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Predicting Habitat Suitability for Tarantula in Peninsular Malaysia by Using Species Distribution Modelling (SDM)

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ABSTRACT. – Theraphosidae, usually referred to as "Tarantula," is an infraorder of the Mygalomorh arachnid family of spiders. It is a large spider with downward-pointing fangs and a hairy body. As of now, few studies were done on Theraphosidaes in Peninsular Malaysia, but those were mainly concentrated on physical taxonomy with brief explanations of the spiders' natural history. This study revealed the prediction of Theraphosidae habitat suitability in Peninsular Malaysia. Species Distribution Modelling (SDM) was used based on Theraphosidae points of occurrence in Peninsular Malaysia. Prediction for habitat suitability was determined from 274 coordinates of occurrence. In the study, a high AUC value of 0.857 indicated a high discrimination power of the predictive model. Tree canopy cover, elevation and forested area were the top three significant factors that could predict the distribution of Theraphosidae species, according to the SDM modelling by using MaxENT. Based on this species distribution modelling study, it was concluded that protecting the hilly forested area in Malaysia was crucial for the protection of Theraphosidae spiders. The study highlighted the influence of environmental factors on Theraphosidae distributions in Peninsular Malaysia and provided insights for future research and conservation efforts.

KEYWORDS: species distribution modelling, Theraphosidae, Malaysia, habitat suitability

INTRODUCTION

Mygalomorph spiders, especially Theraphosidaes are spiders which are commonly known as tarantulas. They are widespread and can be found in many places in the world, indicating a diverse range of habitat requirements (Gallon, 2000; World Spider Catalogue, 2023). During the mating season mature male Theraphosidae spiders usually wander outside their burrow to search for females (Pérez-Miles et al., 2005; Pérez-Miles et al., 2007). In contrast, the females and juveniles usually stay at their burrows (Yáñez and Floater, 2000; Schultz and Schultz, 2009). The juveniles normally do not disperse far from their mothers (Reichling, 2000; Shillington and McEwen, 2006). As compared to other Mygalomorph spiders, Theraphosidae spiders do not disperse over long distance and appear to remain in small areas (Starrett and Hedin, 2007). However, Theraphosidae spiders are widely distributed across the world and inhabit an extensive variety of habitat types. Mygalomorph spiders are predominantly sedentary, making them easier for geographic fragmentation over time with small geographic distributions (Bond et al., 2006; Campbell and EngelBrecht, 2018; De Oca et al., 2020).

Peninsular Malaysia is home to various Theraphosidae species. Some Malaysian species have diverse habits, including arboreal and terrestrial. WSC (2023) reported that Peninsular Malaysia is home to 13 Theraphosidae species in total. Several research on tarantula species were conducted in Peninsular Malaysia, including taxonomy (West and Nunn, 2010; West et al., 2012), checklist (Norma-Rashid and Li, 2009; Razak et al., 2023; Razak et al., 2024) and bioacoustics (Razak et al., 2024). However, no previous studies on tarantula examined the environmental suitability of tarantula species or conducted detailed investigations on their natural history.

In Malaysia, tarantula species can be either arboreal or terrestrial. For example, the genus *Omothymus* comprise arboreal spiders, while the other genera are terrestrial. Some species such as *Psednocnemis jeremyhuffi* have extensive distribution, while some species are endemic, for instance, *Coremiocnemis cunicularia*, which can only be found on Penang Island (West et al., 2012). Several species can only live in high elevation habitats, which are around 1200m such as *Coremiocnemis hoggi* (West and Nunn, 2010). Other Theraphosidaes that are found exclusively in the southern part (Johor district) of Peninsular Malaysia are *Psednocnemis brachyramosa* (West et al., 2012) and *Omothymus violaceopes* (Gabriel and Sherwood, 2019).

Ecological niche modelling (ENM), also known as species distribution modelling (SDM), is widely employed in ecology and biogeography research (Peterson et al., 2015). Several uses of ENM in ecological study include identification of habitat suitability for a species (Guisan and Zimmermann, 2000), prediction about the impact of environmental changes on species distribution (Pearson and Dawson, 2003) and planning measures on conservation work

(Guisan et al., 2013). Up to this day, there were several studies of ENM on arachnid species such as Theraphosidae (Ferretti et al., 2019), huntsman spider (Moradmand and Yousefi, 2022), whip spiders (Palacios and Chirivi, 2023) and recluse spiders (Canals et al., 2016). Previous research on different arachnid species demonstrated that habitat suitability of Theraphosidae species could be estimated by using ENM.

Selection of candidate variables often relies on expert knowledge (Manly et al., 2002). Most methods attempt to identify the smallest combination of variables that produces the best fit the data (Johnson et al., 2006). There are various machine-learning methods for SDM. One of them is maximum entropy (MaxEnt) approach (Elith and Leathwick, 2009) that is widely used in predicting habitat suitability with only the availability of presence data. It was mentioned that MaxEnt is one of the best methods for niche modelling as it has capabilities to reduce the possibilities of overfitting (Valavi et al., 2022). Due to the better performance of MaxEnt in modelling, the method was chosen for this habitat suitability study.

Since the presence-only method does not consider a study site when a species is absent, it is less informative to predict the actual habitat suitability. Therefore, the habitat suitability model prediction can be improved by visiting the study site regularly to measure species detection and occurrence probabilities; hence, absent data can also be counted for another modelling such as occupancy models (MacKenzie et al., 2006; Royle and Dorazio 2008). Lastly, the predictive model offers valuable insights for conservation and land management strategies. Identifying areas of high habitat suitability can guide conservation efforts, ensuring the preservation of crucial habitats for Theraphosidae. Moreover, the model provides a predictive tool for assessing the potential impacts of land-use changes on these arachnids, aiding in sustainable land management practices.

MATERIALS AND METHODS

Study site

This study covered the whole of Peninsular Malaysia, encompassing tropical regions with various geographical landscapes and diverse ecosystems. The largest and most noticeable mountain range, the Titiwangsa Range, runs from the northern tip of the peninsula to Negeri Sembilan. Peninsular Malaysia has a total area of 131 816 km2 with an elevation range of 0 m to 2173 m. Primary records (current sampling) for this study data collection were made at several random sites in forest reserves, recreational areas or any places with presence of Theraphosids. Secondary data were taken from published records and through communication. Theraphosidae occurrence coordinates, recorded at various parts of Peninsular Malaysia is shown in Figure 1.

Species occurrence for niche modelling

The niche modeling is done by analysing the compiled Theraphosidae locations recorded in Peninsular Malaysia, through primary records (sampling coordinates) and secondary records (coordinates from communication and several locations from previous studies (West et al., 2012) from 2010 to 2022) to predict the potential distribution and habitat suitability of Theraphosidaes in Peninsular Malaysia. Data from communication were verified by interviewing the informer regarding the legitimacy of information. The informer also showed proof of Theraphosidae images that they encountered to confirm that they were indeed Theraphosidae spiders with accurate locations where they were discovered. After that, the occurrence points were visited, and the location coordinates were recorded by using Garmin GPSMAP 64s. This analysis was done based on the occurrence of all Theraphosidaes species in Peninsular Malaysia. The coordinates were recorded by using Garmin GPSMAP 64s and android telephone GPS for the sampling records (Primary). As for locations of Theraphosidaes from previous studies, only locations that contained specific coordinates were included. Due to lack of information on occurrence of each Theraphosidae species in Peninsular Malaysia, all gathered data were combined into the niche modelling.

The variables were divided into five categories which were mostly continuous data with only one categorical data. The five categories were climate, topographic, soil, land cover and water point. The Shuttle Radar Topographic Mission (SRTM) elevation and slope model (in degree) with a resolution of 1 arc-second were downloaded from a website (www.opendem.info/download_srtm.html) and subsequently used as digital elevation model (DEM) in meter. Topographic variables were chosen to determine whether the presence of Theraphosidae species was influenced by topographic features. A total of 19 bioclimatic variables (11 temperature and eight precipitation variables) from the WORLDCLIM dataset were essential to reflect the prediction in terms of climatic factor. Moreover, climate is one of the most significant factors which influence species location (Pearson and Dawson, 2003). The Harmonised World Soil Database is a 30 arc-second raster database with different soil mapping units that combine existing regional and national updates of soil information worldwide. The soil- water balance is in 30 arc-seconds uses spatially distributed values of monthly

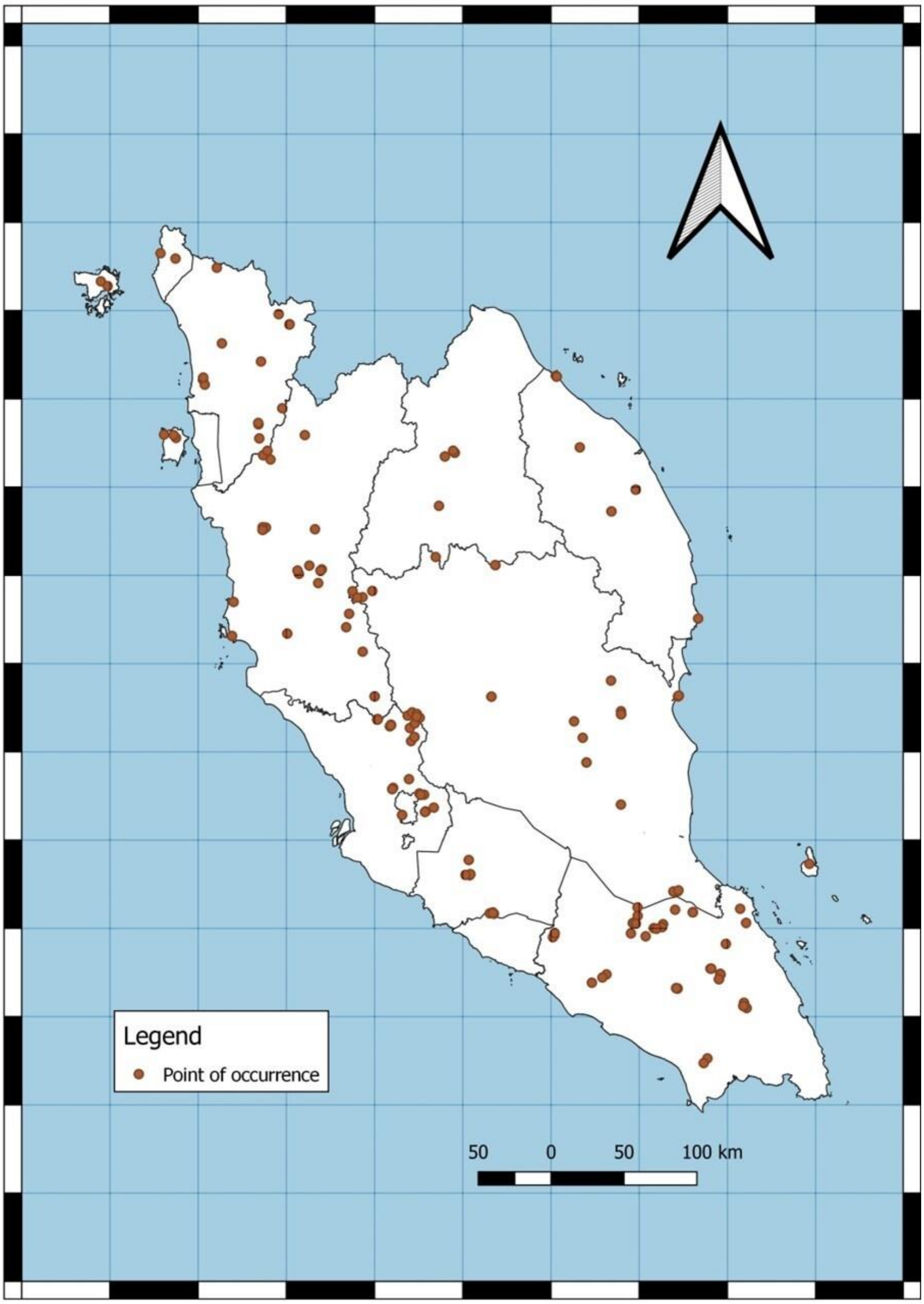

FIGURE 1. Point of occurrence for Theraphosidae in Peninsular Malaysia.

precipitation and monthly potential evapotranspiration (PET) and returns monthly spatially distributed values that define the actual evapotranspiration (AET), runoff (R) and soil water content (SWC). Soil related variables were chosen because soil-dwelling fauna, including terrestrial Theraphosidae, are highly sensitive to changes in soil moisture levels, as highlighted by studies conducted by Kardol et al. (2011) and Manzoni et al. (2012). The land cover was divided into two variables which were percentage tree cover for 2015 (global-30m-landsat-tree-canopy-version-4) and global forest cover loss between 2000 and 2019 (downloaded from Hansen/UMD/Google/USGS/NASA). Forest related variables were used because canopy cover serves as a fundamental component of forest ecosystems, having a significant influence on the ecological dynamics of forest-dwelling animals (Nadkarni et al., 2004). For the water related variables, two variables were used, which were global lake and wetland as well as water occurrence. Water related

TABLE 1. Environmental and climatic variables were used in this study to predict the Theraphosidae habitat suitability and potential distribution.

Variables	Data Source	Type
Climate:		
Bio12 = Annual Precipitation	WorldClim	Continuous
Bio14 = Precipitation of Driest Month		
Bio18 = Precipitation of Warmest Quarter		
Bio19 = Precipitation of Coldest Quarter		
Topographic:		
Elev1 = Elevation	SRTM	Continuous
Soil:		
Hwsd1 = Harmonized World Soil Data	FAO Soils Portal and Figshare	Categorical and
Gswb1 = Global Soil Water Balance		Continuous
Land Cover:		
Gfc1 = Global forest change	GlobalForestWatch.org., and Land Cover	Continuous
Tcc1 = Tree canopy cover	and Land Use Change Program	
Water point:		
Wocc1 = Water Occurrence	Worldwildlife.org and Global Surface water	Continuous

* After running correlation test, only those in bold were used in the final model analysis.

variables were included in this study to determine whether water occurrence affected the presence of Theraphosidae in the study area.

Environmental and climatic variables datasets (Table 1) were used to predict the potential distribution and habitat suitability of Theraphosidae in Peninsular Malaysia. All variables were converted to raster datasets (grid form) with WGS 84 coordinate system projection. The raster file was converted to ASCII format by using QGIS 3.22.0 (QGIS Development Team, 2022). Resampling technique was performed by using R Studio to change the extracted raster file to the same spatial extent and resolution for further analysis. This was to ensure that all raster files were in the same spatial extent and resolution. The adjusted raster file was then used in ENMTools. The correlation between variables was determined by using ENMTools 1.4.4 to check if there was any high correlation between two variables (Warren et al., 2010). Highly correlated variables (for example, slope, annual mean temperature, global lake and wetland) were not included in the model building process. These selected predictor variables are highlighted in Table 1. By using ENM Evaluate package in R, which settings to be used when running Maxent were decided. The model with the lowest AICc could be found from the ENM Evaluate. Those model settings were then used to run MaxEnt. A bias file was prepared by using occurrence data and environmental variables via R-studio. The bias file was then incorporated into the SDM process, often as a covariate in the model. This allowed the model to adjust predictions based on biases present in the data, improving the accuracy and reliability of the model results. Since the occurrence data was more than 50, cross-validations with 10 folds were used in the setting to reduce overfitting.

Analysis

MaxEnt model Version 3.4.4 was used in this analysis to produce a useful predictive model of species occurrence throughout the study area. As explained by Phillips (2017), MaxEnt can be used to predict the potential distribution of a species based on the occurrence data. MaxEnt needs only presence-only data of targeted species to estimate the most uniform distribution (Nazeri et al., 2012). MaxEnt uses both continuous and categorical variables, utilising a sample of background location to contrast against the presence coordinates, given that presence at the background location is unknown (Merow et al., 2013). Nonetheless, this modelling is susceptible to overfitting. It means that the prediction will focus mainly on the presence location. So, to overcome this overfitting, regularisation is the needed component (Elith and Leathwick, 2009). A bias file was also included in this analysis to improve prediction accuracy. By determining the best environmental variables, the most appropriate variables that were not correlated with other factors might be selected as it could interfere with the accuracy of output. Rydgren et al. (2003) stated that after studying their fitness response curves on over 1000 specimens, the frequency of symmetric bell-shaped responses rose.

To interpret the model output, logistic format was used. The percentage of contribution from each variable could be determined by using MaxEnt. The Jackknife method was applied in this process to determine the variable response. MaxEnt excluded each variable alternately during the run. In the end, the result information could explain the importance of each variable by elucidating the effect of variables towards the predictive model. Area under the curve (AUC) was used to measure the discriminatory power of model (Wilting et al., 2010). AUC value ranges from 0.5 to 1. According to Jiménez-Valverde (2012), the AUC values were typically interpreted as follows: 0.5—0.6 (failed), 0.6—0.7 (worthless), 0.7—0.8 (bad), 0.8—0.9 (good), or > 0.9 (outstanding). Cross-validate technique was also implemented in this analysis.

RESULTS

Based on 274 points derived from sampling (243 points), previous research (14 points) and communications (17 points) of Theraphosidae occurrences recorded in Peninsular Malaysia, the predictive tool produced an excellent model of potential Theraphosidae distributions with an AUC value of 0.857. The total number of Theraphosidae species included in this study for occurrence locations was 22, with 11 local species classified to species level and 11 unidentified local Theraphosidae species. The predictive map in Figure 2 featured a series of coloration to indicate certain categories of potential habitat distributions of Theraphosidae species in Peninsular Malaysia. The map had values of potential conflict strength, ranging from 0 to 1. The results were categorised into five range categories which was range of least potential as < 0.2, moderate potential at 0.2—0.4, good potential at 0.4—0.6 and high potential as > 0.6. No potential area was denoted by 0 value. The total area for habitat suitability of Theraphosidae in Peninsular Malaysia was estimated at 29,371km^2, which was about 22 % of total Peninsular Malaysia landmass.

Response curves in Figure 3 illustrate how each variable affected the probability of conflict presence. The value of logistics indicated the probability of habitat suitability corresponding to a particular variable, where the logistic output ranged from 0 to 1. Based on climatic factors, probability of presence increased as annual precipitation increased (Fig. 3a). This was the same with the precipitation of driest month (Fig. 3b) and precipitation of warmest quarter (Fig. 3c). The highest chance to detect a Theraphosidae based on the precipitation of coldest quarter was at 1200mm (Fig. 3d). Details of the habitat suitability based on climatic variables are shown in Figure 2.

These results demonstrated that elevation had potential for the habitat suitability of Theraphosidaes, whereby the probability increased greatly from 0m elevation to around 100m, increasing steadily to about more than 2000m of elevation (Fig. 3e). On the other hand, the global soil water balance showed that it did not give positive response towards habitat suitability, but the habitat suitability was at 1 when the evapotranspiration was about 1100mm (Fig. 3f). The Harmonised World Soil data indicated that only soil of Category 1 did not contribute towards habitat suitability according to the response curve (Fig. 3g). As for the tree canopy cover, it showed that the highest probability for habitat suitability was when the tree canopy covers were 90% (Fig. 3h). The forest indicated that when there was increase in forest cover, the probability for habitat suitability of Theraphosidaes will be increased (Fig. 3i). Lastly, the water occurrence showed that the higher the water occurrence, the less chance for habitat suitability, with more than 0.2% of water causing the probability to drop drastically (Fig. 3j).

Tree canopy cover (Tcc1), elevation (Elev1) and forest cover (Gfc1) were the most contributed variables on the predictive model with percentage values of 43.6%, 25.4% and 9.2%, respectively (Table 2). The highest permutation was recorded by tree canopy cover (29.9%), followed by elevation (20.8%) and forest cover (6.2%), as shown in Table 2. The Jacknife method of test gain (Fig. 4) showed that variable importance was good with the most percentage of contribution, except for Bio12 and Bio19. The variable with highest value of gain when used solely was tree canopy cover, followed by elevation and forest cover. The most important climatic variables on predicted model were Bio14 and Bio 18 when applied independently. Global soil water balance data produced the least useful information for the predictive model with a negative value of the gain in isolation with high value of gain when omitted.

DISCUSSION

A useful predictive model considers the biological, topographic and climatic components of species occurrence data. High AUC value of 0.857 indicated a high discrimination power of the predictive model in the present study. The area of potential habitat distribution was estimated as high across forested part in Peninsular Malaysia. Areas with good and moderate thresholds were demonstrated as borderline, and thus the threshold of areas from 0.2 to 0.6 could be treated

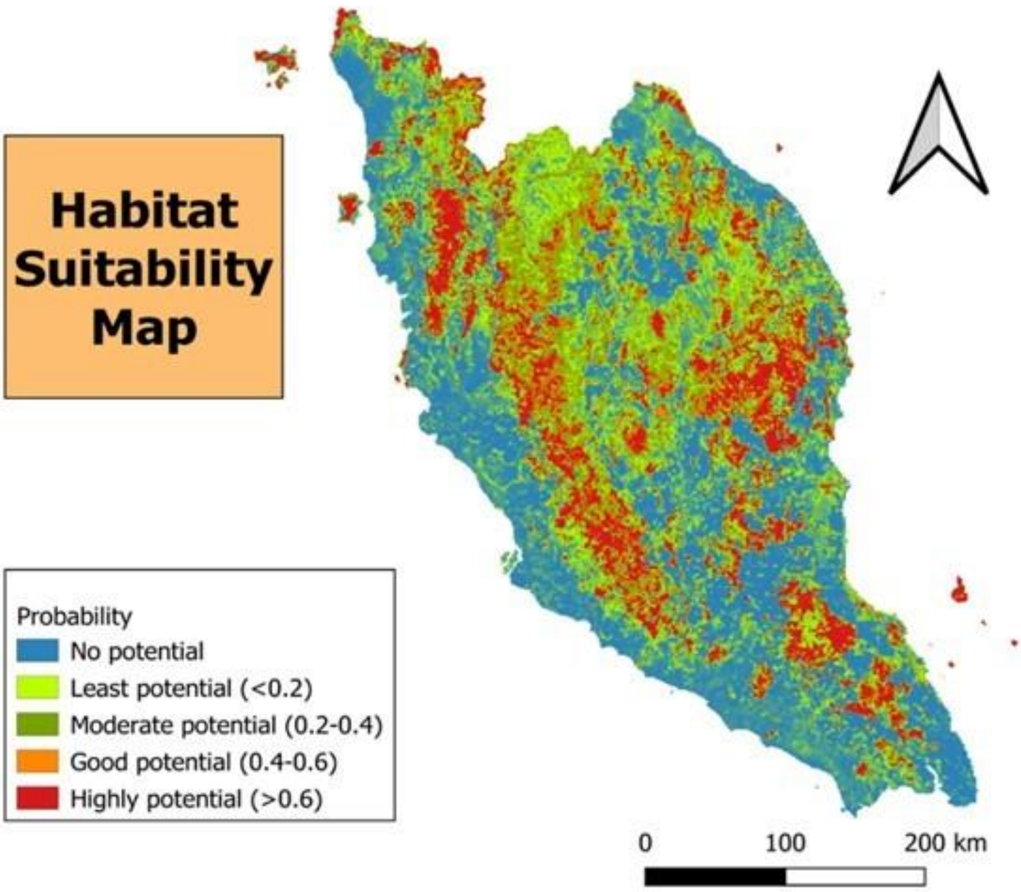

FIGURE 2. Potential distribution of the Theraphosidae according to occurrence records.

as good habitat suitability, following Lima and Calado (2020). It was observed that most potential habitat distribution overlapped with forest reserve area and protected areas, such as National Park and State Park. Response curve and Jackknife evaluation showed that the high probability of Theraphosidae presence was highly influenced by the tree canopy cover. Tree canopy cover was the highest contributor for Theraphosidaes habitat suitability. The tree cover gradient can be used to determine biodiversity of animal as tree cover has light factor which can shape the habitat structure (Vodka et al., 2013).

Elevation is the second variable that highly influenced the presence of Theraphosidae, with higher habitat suitability after 100m elevation. One species like *Brachypelma kahlenbergi* was found from low altitude, close to sea level, to higher elevations inland (Fukushima et al., 2019). This was followed by the forest cover, which affected the habitat suitability greatly. It was because the decline of a species in its current habitat was due to deforestation, mostly caused by agriculture activities (Global Forest Watch, 2019). It showed that other than tree canopy cover, elevation and forest were the major determinants in habitat suitability. Based on the present study, there were several species in Malaysia that can be found only at lowland areas, such as *Psednocnemis brachyramosa* and *Psednocnemis jeremyhuffi*. However, there were also species that only can be found in highland areas, such as *Coremiocnemis hoggi* and *Lyrognathus robustus*. Soil type influenced habitat suitability by the soil characteristics for Theraphosidae to live. Soil characteristics are important for Theraphosidae habitat selection, as observed in *Brachypelma klaasi* whereby the soil affects the daily temperature and humidity of the burrow (Yáñez and Floater, 2020). Several studies were done to describe soil characteristics and Theraphosidae habitat preference (Canning et al., 2014; Machkour M'Rabet et al., 2007; Yáñez and Floater, 2000). For example, *Nesiergus insulanus* prefers sandy loam type of soil (Canning et al., 2014), sandy soil for *Brachypelma klaasi* (Yáñez and Floater, 2000) and clay type of soil for *Brachypelma vagans* (Machkour M'Rabet et al., 2007).

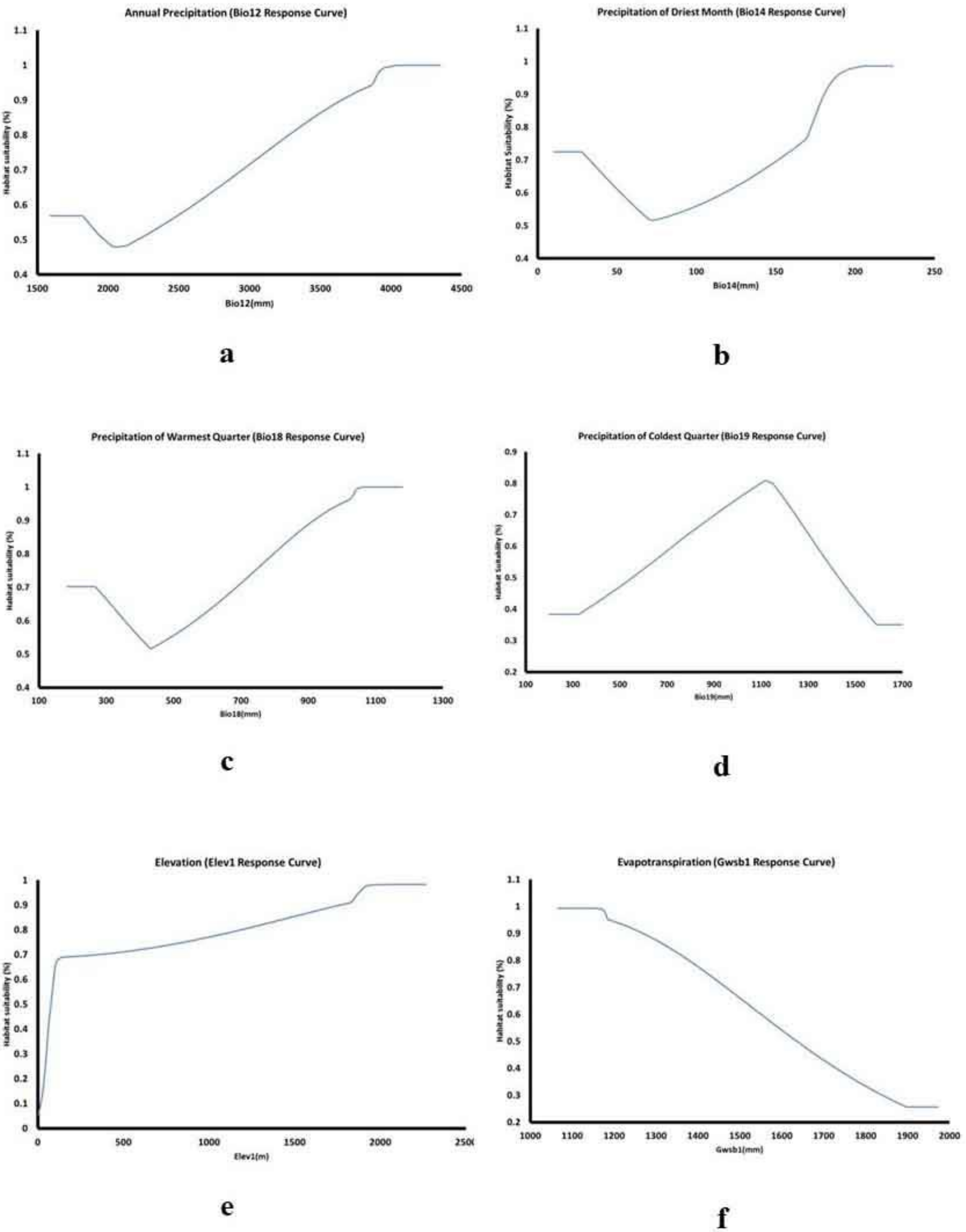

FIGURE 3a-3f. Bioclomatic responses to the 10 predictor. Bioclimatic variables (Bio12, Bio14, Bio18 and Bio19)(mm); Elevation (Elev1)(m); Global soil world data (Gswb1)(mm); Harmonized soil world data (Hswd1)(type); Forest cover (Gfc1)(%); Tree Canopy cover (Tcc1)(%) and water occurrence (Wocc1)(%).

The bioclimatic variables that influenced the potential habitat distribution were precipitation of coldest quarter, precipitation of driest month, precipitation of warmest quarter and annual precipitation. The bioclimatic responses (Fig. 3) variables showed that habitat suitability increased with

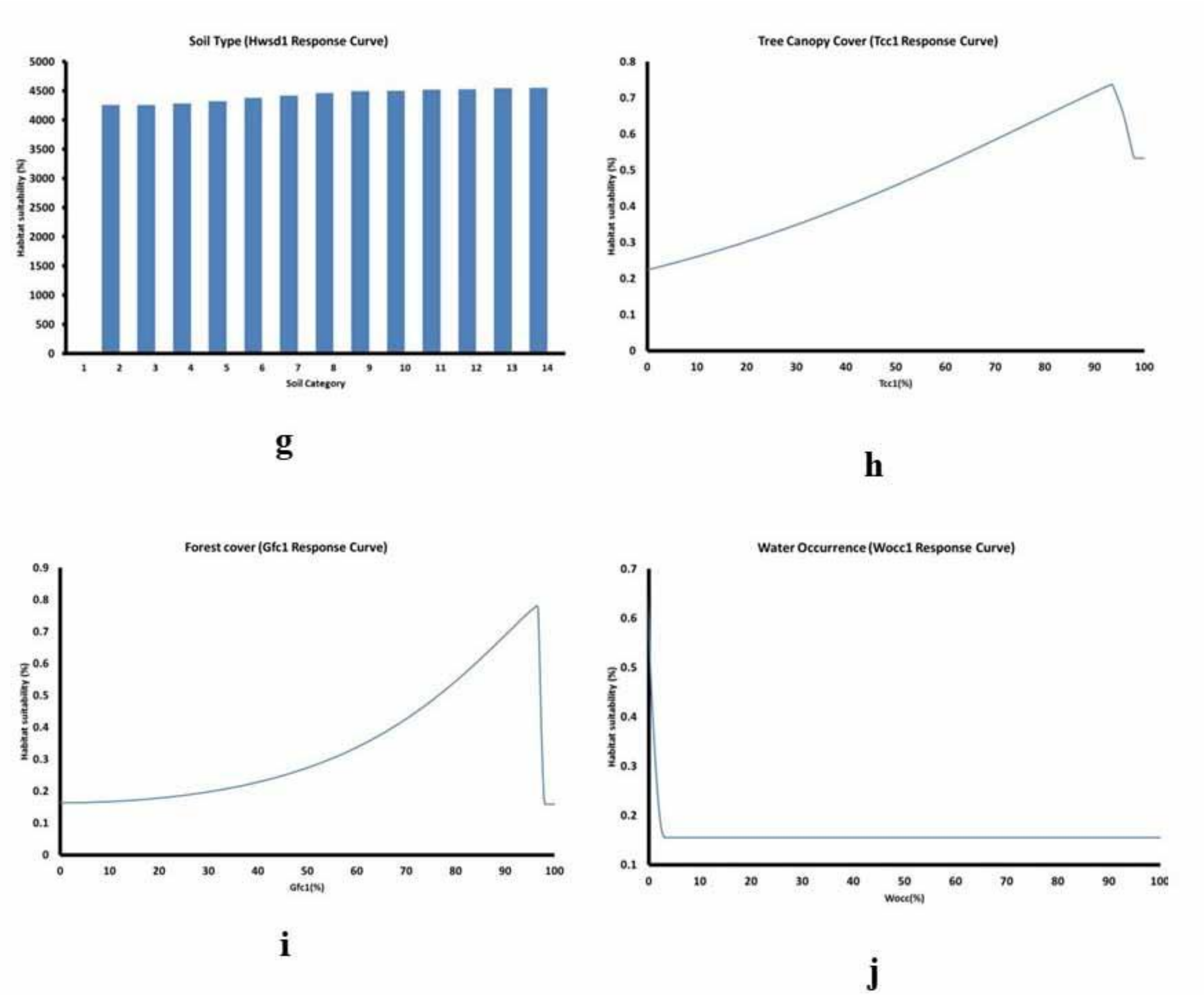

FIGURE 3g-3j. Bioclomatic responses to the 10 predictor. Bioclimatic variables (Bio12, Bio14, Bio18 and Bio19)(mm); Elevation (Elev1)(m); Global soil world data (Gswb1)(mm); Harmonized soil world data (Hswd1)(type); Forest cover (Gfc1)(%); Tree Canopy cover (Tcc1)(%) and water occurrence (Wocc1)(%).

increasing level of precipitation. Several studies showed that moisture and rainfall were one of the abiotic factors that influenced spider assemblages (Hatley and Macmahon, 1980, Arango et al., 2000, Langlands et al., 2006). However, up until now, there is still no studies regarding precipitation influence on Theraphosidae occurrence. Spider behaviours are influenced by surrounding factors, such as temperature, sunlight radiation and precipitation (Wise, 1993; Barth et al., 1988; Zaller et al., 2014; Chai and Wilgers, 2015). The study observed that most tarantula species preferred high humidity areas which typically ranged between 70%—90% humidity.

However, according to Jacknife analysis, the annual precipitation (Bio12) and precipitation of coldest quarter (Bio19) variables were considered the least important variables. The water occurrence showed where surface water occurred in Peninsular Malaysia. The habitat suitability response curve for the surface water occurrence displayed that the higher the frequency of the water occurrence, the less probability for habitat suitability. The Jacknife analysis showed that the water occurrence gave information in determining the Theraphosidae habitat. There were two species of Theraphosidae, namely *Selenocosmia* sp. 'Johor and *Psednocnemis* sp. 'Gunung Ledang' observed living at riverbanks in Peninsular Malaysia. But the burrow was found at a small stream at high elevation. Nonetheless, Theraphosidae is not aquatic animals, which means that Theraphosidae does not live underwater or on top of water, which explained why the model predicted that water occurrence was not highly related with its distribution.

The least important variables for this analysis were the soil water balance. This variable does not make any contribution to this analysis. Soil water balance is the evapotranspiration of the water from the soil. It is the sum of water evaporation and transpiration from a

TABLE 2. Percentage of contribution and permutation importance of each variable into predictive model.

Variables	Data Source	Type
Climate:		
Bio12 = Annual Precipitation	WorldClim	Continuous
Bio14 = Precipitation of Driest Month		
Bio18 = Precipitation of Warmest Quarter		
Bio19 = Precipitation of Coldest Quarter		
Topographic:		
Elev1 = Elevation	SRTM	Continuous
Soil:		
Hwsd1 = Harmonized World Soil Data	FAO Soils Portal and Figshare	Categorical and Continuous
Gswb1 = Global Soil Water Balance		
Land Cover:		
Gfc1 = Global forest change	GlobalForestWatch.org., and Land Cover and Land Use Change Program	Continuous
Tcc1 = Tree canopy cover		
Water point:		
Wocc1 = Water Occurrence	Worldwildlife.org and Global Surface water	Continuous

surface area to the atmosphere. This is maybe due to the climate condition in Malaysia where it is normally wet and humid throughout the year (Tang, 2019). However, as Theraphosidaes live in soil, the soil moisture content and water movement in soil showed that this variable affected the presence slightly. The Jacknife analysis also showed that the test gain for the evaporation and transpiration of water from soil variables showed a negative response. The response curve for these variables showed that the highest probability for presence was highest at 1100mm and gradually decreased until 1900mm.

Additionally, the niche models developed in this study were based on environmental data and may be subjected to uncertainty and error. While these models provided valuable predictions about Theraphosidae habitat suitability in Peninsular Malaysia, they should be interpreted with caution, especially in areas with limited environmental data or where the model assumptions might not hold. Aside from that, the niche modelling in this work focused on various Theraphosidae species in Peninsular Malaysia. As a result, various species of Theraphosidae might have varying ranges of habitat suitability's. However, due to a lack of knowledge and information about the occurrence of each Theraphosidae species in Peninsular Malaysia, the data were insufficient to run the modelling for each Theraphosidae species in Peninsular Malaysia. Therefore, in future studies, more information about a Theraphosidae species occurrence can better anticipate the species niche modelling. Therefore, this work will serve as a baseline for future studies on niche modelling for Theraphosidae in Malaysia.

CONCLUSIONS

Based on this study, species distribution pattern and prediction for habitat suitability of Theraphosidae in Peninsular Malaysia were examined. Species distribution modelling showed that the three variables that highly influenced occurrence of Theraphosidae in Peninsular Malaysia were tree canopy cover, elevation and forest cover. From the modelling, it seemed that Theraphosidae in Peninsular Malaysia generally preferred hilly and forested area with ample amount of canopy cover. Besides that, the modelling showed that the lowland area with human development has no possibility of occurrence. In this study, the GIS procedure and SDMs were applied to show the area of potential presence of tarantula in Peninsular Malaysia. It was also noted that most of the high habitat suitability areas for Malaysian tarantula species were inside the area of National Parks, State Parks and Forest Reserve area. Therefore, it shows that generally Malaysian tarantula species needs a healthy forest with hilly to mountainous area. It is crucial for Malaysia to conserve the forest and avoid destroying forested hills. In order to increase conservation impact on Theraphosidae in Peninsular Malaysia, proper planning on land use, protection of forest reserve and protected areas, enforce regulation on smuggling and poaching activities and increase in scientific research are needed to ensure that their habitats are protected in the future.

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