Predicted Climate Change Impact on Natural Teak Forests in the Greater Mekong Sub-region

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Abstract

Teak (*Tectona grandis*) is one of the most valuable hardwood species. Natural teak forests, largely distributed in South Asia and Southeast Asia, but they are in danger because of over-exploitation, non-sustainable management, encroachment, and potentially the long-term effect of climate change. The objectives of this research are to predict the presence and future geographical range of natural teak forests in the Greater Mekong Sub-region, and to determine the effectiveness of protected areas for *in-situ* conservation. Geo-referenced species occurrences of natural teak across the Mekong region were gathered from previous studies and ongoing ITTO Teak Project in Mekong. In addition, potential environmental requirement variables were developed or gathered from various sources. Maximum Entropy (MaxEnt Model), a present-only spatial distribution model was employed to generate present and predicted species range in 2050 under the CMIP6 scenarios. The results of species distribution models show that the suitable habitats of native teak are likely stable by 2050 as the result of wide climatic tolerance range. However, its distribution in southern Myanmar and northeast Lao PDR would loss climatic suitable habitats, whereas semievergreen forests in northern Myanmar are becoming more suitable by all scenarios.

Keywords: Distribution range, teak, conservation, Mekong, protected areas.

Introduction

Teak (*Tectona grandis*) is one of the most valuable tropical hardwood species in the world due to its captivating wood quality and aesthetics, which finds application in various high-quality products. In addition, its properties like special grain and color, light weight and stability, easy processing and resilience to different biotic and abiotic factors make it versatile (Kaosa-ard 1991), thus it can be used for a wide variety of indoor and outdoor purposes.

Teak is a deciduous tree, which can occur both in mixed deciduous forests as well as evergreen and semi evergreen forests within a latitudinal range of 10° to 25°N (Gyi and Tint, 1995) in South and Southeast Asia, especially India, Myanmar, Thailand and Lao PDR (Kollert and Cherubini 2012). The tolerance range of annual precipitation is very wide from 1,250 mm to 3,750 mm and temperatures from 13°C to 43°C. Teak grows best in light exposed areas and in hilly areas below 900 meters from mean sea level (Pandey and Brown 2000).

The total global area of natural teak forests in 2010 is estimated to account for 29 million ha. Nearly half of these forests are located in Myanmar. Natural teak forests diminish constantly due to unsustainable logging and encroachment for agriculture (Kollert and Cherubini 2012; FAO, 2020). The highest loss of natural forest area during 1976-2010 was found in all countries and it resulted in logging bans in natural teak forests (Roshetko et al. 2013). Teak plantations are an alternative way to partly accommodate the constant demand for teak wood. The establishment of teak plantations has a long tradition in different continents and countries. The first teak plantations were established in Java and Muna, Indonesia in the seventh century (Gyi and Tint, 1995). Currently, teak plantations are found worldwide. About 94 % of the global teak plantation area is located in Tropical Asia, followed by Tropical Africa (4.5 %) and a marginal rest in Tropical America (Midgley et al. 2007).
Besides human disturbances, climate change and extreme events are becoming threats to tropical forests, including teak forests (Trisurat et al., 2018). Among all proxy archives, tree rings are a highly promising indicator of

ecological and environmental processes because they are highly sensitive to climatic variation. Muangsong et al. (2020) revealed that the tree-ring cellulose δ18O of 146-year-old teak, spanning between AD 1871 and 2016, are modulated not only by the local rainfall amount, but also by large-scale convection, which varies between different seasons and over time. In addition, Ring width data show a moderately positive response to monsoon rainfall in Thailand (Lumyai and Duangsathaporn, 2017), Myanmar (D'Arrigo et al., 2011), and India (Sengupta et al., 2017). In contrast, the increasing moisture stresses during months of the early growing season is crucial for determining the growth of teak trees (Sengupta et al., 2017; Upadhyay et al., 2021).

In the landscape studies, Deb et al (2017) indicated that changes in annual precipitation, precipitation seasonality and annual mean actual evapotranspiration may result in shifts in the distributions of native teak and teak plantations across tropical Asia. Pirovani et al (2018) also found that the reduction in monthly rainfall and an increase in average air temperature by 2.1 °C reduce suitable cultivation area of teak in Brazil. Likewise, the net primary productivity of the Zambian Zambezi teak forests was projected to decrease by 0.01% and 0.04% by the end of the 21st century under RCP8.5 and RCP4.5 as the results from the reduced rainfall coupled with increasing temperature (Ngoma et al., 2019).

The sixth phase of the Coupled Model Intercomparison Project (CMIP6), which combined the scenarios of two pathways, a Shared Socioeconomic Pathway (SSP) and an RCP was recently published in 2019 (Durack, 2020). In this study, we developed a species distribution model to predict presence and future geographical range of natural teak forests in the Greater Mekong Sub-region (GMS), and to determine the effectiveness of protected areas for *in-situ* conservation.

Methodology

The study covers Myanmar, Lao PDR, and Thailand, which have natural teak forests. It accounts for approximately 1.4 million km^2 or 61% of the total land area in the GMS. It is a very dynamic and fast-changing region that has made significant socio-economic progress since 1990 resulting in significant impacts on natural and forest resources. Between 1990 and 2020, a total of 9 million ha of forest were lost, with an average annual decrease of 1.11% over the period (FAO, 2020). All countries in the GMS except Viet Nam have reported falling forest cover, with Myanmar reporting the highest rates of deforestation (1.17% annually). Forest cover in Thailand is quite stable after 2000 due to increased efforts of forest protection and expansion of protected areas.

Steep topography is predominant in Lao PDR, while flat terrain is common on the plateau in northeast Thailand and central Myanmar. Average annual rainfall ranges from less than 1,000 mm in the dry zone of central Myanmar and the northern Lao PDR to more than 5,000 mm along the coastline of Myanmar. Rainfall in the GMS is influenced by seasonal monsoons, and cyclones from the South-China Sea, and the effects of topography (MRC, 2011). Besides tropical monsoons, climatic conditions in the GMS are affected by El Nin˜ o–Southern Oscillation (or ENSO events) on an approximately 10-year cycle (Rasanen et al. 2016). The downscaled climatic data indicated that annual rainfall in the LMB is expected to increase by 200 mm from the baseline by 2030, and 300 mm by 2060 under the wetter scenario. The maximum increment is predicted in Vietnam, whereas substantial loss is expected in northeast Thailand under the medium (RCP) 4.5, and high emission (RCP 8.5). In addition, the low emissions (RCP 2.6) would also increase temperature by about 0.4 °C across the LMB. Rising temperatures (by 1.5 and 3 °C) are expected for the RCP 4.5, and the RCP 8.5, respectively.

We compiled georeferenced presence-only teak occurrence records of native stands from a variety of sources, including Thailand's systematical forest inventory plots (Trisurat et al. 2020), the Global Biodiversity Information Facility Data Portal (GBIF: http://www.gbif.org/), the Botanical Information and Ecology Network or BIEN (http://bien.nceas.ucsb.edu/bien/), and published literature. To clean the records, we undertook several steps, including: removal of duplicate records, removal of spurious locations outside the species's known geographic range and teak plantations (Saroch Wattanasuksakul, personal communication), and elimination of spatial clusters of locations. We filtered the spatially auto-correlated occurrence records at 10 km^2 using the SDM tool (Brown et al., 2017) for analysis at the landscape level.

Environmental variables that directly or indirectly affect the native teak distribution at an environmental heterogenous scale were developed. Physical variables include altitude (from Shuttle Radar Topography Mission - SRTM), and slope. Soil characteristics were obtained from FAO (2012) and ISRIC-World Soil Information version 2.0. Other variables include the annual Aridity Index (AI) (Trabucco and Zomer, 2019), and reference evapotranspiration (ETo). The ETo was derived from the modified Hargreaves equation (Subburayan et al. 2011) based on maximum and minimum monthly temperature and monthly precipitation. AI was calculated as mean annual precipitation divided by annual ETo. In addition, mean tree density per km^2 was also downloaded from Crowther et al. (2015) version 2. We used uncorrelated 10 bioclimatic variables from WorldClim ver. 2.1 (https://www.worldclim.org/data/cmip6/cmip6climate.html) based on averages of 1970-2000 at 30-second resolution (approximately 1 km) as the baseline (Table 1). For the projected distribution in 2050, we treated other variables stable and changed only climatic variables to the same bioclimatic variables projected by four CMIP6 SSPs: 1-26, 2-45, 3-70 and 5-85 processed from (CanESM5 and GFDL-ESM4). All environmental variables were resampled to 30 second or 1 km resolution, which is appropriate for analysis at the national level.

The maximum entropy method (MaxEnt) was used to generate species distribution (Phillips et al. 2006), because it works well with only-presence data. We executed MaxEnt for 5 replications to avoid sampling errors and used a default MaxEnt setting. The MaxEnt outputs are the continuous probability ranging between 0.0-1.0. We converted the output into binary presence-absence maps using the 10 percentile training presence thresholds (Trisurat et al., 2018) and evaluated the predictive performance of the models using the area under the curve (AUC) metric. Any pixels having equal or greater than the threshold values were reclassified as presence, otherwise absence. Future distributions were analyzed using the predicted climatic variables in 2050, while other variables were treated as stable. The predicted binary maps were masked with the existing forest cover map (SERVIR-Mekong; https://servir.adpc.net/geospatial-datasets) to define the remaining distribution in the study area.

The extent of protected areas was downloaded from the Protected Planet website (https://www.protectedplanet.net/en), which provides the most up to date and complete source up-to-date data on protected areas.

Results and discussion

The total number of teak occurrences were 1,579 records largely from Thailand (854 records or 54% of the total records). After filtering the locality data, the occurrence points were reduced to 383 records. Of this number, 221 records were located in Thailand, followed by Myanmar (133 records) and Lao PDR (29 records).

The considerable predictor variables and their percentage contribution in the MaxEnt models are shown in Table 1. The key predictor variables for natural teak distribution were ETo (23.56%), followed by tree density (18.54%), AI (11.46%), elevation (10.4%), and latitude (8.12%). The results highlight that climate seasonality rather than the mean annual climate is more important for the distribution of natural teak. The average 10 percentile logistic threshold (10P) of 0.22 (ranging from 0.19-0.23) was used to classify the probability values to derive the predicted presence and absence of teak. In addition, the training and test AUC scores of 0.89 indicate excellent discrimination ability in predicting the potential current and future distributions of teak under different climate scenarios.

The predicted distribution of native teak at present covered an area of 38.10 million ha or 25.91% of the study area. Of this figure, 22.02 million ha was predicted in Myanmar, 16.43 million ha in Thailand, and 5.68 million ha in Lao PDR. Suitable areas are mainly clustered between latitudes 17° to 22°N across the borders of the three countries. Northern Myanmar dominated by semi-evergreen forests shows less suitability, and teak does not grow to a great size and usually scattered individuals or in small groups (Gyi and Tint, 1995) compared to mixed deciduous forests. Using the existing land use map (SERVIR-Mekong), it was predicted that the remaining teak areas in 2018 covered a similar extent of 30 million ha or 20% of the study area, which is slightly over the estimation by Kollert and Cherubini (2012). About 78% of the total potential habitats, whereas 57% of these forests are located in Myanmar. This is due to the overestimation of forest cover in Lao PDR and Myanmar (Forest Department, 2020) generated by SERVIR-Mekong.

Table 1 Variables and their contributions in the MaxEnt models for teak (*Tectona grandis*)

		Contribution to the MaxEnt models (%)			
Variable	Description	%	Min	Max	SD
BIO1	Annual mean temperature	0.00	0.00	0.00	0.00
BIO8	Mean temperature of wettest quarter	4.64	3.00	6.40	1.48
BIO9	Mean temperature of driest quarter	0.12	0.00	0.30	0.10
BIO10	Mean temperature of warmest quarter	2.14	0.10	4.30	1.58
BIO11	Mean temperature of coldest quarter	0.36	0.30	0.50	0.08
BIO12	Annual precipitation	0.60	0.00	1.60	0.70
BIO16	Precipitation of wettest quarter	0.98	0.20	1.90	0.68
BIO17	Precipitation of driest quarter	0.60	0.00	1.40	0.58
BIO18	Precipitation of warmest quarter	3.82	2.60	6.00	1.25
BIO19	Precipitation of coldest quarter	2.38	1.70	2.90	0.52
AI	Aridity index	11.46	9.10	15.80	2.53
ETo	Reference evapotranspiration	23.56	19.40	27.20	2.53
DEM	Elevation	10.04	8.60	12.40	1.35
SLOPE	Slope	3.36	0.20	6.30	2.45
LAT	Latitude	8.12	6.00	10.20	1.47
SOIL	FAO soil unit	5.24	3.80	8.60	1.79
BLDTICM	Soil depth	2.78	1.60	4.10	0.90
BLDFIE	Soil bulk density	1.06	0.30	1.70	0.63
TREE_DENS	Tree density per km2	18.54	16.40	20.80	1.68

The predicted distribution areas under the four CMIP6 scenarios show that the suitability of native teak will be stable at 20% of the total study area, except the CMIP6 SSP12-6 and SPP5-85 scenarios. However, its current natural ranges would either gain or lose suitable habitats of 10% of the existing natural ranges by 2050 (Table 2, Figure 1). Some forest patches in western Lao PDR and southern Myanmar are likely to lose climate suitability, whereas some patches situated in semi-evergreen forests in northern Myanmar are likely to become suitable in the future.

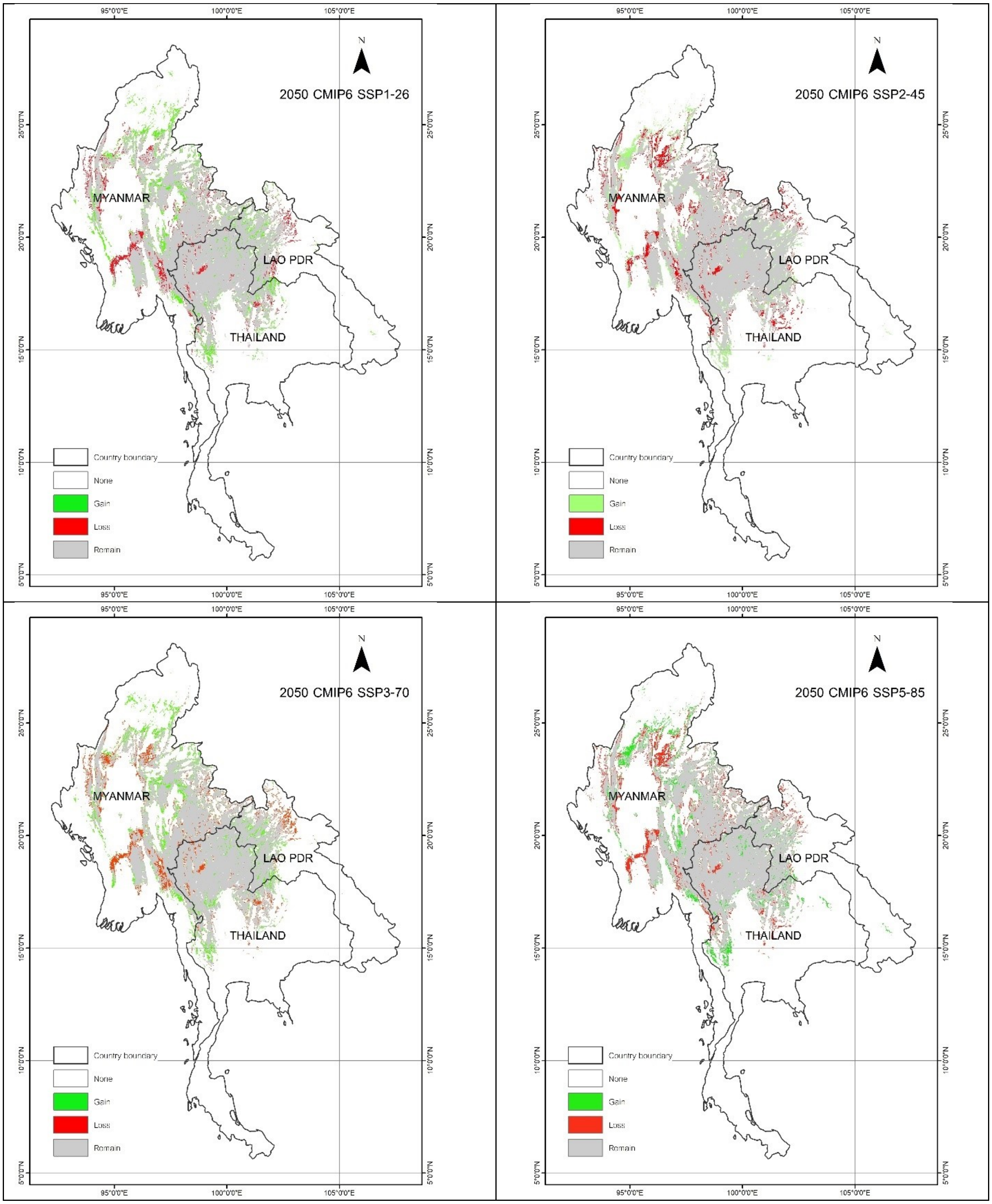

Figure 1 Predicted climate change impact on teak distribution by 2050 under CMIP6 scenarios

Table 2 Estimated extend of occurrence, gain, and loss in the suitable range

Scenario	Suitable area		Remain	Gain	Loss	Remaining suit area	
	(mill ha)	%	(mill ha)	(mill ha)	(mill ha)	(mill ha)	%
Baseline	38.10	25.91				30.12	20.73
SSP1-26	39.08	26.61	35.08	4.04	2.99	30.83	20.75
SSP2-45	37.18	25.28	33.82	3.36	4.24	29.10	19.57
SSP3-70	38.02	25.84	34.58	3.44	3.49	29.94	20.13
SSP5-85	37.02	25.22	33.52	3.57	4.55	28.71	19.31

The Protected Planet (https://www.protectedplanet.net/en) indicates that the extent of protected areas in Myanmar, Thailand, and Lao PDR cover about 3.43, 3.60 and 11.03 million ha or 5, 15, and 21% of the country land area, respectively. The model results reveal that 0.35 million ha, 0.26 million ha, and 5.36 million ha of suitable areas are found inside protected areas of Myanmar, Lao PDR and Thailand, respectively. These imply that the percentage of protected area contributions are approximately 2, 5 and 40%, respectively.

Conclusion

A total number of 383 georeferenced occurrences of teak from various sources were used to model its distribution under the baseline and the four CMIP6 scenarios: SSP1-26, SSP2-45, SSP3-37, and SSP5-85. The species distribution models show excellent performance to predict the current and future teak distributions. The key predictor variables for natural teak distribution were annual reference evapotranspiration, followed by tree density, aridity index, elevation, and latitude. Although teak has a wide climatic tolerance range, climate seasonality shows more important than annual precipitation and mean temperature because teak prefers distinct climatic conditions between wet and dry seasons.

The model results predicted the potentially suitable areas at the baseline and under the four CMIP6 scenarios cover about 25% of the total study area. The current habitats inside the remaining forest cover encompass about 30 million ha or 20% of the total study area. Protected areas in Thailand contribute about 40% of the remaining suitable area of the country, whereas its contribution is less for Myanmar and Lao PDR. Its current natural ranges would either gain or lose suitable habitats of 10% of the existing ranges by 2050. Some forest patches in western Lao PDR and southern Myanmar are likely to disappear and its future climate suitability would shift toward northern Myanmar.

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