DISTRIBUTION AND PREDICTING ENVIRONMENTAL SUITABILITY OF *SERGENTOMYIA GEMMEA* AND *SERGENTOMYIA BARRAUDI* (DIPTERA: PSYCHODIDAE) IN THAILAND

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Abstract. In Thailand, epidemiology of leishmaniasis, a neglected vector-borne disease, is not clearly understood. Identification of proven biological sandfly vectors is crucial to prevent and control the disease; however, vectors of leishmaniasis still remain unclear and have yet to be confirmed. *Sergentomyia* is the most predominant genus of which DNA of *Leishmania martiniquensis* were detected in the gut of *S. barraudi* and *S. gemmea* suggesting these species could possibly serve as potential vectors in Thailand. This study predicted environmental suitability and geographic range of *S. gemmea* and *S. barraudi* in Thailand. Localities of *S. gemmea* and *S. barraudi* from published articles of sandflies in Thailand were mapped and ecological niche models were created to estimate distribution, the first predictive geographic distribution in Thailand of *S. gemmea* and *S. barraudi*, and influencing environmental factors, revealing *S. gemmea* commonly resided in peridomiciliary areas surrounded with orchards, palm and rubber plantations in the southern region, while *S. barraudi* could be found in many regions of the country. The distribution of these species was limited by similar habitat suitability; however, certain bioclimatic variables conferred comparatively beneficial fitness to *S. barraudi*. The study provides the first preliminary picture and understanding of the geographic distribution and associated environmental factors that could be vital in future studies of the role of *S. gemmea* and *S. barraudi* as potential biological vectors of *Leismania* in Thailand.

Keywords: sandfly, environmental factors, geographic distribution, Thailand

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INTRODUCTION

Leishmaniasis, a vector-borne disease caused by intracellular protozoan of the genus *Leishmania*, is widespread in tropical and subtropical regions (Alvar *et al*, 2012; Steverding, 2017) and is recognized as the second most important leading parasitic disease, after malaria, causing global mortality and morbidity in which an estimated 700,000-1 million new cases and 20,000-30,000 deaths occur annually (WHO, 2010; WHO, 2018).

In Thailand, leishmaniasis was first described in the southern region of the country in 2008 and is now considered an emerging disease (Sukmee *et al*, 2008). However, epidemiology of the disease is not clearly known, especially regarding hosts and vectors, although asymptomatic and symptomatic patients have been increasingly reported, since first case report in 2008 rising to 182 (25.1%) asymptomatic cases among patients with HIV/AIDS in 2015 (Kanjanopas *et al*, 2013; Leelayoova *et al*, 2017; Manomat *et al*, 2017). Autochthonous cutaneous (CL) and visceral leishmaniasis (VL) is clearly associated with *Leishmania martiniquensis* and *L. siamensis* infection (Leelayoova *et al*, 2017) and co-infection with the human immunodeficiency virus (HIV) can produce a more complicated and severe disease (Lindoso *et al*, 2016). Cases of symptomatic autochthonous CL and asymptomatic VL have been reported since 2008 (Leelayoova *et al*, 2017; Manomat *et al*, 2017).

Leishmania parasites are associated with and transmitted by infected phlebotomine sandflies comprising 98 species of the genera *Phlebotomus* and *Lutzomyia*, which have been described as potential vectors to humans (Maroli *et al*, 2013). Approximately 800 sandfly species have been identified in the subfamily Phlebotominae (Aspock *et al*, 2008), notably *Lutzomyia* spp found in the New World, and *Sergentomyia* spp and *Phlebotomus* spp known only to exist in the Old World (Alkan *et al*, 2013; Maroli *et al*, 2013; Ergunay *et al*, 2014).

Identification of the vectors that still remains unknown in Thailand is crucial to prevent and control transmission of leishmaniasis in the country (Kanjanopas *et al*, 2013; Chusri *et al*, 2014). Survey studies of the distribution of sandfly species and their habitats were conducted in central, western, northern, northeastern, and southern Thailand where three genera, namely, *Idiophlebotomus*, *Phlebotomus* and *Sergentomyia*, were identified of which *Sergentomyia* is the most predominant genus reported in all study areas (Apiwathnasorn *et al*, 1989; Apiwathnasorn *et al*, 1993; Depaquit *et al*, 2006; Polseela *et al*, 2007; Sukmee *et al*, 2008; Apiwathnasorn *et al*, 2011; Polseela *et al*, 2011a, b; Sukra *et al*, 2012). The biological vector of CL and VL is unclear and has not yet been confirmed in Thailand where *L. martiniquensis*, a causative agent of autochthonous visceral leishmaniasis, has been commonly reported in southern Thailand (Kanjanopas *et al*, 2013; Chusri *et al*, 2014). However, DNA of *L. martiniquensis* was detected in the gut of *S. gemmea* and *S. barraudi* suggesting they could probably serve as potential vectors of *L. martiniquensis* (Leelayoova *et al*, 2017).

The distribution and abundance of sandfly vectors and hosts are influenced by various physical factors, *viz*. temperature, rainfall, relative humidity, altitude, latitude, surface water and wind, as well as biotic factors, such as vegetation, host species, predators, competitors, parasites and human interventions (Lane, 1993), all of which can affect spatial and temporal distribution of vectors and reservoirs, which in turn impact epidemiology and dynamics of pathogen transmission (Rohr *et al*, 2011). Different approaches for the study of demographic and geographic distributions of vector-borne diseases, such as geographic information systems mapping (GIS), remote sensing (Rogers and Randolph, 2003), climate-based modeling (Brownstein *et al*, 2003), and species distribution or ecological niche modeling (ENM) (Neerinckx *et al*, 2008) have been used. ENM was developed to infer environmental requirements of a species (Masuoka *et al*, 2010) and to predict species distribution (Elith *et al*, 2006; Alvar *et al*, 2012) through examination of environmental conditions at known locations of suspected species and subsequent identification of areas of similar environmental conditions to estimate probability of the presence of selected species (Phillips *et al*, 2006).

L. martiniquensis, a zoonotic protozoan, was recently reported in Thailand (Muller *et al*, 2009; Lobsiger *et al*, 2010; Reuss *et al*, 2012; Chusri *et al*, 2014) and, thus, the distribution of potential vectors can play a role in the maintenance of the transmission cycle. In our study, localities of *S. gemmea* and *S. barraudi* obtained from published articles of sandfly species in Thailand were mapped and used to create ENMs estimating the distribution and influencing environmental factors of these *Sergentomyia* spp in the country. The ENM generated the first predictive geographic distribution of two potential leishmaniasis vectors and environmental conditions associated with the presence of the vectors, which should assist in our understanding of leishmaniasis vector distribution in Thailand.

MATERIALS AND METHODS

Study area and data collection

This study focused within the coordinates 97° E, 105° E and 5° N, 20° N of Thailand. The analysis was based on a set of *S. gemmea* and *S. barraudi* records compiled from published articles. Latitude and longitude data of the sandflies were used when available, and, if not, the locations were extrapolated based on the coordinate points of the closest locality to the collecting locations, such as a town or city. The coordinates of the sandfly localities were converted to a map layer and plotted on a base map of Thailand (GADM Database, www.gadm.org) using a Geographic Information System (GIS) Program, ArcGIS version 10 (Environmental Systems Research Institute, Redlands, CA). In total, 27 and 39 points of *S. gemmea* and *S. barraudi* records respectively were obtained from the publications of sandfly surveys in Thailand (Kongkaew *et al*, 2007; Polseela *et al*, 2007; Apiwathnasorn *et al*, 2011; Polseela *et al*, 2011a, b; Polseela, 2012; Sukra *et al*, 2012; Kanjanopas *et al*, 2013; Chusri *et al*, 2014; Panthawong *et al*, 2015).

Environmental data

Thirty-eight environmental raster layers (1 altitude, 1 land cover, 24 temperatures, and 12 precipitations) were used in ENMs. Each raster layer was re-sampled to a 1-km^2 pixel, geo-referenced and subset to the study area, and then, data layers of *S. gemmea* and *S. barraudi* presence were overlaid. Bioclimatic data used for modeling were obtained from WorldClim version 1.4 (http://www.worldclim.org) consisting of total precipitation, and mean minimum and maximum temperatures from January to December. Gridded WorldClim precipitation and temperature data were averaged from 1950 to 2000 for each month based on monthly ground weather station measurements (Hijmans *et al*, 2005). The global elevation data obtained from WorldClim was re-sampled to a 1-km resolution from NASA Shuttle

Radar Topography Mission (SRTM) and then processed to the same projection and scale as the other WorldClim layers. Land cover data using FAO Land Cover Classification System (LCCS) were retrieved from Global Land Cover 2000 database produced by the European Commission, Joint Research Centre (http://forobs.jrc.ec.europa.eu/products/glc2000). Data were hierarchical classifications translated to a more generalized global land cover classes that consisted of 19 land cover classes to describe types of vegetation and density of the land cover, independent of the geo-climatic zone, such as temperate or tropical forests. Land cover data were used in original format, where 1 pixel = 1 km^2.

Ecological niche modeling

In order to model geographic distribution and influencing environmental factors of two *Sergentomyia* sandfly species in Thailand, the maximum entropy method in MaxEnt 3.2.1 modeling program (http://www.cs.princeton.edu/~schapire/maxent/) (Phillips *et al*, 2006) was employed. A maximum entropy algorithm was applied to analyze values of environmental layers to estimate range of presence probability of the species over a geographic region (Phillips *et al*, 2004; Phillips *et al*, 2006). Twenty-five percent of randomly selected occurrence points were enlisted to test accuracy of the model testing points, and the remaining occurrence points were used to build the model training points.

Contribution of the environmental variables was tested by jackknife analysis in MaxEnt program to calculate the importance of each environmental variable by measuring the training gain of the variables used individually as well as in combination with other variables. When a variable produces a high training gain when used alone in the model, the variable is considered important, and the variable is also considered important if the training gain is low when the variable is removed from the model (Phillips *et al*, 2006). The model is deemed accurate when area under the curve (AUC) is >0.8 and minimum training presence *p*-value <0.05 (Phillips and Dudik, 2008). The probability values of occurrence underneath locations were extracted and examined using ArcGIS version 10.

Statistical analysis

For comparison of environmental values, pixel values underneath each recorded location of *S. gemmea* and *S. barraudi* extracted using ArcGIS version 10 were employed. Nonparametric Mann-Whitney *U* test was used to compare geographic and bioclimatic characteristics between the two sandfly species, and Pearson χ^2 test to compare land cover and region categories. Statistical analysis was conducted using SPSS version 11.5 (SPSS, Chicago, IL). For all statistical tests a *p*-value <0.05 is considered significant.

RESULTS

ENM demonstrated reliability and accuracy of predictive distribution of *S. barraudi* and *S. gemmea* that gained the highest AUC training point and *p*-value of significance (AUC = 0.959 and 0.973; p = 0.008 and <0.001, respectively) (Table 1). Jackknife test of importance of each environmental variable showed low regularized training gain variables observed during the summer months (April to June) (tmax04 - tmax06) for both *S. barraudi* and *S. gemmea*, whereas regularized training gains during the rainy and dry seasons (July to February) (tmax07 - tmax02) were higher (Fig 1).

Table 1
MaxEnt model accuracy analysis of *Sergentomyia barraudi* and *S. gemmea*.

Species	AUC training point[a]	AUC test point[a]	*p*-value of minimum training presence
S. barraudi	0.959	0.882	0.008
S. gemmea	0.973	0.906	<0.001

[a]Area under the curve of 0.5 is a random prediction, and a value >0.9 indicates high reliability and <0.7 poor reliability. The training data (based on 75% of records) are the points used to build the model and the test data (25% of records) are used only for testing the model's accuracy.

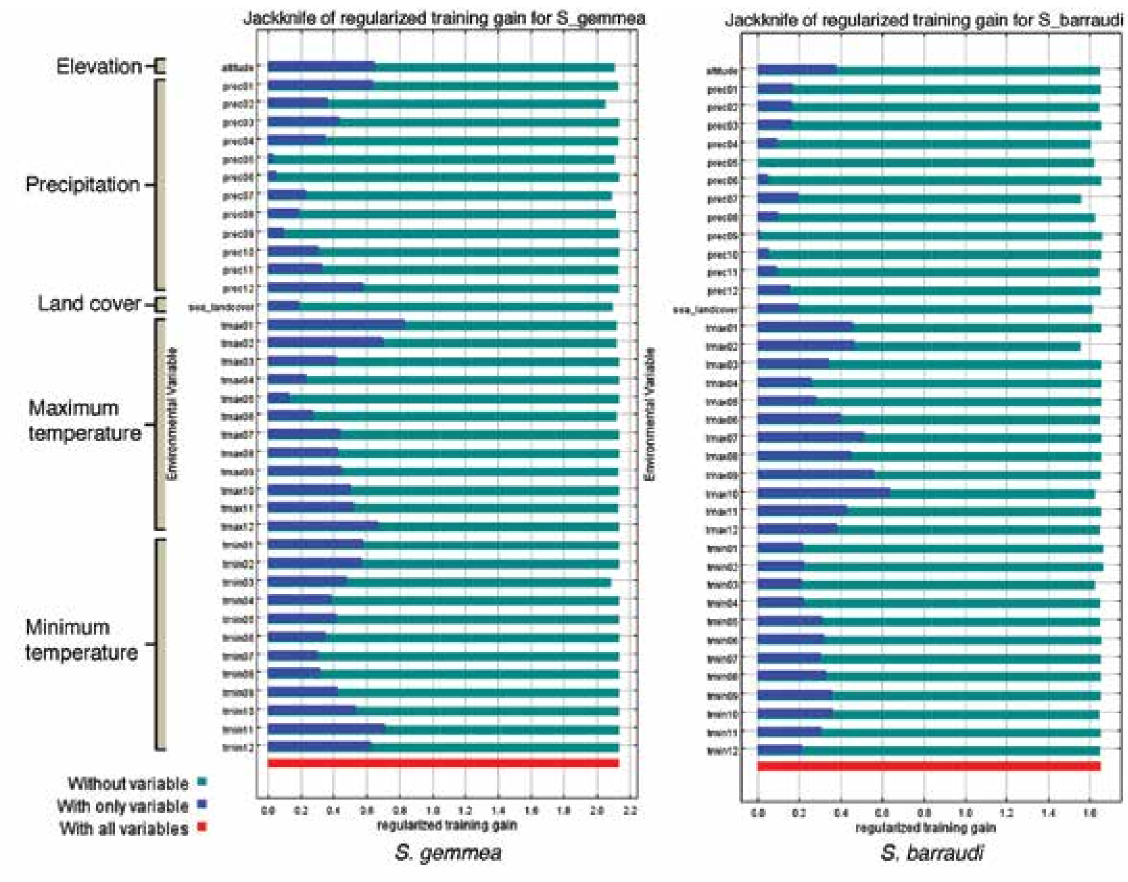

Fig 1-Jackknife regularized training gain of *Sergentomyia barraudi* and *S. gemmea*. Red bar represents training gain achieved by a model using all variables, dark blue bar training gain achieved in a model using a single variable and aqua bar training gain achieved when that particular variable is dropped from the model. altitude, elevation (m); prec, precipitation (mm); sea_landcover, Southeast Asia land cover; tmax, maximum temperature (°C); tmin, minimum temperature (°C); 01–12, January - December.

Results of the test indicated the environmental variable with highest gain using the prediction power of the model alone was maximum temperature for *S. barraudi* and *S. gemmea* (tmax10 and tmax01, respectively). Average precipitation variables during the dry and summer seasons (November to April) (prec11 - prec04) were important for environmental suitability for only *S. gemmea*. Contribution ratios demonstrated three major variables were important for both *S. barraudi* and *S. gemmea*, namely, elevation (altitude = 10.5 and 14.6, respectively), annual precipitation in January (prec01 = 9.7 and 16.9, respectively) and maximum temperature in February (tmax02 = 21.3 and 15.9, respectively) (Tables 2 and 3). These three variables contributed 41.5% and 47.4% to the model building of *S. barraudi* and *S. gemmea*, respectively, suggesting their high importance in influencing the presence of these two sandfly species in Thailand.

Table 2
Minimum (min), maximum (max) and mean values and percent contribution of environmental data layers for *Sergentomyia gemmea* model.

Variable	Description	Min	Max	Mean	Percent contribution
altitude	Altitude (elevation above sea level), m	6	280	73.85	14.6
SEA land-cover	Class of land cover	N/A	N/A	N/A	3.5
prec01	Precipitation of January, mm	1	164	39.74	16.9
prec02	Precipitation of February, mm	10	53	27.11	13.6
prec03	Precipitation of March, mm	24	95	56.81	2.1
prec04	Precipitation of April, mm	61	200	114.41	1.0
prec05	Precipitation of May, mm	149	355	207.37	0.8
prec06	Precipitation of June, mm	91	426	189.41	0.1
prec07	Precipitation of July, mm	111	375	204.93	2.2
prec08	Precipitation of August, mm	111	399	229.63	2.9
prec11	Precipitation of November, mm	17	468	177.78	0.1
prec12	Precipitation of December, mm	3	361	91.07	0.4
tmax01	Mean maximum temperature of January, °C	29.6	31.8	31.0	14.0
tmax02	Mean maximum temperature of February, °C	31.3	34.1	32.8	15.9
tmax06	Mean maximum temperature of June, °C	30.7	34.2	32.3	0.7
tmax09	Mean maximum temperature of September, °C	29.9	32.1	31.2	0.9
tmax11	Mean maximum temperature of November, °C	29.1	31.6	30.3	1.1
tmax12	Mean maximum temperature of December, °C	28.7	31.1	30.0	2.3
tmin03	Mean minimum temperature of March, °C	17.7	24.0	21.8	2.3
tmin11	Mean minimum temperature of November, °C	18.2	22.9	21.6	0.1
tmin12	Mean minimum temperature of December, °C	14.0	22.8	20.1	4.5

N/A, not available; SEA, Southeast Asian.

Table 3
Minimum (min), maximum (max) and mean values and percent contribution of environmental data layers for *Sergentomyia barraudi* model.

Variable	Description	Min	Max	Mean	Percent contribution
Altitude	Altitude (elevation above sea level), m	5	393	105.79	10.5
SEA land-cover	Class of land cover	N/A	N/A	N/A	2.6
prec01	Precipitation of January, mm	1	188	31.15	9.7
prec02	Precipitation of February, mm	3	56	23.74	7.0
prec03	Precipitation of March, mm	13	95	46.64	0.1
prec04	Precipitation of April, mm	44	200	95.72	9.3
prec05	Precipitation of May, mm	119	355	193.23	2.1
prec07	Precipitation of July, mm	105	438	197.82	3.4
prec08	Precipitation of August, mm	110	484	228.54	1.2
prec09	Precipitation of September, mm	146	502	273.72	0.2
prec10	Precipitation of October, mm	79	352	203.64	0.1
prec11	Precipitation of November, mm	10	507	127.15	1.3
tmax02	Mean maximum temperature of February, °C	30.4	34.5	32.76	21.3
tmax06	Mean maximum temperature of July, °C	30.7	33.8	32.45	1.2
tmax09	Mean maximum temperature of September, °C	29.9	32.4	31.30	11.8
tmax10	Mean maximum temperature of October, °C	30.0	32.2	31.03	6.3
tmax11	Mean maximum temperature of November, °C	28.8	31.6	30.30	6.0
tmax12	Mean maximum temperature of December, °C	26.8	31.3	29.80	0.1
tmin03	Mean minimum temperature of March, °C	15.7	24.3	21.46	3.4
tmin04	Mean minimum temperature of April, °C	19.6	25.5	23.29	0.5
tmin06	Mean minimum temperature of June, °C	22.7	25.2	23.67	1.5
tmin08	Mean minimum temperature of August, °C	22.5	24.7	23.54	0.4
tmin11	Mean minimum temperature of November, °C	17.2	23.1	20.88	0.1
tmin12	Mean minimum temperature of December, °C	13.0	22.8	18.71	0.2

N/A, not available; SEA, Southeast Asian.

Similar response curve was observed for both sandfly species (Fig 2a), which showed the probability of sandfly presence decreased with increase in elevation. Presence of *S. barraudi* and *S. gemmea* were rarely observed at elevations >500 m, and no significant difference in the influence elevation between the two species (mean elevation ± SD = 106 ± 18 and 74 ± 17, respectively). The response curves of annual precipitation for each month exhibited concordance in probability of the presence in both sandfly species, decreasing as annual precipitations increased and limited to approximately 300 mm both (Fig 2b). Mean annual precipitation for *S. barraudi* and *S. gemmea* presence during the dry and summer seasons (85 ± 6 and 107 ± 8 mm, respectively) is significantly lower than that during the rainy season (215 ± 6 and 222 ± 10 mm, $p<0.001$ and <0.001, respectively). Concordance of the presence

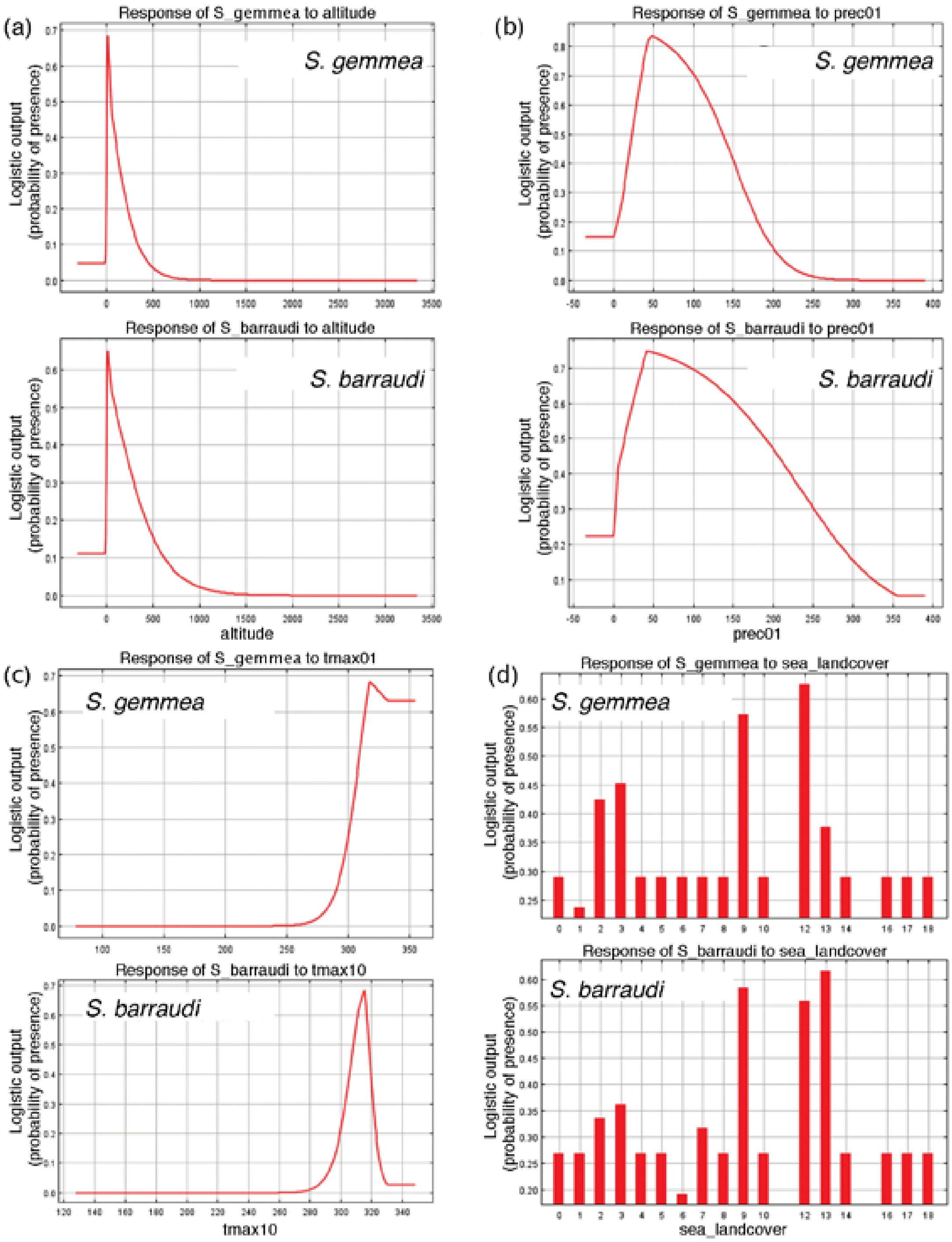

Fig 2-Predicted probability of *Sergentomyia barraudi* and *S. gemmea* versus selected variables. a). Elevation (altitude). b). Precipitation in December (prec12, mm). c). Maximum temperature in February (tmax02, °C). d). Class of Southeast Asian land cover (sea_landcover). Temperature (°C) = x-axis value × 0.1°C.

probability was observed for all 12 months for both sandfly species, increasing with the maximum temperature and limited to 31-34°C (Fig 2c). There is no significant difference between the mean temperature for presence probability for *S. barraudi* and *S. gemmea* (32.1 ± 0.9 and 32.0 ± 0.9°C, respectively); however, mean maximum temperature for *S. barraudi* and *S. gemmea* presence during the dry and rainy seasons (31.5 ± 0.8 and 31.5 ± 0.9°C, respectively) is significantly lower than that during the summer season (33.8 ± 1.5 and 33.4 ± 1.6°C, $p<0.001$ and <0.001, respectively). Similar suitable land cover was observed for *S. barraudi* and *S. gemmea* presence (Fig 2d) where high probability was found in cropland/natural vegetation as well as in unflooded cultivated and managed land cover (classes 9 and 12) (Table 4). Nonetheless, *S. barraudi* was also found in flooded, cultivated and managed land cover (class 13).

ENM of geographic distributions of *S. barraudi* and *S. gemmea* in Thailand revealed a common distribution across the southern region, having the highest probability of sandfly presence, ranging from 0.6 to 1.0. Distribution of *S. barraudi* was common along both coast sides of the southern region, whereas *S. gemmea* was mostly in provinces located along the Andaman side except for Surat Thani Province, located on the coast of the Gulf of Thailand (Fig 3). In contrast to *S. gemmea*, with a high probability of presence in

Table 4
Number of *Sergentomyia barraudi* and *S. gemmea* coordinates in different classes of land cover.

Class of land cover (number)	*S. gemmea* (number)	*S. barraudi* (number)
Sea (0)	-	-
Tree cover, evergreen (1)	1 (85)	1 (59)
Mosaic: tree cover, vegetation or cropland (2)	-	-
Tree cover, deciduous (3)	2 (2)	2 (2)
Tree cover, regularly flooded mangrove (4)	-	-
Tree cover, regularly flooded swamp (5)	-	-
Mosaic and dominant shrub cover, mainly evergreen (6)	2 (612)	3 (1,090)
Mosaic and shrub cover dominant, mainly deciduous (7)	2 (4)	3 (38)
Shrub cover, mainly deciduous (dry or burst) (8)	-	-
Mosaic of cropland/other natural vegetation (shifting cultivation in mountains) (9)	6 (1,411)	7 (52)
Herbaceous cover (including alpine grassland) (10)	-	-
Sparse herbaceous cover >3,000 m (11)	-	-
Cultivated and managed, non-irrigated (mixed) (12)	11 (1,029)	15 (94)
Cultivated and managed, irrigated (flooded, rice, shrimp farms) (13)	3 (3)	8 (8)
Bare area (rock and lime stone) (14)	-	-
Snow and ice (15)	-	-
Artificial surface (16)	-	-
Water body (17)	-	-
No data (18)	-	-

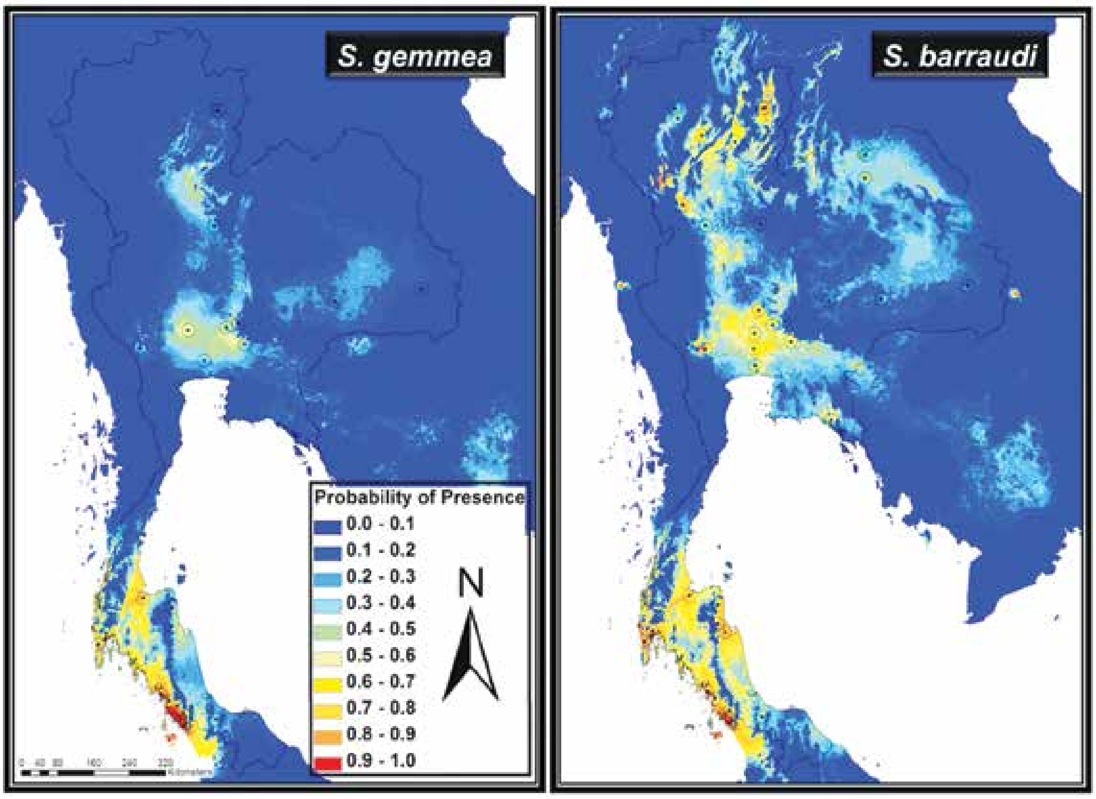

Fig 3-MaxEnt model of *Sergentomyia barraudi* and *S. gemmea*. Darker red indicates areas estimated to have higher probability of presence and darker blue lower probability presence.

southern compared to the rest of Thailand (χ^2 = 15.519, p = 0.001), *S. barraudi* was predicted to be broadly distributed across the whole country (Table 5).

DISCUSSION

MaxEnt is a robust algorithm based on machine learning responses designed to make predictions from data of presence only (Phillips *et al*, 2006; Phillips and Dudik, 2008) for predictive spatial risk modeling, such as species distribution modeling and or ENM. Using the latter, the current study produces the first geographic range and associated environmental factors of *S. barraudi* and *S. gemmea* in Thailand, albeit localities of complex species such as *S. barraudi* were not included in the model prediction due to unavailable data. Although the predictive distribution of these two species based on data of their presence obtained from limited published articles might not represent the actual distribution of sandflies in the whole country, the ENM has provided a preliminary view of the geographic distributions and environmental suitability for the presence of these sandfly species, which could be matched with the localities of VL cases in the country. Recently, asymptomatic *Leishmania* infection among patients with HIV / AIDS has been reported with 25.1%

Table 5
Distribution of *Sergentomyia barraudi* and *S. gemmea* based on probability of presence in different regions of Thailand.

Region	*S. gemmea*		*S. barraudi*	
	Province	Probability of presence	Province	Probability of presence
Southern	Satun	≤1.0	Satun	≤1.0
	Phuket	≤0.9	Nakhon Si Thammarat	≤0.9
	Surat Thani	≤0.9	Phang-Nga	≤0.9
	Trang	≤0.9	Phuket	≤0.9
	Krabi	≤0.8	Surat Thani	≤0.9
	Phang-Nga	≤0.8	Trang	≤0.8
			Chumphon	≤0.7
			Krabi	≤0.7
			Ranong	≤0.7
Northern	Not specified	-	Nan	≤0.9
			Tak	≤0.9
			Phrae	≤0.8
			Lampang	≤0.7
			Phayao	≤0.7
			Uttaradit	≤0.7
Central	Not specified	-	Kanchanaburi	≤1.0
			Lop Buri	≤0.9
			Ang Thong	≤0.8
			Saraburi	≤0.8
			Suphan Buri	≤0.8
			Nakhon Sawan	≤0.7
			Pathum Thani	≤0.7
			Phra Nakhon Si Ayutthaya	≤0.7

prevalence in Trang Province, southern Thailand (Manomat *et al*, 2017), where a high probability of the presence of *S. gemmea* (≤0.9) and *S. barraudi* (≤0.8) were estimated in our study, demonstrating the beneficial advantage of the model in studies of vector-host interaction and *Leishmania* transmission.

Temperature was one important factor for the presence of *S.barraudi* and *S. gemmea*, which was limited to 31-34°C, observed during the rainy and dry rather than the hotter summer seasons. Temperature seasonality has been identified as an important variable in that in Europe winter temperature controls the distribution of sandfly species by influencing the diapause of eggs and the survival of sandflies (Medlock *et al*, 2014; Koch *et al*, 2017).

Precipitation was another important factor for *S. gemmea* but not for *S. barraudi* presence, suggesting that *S. gemmea* might be sensitive and less adaptive to climate change, as reflected in its specific habitat suitability and geographic distribution. Although a certain amount of moisture is needed for sandflies to develop and survive (Kasap and Alten, 2005; Kasap and Alten, 2006), heavy rainfall can terminate the population by killing adults and immature stages (Simsek *et al*, 2007). Our results are consistent with other studies in South America on the effect of rainfall, which reported the two sandfly species are commonly found during the dry and summer seasons when precipitation is less (Gomez-Bravo *et al*, 2017). Interestingly, Polseela *et al* (2007) reported a low monthly rainfall during June 2006 of approximately 300 mm corresponding to 50-300 mm of annual precipitation estimated by ENM. Therefore, bioclimatic seasonal factors, such as temperature and precipitation, are suggested to be factors governing the geographic distribution of S. *barraudi* and *S. gemmea*, and changes in these factors could reduce or promote the distribution of these sandfly species.

Selective habitat suitability of both sandfly species distribution indicated association with cultivated and managed cropland types of vegetation, regions where leishmaniasis is also prevalent, *eg*, in peridomiciliary areas surrounding with orchards, palm and rubber plantations of southern Thailand (Sukra *et al*, 2012; Kanjanopas *et al*, 2013; Chusri *et al*, 2014,). Previous studies also reported a diversity of cave-dwelling sandflies, collected in caves located in central and northern Thailand (Polseela *et al*, 2007; Polseela *et al*, 2011a), with a lower proportion of *S. gemmea* (0.5-11%) in caves of central and northern regions than that (46-93%) in croplands of the south (Sukra *et al*, 2012). As ENM in the study was based on data limited to those in the literature, leaving out large non-survey areas, further surveillance and observations are needed to validate the selective habitat suitability in *S. gemmea* and *S. barraudi* populations. These validated specific suitable habitats should beneficially facilitate reliable determination of actual distribution of *S. gemmea* and *S. barraudi* in Thailand. It is worth noting DNA barcoding has recently been introduced to investigate species diversity of sandflies, but has been limited to sandflies collected only in caves (Polseela *et al*, 2016; Sukantamala *et al*, 2017).

In summary, we used ENM to predict the distribution of two sandfly species, *S. barraudi* and *S. gemmea*, in Thailand, demonstrating *S. gemmea* predominant in the southern region and *S. barraudi* widely distributed across different regions of the country. Bioclimatic variables were important environmental factors influencing the presence of the sandflies; however, *S. barraudi* showed better adaptation as evidenced by the comparatively lower detrimental impact of environmental factors on this species. Although ENM was based on elevation, precipitation, land cover, and maximum and minimum temperatures, the distribution of sandflies might also depend on other environmental factors, such as soil type, land-use or wind patterns limiting their flight activity (Claborn, 2010), requiring further clarification as to which factors crucially affect and are linked to the distribution of the sandflies population. This first ENM approach to mapping and predicting geographic distributions and environmental suitability of *S. barraudi* and *S. gemmea* should encourage future studies in locating specific collecting sites as well as surveillance methods, especially, regarding the role of *S. barraudi* and *S. gemmea* as potential biological vectors of *Leishmania* in Thailand.

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