2011

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Applied Geography 31 (2011) 1106–1114

Contents lists available at ScienceDirect

Applied Geography

journal homepage: www.elsevier.com/locate/apgeog

# Plant species vulnerability to climate change in Peninsular Thailand

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*Keywords:*
Climate change
Maxent
Peninsular Thailand
Plant species
Species distribution
Species vulnerability

A B S T R A C T

The objective of this research study was to evaluate the consequences of climate change on shifts in distributions of plant species and the vulnerability of the species in Peninsular Thailand. A sub-scene of the predicted climate in the year 2100, under the B2a scenario of the Hadley Centre Coupled Model, version 3 (HadCM3), was extracted and calibrated with topographic variables. A machine learning algorithm based on the maximum entropy theory (Maxent) was employed to generate ecological niche models of 66 forest plant species from 22 families. The results of the study showed that altitude was a significant factor for calibrating all 19 bioclimatic variables. According to the global climate data, the temperature in Peninsular Thailand will increase from 26.6 °C in 2008 to 28.7 °C in 2100, while the annual precipitation will decrease from 2253 mm to 2075 mm during the same period. Currently, nine species have suitable distribution ranges in more than 15% of the region, 20 species have suitable ecological niches in less than 10% while the ecological niches of many *Dipterocarpus* species cover less than 1% of the region. The number of trees gaining or losing climatically suitable areas is quite similar. However, 10 species have a turnover rate greater than 30% of the current distribution range and the status of several species will in 2100 be listed as threatened. Species hotspots are mainly located in large, intact protected forest complexes. However, several landscape indices indicated that the integrity of species hotspots in 2100 will deteriorate significantly due to the predicted climate change.



## Introduction

Thailand has a species-rich and complex biodiversity that differs in various parts of the country (Wikramanayake et al., 2002). The Kingdom harbours one of the 25 global biodiversity hotspots (Myers, Mittermeier, Mittermeier, & Kent, 2000), supporting approximately 7–10% of the world's plant, bird, mammal, reptile, and amphibian species (ONEP, 2006). Biodiversity provides both direct and indirect benefits to people, especially the rural poor (Millennium Assessment, 2005). In addition, it has been considered an important resource base for socio-economic development in Thailand (National Economic and Social Development Board, 2007). Unfortunately, the biodiversity of Thailand is under severe threat, especially from deforestation (Stibig et al., 2007). The results from the monitoring in the last four decades show that the rate is considered to be one of the fastest rates of deforestation in the tropics (Middleton, 2003). Besides deforestation, climate change has also become a global threat to biodiversity. Changes in climate have the potential to affect both the geographic location of ecological systems and the mix of species that they contain (Secretariat of the Convention on Biological Diversity, 2003).

In recent years, a number of GIS-based modeling methods of species distributions have been developed for assessing the potential impacts of climate change, especially when detailed information about the natural history of the species is lacking (Anderson, Laverde, & Peterson, 2002; Peralvo, 2004). Species-distribution models (SDMs) are based on the assumption that the relationship between a given pattern of interest (e.g. species abundance or presence/absence) and a set of factors assumed to control it can be quantified (Anderson, Lew, & Peterson, 2003; Anderson & Martinez-Meyer, 2004; Guisan & Zimmermann, 2000; Raxworthy et al., 2003; ). Therefore, this methodology allows us to predict the potential distribution of a species even for areas that suffer from incomplete and biased samplings, or for areas where no collections have been made (Araujo & Guisan, 2006; Elith et al., 2006).

Miles, Grainger, and Phillips (2004) used spatial distribution models to predict current and future species distributions in the Amazonia. The results indicated that up to 43% of a sample of species in the region could become non-viable by 2095. In addition, approximately 59% of plant and 37% of bird species in the Northern Tropical Andes will become extinct or classified as critically endangered

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0143-6228/$ – see front matter © 2011 Published by Elsevier Ltd.
doi:10.1016/j.apgeog.2011.02.007

species by the year 2080 as a result of the A2 climate change scenario (Cuest-Comocho, Ganzenmuller, Peralvo, Novoa, & Riofrio, 2006). Habitats of many species will move poleward or upward. The climatic zones suitable for temperate and boreal plant species may be displaced 200–1200 km poleward. Parolo and Rossi (2008) compared historical records (1954–1958) with results from recent plant surveys (2003–2005) from alpine to aquatic ecosystems in the Rhaetian Alps, northern Italy and reported an increase in species richness from 153 to 166 species in higher altitudes. In addition, Trivedi, Morecroft, Berry, and Dawson (2008) indicated that Arctic-alpine communities in protected areas could undergo substantial species turnover, even under the lower climate change scenario for the 2080s.

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) indicated that the mean temperature in Thailand will raise by 2.0–5.5 °C by 2100 under the regionally-oriented economic development scenario of the Hadley Centre Coupled Model, version 3 (HadCM3 A2) (IPCC, 2007). Boonpragob and Santisirisomboon (1996) predicted that the temperature in Thailand will increase by 1.5–2.0 °C and annual rainfall in the south will increase by 40% by 2100. These changes would cause effects on Thai forests. The area of the subtropical life zone would decline from about 50% to 12–20% of the total cover, whereas the tropical life zone would expand its cover from 45% to 80%.

Trisurat, Alkemade, and Arets (2009) used a species distribution model and fine resolution (1 km) climate data to generate ecological niches of forest plant species in northern Thailand. The results showed high turnover rates, especially for evergreen tree species. The assemblages of evergreen species or species richness are likely to shift toward the north, where lower temperatures are anticipated for year 2050. In contrast, the deciduous species will expand their distribution ranges. A similar study was conducted by Zonneveld, Van, Koskela, Vinceti, and Jarvis (2009) to estimate the potential occurrence of *Pinus kesiya* Royle ex Gordon and *Pinus merkusii* Jungh. & De Vriese in Southeast Asia. The results revealed that lowland *P. merkusii* stands in Cambodia and Thailand are expected to be threatened mostly by climate alterations. This is due to maximum temperatures in the warmest month in 2050 predicted to be above 36 °C will increase beyond the tolerance range of *P. merkusii* and will kill adult trees of this species (Hijmans et al., 2005) and work against recruitment success at the stand and site scales, but not at the regional scale (Zimmer & Baker, 2008).

Peninsular Thailand covers a major floristic and climatic transition zone with both wet tropical rainforests as well as seasonal evergreen tropical forests of the Indo-Sundaic region. However, studies of effects of climate change on the geographical species' distribution at present and in the future are lacking. Baltzer, Davies, Nursupardi, Abul Rahman, and La Frankie (2007) and Baltzer, Gregoire, Bunyavejchewin, Noor and Davies (2008) investigated the mechanisms constraining local and regional tree species distributions in the Kanger–Pattani Line in the Indo-Malay region. The results showed that inherent differences in physiological traits were contributing to drought tolerance and are associated with differences in tropical tree species distributions in relation to rainfall seasonality. These results strongly implicate climate as a determinant of tree species distributions around the Kanger–Pattani Line. Hence, the objective of this research study is to evaluate the consequences of climate change on species shifts in distributions, and species vulnerability in the Peninsular Thailand.

## Methods

### *Study area*

Peninsular or Southern Thailand is situated between 5°37′ - 11°42′ North latitudes and 98° 22′ - 102° 05′ East longitudes. It covers 14 provinces and encompasses an area of approximately 70,700 $km^2$ or 14% of the country's land area (Fig. 1). Currently, protected areas cover approximately 14.8% of the region. Peninsular Thailand varies in width from roughly 50–22 km, and a mountainous backbone runs its full range oriented north–south. The average annual temperature is 26.6 °C. Annual precipitation is over 2000 mm for most of the area and exceeds 3000 mm in some parts. Rainfall increases southward as the length of the dry season and the magnitude of pre-monsoon drought stress declines. The southern mountain ranges receive rain from both the northeast and southwest monsoons.

According to World Wild Fund for Nature (2008), Peninsular Thailand encompasses the southern portion of the Tenasserim–South Thailand semi-evergreen rain forests eco-region. It is mainly influenced by Malaysian flora in the south and Burmese flora in the northern part (Raes & Van Welzen, 2009). Santisuk et al. (1991) classified forest types in the Peninsular Thailand into 2 categories, i.e. Peninsular Wet Seasonal Evergreen Forest and Malayan Mixed Dipterocarp Forest. Peninsular Wet Seasonal Evergreen Forest encompasses Chumpon Province to the north boundary of the Kangar–Pattani Line, while the Malayan Mixed Dipterocarp Forest covers parts of the Kangar–Pattani Line. Tropical rainforest trees in the family Dipterocarpaceae dominate forests throughout the peninsular region but species change both with elevation and latitude.

Forest cover in Peninsular Thailand declined from 42% in 1961 (Charuphat, 2000) to 30% in 2008 (Land Development Department, 2008), which was the second highest deforestation rate after northern Thailand. The main threat is encroachment for rubber and oil palm plantations.

### *Data on land use, socio-economic and biophysical factors*

A set of environmental variables that may directly or indirectly affect the patterns of tree distribution were created. These variables included biotic and physical factors. Remaining forest cover (biotic factor) was extracted from a 1:50,000 land use map of 2008 (Land Development Department, 2008). It should be noted that the scope of this study covers only terrestrial ecosystems, thus mangrove forests and wetlands are not included. In addition, we treated environmental variables as stable, except climatic variables because our research study emphasized the consequences of future climate change on plant distributions.

The physical factors were made up of four topographic inputs (altitude, slope, aspect and proximity to stream), as well as soil texture, and bio-climate variables (http://cres.anu.edu.au/outputs/anuclim/doc/bioclim.html) Contour lines (20-m intervals) were digitized from topographic maps at a scale of 1:50,000 (Royal Thai Survey Department, 1992). Then, digital elevation models of altitude, aspect and slope were interpolated from contour lines. In addition, a soil map at scale 1:100,000 was obtained from the Land Development Department.

The present (year 2000) and future world climate dataset predicted for 2100 and generated by the HadCM3 B2a climate change scenario (local sustainability and social equity) was obtained from the TYN SC 2.0 dataset (Mitchell, Carter, Jones, Hulme, & New, 2004). The original monthly temperature and rainfall values of TYN SC 2.0 climate datasets generated at a spatial resolution of 0.5° (approximately 45 km) were converted to Raster ASCII grids (*.asc). Then, the coarse resolution climatic variables were re-sampled to a resolution of 1 km using the interpolation method (Theobald, 2005). The 1-km resolution was chosen as an appropriate size for regional assessment and an intermediate point between the high resolution of digital elevation model (DEM) generated from the 20-m interval contour line, and the coarse resolution of the climatic variables. In addition, the world climate data of year 2000 were calibrated with local climate data recorded from weather stations

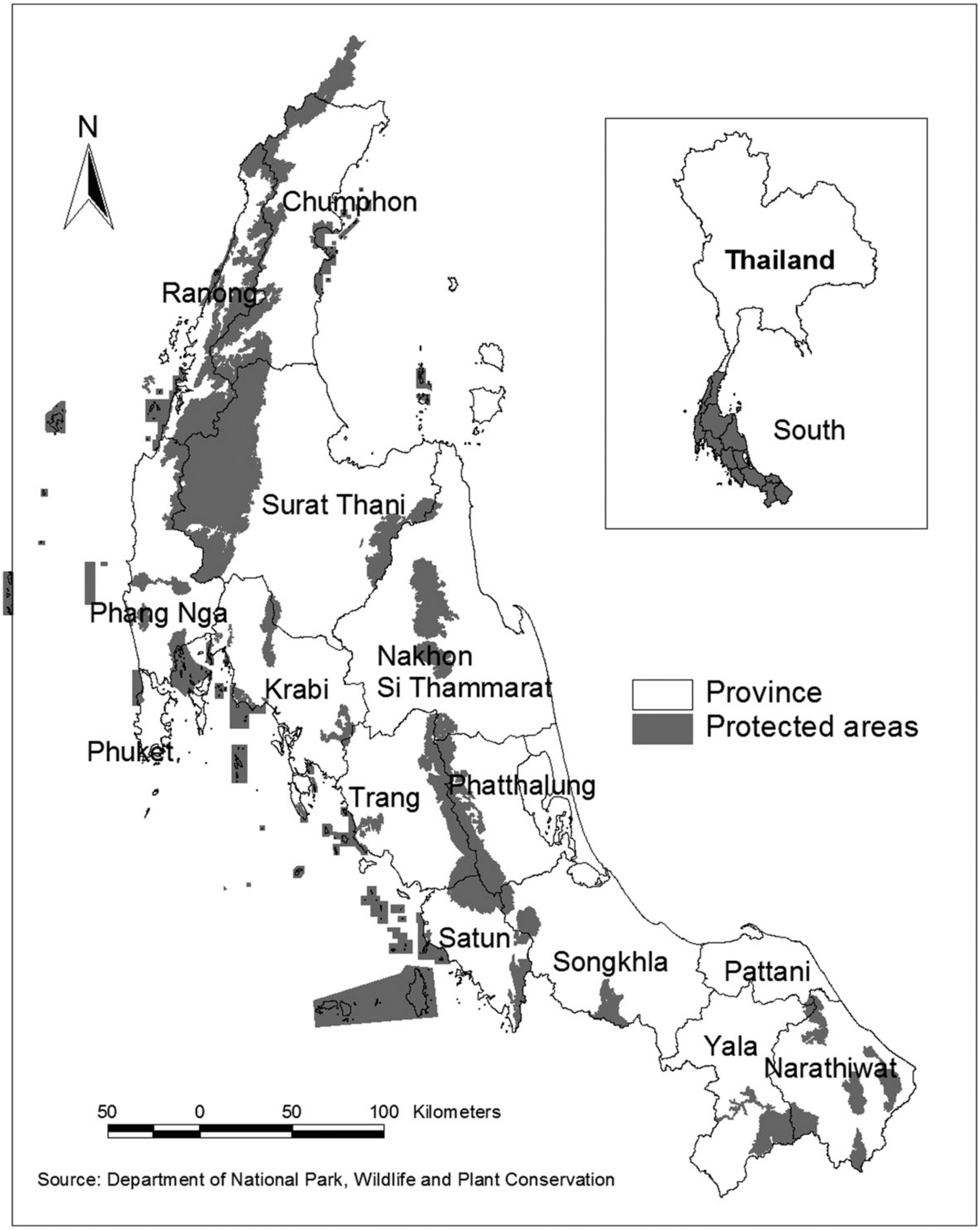


**Fig. 1.** Location of the study area in Thailand.

across the Peninsular using linear multiple regressions and latitude, longitude and DEM as independent variables to reduce statistical error (Hutchinson, 1995). In addition, the Pearson's correlation coefficient was employed to evaluate correlation between local climate data and calibrated climate data. Later, the 12 calibrated monthly temperature and rainfall grids were used to generate 19 biological climate variables (bio-climate) in order to create more biologically meaningful variables. The bio-climate variables represent annual trends, seasonality and extreme or limiting environmental factors.

*Species distribution modeling*

The processes for mapping forest tree distributions in the peninsular region include three main steps: (1) collection of tree occurrences; (2) selection of candidate species; and (3) generation of species distribution models.

*Collection of tree presence data*

We collected tree presence points from the Forest Herbarium of the Department of National Park, Wildlife and Plant Conservation, as well as from the on-going Forest Resource Inventory Project and the Project on Preparatory Studies to Install a Continuous Monitoring System for the Sustainable Management of Thailand's Forest Resources (RFD/ITTO, 2002). Both projects established a uniform fixed grid of 10 × 10 km and 20 × 20 km, respectively over the entire country for measuring trees and their environments. In the Peninsular Thailand, there are 260 plots and 160 plots located in forest areas. However, 25 plots are located in the three most southern provinces, Pattana, Yala and Narathiwat provinces, which all have security problems. The measurements were therefore not conducted there, but the extent of the study area in species modeling also covers these three provinces.

*Selection of species*

Firstly we used, for selection of candidate tree species for modeling, three criteria developed by the Asia Pacific Forest Genetic Resources Programme (APFORGEN) to select vascular plant priorities for genetic resources conservation and management (Sumantakul, 2004), i.e. (1) commercial importance and demand for plantation to maintain ecosystem functions and services; (2) level of within-species variation, and (3) level of threat or risk of extinction. Secondly, only tree species with a minimum quantity of 20 records were chosen to be sufficient for generating species distribution models and testing the accuracy in the next steps. Thirdly, the representatives of tropical hardwood trees in the Peninsular wet seasonal evergreen forest and Malayan mixed Dipterocarp forest were selected.

*Generation of species distribution models*

The species distribution maps were developed using a niche-based model or the maximum entropy method (Maxent) (Peterson et al., 2001). The models operate by establishing a relationship between a known range of a species and the climatic variables within this range. Then, the models use this relationship to identify other regions where the species may inhabit under climate change at present and in the future. The advantages of Maxent include the following: (1) it requires only presence data and environmental information and still performs best with limited records (Wisz et al., 2008), (2) it can utilize both continuous and categorical variables, and (3) efficient deterministic algorithms have been developed that are guaranteed to converge to the optimal probability distribution (Phillips, Anderson, & Schapire, 2006).

We ran Maxent using a convergence threshold of 10 with 1000 iterations as an upper limit for each run. For each species, occurrence data were divided into two datasets. Seventy-five percent of the sample point data was used to generate species distribution models, while the remaining 25% was kept as independent data to test the accuracy of each model. In addition, the area under the curve (AUC) of a receiver operating characteristic (ROC) curve was used to assess the accuracy of each model (Hosmer & Lewshow, 2000).

The outputs of the Maxent model were the continuous probability of the occurrence between the range of 0.0–1.0, where higher values mean better suitability and vice versa. We transformed the predicted values into a binary prediction. The logistic threshold at maximum training sensitivity plus specificity was use for binary classification. This threshold value was proven as one of promising approaches for predicting species distributions (Cuest-Comocho et al., 2006; Liu, Berry, Dawson, & Pearson, 2005). If the probability value was equal or greater than this threshold value, it was classified as presence, otherwise absence. Then, the potential presence was masked by the remaining forest cover derived from the 2008 land use map (Land Development Department, 2008).

*Assessment of impacts of climate change*

We assessed the impacts of climate change both on the spatial patterns of individual species and on the species richness distribution changes. For each species the assessment was done in terms of the percentage of species gain (new arrival) and species loss (no longer exists in the future) under predicted climate change. In addition, the calculation of species turnover rate was modified from the $\beta$ diversity metrics proposed by Cuest-Comocho et al. (2006) as shown below:

$$T = 100 \times \left[\frac{(G+L)}{(SR+G)}\right]$$

Where, $T$ = species turnover rate; $G$ = species gain; $L$ = species loss, and $SR$ = current species distribution. A turnover rate of 0 indicates that the species assemblage does not change, whereas a turnover rate of 100 indicates that they are completely different from previous conditions.

In addition, we superimposed the distribution maps of all 66 species to obtain a species richness map. The accumulated species occurrences were classified into 5 classes: very low (1–12 species), low (13–24 species), moderate (25–36 species), high (37–48 species), and very high (≥49 species). Plant hotspots or priority areas for conservation were determined by combining high and very high classes. We assessed landscape patterns of plant hot spots in terms of the total area, number of patches and total core area (1-km radius from edge). The FRAGSTATS 3.0 software (Mcgarigal & Marks, 1995) was used to assess landscape structure and fragmentation indices of species richness classes, such as total area, number of patches, mean patch size, total core area and mean core area. These indices also imply climate change impacts on biodiversity.

## Results

*Species occurrence observations*

Based on the forest inventory projects and the specimens from the Forest Herbarium there were all together 5048 occurrence records of 733 species from 90 families and 323 genera. Considering the proposed criteria, we selected 66 tree species from 20 families to develop species distribution models. The five dominant families were Annonaceae, Euphobiaceae, Dipterocarpaceae, Meliaceae and Myrtaceae. Besides the above dominant families, the remaining families were Anacardiaceae, Anonaceae, Apocynaceae, Bombaceae, Burseraceae, Ebenaceae, Fabaceae, Guttiferacae, Memecylaceae, Moraceae, Rhizopheraceae, Sapindaceae, Sapotaceae, Tiliaceae and Xanthophylilaceae.

*Calibrated global climate data*

The results of the regression models indicated that altitude, slope and aspect were significant factors for calibrating world climate data to local conditions (Table 1). In contrast, latitude and longitude were not significant factors. This may be due to the length of Peninsular Thailand, and its quite narrow width (Tangtham Personal communication). Altitude was a significant factor for all bioclimatic variables, except minimum temperature of coldest month. Slope is significant for calibrating mean diurnal range, isothermality, temperature seasonality, maximum annual range and minimum temperature of coldest month. Besides mean diurnal range and temperature annual range, aspect was significant for many precipitation variables (e.g. annual precipitation, precipitation of driest month, and precipitation of wettest quarter). This is

**Table 1**
Multiple linear regression equations to calibrate global bioclimatic variables to local condition and coefficient of determination ($R^2$).

| Bioclimatic variable | Description | Multiple linear regression* | $R^2$ |
|---|---|---|---|
| Bio1 | Annual mean temperature | Bio1_th = 70.025 − 0.012Alt + 0.005Asp + 0.743Bio1 | 0.841 |
| Bio2 | Mean diurnal range | Bio2_th = −32.196 − 0.008Alt − 0.017Asp − 1.559Slp + 1.317Bio2 | 0.555 |
| Bio3 | Isothermality (Bio2/Bio7 × 100) | Bio3_th = −1.416 + 0.014Alt − 1.526Slp + 0.986 | 0.303 |
| Bio4 | Temperature seasonality | Bio4_th = 726.103 + 0.631Alt − 6.882Slp + 0.665Bio4 | 0.926 |
| Bio5 | Max. Temperature of warmest month | Bio5_th = 21.365 − 0.014Alt + 0.951Bio5 | 0.689 |
| Bio6 | Min. temperature of coldest month | Bio6_th = 65.598 − 4.868Slp + 0.635Bio6 | 0.244 |
| Bio7 | Temperature annual range (Bio5 − Bio6) | Bio7_th = -13.813 + 0.013Alt − 0.025Asp − 2.803Slp + 1.050Bio7 | 0.745 |
| Bio8 | Mean temperature of wettest quarter | Bio8_th = 134.989 − 0.019Alt + 0.483Bio8 | 0.773 |
| Bio9 | Mean temperature of driest quarter | Bio9Th = 86.465 − 0.041Alt + 0.687Bio9 | 0.890 |
| Bio10 | Mean temperature of warmest quarter | Bio10th = 66.634 − 0.010Alt + 0.784Bio10 | 0.763 |
| Bio11 | Mean temperature of coldest quarter | Bio11_th = 85.255 − 0.040Alt + 0.683Bio11 | 0.935 |
| Bio12 | Annual precipitation | Bio12_th = −114.137 + 0.280Alt − 0.502Asp + 1.090Bio12 | 0.888 |
| Bio13 | Precipitation of wettest month | Bio13_th = −60.975 − 0.106Alt + 1.195Bio13 | 0.865 |
| Bio14 | Precipitation of driest month | Bio14_th = −1.248 − 0.001Alt + 0.001Asp + 1.072Bio14 | 0.862 |
| Bio15 | Precipitation seasonality | Bio15_th = 5.965 − 0.015Asp + 0.927Bio15 | 0.729 |
| Bio16 | Precipitation of wettest quarter | Bio16_th = −113.376 + 0.161Alt − 0.300Asp + 1.143Bio16 | 0.897 |
| Bio17 | Precipitation of driest quarter | Bio17_th = −5.306 + 0.016Alt + 1.047Bio17 | 0.915 |
| Bio18 | Precipitation of warmest quarter | Bio18_th = 114.362 + 0.124Alt + 0.620Bio18 | 0.425 |
| Bio19 | Precipitation of coldest quarter | Bio19_th = 142.809 − 0.399Alt + 0.642Bio19 | 0.272 |

Notes: Bio1_th = calibrated annual mean temperature (Bio1) to local condition; Alt = altitude; Asp = aspect; Slp = slope.

because the western part of Peninsular Thailand receives more rainfall than the eastern part due to monsoon and mountain effects.

The results of the calibration indicate that mean temperature in Peninsular Thailand under the B2 scenario will increase from 26.6 °C at present to 28.7 °C in 2100. In addition, the maximum temperature of warmest month, minimum temperature of coldest month, and mean temperature of warmest quarter will increase approximately 1.5–2 °C. Meanwhile, annual rainfall will slightly decrease from 2253 mm in 2000 to 2075 mm in 2100. However, precipitation of wettest month and precipitation of wettest quarter are likely to increase, but precipitation in the driest month, driest quarter and warmest quarter will decrease. These phenomena imply high rainfall intensity in rainy season and severe drought in summer.

*Species distribution models*

All environmental factors were correlated with the occurrence of the selected tree species. However, the relationships and contributions of climate and environmental factors varied from species to species. For instance, slope, aspect, altitude, soil and isothermality, temperature annual range, precipitation of driest month and precipitation of warmest quarter were significant for more than 40 of the selected species. Meanwhile, annual mean temperature and mean temperature of coldest quarter were significant for 10 and 11 species, respectively. Among 19 bioclimatic variables three temperature variables (isothermality, mean temperature range, and mean temperature of the warmest quarter), and three precipitation variables (annual precipitation, precipitation of driest period and precipitation of the coldest quarter) were considerable contributors to tree distributions in Peninsular Thailand. In contrast, maximum temperature of the warmest period, mean temperature of the coldest quarter and precipitation seasonality were low contributors.

The performances of the ecological niche models were surprisingly good (AUC ranged from 0.85–0.97). The best predictive models were found for *Polyalthia hypoleuca* (AUC = 0.97). The levels of accuracy for plants derived from the testing data varied relatively behind the training data (ranging from 0.81 to 0.92). The disagreement may have occurred because there were fewer points for plant species. Nevertheless, the ecological niche models were considered to be excellent in discriminating between predicted presence and predicted absence (Hosmer & Lewshow, 2000).

*Spatial distribution pattern and change*

The results of species distribution models indicated that currently nine species have suitable distribution ranges of more than 15% of the region. These species are *Bouea oppositifolia* (Roxb.), *Parashorea stellata* Kurz, *Diospyros buxifolia* (Blume), *Parkia speciosa* Hassk., *Lansium domesticum* Correa, *Instia palembanica* Mig., *Nephelium cuspidatum* Blume, *Schima wallichii* (DC.) and *Microcos paniculata* L. The largest extent of occurrence is predicted for *M. paniculata*, which covers approximately 21% of the peninsular region or 69% of the remaining forest area (Fig. 2). In addition, 20 species have suitable ecological niches of less than 10% of the region. The ecological niches of five out of a total of 14 *Dipterocarpus* species (*Dipterocarpus alatus* Roxb. Ex G. Don, *Dipterocarpus chartaceus* Symington, *Dipterocarpus dyeri* Pierre, *Dipterocarpus gracilis* Blume, and *Dipterocarpus grandiflorus* (Blanco) cover 5% or less).

Thirty-one tree species will lose suitable ecological niches and 35 tree species will gain more suitable niches under the predicted climate conditions. Meanwhile, for most tree species the total extent of occurrence at present and in the future are not substantially different, except for *D. gracilis, D. grandiflorus, Parkia timoriana* Merr., and *I. palembanica,* which have greater than 20% difference of suitable niches. The predicted impacts are more severe for the first two *Dipterocarpus* species because their current suitable niches cover less than 1% of the region.

The spatial patterns of species distribution before and after climate change are significantly different for all species due to the variation in species-specific responses. The average turnover rate of all tree species is approximately 21%. Major shifts in distribution are predicted for 12 species that have turnover rates greater than 30% (Table 2). For instance, *Anisoptera costata* Korth. is expected to gain 46% new area, but it would lose approximately 52% of its existing distribution range. In addition, *D. alatus* is expected under the B2 2100 climate scenario to gain new suitable habitats of approximately 19%, but lose 47% of its current distribution range.

*Effects on plant hotspots*

The total area of hotspots will decrease from 8.4% in 2008 to 8.1% in 2100 (Fig. 3). Approximately 74 and 75% of the total predicted tree habitat was in protected area system, and the remaining areas were located in buffer zones or remnant forests. In addition, the results of FRAGSTATS revealed that the number of hotspot patches

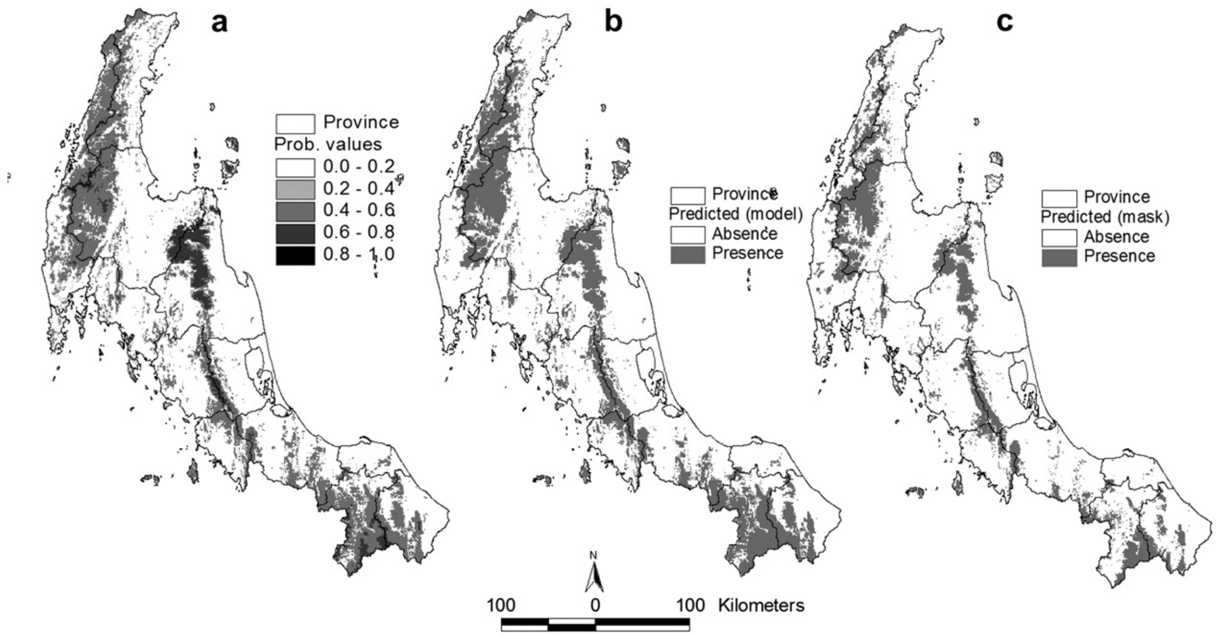


**Fig. 2.** a) Probability distributions of M. paniculata L. b) potential presence derived from ecological niche model; and c) remaining area after masked by forest cover in 2008.

will decrease from 633 in 2008 to 577 in 2100. The number of hotspot patches corresponds to the mean patch size index, which shows that the mean patch size of hotspots will decrease from 2223 ha in year 2008 to 1483 ha for the predicted climate in 2100. In addition, in the next century the accumulated core areas will substantially decline, approximately 54% for very high richness class and 33% for high richness class. Small, fragmented tree richness patches surrounded by agricultural land uses can be considered as degraded or cool spots (Myers et al., 2000).

## Discussion

### *Downscaling climate data*

Our study shows that topographic factors are useful for calibrating coarse global climate data to a fine scale in order to fit local conditions. The calibrated climate data show that the mean temperature will increase approximately 2 °C, which is similar to the prediction of Boonpragob and Santisirisomboon (1996). The annual rainfall will slightly decrease in 2100, which is opposite to the findings of Boonpragob and Santisirisomboon (1996). This may be because the previous study simply used a coarse resolution of climate data (45 $km^2$) and did not calibrate to local conditions. Nevertheless, it is essential to consider other methods to see whether the finer-scale calibration can be improved enough to be used in species modeling at local and regional scales. For example, the thin plate smoothing splines using ANUSPLIN-licensed software might be a promising option (Hutchinson, 1995). Previous research indicates that this commercial software can yield higher accuracy than normal statistical regression methods (Hutchinson, 2000).

### *Species distribution model*

The distributional data for most species in Thailand are incomplete. Previous collections are often mostly based on accessibility to the areas, leading to biased samplings (Parnell et al., 2003), while the cultivated lowlands are largely ignored (Parnell et al., 2003; Santisuk et al., 1991). In this study, we used the Maxent model to predict the climate niches for plants under current and predicted climate conditions across the Peninsular Thailand. The MAXENT was chosen because it requires only presence data and has been proven to perform better than other presence-only species distribution models (Peterson, Papes, & Eaton, 2007; Phillips et al., 2006). However, we were able to predict only 66 species of the total 733

**Table 2**
Percentages of suitable niches, species gained and species lost for selected tree species with a turnover rate greater than 30% in the Peninsular Thailand for year 2008 and 2100.

| Family | Scientific name | 2008 | 2100 | 2008–2100 (%) | | | |
|---|---|---|---|---|---|---|---|
| | | | | +/− | Gain | Loss | Turnover |
| Dipterocarpaceae | *Anisoptera costata* Korth. | 10.34 | 9.70 | −9.51 | 45.65 | 51.82 | 66.92 |
| Dipterocarpaceae | *Dipterocarpus alatus* Roxb. Ex G. Don | 0.18 | 0.13 | −18.75 | 19.20 | 47.20 | 55.70 |
| Dipterocarpaceae | *Dipterocarpus chartaceus* Symington | 0.49 | 0.19 | 0.00 | 1.16 | 62.50 | 62.93 |
| Dipterocarpaceae | *Dipterocarpus costatus* C.F. Gaertn. | 6.37 | 6.10 | 2.69 | 23.80 | 28.12 | 41.94 |
| Dipterocarpaceae | *Dipterocarpus dyeri* Pierre | 4.40 | 4.32 | 0.23 | 24.01 | 25.65 | 40.05 |
| Dipterocarpaceae | *Dipterocarpus grandiflorus* Blanco | 5.07 | 2.41 | −51.70 | 0.31 | 52.74 | 52.89 |
| Euphorbiaceae | *Croton* spp. | 12.66 | 10.40 | −14.54 | 8.25 | 26.14 | 31.77 |
| Fabaceae | *Parkia timoriana* Merr. | 3.14 | 4.24 | 38.56 | 42.01 | 6.87 | 34.41 |
| Guttiferae | *Calophyllum calaba* L. | 4.70 | 4.90 | −3.35 | 26.80 | 22.54 | 38.91 |
| Moraceae | *Ficus racemosa* L. | 4.87 | 5.54 | 12.83 | 28.24 | 14.49 | 33.32 |
| Moraceae | *Ficus retusa* L. var. *retusa* | 8.97 | 12.60 | −6.87 | 43.59 | 3.07 | 32.50 |
| Myrtaceae | *Syzygium* spp. | 6.83 | 6.54 | 6.86 | 15.53 | 19.76 | 30.54 |

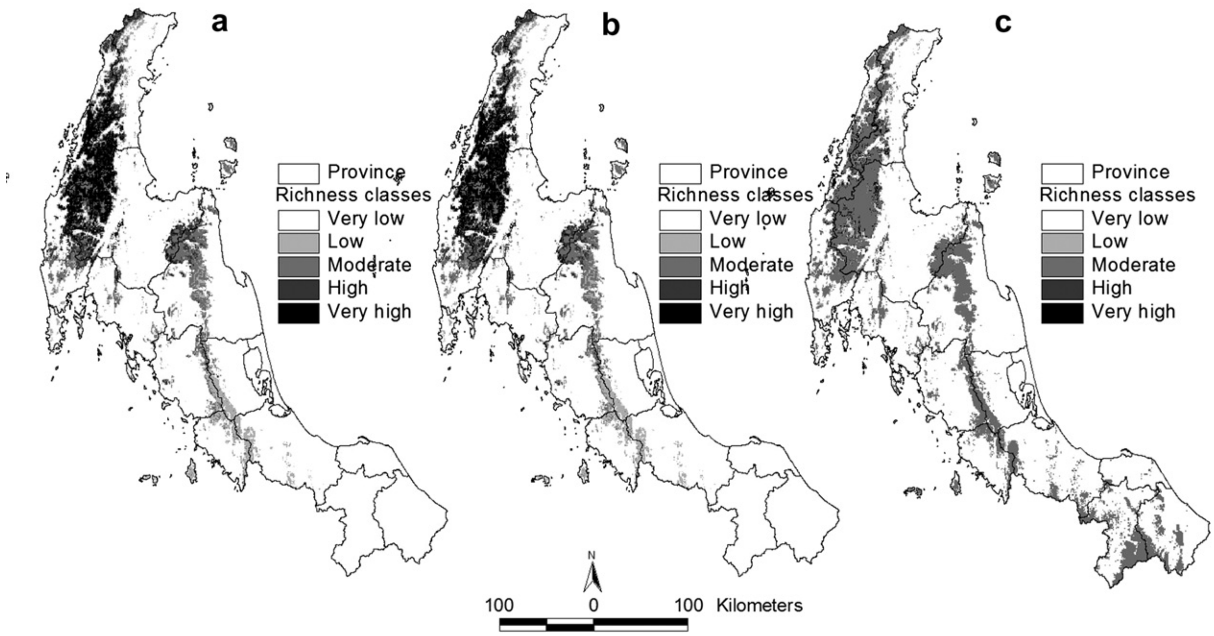


**Fig. 3.** Distributions of tree species richness in the Peninsular Thailand: a) year 2008; b) year 2050; c) year 2100.

species. This was due to the limited number of occurrence records for the remaining species and occurrence data gathered from a uniform fixed grid (RFD/ITTO, 2002) that likely ignored the remnant forest patches in between. These problems can be reduced in the future by conducting more field surveys outside existing areas or by gathering data from all available sources, i.e. herbarium collections, taxonomic literature, ecological communities and selected databases, in particular from, two specialized search engines, The Species Analyst (http://speciesanalyst.net) and REMIB (www.conabio.gob.mx/remib/remib.html).

In this study, we emphasized the consequences of future climate change on plant distributions, therefore other environmental variables were treated as stable. However, climate change is only one of many stressors to biodiversity, and climate change has a much lower impact compared to the other driving stressors (Alkemade et al., 2009; Trisurat, Alkemade, & Verburg, 2010; Verboom, Alkamade, Klijn, Metzger, & Reijnen, 2007). However it will be a more important driver in the 21st century (Leadley et al., 2010). Based on meta-analyses of peer-reviewed literature, Alkemade et al (2009) and Millennium Assessment (2005) indicated that leading anthropogenic pressures on biodiversity at regional and global levels are land use change, fragmentation, over-exploitation, infrastructure development, nutrient loading and climate change. Future researchers should elaborate on the interactions between deforestation and climate change on species extinctions and to define the critical tipping points that could lead to large, rapid and potentially irreversible changes. These studies are lacking for tropical rainforests in Southeast Asia (Leadley et al., 2010).

*Sensitivity*

All tree species showed different responses to predicted climate change due to their different species-specific requirements or ecological niches. Our results indicated that *Dipterocarpus* species are more vulnerable to future climate change than species in other families. This is because wet *Dipterocarpus* species in the region with a prolonged rainy season are less drought tolerant than species found in dry monsoonal habitats (Baltzer et al., 2007). They also have less desiccation tolerant leaves (Baltzer, Davies, Bunyavejchewin, & Noor, 2008) and wood properties (Baltzer, Gregoire, Bunyavejchewin, Noor, & Davies, 2009) particularly at the seedling recruitment stage (Kursar et al., 2009). Wet evergreen species do not have the adaptive traits to penetrate into drier forests through seedling recruitment (Comita & Engelbrecht, 2009; Kursar et al., 2009). Therefore, wet evergreen forests are likely to retreat wherever rainfall patterns shift at the margins (Malhi et al., 2009), but more laboratory research are needed to further confirm this assumption.

*Species loss and conservation planning*

Our results predicted that 31 tree species will lose suitable ecological niches in 2100. The magnitude of climate change impact in Peninsular Thailand is less significant than other regions, such as northern Thailand (Trisurat et al., 2009), the Northern Tropical Andes (Cuest-Comocho et al., 2006) and Amazonia (Miles et al., 2004). Twelve tree species, or nearly 20% of all selected species, have projected turnover rates greater than 30% of the current distribution ranges. The problem is more severe for many *Dipterocarpus* species, which have limited distribution ranges.

It should be noted that this research used the HadCM3 B2a scenario because it is in line with the government policy on sufficiency economy development (National Economic and Social Development Board, 2007). However, future development in Thailand will likely be driven by regional-oriented economic development (HadCM3 A2 scenario), especially from China. Therefore, higher emissions of greenhouse gases and raising temperature could be expected. These future phenomena would possibly cause more impacts on peninsular Thailand's biodiversity.

At present most protected areas are located in high altitudes that are not favorable niches for *Dipterocarpus* species (Raes & Van Welzen, 2009; Santisuk et al., 1991; Trisurat, 2007). Furthermore, lowland forests outside protected areas are vulnerable for deforestation due to high demand for rubber and oil palm plantations. Therefore, future climate change uncertainty and continuation of deforestation would diminish biodiversity and increase the risk of species extinction in Peninsular Thailand far beyond our expectations derived from this research, particularly for *Dipterocarpus* species. These effects can be mitigated by strict law enforcement in protected areas because approximately 75% of the total predicted plant habitat was in the protected area system. In addition, extending existing protected area coverage (14.8% of the region) to include the areas under deforestation threat and future ecological niches is needed. These conservation efforts are not only to mitigate climate change impacts but also to implement gap analysis and the protected area system plan as mentioned in the 2010 and post 2010 biodiversity targets.

## Conclusion

Besides deforestation, global climate change is now becoming another serious threat to biodiversity because it has the potential to cause significant impacts on the distribution of species and the composition of habitats. In this study, we selected 66 tree species as candidate species to evaluate the impact of climate change on species distribution in Peninsular Thailand. In addition, we calibrated the coarse global climate data for the year 2100 generated by the HadCM3 B2a scenario to local conditions using topographic variables. Then, we used the Maxent model to simulate species distributions.

The results from bioclimatic variables analyses indicate that there will be higher rainfall intensity in the rainy season and longer droughts in the dry month(s). In addition, the spatial distribution models show that, for the total extent of the occurrence of all selected plant species, there is no significant difference between current and predicted climate change conditions, except for some dipterocarp species. However, future climate change can create significant impacts on shifting distributions of tree species. The average turnover rate of all tree species is approximately 21% and major shifts are predicted for 12 species that have turnover rates greater than 30%from current distribution ranges, particularly dipterocarp species. Therefore, the effects on wet evergreen species of limited distributions in the Peninsular Thailand are similar the monsoonal and a seasonal wet forest in Amazonia but the magnitude of climate change impact in Peninsular Thailand is less significant.

The hotspots of selected species are predicted to change in 2100. They will decrease and become fragmented. The total core area and the mean core area are diminishing as well. It is therefore recommended, in order to mitigate future species loss due to climate change, to effectively manage protected areas and to extend existing protected areas to cover the areas under deforestation threat and future species transformations. This is due to biodiversity not only being an essential component of human development and security in terms of proving ecosystem services, it is also important for its own right to exist in the world.

## Acknowledgements

We would like to thank the National Research Council of Thailand and the Asian Institute of Technology – Royal Thai Government (AIT-RTG) for funding this research project. In addition, we are grateful to the Royal Forest Department, Department of National Park, Wildlife and Plant Conservation and Land Development Department for providing information and Nipon Tangtham for his valuable comments during the preparation of manuscript. In addition, we are grateful to both the reviewers and the Editor-in-Chief for the constructive comments for improving this manuscript.

## References

Alkemade, R., van Oorschot, M., Nellemann, C., Miles, L., Bakkenes, M., & Brink, B Ten. (2009). GLOBIO3: A Framework to investigate options for reducing global terrestrial biodiversity loss. *Ecosystems, 12*(3), 349–359.

Araujo, M. B., & Guisan, A. (2006). Five (or so) challenges for species distribution modelling. *Journal of Biogeography, 33*, 1677–1688.

Anderson, R. P., Laverde, M., & Peterson, A. T. (2002). Geographical distributions of spiny pocket mice in South America: insights from predictive models. *Global Ecology and Biogeography, 11*, 131–141.

Anderson, R. P., Lew, D., & Peterson, A. T. (2003). Evaluating predictive models of species' distributions: criteria for selecting optimal models. *Ecological Modeling, 162*, 211–232.

Anderson, R. P., & Martinez-Meyer, E. (2004). Modeling species' distributions for preliminary conservation assessments: an implementation with the spiny pocket mice (Heteromys) of Ecuador. *Biological Conservation, 116*, 167–179.

Baltzer, J. L., Davies, S. J., Nursupardi, M. N., Abul Rahman, K., & La Frankie, J. V. (2007). Geographical distributions in tropical trees: can geographical range predict performance and habitat association in co-occurring tree species? *Journal Biogeography, 34*, 916–1926.

Baltzer, J. L., Davies, S. J., Bunyavejchewin, S., & Noor, N. S. M. (2008). The role of desiccation tolerance in determining tree species distributions along the Malay–Thai Peninsula. *Functional Ecology, 22*, 221–231.

Baltzer, J. L., Gregoire, D. M., Bunyavejchewin, S., Noor, N. S. M., & Davies, S. J. (2009). Coordination of foliar and wood anatomical traits contributes to tropical tree distributions and productivity along the Malay-Thai Peninsula. *American Journal of Botany, 96*, 2214–2223.

Boonpragob, K., & Santisirisomboon, J. (1996). Modeling potential change of forest area in Thailand under climate change. *Water, Air and Soil Pollution, 92*, 107–117.

Charuphat, T. (November 2000). Remote sensing and GIS for tropical forest management. Pp. 42–49 in GIS Application Center. In *Proceedings of the Ninth regional Seminar on Earth Observation for tropical ecosystem management* (pp. 20–24). Khao Yai, Thailand: The National Space Development Agency of Japan, Remote Sensing Technology Center of Japan, RFD, and GIS Application Center/AIT, Khao Yai National Park Thailand.

Comita, L. S., & Engelbrecht, B. M. J. (2009). Seasonal and spatial variation in water availability drive habitat associations in a tropical forest. *Ecology, 90*(10), 2755–2765.

Cuest-Comocho, F., Ganzenmuller, A., Peralvo, M., Novoa, J., & Riofrio, G. (2006). *Predicting species' niche distribution shifts and biodiversity change within climate change scenarios: A regional assessment for bird and plant species in the Northern Tropical Andes*. Peru: Biodiversity Monitoring Program, EcoCiencia.

Elith, J., Graham, C. H., Anderson, R. P., Dudik, M., Ferrier, S., Guisan, A., et al. (2006). Novel methods improve prediction of species' distributions from occurrence data. *Ecography, 29*, 129–151.

Guisan, D. C. A., & Zimmermann, N. E. (2000). Predictive habitat distribution models in ecology. *Ecological Modeling, 135*, 147–186.

Hijmans, R. J., Guarino, L., Jarvis, A., O'brien, R., Mathur, P., Bussink, C., et al. (2005). DIVA-GIS Version 5.2 manual. Retrieved October 15, 2010 Available at http://www.diva-gis.org/.

Hosmer, D. W., & Lewshow, S. (2000). *Applied logistic regression* (2nd ed.). New York: Chichester, Wiley.

Hutchinson, M. F. (1995). Interpolating mean rainfall using thin plate smoothing splines. *International Journal of GIS, 9*, 305–403.

Hutchinson, M. F. (2000). *ANUSPLIN, ver 4.1. user guide*. Canberra, Australia: Centre for Resource and Environmental Studies, The Australian National University.

IPCC. (2007). *Climate change 2007: Synthesis report. Contribution of working Groups I, II and III to the Fourth assessment report of the Intergovernmental Panel on climate change*. Geneva, Switzerland: IPCC. 104 pp.

Kursar, T. A., Engelbrecht, B. M. J., Burke, A., Tyree, M. T., El Omari, B., & Giraldo, J. P. (2009). Tolerance to low leaf water status of tropical tree seedlings is related to drought performance and distribution. *Functional Ecology, 23*(1), 93–102.

Land Development Department. (2008). *Land use map in 2008*. Bangkok: Ministry of Agriculture and Co-operatives.

Leadley, P., Pereira, H. M., Alkemade, R., Fernandez-Manjarres, J. F., Proenca, V., Scharlemann, J. P. W., et al. (2010). Biodiversity scenarios: projections of 21st century change in biodiversity and associated ecosystem services. In*Technical Series, No. 50* (pp. 132). Secretariat of the Convention on Biological Diversity, Montreal.

Liu, C., Berry, P. M., Dawson, T. P., & Pearson, R. G. (2005). Selecting thresholds of occurrence in the prediction of species distributions. *Ecography, 28*, 385–393.

Malhi, Y. L., Aragao, C., Galbraith, D., Huntingford, C., Fisher, R., Zelazowski, P., et al. (2009). Exploring the likelihood and mechanism of a climate-change-induced dieback of the Amazon rainforest. *Proc. Nat. Acad. Sciences, 106*, 20610–20615.

Mcgarigal, K., & Marks, B. (1995). *FRSGSTATS: spatial pattern analysis program for quantifying Landscape Structure*. Gen. Tech. Rep. Portland: PNW-GTR-351.

Mellinium Assessment. (2005). *Ecosystem and human well-being: synthesis*. Washington, D.C: World resources Institute.

Miles, L., Grainger, A., & Phillips, O. (2004). Impact of global climate change on tropical forest biodiversity in Amazonia. *Global Ecology and Biogeography, 13*, 553–565.

Mitchell, T. D., Carter, T. R., Jones, P. D., Hulme, M., & New, M. (2004). *A comprehensive set of high-resolution grids of monthly climate for Europe and the* *globe: The observed record (1991–2000) and 16 scenarios (2001–2100)*. Tyndall Working Paper 55. Norwich, UK: Tyndall Center, UEA. Retrieved September 25, 2010, Available at http://www.tyndall.ac.uk.

Middleton, D. J. (2003). Progress on the flora of Thailand. *Telopea, 10*, 33–42.

Myers, N., Mittermeier, R. A., Mittermeier, C. A., da Fonseca, A. B., & Kent, J. (2000). Biodiversity hotspots for conservation priorities. *Nature, 403*, 853–858. http://www.nature.com/nature/journal/v403/n6772/abs/403853a0.html.a3.

National Economic and Social Development Board. (2007). *The Tenth National economic and social development plan: 2007–2011.* Bangkok: Prime Minister Office.

ONEP (Office of Natural Resources and Environmental Policy and Planning). (2007). *Thailand red data: Vertebrates*. Bangkok: Ministry of Natural Resources and Environment.

Parnell, J. A. N., Simpson, D. A., Moat, J., Kirkup, D. W., Chantaranothai, P., Boyce, P. C., et al. (2003). Plant collecting spread and densities: their potential impact on biogeographical studies in Thailand. *Journal of Biogeography, 30*, 193–209.

Parolo, G., & Rossi, G. (2008). Upward migration of vascular plants following a climate warming trend in the alps. *Basic and Applied Ecology, 9*(2), 100–107.

Peralvo, M. F. 2004. *Identification of biodiversity conservation priorities using predictive modeling: An application for the tropical dry forests of western Ecuador and northern Peru*. MSc. Thesis. University of Texas. Austin.

Peterson, A. T. (2001). Predicting species' geographical distributions based on ecological niche modeling. *Condor, 103*, 599–605.

Peterson, A. T., Papes, M., & Eaton, M. (2007). Transferability and model evaluation in ecological niche modeling: a comparison of GARP and Maxent. *Ecograph, 30*, 550–560.

Phillips, S. J., Anderson, R. P., & Schapire, R. E. (2006). Maximum entropy modeling of species geographical distributions. *Ecological Modelling, 190*, 231–259.

Raes, N., & Van Welzen, P. C. (2009). The demarcation and internal division of Flora Malesiana: 1857–Present. *Blumea, 54*, 6–8.

Raxworthy, C. J., Martinez-Meyer, E., Horming, N., Nussbaum, R. A., Schneider, G. E., Ortega-Huerta, M. A., et al. (2003). Predicting distributions of known and unknown reptile species in Madagascar. *Nature, 426*, 837–841.

RFD/ITTO. (2002). *Preparatory studies to install a continuous monitoring system for the sustainable management of Thailand's forest resources: Project: PD 2/99 Rev. 2 (F)*. Bangkok: Royal Forest Department (RFD) and the International Tropical Timber Organization (ITTO).

Royal Thai Survey Department. (2002). *Topographic map at scale 1:50,000*. Bangkok, Thailand: Ministry of Defense.

Santisuk, T., Smitinand, T., Hoamuangkaew, W., Ashton, P., Sohmer, S. H., & Vincent, J. R. (1991). *Plants for our future: Botanical research and conservation needs in Thailand*. Bangkok: Royal Forest Department.

Secretarial of the Convention on Biological Diversity. (2003). *Interlinakages between biological diversity and climate change. Advise on the integration of biodiversity considerations into the implementation of the United Nations Framework Convention on Climate Change and Its Kyoto protocol*. In *(CBD Technical Series, no. 10*. (Montreal).

Stibig, H. J., Belward, A. S., Roy, P. S., Rosalina-Wasrin, U., Agrawal, S., Joshi, P. K., et al. (2007). A land-cover map for South and Southeast Asia derived from spot-vegetation data. *Journal of Biogeography, 34*, 625–637.

Sumantakul, V. (2004). Status of forest genetic resources conservation and management in Thailand. In T. Luoma-Aho, L. T. Hong, V. Ramanatha Rao, & S. C. Sim (Eds.), *Proceedings of the Asia Pacific forest genetic resources Programme (APFORGEN) Inception Workshop, Kepong, Malaysia, 15–18 July, 2003* (pp. 265–289). Serdang, Malaysia: IPGRI-APO.

Theobald, D. M. (2005). *GIS concepts and ArcGIS methods* (2nd ed.). Colorado, USA: Colorado State University.

Trisurat, Y. (2007). Applying gap analysis and a comparison index to assess protected areas in Thailand. *Environmental Management, 39*, 235–245.

Trisurat, Y., Alkemade, R., & Arets, E. (2009). Projecting forest tree distributions and adaptation to climate change in northern Thailand. *Journal of Ecology and Natural Environment, 1*(3), 55–63.

Trisurat, Y., Alkemade, R., & Verburg, P. (2010). Projecting land use change and its consequences for biodiversity in northern Thailand. *Environmental Management, 45*, 626–639.

Trivedi, M. R., Morecroft, M. D., Berry, P. M., & Dawson, T. P. (2008). Potential effects of climate change on plant communities in three montane nature reserves in Scotland, UK. *Biological Conservation, 141*(6), 1665–1675.

Verboom, J., Alkamade, R., Klijn, J. A., Metzger, M. J., & Reijnen, R. (2007). Combining biodiversity modeling with political and economical development scenarios for 25 countries. *Ecological Economics, 62*, 267–276.

Zimmer, H., & Baker, P. (2009). Climate and historical stand dynamics in the tropical pine forests of northern Thailand. *Forest Ecology and Management, 257*(1), 190–198.

van Zonneveld, M., Koskela, L., Vinceti, B., & Jarvis, A. (2009). Impact of climate change on the distribution of tropical pines in Southeast Asia. *Unasylva, 60*, 24–29.

Wikramanayake, E. D., Dinerstein, E., Loucks, C. J., Olson, D. M., Morrison, J., Lamoreux, J., et al. (2002). *Terrestrial ecoregions of the indo-pacific: A conservation assessment*. Washington D.C: Island Press. (Covelo and London).

Wisz, M. S., Hijmans, R. J., Li, J., Peterson, A. T., Graham, C. H., & Guisan, A. (2008). Effects of sample size on the performance of species distribution models. *Diversity and Distributions, 14*, 763–773.

World Wild Fund For Nature. (2008). Tenasserim-South Thailand semi-evergreen rain forests. In Cutler J. Cleveland (Ed.), *Encyclopedia of Earth*. Washington, D.C: Environmental Information Coalition, National Council for Science and the Environment. Retrieved October 20, 2010, Available at. http://www.eoearth.org/article/Tenasserim-South_Thailand_semi-evergreen_rain_forests.