East Asia, predicted for future 2050, climatic conditions are shown (blue, purple and pink shades). Likelihood of occurrence for the given pixel (from 0= unlikely to 1= very likely) is specified in the legend. The consensus forecast for future 2050, climatic conditions is based on 36 individual models



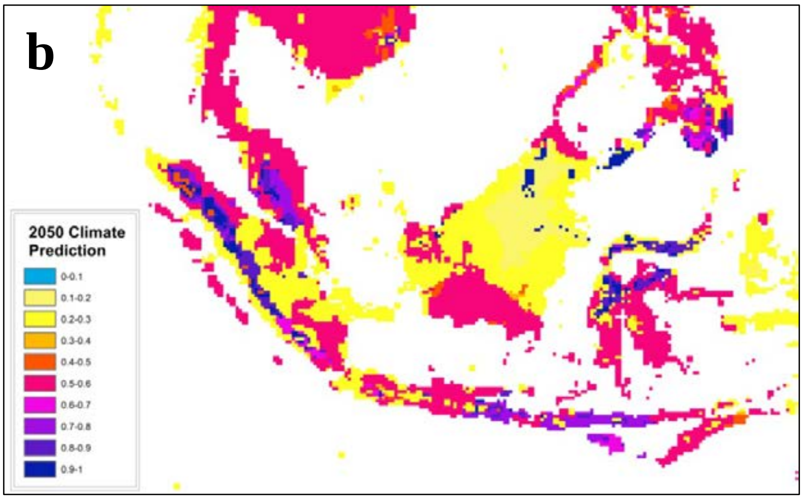


Figure 8: Potential range of distribution for *A. terpsicore* in Borneo, predicted under (a) current climatic and (b) future 2050 climatic conditions are shown (blue, purple and pink shades). Likelihood of occurrence for the given pixel (from 0= unlikely to 1= very likely) is specified in the legend. The consensus forecast for current climatic conditions is based on six and for future from 36 individual models

5. Discussion

India and Sri Lanka are known to be the native lands of *A. terpsicore* but in the past couple of decades this tiny nymphalid has explored and established prosperously in the region of South-East Asia, which includes particularly Thailand, Vietnam, Laos, Cambodia, Peninsular Malaysia and Singapore [40-43,58,59]. With the help of internet sites but of photographic evidence, the detailed distribution of *A. terpsicore* was compiled. After the reports of author [42], the detailed distribution of this species for India, Sri Lanka, Thailand and Vietnam was provided by [51]. Following that the detailed distributional map of *A. terpsicore's* occurrence for the above mentioned region was executed. The presence of *A. terpsicore* as a species from Indonesia (Lambok) was obtained from [44] which provided its latest record in this region. However, when tracked there was plenty of photographic evidence from different online sites (particularly for Lepidoptera) that provided the establishment this butterfly in the Indo-Australian region. Later on it was reported to be encountered from Timor and Australia as well [45]. As a matter of fact, in recent times it has also been encountered in the Southern foothills of Bhutan [46] and potentially denies the statement from [60] that this species is rarely found in northern and north-eastern areas of Southern India. In Borneo Island it was collected for the first time in Kota Samarahan, Sarawak (in 2013) [47]. While in Western Kalimantan the latest literature was published by [48] from Mandor Landak Regency and they did not mentioned its first presence in Kalimantan (Indonesia), although [49] described this species from five locations of East and West Kalimantan.

The migration and establishment of *A. terpsicore* in the South-East Asian region is still unclear, but on the other hand the hypothesis proposed by [45] were quite supportive about its presence and concludes that:

- The species was accidentally and recently introduced into Indo-China from India/ Sri Lanka.
- The species naturally expanded its range and colonized in Thailand via Myanmar (Burma).
- The species always existed in the region but become abundant due to the modification of the environment (climate change) and forest degradation.

With the detailed investigation the second and third hypothesis are much more acceptable due to the bottom line of alteration in environment (anthropogenic climate change) and forest degradation, clearing of lands for agricultural purposes alternatively provides the suitable habitat for the growth of its larval host-plant and establishment [45 and 49].

Throughout Southeast Asia, forests are rapidly being logged, particularly in Malaysia [61,62]. In Borneo, through the course of past decades, the forest area has been transformed on a larger scale into Palm-oil or *Acacia* plantations [63] creating open habitats, half open habitats and short grass areas, which are intensely habitable for *A. terpsicore* [49]. This species was enormously encountered feeding on *P. foetida* in Borneo. *Passiflora foetida* is an exotic wild plant, chiefly found in areas of pronounced wet season and irrepressibly grows on upland rice paddies and other crops. It is more common in forest clearings, plantations, rough pastures, roadsides and wastelands. Sometimes, it is cultivated in coconut plantations as soil cover with the intention to control grass or erosion, chiefly in Borneo and Philippines [64]. One of the main reason, for the rapid spread of *A. terpsicore* within the region is the availability of suitable habitat and this should not be taken for granted.

The invading capacity of a species is simply a reflection of the width of their fundamental niche [65] and working with niche-based models calibrated in the native range by relating species observations to the climatic variables are commonly used to predict the potential spatial extent of species invasion [1,56]. Range expansion studies, with regards to the butterfly species is more dominant in the European and Western parts of the world, suggesting the results (range expansion) as influences of climate change as well as habitat loss. The reports provided by authors [9,62,66,67] specifies that due to wide distributional history and ecology, butterflies are tracked for their range expansion towards higher altitudes and latitudes.

To estimate the range size (EOO) the occurrence record of *A. terpsicore* was utilized and resulted to be covering an area of about 322766 km^2 in Borneo. SDMs projections forecasted the current and future's climatically suitable range margins for *A. terpsicore* in Borneo and adjacent regions. The consensus projections of SDMs showed that the range expansion of *A. terpsicore* will likely to increase in the Indo-Australian region with the warning that this species has the potential of becoming an invasive species which is consistent with the reports of [45].

The nearest areas predicted to be habitable with suitable climate were predominantly Sulawesi Island and the Philippines. At least a decade before in the Indo-Pacific region, the genus *Acraea* was weakly observed with four to five species inhabiting in India, Burma and China. In addition to that the butterfly fauna of Sulawesi Island was also characterized by only two species of *Acraea,* with no supportive information of *A. terpsicore* to reside the island (with supplementary information to include here is, at that time the following genus was suddenly lacking from Peninsular Malaysia, Borneo and Philippines) [68].

Currently *A. terpsicore* is still in the phase of expanding its range in Borneo. Studies have indicated that invasive species conserve their climatic niche in the invaded ranges profoundly relies on the assumptions of climate matching approach [69]. But it must also be considered that climate change may create opportunities for niche differentiation as well as adaptation of evolution for non-native species in invaded regions [70].

6. Conclusion

Acraea terpsicore in Borneo has a successful distribution range covering mostly eastern and western parts of the island and will follow the trend of range expansion via dispersal to the nearby adjacent areas. Predominantly includes the Sulawesi Island and the Philippines, which were predicted as the most potentially climatically habitable regions in near future. Here concluding to the fact that *A. terpsicore* being an invasive species, it has to choose establishment by colonizing the habitable range margins in non-native regions rather than becoming an invasive species at the first place.

Also it has the potential to invade further the nearby regions that comprehends plenty of resources of its larval host plant range and achieving a foothold in dispersal and establishment in Southeast Asian region.

7. Recommendations

This exotic species has a strong prospective to invade further and must be closely monitored in this newly invaded region for its probability of acquiring new larval host plants. It is further recommended to forecast the species distributional range margins via SDMs in relation to its preferred host plant in this region.

Which can alternatively scrutinize the accuracy of prediction of SDMs and the likelihood of exotic species invasion capability to be established in a novel range.

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8. Appendix

Distributional data of *Acraea terpsicore* in Indo-Australian region (published and unpublished record)

Table 4

No.	Location	Country	Author(s)/ Source	Year	Latitude	Longitude
1	Bangalore	India	Shashikumar and Venkatesha	2008	12° 58' 17.7564" N	77° 35' 40.4268" E
2	Nehru Garden, Nasik	India	Shodhganga	2007	19° 59' 50.8308" N	73° 47' 23.2872" E
3	N.W. Ghats	India	Padhye and his colleagues	2013	25° 31' 57.864" N	76° 4' 25.8888" E
4	Gujrat	India	Sharma and Ahmed	2013	23° 1' 21.018" N	72° 34' 16.9032" E
5	Madhya Pardesh	India	Tiple	2012	22° 58' 24.3228" N	78° 39' 24.8184" E
6	Andhera Pardesh	India	Gupta and his colleagues	2012	15° 54' 46.44" N	79° 44' 23.9532" E
7	Maharashtra	India	Rane and Ranade	2004	19° 45' 5.328" N	75° 42' 49.9968" E
8	Mumbai	India	Arun	2010	19° 4' 33.5424" N	72° 52' 39.5616" E
9	kerala	India	Chrefredearth	2012	8° 26' 29.3964" N	76° 59' 39.3972" E
10	Kerala	India	Aneesh and his colleagues	2013	10° 51' 1.8576" N	76° 16' 15.8988" E
11	Dehli	India	Larsen	2005	21° 33' 58.9716" N	73° 13' 13.8252" E
12	Veshakapatnam	India	Ramana	2010	17° 41' 12.5376" N	83° 13' 6.5352" E
13	Punyagiri	India	Ramana	2010	18° 6' 34.83" N	83° 5' 37.8384" E
14	Ananthagiri	India	Ramana	2010	18° 11' 48.7428" N	82° 59' 52.3068" E
15	Ratnagiri	India	Ramana	2010	16° 59' 24.774" N	73° 18' 43.2828" E
16	Orrisa	India	Mishra and his colleagues	2010	20° 57' 5.9976" N	85° 5' 54.6864" E
17	Tamilnadu	India	Alagumurugan and his colleagues	2011	11° 7' 37.6428" N	78° 39' 24.8184" E
18	Assam	India	Bawri	2014	26° 12' 2.1744" N	92° 56' 15.2664" E
19	Dhobigat Durgapore	India	Beas Chakraborty	2014	23° 35' 14.3268" N	87° 17' 32.2548" E
20	Kuppam	India	Rohit	2013	12° 44' 49.3116" N	78° 19' 58.8576" E
21	Madras	India	NLBIF	1972	13° 4' 57.648" N	80° 16' 14.5848" E
22	Kakachi	India	Soubadra devi	1999	11° 19' 8.5656" N	76° 44' 24.522" E
23	Jharkand	India	Vijay Anand	2013	22° 39' 57.4272" N	85° 37' 52.3344" E

No.	Location	Country	Author(s)/ Source	Year	Latitude	Longitude
24	Western Ghats	India	Vidvalagan and his colleagues	2014	11° 25' 40.9656" N	76° 33' 37.3788" E
25	Andhra Pradesh	India	J. M. Grag	2008	13° 26' 31.4088" N	79° 49' 20.0316" E
26	Randoluwa	Sri Lanka	D. Tilakartana	1985	7° 8' 31.0452" N	79° 53' 39.318" E
27	Gonawela	Sri lanka	Talbot	1947	7° 52' 22.9944" N	80° 46' 18.4692" E
28	Sarpang Distt.	Bhutan	Nidup	2015	26° 56' 14.2944" N	90° 29' 16.7712" E
29	Dhaka	Bangladesh	Islam and his colleagues	2011	23° 48' 37.1952" N	90° 24' 45.0648" E
30	Kumaon	Nepal	Smith	1989	29° 16' 45.6636" N	79° 28' 13.4004" E
31	Mai Hong Son	Thailand	West	1996	19° 18' 7.308" N	97° 57' 55.5732" E
32	Krabi	Thailand	Olli Vesikko	2004	8° 5' 10.68" N	98° 54' 22.6188" E

No.	Location	Country	Author(s)/ Source	Year	Latitude	Longitude
33	Phu Kha	Thailand	Y.Inayoshi and K.Saito	1991	19° 5' 22.9956" N	101° 4' 2.6976" E
34	Chonburi	Thailand	Y.Shiraishi	1990	13° 21' 40.1148" N	100° 59' 4.8192" E
35	Chang Mai	Thailand	Y.Inayoshi and K.Saito	1986	18° 47' 15.8892" N	98° 59' 35.2608" E
36	Chaiyaphum	Thailand	Pinratana	1996	15° 48' 24.5412" N	102° 1' 53.4108" E
37	Kaeng Tana	Thailand	Yamaguchi and Aoki	2002	15° 17' 58.3692" N	105° 28' 36.5916" E
38	Doi Tao	Thailand	Nishimura	1994	17° 56' 39.1992" N	98° 38' 36.8124" E
39	Pua	Thailand	Nishimura	1994	19° 9' 54.4752" N	100° 54' 26.1072" E
40	Phu Sawan	Thailand	Nishimura	1994	13° 0' 48.9996" N	99° 40' 31.0008" E
41	Lamphun	Thailand	Nishimura	1994	18° 34' 28.0596" N	99° 0' 31.3992" E
42	Qui Nhon	Veitnam	Nishimura	1994	13° 46' 58.6812" N	109° 13' 10.7868" E
43	Dinh Quan	Veitnam	Nishimura	1994	11° 11' 37.554" N	107° 20' 36.5712" E
44	Phnum Kulen	Combodia	Onodera	2009	13° 34' 32.9988" N	104° 4' 30" E
45	Vientiane	Laos	Osada and his colleagues	1999	17° 58' 32.5416" N	102° 37' 59.1744" E
46	Perlis	Malaysia	Arshad and his colleagues	1996	6° 26' 41.6868" N	100° 12' 17.1684" E
47	Langkawi Island	Malaysia	Wong Tet Seng	1993	6° 22' 41.4984" N	99° 47' 24.6408" E
48	Pennag	Malaysia	Wong Tet Seng	1993	5° 21' 55.6488" N	100° 27' 32.4324" E
49	Negri Sambilan	Malaysia	Wong Tet Seng	2003	2° 43' 32.9016" N	101° 56' 32.5608" E

50	F.T, KL	Malaysia	Narong Jaturas (BOLD)	2015	3° 9' 25.0164" N	101° 42' 44.2908" E
51	Selangor	Malaysia	M. Sufian Azirun	2005	2° 51' 37.7064" N	101° 21' 56.88" E
52	Selangor	Malaysia	Gerald Lee Zhang Yang	2015	3° 2' 30.4908" N	101° 47' 35.07" E
53	Malacca	Malaysia	See Saw Pang	2015	2° 19' 39.2556" N	102° 14' 57.8472" E
54	Negari Sambilan	Malaysia	Lee See Mun	2015	2° 41' 19.2552" N	101° 54' 52.0488" E
55	Aman puri	Malaysia	NG Say chong	2015	3° 12' 49.8204" N	101° 36' 54.4824" E
56	Punngol wasteland	Singapore	Federick ho	2009	1° 21' 7.4988" N	103° 49' 11.4096" E
57	Pulau Serangoon	Singapore	Kerry Pereira	2015	1° 21' 19.2852" N	103° 52' 4.3356" E
58	Pulau Ubin	Singapore	Khew	2008	1° 24' 45.3312" N	103° 57' 28.4688" E
59	Botanic garden	Singapore	Khew	2009	1° 18' 49.824" N	103° 48' 57.2904" E
60	Kota Samarahan	Malaysia	Noor Amira	2013	1°27’10.498”N	110°27’26.83”E
61	Kuching	Malaysia	Sabina Noor	2015	1°30’34.164”N	110°21’34.149”E
62	Kuching	Malaysia	Sabina Noor	2015	1°30’54.037”N	110°20’46.286”E
63	Kuching	Malaysia	Sabina Noor	2015	131’29.474”N	11023’45.249”E
64	Samariang	Malaysia	Noor Amira	2013	1°36’29.881”N	110°19’35.883”E
65	Samariang	Malaysia	Abang. F	2014	1°35’3.962”N	110°19’28.852”E
No.	**Location**	**Country**	**Author(s)/ Source**	**Year**	**Latitude**	**Longitude**
66	Samariang	Malaysia	Noor Amira	2013	1°37’44.968”N	110°20’13.827”E
67	Assajaya	Malaysia	Noor Amira	2014	1°32’’58.031”N	110°40’14.891”E
68	Serian	Malaysia	Alley Majau	2016	1°8’52.048”N	110°35’3.461”E
69	Sri Aman	Malaysia	Tham Vivian	2014	1°19’60”N	111°40’.0”E
70	Batam	Indonesia	Subaraj Rajathuri	2006	1° 2' 44.2536" N	104° 1' 49.6344" E
71	Lambok	Indonesia	Matsomoto	2012	8° 39' 3.5244" S	116° 19' 29.7984" E
72	Wagait Beach	Australia	Braby and his colleagues	2013	12° 26' 8.0016" S	130° 44' 53.0016" E
73	Dundee Beach	Australia	Braby and his colleagues	2013	12° 45' 27.1512" S	130° 23' 34.2528" E
74	Darwin	Australia	Braby and his colleagues	2013	12° 27' 48.384" S	130° 50' 44.3112" E

75	Herbert	Australia	Braby and his colleagues	2013	12° 32' 32.3484" S	131° 9' 25.8804" E
76	Adelaide River	Australia	Braby and his colleagues	2013	13° 14' 30.7644" S	131° 6' 49.788" E
77	Kununurra	Australia	King and Daniel	2013	15° 46' 42.7476" S	128° 44' 30.066" E
78	Banjarmasin	Indonesia	Hidayati Rahima	2014	3°19’6.984”S	114°35’39.762”E
79	Mount Besar	Indonesia	Exotic insects	2014	02°42’39”S	115°37’32.999”E
80	M. Land. Regency	Indonesia	Florida and his colleagues	2015	0°19’4.778”N	109°25’33.281”E
81	Kab. Ketapang	Indonesia	Iqbal and his colleagues	2015	02°16’35.9”S	110°52’07.6”E
82	Kab. ketapang	Indonesia	Iqbal and his colleagues	2015	02°01’45.3”S	110°47’43.0”E
83	Sengkuang village	Indonesia	Iqbal and his colleagues	2015	02°20’54.1”S	110°46’49.0”E
84	Perigi village	Indonesia	Iqbal and his colleagues	2015	0°42’30.478”N	109°30’43.203”E
85	Bukit Pelagi	Indonesia	Iqbal and his colleagues	2015	0°30’54.5”N	117°36’28.0E
86	Jambi	Indonesia	Geoff Welch	2008	0° 35' 23.0064" S	101° 20' 35.1816" E
87	Bengkulu	Indonesia	Nurul Iman Supardi	2012	3° 47' 34.242" S	102° 15' 38.7504" E
88	Bali	Indonesia	LEPIDIGI	2014	8° 41' 41.0532" S	115° 15' 46.8504" E
89	Lampung	Indonesia	Gita Persada Bt. Park	2009	4° 33' 30.906" S	105° 24' 24.5088" E
90	Flores	Indonesia	Exotic insects	2014	8° 39' 26.5752" S	121° 4' 45.732" E
91	Moa Island	Indonesia	Exotic insects	2014	8° 13' 0.0012" S	128° 10' 59.9988" E
92	Bogor	Indonesia	Braby and his colleagues	2009	6° 12' 31.5468" S	106° 50' 44.1564" E
93	Baucau	Timor	Braby and his colleagues	2012	8° 28' 23.1636" S	126° 27' 19.3428" E
94	Sumba	Indonesia	Braby and his colleagues	2012	9° 41' 57.6384" S	119° 58' 26.5908" E
95	Yogyakarta, Java	Indonesia	A.Z's Lepidoptera	2012	7° 47' 44.088" S	110° 22' 10.164" E