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Research article

MaxEnt model for predicting potential distribution of *Vitex glabrata* R.Br. in Thailand

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Abstract

In addition to various ethnobotanical uses, *Vitex glabrata* R.Br. is becoming important in the agricultural chemical industry, because its bark contains a high amount of 20-hydroxyecdysone. This compound is a major substrate for synthesis of the brassinosteroid-mimic compound named 7,8-dihydro-8α-20-hydroxyecdysone (DHECD) which has been shown to increase agricultural productivity. Therefore, surveying the habitat suitability of *V. glabrata* is important for sustainable management of DHECD production. A maximum entropy (MaxEnt) species distribution model was used to predict the probability of occurrence and to determine relevant environmental factors influencing the distribution of *V. glabrata* in Thailand. Presence-only data was used from 44 verified localities of specimens in Thai herbaria and 17 geo-referenced locations from the Global Biodiversity Information Facility. Twenty environmental variables (19 bioclimatic variables and also altitude from the WorldClim database), were used to model its distribution and potential habitat. Environmental variable contributions were evaluated using jackknife and randomized testing. The important variables in this model were: temperature seasonality, altitude and precipitation of driest month, respectively. A high probability of *V. glabrata* occurrence was predicted for approximately 21% of Thailand, including the south and some eastern and western parts. Another 28% of the country (some of the northern, northeastern and western parts) had a medium probability of occurrence for *V. glabrata*. The current populations of *V. glabrata* should be thoroughly surveyed in these areas with medium to high probabilities for the sustainable land use management of this plant as tha source of brassinosteroid-mimic production.

Introduction

Vitex glabrata R.Br. is a tree locally known as 'Khai-Nao' in Thai and belongs to family Lamiaceae and is distributed in dipterocarp and dry evergreen forests (Chantaranothai, 2011). It is widespread through South Asia, Southeast Asia, the islands of New Guinea and in Northern Australia (Global Biodiversity Information Facility, 2017). This plant has many ethnobotanical uses (Siniaparaya et al., 2007; Rani and Sharma, 2012), but now it is becoming more important in the agricultural chemical industry because its bark contains a high amount of 20-hydroxyecdysone (ECD). Using only one step, this compound can be synthesized into DHECD (7,8-dihydro-8α-20-hydroxyecdysone) and other derivatives (Suksamran et al., 1998). This newly synthesized compound has been shown to enhance agricultural productivity in many economic plants (Zaharah et al., 2012; Thussagunpanit, 2013; Sonjaroon, 2014; Matmarurat, 2016; Chumpookam et al., 2017). Despite its potential, the distribution and occurrence of *V. glabrata* in Thailand are not well-documented in the literature, making it difficult to develop a sustainable management plan for the production of DHECD from the bark of this plant.

Species distribution models (SDMs) have been widely applied in biogeography, ecology and biodiversity over the past decade (Shcheglovitova and Anderson, 2013; Beck et al., 2014; Radosavljevic and Anderson, 2014). They are a quantitative way of estimating species geographic ranges from occurrence records and the environmental conditions found there (Beck et al., 2014). The maximum entropy model (MaxEnt) is one of the most widely used SDMs with presence-only data. It has been used to predict suitable areas for occurrence by finding a correlation between species existence and its biophysical environment to predict the current distribution of the selected species (West et al., 2016). This technique showed a high predictive power using both large and very small sample sizes (Phillip et al., 2006; Elith

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et al., 2011). In Thailand, this model has been extensively used in the assessment of conservation status and evaluating adaptation of wildlife and forest to climate change (Trisurat et al., 2009; Klorvuttimontara et al., 2011; Trisurat et al., 2011; Jenks et al., 2012). Moreover, in term of public health, the MaxEnt has also been used to create a predictive risk map for parasite disease distribution of the liver fluke which causes opisthorchiasis (Suwannatrai et al., 2017).

The present study compiled all available data on the occurrence of *Vitex glabrata* and bioclimatic variables to determine suitable areas for this species in Thailand based on species distribution modelling. The main objective of this study was to estimate probability of species occurrence of *V. glabrata* in Thailand from environmental variables using the MaxEnt model. The results from the model will be used to inform management of *V. glabrata* for future use as a source of naturally occurring ECD.

Materials and Methods

Study area

Thailand is located in continental Southeast Asia between 5°37'N and 20°27'N and between 97°22' E and 105°37' E. The country area is approximately 513,115 km^2. The elevation ranges from sea level to 2,565 m (the top of Doi Intanon). The flora of Thailand has been divided into seven different regions, approximately corresponding with rainfall and current vegetation regions: North, Northeast, East, Southeast, Central, Southwest and Peninsula (Maxwell, 2004). Thai Meteorological Department (2014) summarized meteorological information on the country as follows. The climate of Thailand is under the influence of monsoon winds of seasonal character, including southwest and northeast monsoons. The southwest monsoon brings a stream of warm moist air from the Indian Ocean towards Thailand from mid-May until early October, causing abundant rain over the country. Usually, most areas of the country receive 1,200–1,600 mm a year except for Ranong Province on the west-coast of the peninsula and Trat Province in southeast that have more than 4,500 mm a year. The northeast monsoon begins from mid-October to mid-February, bringing the cold and dry air from the anticyclone in China mainland over major parts of Thailand, especially the northern and northeastern parts. The seasonal temperature of Thailand, the warmest period of the year in Thailand is in March to May, when the maximum temperature usually reaches near 40°C, while the coldest period of the year is in December to January, when minimum temperatures may decrease to near or below zero.

Occurrence data

In total, 44 records for *V. glabrata* were compiled and verified from four herbaria in Thailand, consisting of 10 records from the Bangkok Herbarium, Bangkok (BK), 27 records from the Forest Herbarium, National Park, Wildlife and Plant Conservation Department (BKF), 2 records from the Queen Sirikit Botanic Garden, Chiang Mai (QBG) and 5 records from the herbarium of the Department of Biology, Prince of Songkla University (PSU). Moreover, additional geo-referenced coordinates were obtained from the Global Biodiversity Information Facility (Global Biodiversity Information Facility, 2017) which resulted in seven records after excluding data with missing or clearly false locality coordinates. However, some herbaria records were without latitude and longitude. Therefore, the localities of these specimens were geo-referenced from the descriptive data in Google Earth Pro Version 7.3 (DigitalGlobe 2017; http://www.earth.google.com).

The occurrence data were selected on the basis of the following criteria: 1) the physical sample, when available, matched the description of the species; 2) the label clearly described the locality of collecting area, especially the coordinates or at least the district name which could be geo-referenced; and 3) where a locality had more than one specimen, only one specimen was chosen to represent the occurrence in the model.

Environmental variables

Twenty environmental variables were used as predictors of *V. glabrata* habitat distribution. Nineteen bioclimatic variables were obtained from WorldClim dataset version 2 (http://www.worldclim.org/) consisting of: annual mean temperature (bio1), mean diurnal range (bio2), isothermality (bio3), temperature seasonality (bio4), maximum temperature of warmest month (bio5), minimum temperature of coldest month (bio6), annual temperature range (bio7), mean temperature of wettest quarter (bio8), mean temperature of driest quarter (bio9), mean temperature of warmest quarter (bio10), mean temperature of coldest quarter (bio11), annual precipitation (bio12), precipitation of wettest month (bio13), precipitation of driest month (bio14), precipitation seasonality (bio15), precipitation of wettest quarter (bio16), precipitation of driest quarter (bio17), precipitation of warmest quarter (bio18) and precipitation of coldest quarter (bio19). Altitudinal data (based on a digital elevation model) were also obtained from the WorldClim website. All environmental variables were resampled using a 30 arc-second grid to provide approximately 1 km^2 spatial resolution (Fick and Hijmans, 2017).

Maximum entropy model

Distribution models were generated using MaxEnt (version 3.4.1; Phillips et al., 2006). The software requires as input data the geographical locations of species occurrences and gridded data of environmental variables. In the current study Maxent was used to fit a species distribution model to a random sample of 70% of the species occurrence data (training), with the remaining 30% of the data used to assess (testing) model performance. Following López-Martínez et al. (2016), the parameters were set as: maximum number of iterations (500), convergence threshold (0.00001), default prevalence (0.5), regularization multiplier (1), replicated run type (cross-validate), max number of background points (10,000) and replicates (10).

The threshold-independent area under the curve (AUC) of the receiver operating characteristic (ROC) plot was used to assess the quality of the prediction. An AUC value of 0.5 shows that model predictions are not better than random expectation, while values of 0.5–0.7 indicate poor performance, 0.7–0.9 reasonable or moderate performance and >0.9 high performance (Peterson et al., 2011). Variable contributions were also computed and a jackknife test was performed of regularized training gain for estimating the importance of the influence of each environmental variable on *V. glabrata*' modelling performance.

Based on the probability data from MaxEnt, areas in the country were classified into three levels according to the probability of occurrence of *V. glabrata*: high (80th percentile of the probability distribution), medium (between 50th and 80th percentiles of the probability distribution), and low probability (less than or equal to 50th percentile of the probability distribution). The classification facilitated assessment of the potential distribution of *V. glabrata* in Thailand.

Results and Discussion

Based on the MaxEnt modelling, the average test AUC for the replicate 10 runs was 0.744 with a standard deviation of 0.182. Moreover, the AUC values of the model for the training and test data were 0.887 and 0.742, respectively, indicating that the model had a reasonable or moderate performance to predict *Vitex glabrata* distribution in Thailand (Peterson et al., 2011). The probabilities of occurrence for *V. glabrata* ranged from 0 to 1, with the 80th percentile at 0.45 and the 50th percentile at 0.23. Therefore, an area with a probability of 0.45 or greater was considered to have a "high" probability of occurrence, an area with a probability of 0.23–0.45 was considered "medium" and the rest of the area with a probability lower than 0.23 was considered to have "low" probability of occurrence.

The probability classes (high, medium, low) were plotted onto a map of Thailand (Fig. 1). The area with a high probability of species occurrence covered approximately 21% of the area of Thailand and included most of the southern area as well as scattered portions of Eastern and Western Thailand. The areas with medium probability covered approximately 28% of the country, scattered in upper Northern and Northeastern Thailand, being most of the Tenasserim Hills including both Prachuap Khiri Khan and Chumphon provinces and some of the western part of Kanchanaburi province. The remaining areas were considered to have a low probability of finding *V. glabrata*, covering about 51% of the country, including most of central Northern Thailand, Northeastern Thailand and the lowlands of Central Thailand.

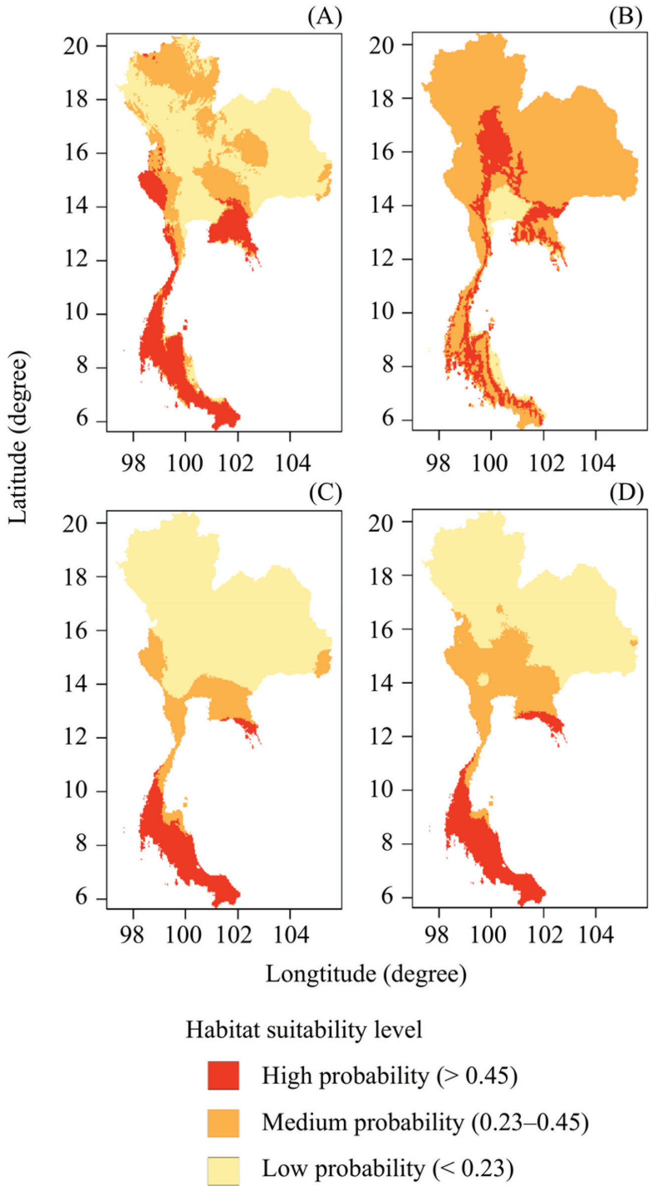

Fig. 1 Habitat suitability map of *Vitex glabrata* occurrence in Thailand using MaxEnt modelling with various sets of variables: (A) with all environmental variables; (B) with only temperature seasonality; (C) with only altitude; (D) with only precipitation of driest month

Moreover, the model also estimated the relative contributions of the environmental variables in the species distribution model (Table 1). Out of the 20 variables, 18 contributed to modeling *V. glabrata* distribution. However, temperature seasonality, altitude and precipitation of driest month were among the significant contributors to the habitat suitability distribution of *V. glabrata*. In addition, the results of the jackknife test of variable importance showed that the environmental variable with the highest performance when used in isolation was temperature seasonality, which therefore appeared to be the most informative variable by itself. The environmental variable that decreased the performance the most when it was omitted was altitude (Fig. 2). Therefore, altitude appeared to provide unique and critical information that was not present in any other variables in the model (Fig. 1).

Chantaranothai (2011) reported *V. glabrata* can be found in dipterocarp and dry evergreen forests, in an altitude range of 10-1,280 m. Furthermore, it was found in most of peninsular of Thailand (11 provinces). In this area, the climate is not very seasonal, meaning that the temperature and precipitation vary very little between different times of the year. The mean temperature is approximately 23.8^{o}C with mean annual precipitation of around 2,228 mm. (Thai Meteorological Department, 2014). The current model results and previous floristics data suggested that new potential areas for *V. glabrata* should be mostly in lowland areas with low seasonality and moderate temperature. Such characteristics can be found in a larger part of Eastern and Northeastern Thailand, where currently there are low to moderate probabilities of occurrence. This could be because relatively fewer collections have been made in these areas, resulting in fewer records of *V. glabrata* and other plants in general. This area also has high climate seasonality, which has been shown to be negatively associated with the occurrence of *V. glabrata* (Fig. 1, Chantaranothai 2011).

The current results provide an estimate for the fundamental niche in the abiotic environmental space, which this species inhabits (Fourcade et al., 2014). It may be concluded that temperature seasonality, altitude and precipitation in the driest month were the most influential variables for predicting the distribution of *V. glabrata*, with potential localities being in Southern Thailand and some of Eastern and Western Thailand (Table 1 and Fig. 1). The potential habitat distribution map for *V. glabrata* can help researchers in planning searching for new populations and in identifying priority survey sites. It is expected that intended surveys to identify *V. glabrata* in areas classed as high or moderate probability (such as areas in Southern and Eastern Thailand) will verify the accuracy of the MaxEnt modelling. The results can help with the management of this plant as a source of novel agrochemical products.

Conflict of Interest

The authors declare that there are no conflicts of interest.

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Table 1 Environmental variables used in the study and their percentage contribution and permutation importance in the MaxEnt model for predicting occurrence of *Vitex glabrata* in Thailand

Environmental variable	Contribution (%)	Permutation importance
Temperature seasonality (bio4)	58	4.6
Altitude (alt)	10.2	10.5
Precipitation of driest month (bio14)	7.8	25.9
Precipitation of warmest quarter (bio18)	5.5	6.8
Precipitation of wettest quarter (bio16)	3.8	12.4
Precipitation of coldest quarter (bio19)	3.7	1.3
Annual precipitation (bio12)	3.1	19.9
Max temperature of warmest month (bio5)	1.5	2
Mean diurnal range (bio2)	1.4	5.3
Temperature annual range (bio7)	1.1	0.1
Mean temperature of wettest quarter (bio8)	0.9	2.1
Precipitation of wettest month (bio13)	0.9	4
Precipitation of driest quarter (bio17)	0.6	0.5
Precipitation seasonality (bio15)	0.5	0.8
Mean temperature of warmest quarter (bio10)	0.4	0
Isothermality (bio3)	0.1	0
Mean temperature of coldest quarter (bio11)	0.1	1.1
Mean temperature of driest quarter (bio9)	0.1	2.1
Annual mean temperature (bio1)	0	0.3
Min temperature of coldest month (bio6)	0	0

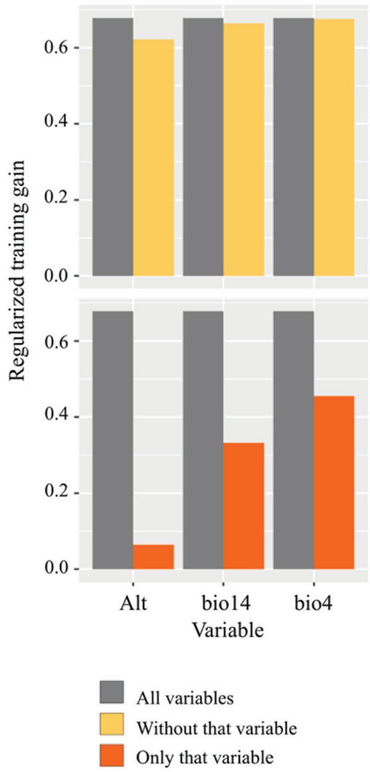

Fig. 2 Three important variables of the 20 used in modelling *Vitex glabrata* distribution with jackknife testing of regularized training gain when a variable was excluded from the model (A) and if only one variable was estimated in the model (B), compared to the full model, where alt = altitude, bio14 = precipitation of driest month and bio4 = temperature seasonality

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