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Identifying the potential geographic distribution for *Castanopsis argentea* and *C. tungurrut* (Fagaceae) in the Sumatra Conservation Area Network, Indonesia

TRY SURYA HARAPAN[1,2,♥] , NURAINAS[1,3], SYAMSUARDI[1,3,♥♥], AHMAD TAUFIQ[1,4]

[1]Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Andalas. Jl. Universitas Andalas, Limau Manis, Padang 25163, West Sumatra, Indonesia. Tel./fax. +62-751-71671, ♥email: trysuryaharapan@gmail.com, ♥♥email: syamsuardi@sci.unand.ac.id
[2]Southeast Asia Biodiversity Research Institute, Chinese Academy of Sciences & Center for Integrative Conservation, Xishuangbanna Tropical Botanical Garden, Chinese Academy of Sciences. Mengla, Yunnan 666303, China
[3]Herbarium of Universitas Andalas. Jl. Universitas Andalas, Limau Manis, Padang 25163, West Sumatra, Indonesia
[4]Department of Biological Sciences, Graduate School of Science, Tokyo Metropolitan University. Minami-Osawa, Hachioji-shi, Tokyo 192-0397, Japan

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Abstract. *Harapan TS, Nurainas, Syamsuardi, Taufiq A. 2022. Identifying the potential geographic distribution for* Castanopsis argentea *and* Castanopsis tungurrut *(Family: Fagaceae) in the Sumatra Conservation Area Network, Indonesia. Biodiversitas 23: 1726-1733.* Recently, *Castanopsis argentea* (Blume) A.DC. and *Castanopsis tungurrut* (Blume) A.DC. have been listed as endangered species by the International Union for the Conservation of Nature (IUCN). For conservation planning, it is important to know the full distribution of species. This study aimed to predict the potential distribution of *C. argentea* and *C. tungurrut* using MaxEnt, and understand key factors responsible for the distribution of these species. A total of 53 occurrences and six environmental variables were used to model their distribution. The AUC values of *C. argentea* and *C. tungurrut* were 0.86 and 0.91, respectively, and the models suggest the distribution of both species is mainly influenced by elevation, and temperature seasonality for *C. tungurrut*. The predicted distributions of the species are in the mountains of the western part of Sumatra, and their range includes 12 conservation areas that have highly suitable habitats for both species. After generating the MaxEnt prediction map, we conducted field validation to validate the model predictions. Field surveys in two predicted areas showed that the predicted distribution maps accurately estimated the distribution of *C. argentea* and *C. tungurrut* at those localities.

Keywords: Conservation, distribution, endangered plants, phytogeography, spatial modeling

INTRODUCTION

Indonesia is home to hundreds of threatened tree species, including members of the family Fagaceae. The Fagaceae is a large angiosperm family comprising eight genera with more than 700 species, of which 112 species have been recorded in Indonesia (Purwaningsih and Pulosakan 2016). This paper investigates two Indonesian species in the family which are listed as Endangered under IUCN criteria, *Castanopsis argentea* (Blume) A.DC. and *C. tungurrut* (Blume) A.DC. (Barstow and Kartawinata 2018a,b). According to Indonesian Forum for Threatened Trees (FPLI), the trees are considered vulnerable to extinction and are protected nationally by Indonesian Law P.106/MENLHK/SETJEN/KUM.1/12/2018. Besides edible fruits, the durable wood of many species of *Castanopsis* are used for constructing houses, making wood charcoal and their bark is used for dyeing rattan work black (Soepadmo and van Steenis 1972). *Castanopsis* spp. are also considered to be indicators of superior arable lands (Soepadmo and van Steenis 1972). Hence these species are of high utility, and overuse of timber from these species will contribute to decreasing their populations and increase the threat of extinction. In Sumatra, the two species under study are recorded mainly from the Barisan Mountains in the west of the island (Figure 1) (Laumonier 1997). *Castanopsis argentea* is also found in Java, Indonesia (Mt. Ungaran, and on Mt. Wilis at Ngebel) and *C. tungurrut* is also found in the Malay Peninsula, Simalur and Banka Island, and West Java (Soepadmo and van Steenis 1972).

Numerous factors such as agricultural clearing, forest fires, illegal logging, illegal mining, and transport infrastructure close to the forest are ascribed to biodiversity loss. The Indonesian government is drafting a plan to build a massive Trans-Sumatra Highway for connecting Sumatra's entire island in 2024. Any infrastructure development plan has its share of negative consequences on its surrounding ecosystems (Sloan et al. 2019). For conservation planning, it is important to know which species is distributed where, so that appropriate infrastructural development could be guided. Understanding species distribution with a full ground survey is costly and time-consuming. A number of distribution modelling methods have been developed to help predict the distribution of species, including those employing principle of Maximum Entropy (Phillips et al. 2006). These models incorporate environmental data to define the environmental niche of the species (McShea 2014).

Maximum entropy (MaxEnt) is a widely used modeling method for predicting species distribution in poorly-surveyed areas. The algorithm typically outperforms other methods based on predictive accuracy (Merow et al. 2013). Compared to other SDM tools, a maximum entropy algorithm can develop a good model with small number of occurrences (Harapan et al. 2020). Because of this reason, many studies on threatened plants, which typically have small amounts of occurrence data, use MaxEnt to model species distributions (Adhikari et al. 2012; Yang et al. 2013; Padalia et al. 2014; Pradhan 2015; Remya et al. 2015; Yuan et al. 2015; Yi et al. 2016; Pranata et al. 2019; Ito et al. 2020; Anand et al. 2021; Du et al. 2021; Felix et al. 2021; Liu et al. 2021; Mahatara et al. 2021; Nguyen et al. 2021; Purohit and Rawat 2021; Su et al. 2021; Yang et al. 2021; Ye et al. 2021). With effective conservation planning focused on ensuring redundancy and resiliency for sustainable future populations (Redford et al. 2011), SDMs are a valuable tool for the conservation community (Mcshea 2014). This study aims to predict the potential distribution of *C. argentea* and *C. tungurrut* in the Sumatra Conservation Area Network, Indonesia and to understand key factors responsible for the distribution of these species.

MATERIALS AND METHODS

Study area

Castanopsis argentea occurrences were identified based on field surveys between December 2017 to January 2019 in West Sumatra (Nyarai and Universitas Andalas Biological Forest), North Sumatra (Sarula) and at the border between West Sumatra and Jambi Province (Kerinci Seblat National Park), Indonesia. Occurrences of *C. tungurrut* were derived from herbarium specimen records and GBIF records. A total of 52 occurrences (Figure 1) were collected from our field surveys, Herbarium of Andalas (Voucher Code: ANDA 0001-0005, ANDA 33381 for *C. argentea* and ANDA 00124-00141 for *C. tungurrut*) and the Global Biodiversity Information Facility (GBIF 2020a,b).

Species description

The diagnostic characteristic of Fagaceae is the cupule, a woody bract that partially covers the fruit. The *C. argentea* and *C. tungurrut* have similar-looking sharply spiny cupules. The cupule of *C. argentea* lacks branched spines, and there are 3 fruits in a cupule, whereas *C. tungurrut* has only a single fruit per cupule, which possesses branched slender spines. The leaves of *C. argentea* are glossy above and distinctly silvery below. *Castanopsis tungurrut* leaves are glossy above, widest in the middle and slightly acute at the leaf blade base (Figure 2).

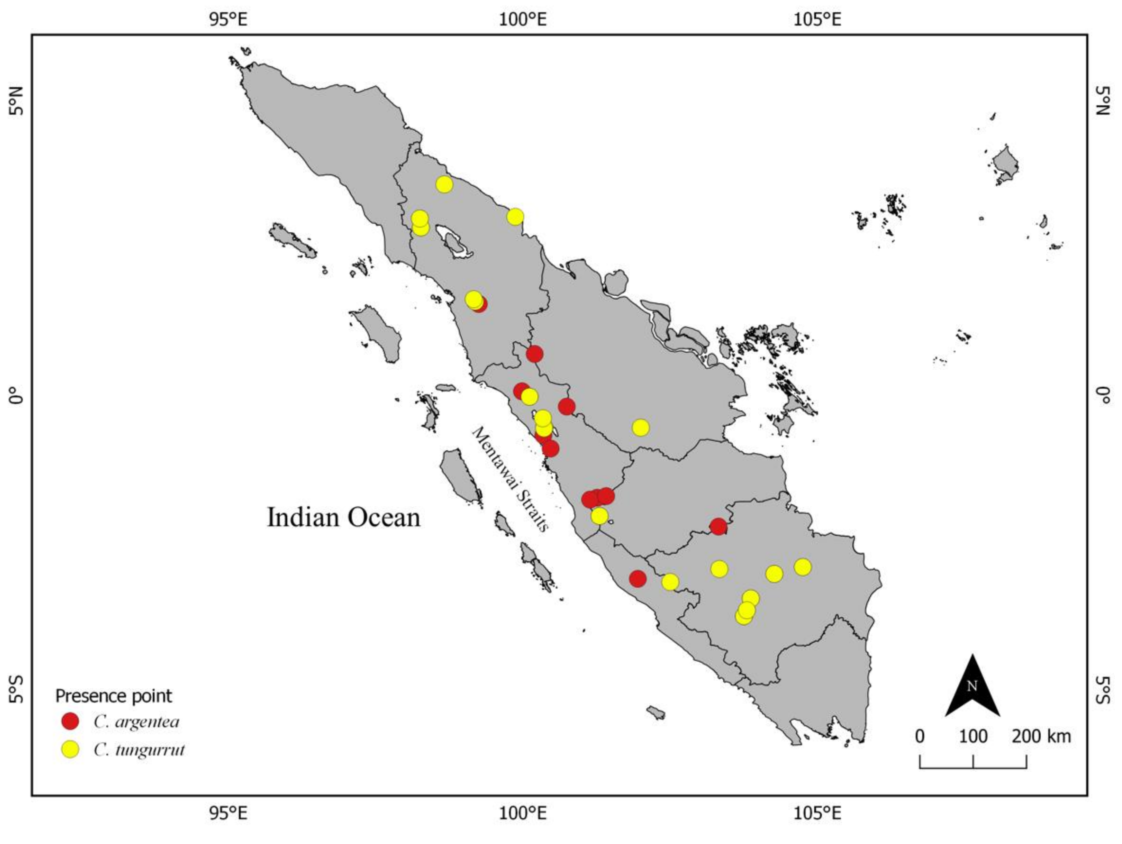

Figure 1. Map of Sumatra, Indonesia and the occurrence data of the targeted *Castanopsis argentea* and *C. tungurrut*

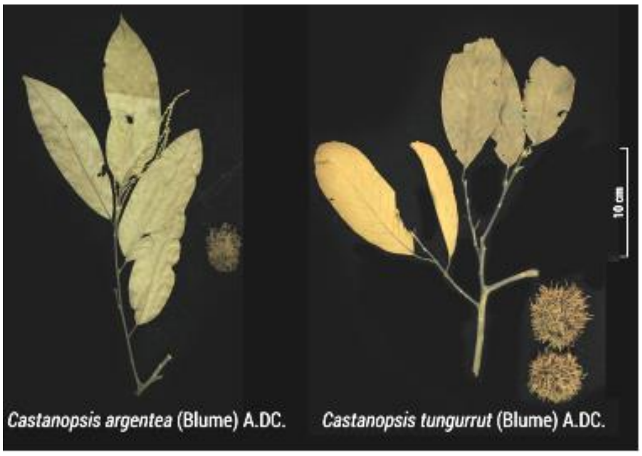

Figure 2. The dry specimen of *Castanopsis argentea* and *C. tungurrut*

Species distribution modeling

MaxEnt ver. 3.4.1 was used to identify the potential distribution of *C. argentea* and *C. tungurut* in Sumatra. All coordinates from species occurrences were converted to decimal degrees. We included the following environmental data in the models. Altitude derived from a digital elevation model (DEM) was obtained from Jarvis et al. (2008), climatic variables were downloaded from WorldClim (Hijmans 2020), and soil quality was obtained from Fischer et al. (2008). All remote sensing raster data were resampled to 1 km spatial resolution using the R Raster package (Hijmans 2020). All rasters in geotiff format were converted to ASC format. Species distribution modelling requires variable selection to enhance the analytical power and avoid the model overfitting (Fourcade et al. 2014; Yi et al. 2016; Pradhan and Setyawan 2021), hence we used PCA to inform the exclusion of highly correlated environmental variables. If two environmental variables were significantly correlated (R>0.8), only one was selected as a predictor (Harapan et al. 2020). Of the original 21 variables, six variables were chosen, including elevation, soil quality, temperature seasonality, precipitation of warmest quarter, temperature annual range and precipitation of wettest quarter (Table 1). On the MaxEnt configuration, auto functions of the predictor variables were selected for inclusion in the model. We followed recommended default values that were used for the convergence threshold (10^{-5}) and a maximum number of 500 iterations (Harapan et al. 2020). Ten replicated model and background samples functions were used for determining a good species location to reflect the environmental conditions that one is affected in contrasting on species presences based on the spatial scale (Saupe et al. 2012; Merow et al. 2013).

Distribution value in conservation areas

Raster output from MaxEnt bearing habitat suitability values from 0-1 for each species was loaded in R and the values were reclassified with Raster package (Hijmans 2020) to produce a potential distribution map with ≥ 0.8 thresholds (Figure 3). We used a Sumatra conservation area shapefile derived from http://www.globalforestwatch.org to check the species coverage inside and outside conservation areas according to their predicted distribution. The shapefile was read into a spatial polygons data frame using the readOGR function in the rgdal package (Bivand et al. 2020).

RESULTS AND DISCUSSION

Castanopsis distribution model

The predicted distributions showed the *Castanopsis* species have a considerable range overlap (Figure 3). The highest potential distribution zones in Indonesia for *C. argentea* were located along with the Barisan mountain range, with *C. tungurrut* having a wider potential distribution in the north of the island in the Lake Toba environs. These species also showed distribution zones in the southern of the island (Bengkulu - Lampung Province).

The success of the model in predicting the distributions for both *Castanopsis* species was checked using mean area under curve (AUC); the model performances were satisfactory based on AUC values (Table 2). Analyses of environmental variable contributions to each of the models are different between species. Elevation, soil quality, and temperature seasonality were the most important variables for *C. argentea* while the most important variables for *C. tungurrut* were elevation, temperature seasonality, and precipitation of warmest quarter (Table 1).

Elevation was by far the highest contributing variable influencing the predicted distribution for both species. Based on a habitat suitability threshold of 0.8, suitable habitat for C. argentea was above 700 m while for *C. tungurrut* it was above 1700 m altitude (Figure 4). Both *Castanopsis* species occur in slight-moderate soil limitation that restricts their land use (Class 1 soils category) and is found in the environment with low seasonality. Suitable habitat for *C. tungurrut* receives about 800-1200 mm precipitation in warmest quarter.

Table 1. Contributing environmental variables for *Castanopsis argentea* (*Ca*) and *C. tungurrut* (*Ct*)

Code	Variable	Contribution (%)	
		Ca	*Ct*
DEM	Elevation	48.6	28.9
S	Soil Quality	28.2	14.7
bio4	Temperature Seasonality	16.3	25.4
bio18	Precipitation of Warmest Quarter	3	19.8
bio7	Temperature Annual Range	2	6.5
bio16	Precipitation of Wettest Quarter	1.9	4.7

Table 2. Model performance and total covered area of *Castanopsis argentea* and *C. tungurrut*

Species	Presence record	AUC	Model Performance (Swets 1988)	Total suitable area covered (>0.8)
C. argentea	15	0.91	Excellent	33,736 km^2
C. tungurrut	37	0.86	Good	54,960 km^2

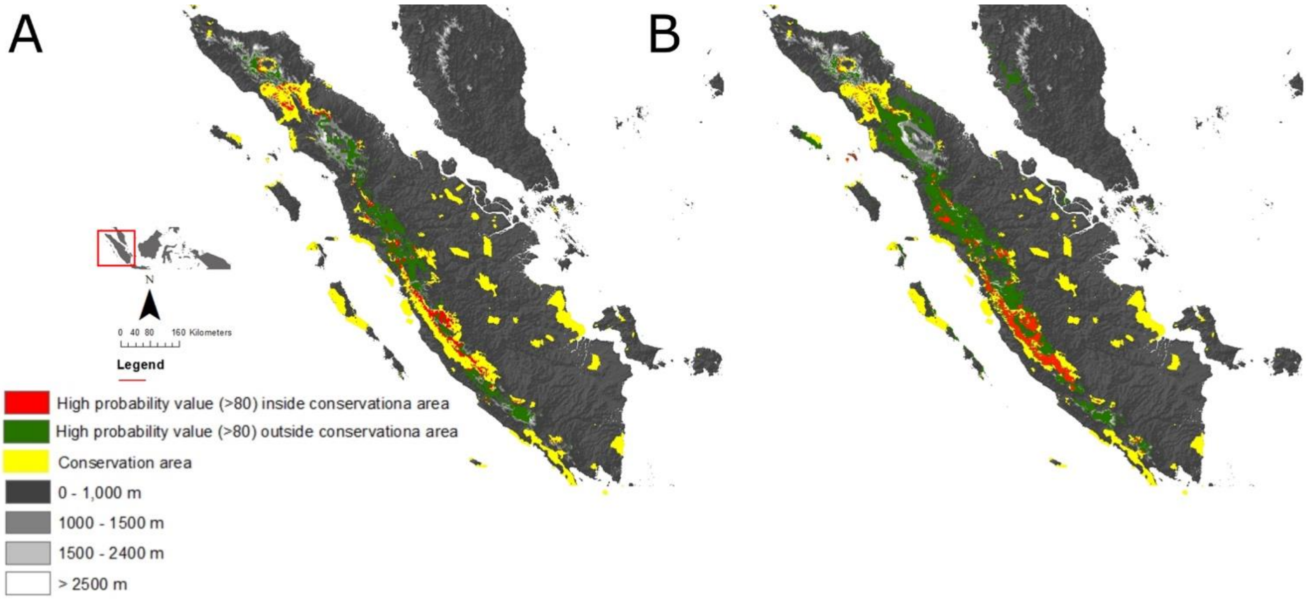

Figure 3. The predicted distribution of: A. *Castanopsis argentea,* B. *C. tungurrut* in Sumatra, Indonesia

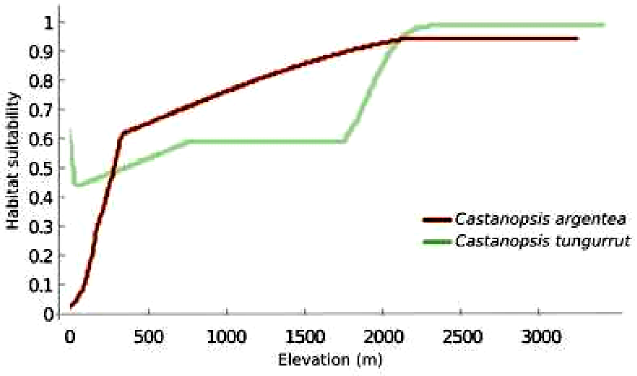

Figure 4. Response of *Castanopsis argentea* and *C. tungurrut* to elevation

In this study, we showed the conservation area that are suitable for both the species. West Sumatra, North Sumatra and Jambi conservation area networks were the most suitable areas. The modeled distributions of both species suggest that they are well covered by the conservation areas of Sumatra, Indonesia (Figure 5).

Field validation

After identifying areas with the highest probability of occurrence for both species in Sumatra, Indonesia, we chose Marapi Mountain, West Sumatra and Mount Tujuh, Jambi to do field surveys for both species. A total of 5 individuals of *C. argentea* and 11 individuals of *C. tungurrut* were recorded across the sites (Figure 6).

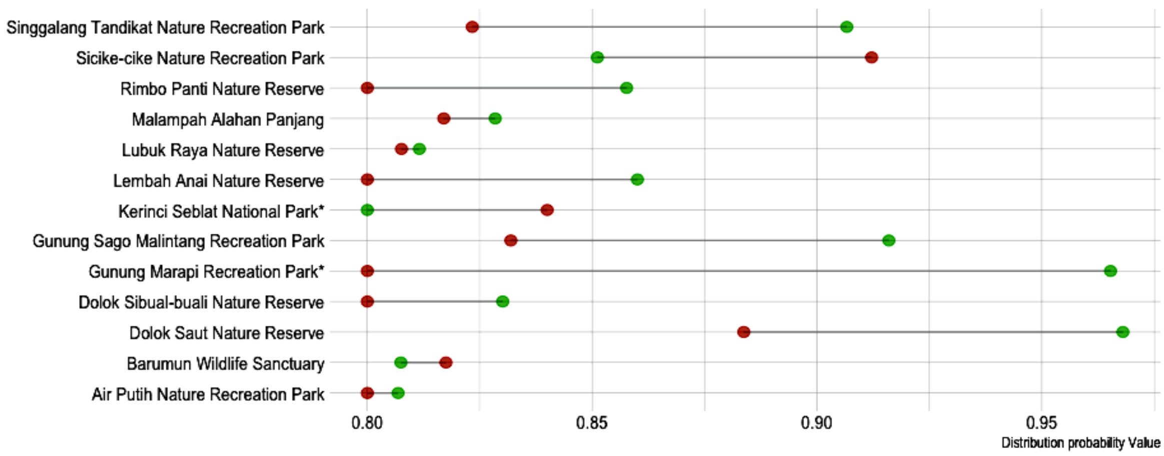

Figure 5. The distribution probability value (%) in Conservation Areas for *Castanopsis argentea* and *C. tungurrut*. Red circles are *C. argentea*; green circles are *C. tungurrut*. *Field validation site

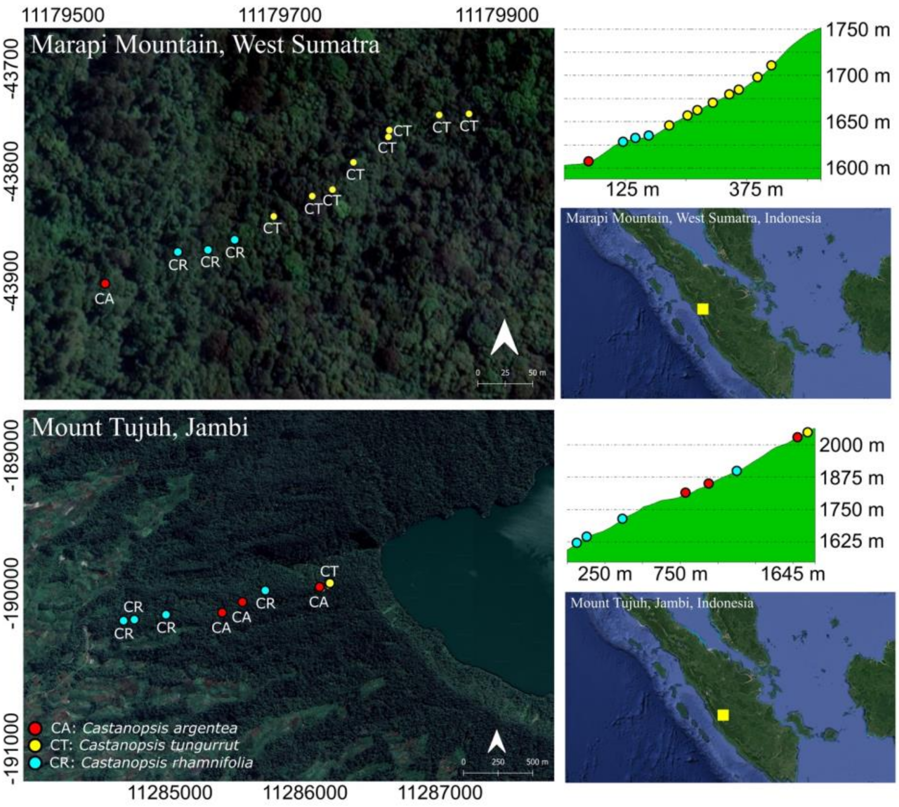

Figure 6. Map of ground validation for *Castanopsis argentea* and *C. tungurrut* in Marapi Mountain and Mount Tujuh, Indonesia

In addition, we also recorded *C. argentea* occurrences in Baruah Gunuang, West Sumatra, Indonesia (0.02329, 100.40715) and along the Padang - Solok road, West Sumatra (-1.03290, 100.68198). These areas were also predicted as highly suitable habitats outside protected areas. Voucher specimens were deposited in Herbarium ANDA (ANDA38871- ANDA38879).

Discussion

Prior to this study, little was known about the potential distribution of the endangered tree species *C. argentea* and *C. tungurrut* in Sumatra, Indonesia, and how much of this was represented in the protected area network. Using a modelling approach, we used herbarium and field records to predict the distribution of both species and overlaid this with a map of protected areas. We also gained insight into the environmental variables which are most important in determining the distribution of the species. This approach allowed us to understand better future threats to the species from land use change.

Our model suggested *C. argentea* and *C. tungurrut* are strongly influenced by elevation (Table 1). Previous studies (Pielou 1979; Adhikari et al. 2012; Chunco et al. 2013; Yi et al. 2016; Kamyo and Asanok 2020) have reported a significant relationship between elevation and plant distribution. Environmental characteristics are very important for determining potential species distributions, and analyzing the various environmental factors related to a habitat. It is also essential to discover the potential presence of a species in their habitat and to recognize basic ecological knowledge of the species (Koo et al. 2019). The limitation of this study is MaxEnt model only predicts species distribution by analyzing the relationship between species and selected environmental variables using presence data. The model suggests the presence of species in areas with suitable environmental conditions (Li et al. 2020). Besides the environmental variables, the distributions of the species are also affected by biotic factors, speciation mechanisms, and dispersal ability (Kaky et al. 2020). However, despite model limitations, MaxEnt can determine habitat use and species distribution across many different taxa and localities generated from incomplete data.

Our field surveys revealed *C. argentea* and *C. tungurrut* are closely distributed with *C. rhamnifolia* (Figure 6). Based on recorded occurrences, *C. argentea* population is relatively small in size compared to *C. tungurrut*. Whitmore (1972) and Laumonier (1997) reported these taxa as important components from lowland to high montane forest. Our model confirmed that the altitudinal characteristics of the plant is consistent with Fujii et al. (2006) who conducted topographic census of Fagaceae in West Sumatra. The study reported distribution of *C. argentea* at altitudinal range of 1200-1800 m and *C. tungurrut* at 1400-1800 m but also in the lowlands at about 400 m (Fujii et al. 2006). Our field surveys in two areas with a high probability of occurrence indicated that both of these species could be available in 2000 m asl at Gunung Tujuh, Indonesia (Kerinci Seblat National Park). Similar to the predictions of the model, Laumonier (1997) recorded *C. argentea* in upper montane forest about 2300 m in West Sumatra, Indonesia. It is indicated these endangered species occur at high altitudes in montane forest, however, according to IUCN (Barstow and Kartawinata 2018a,b), *C. tungurrut* has distributional range up to 1920 m and 150-1400 m for *C. argentea*, while those reports also suggest that both species are almost extinct in lowland areas due to conversion of their native habitat to palm oil plantation. Although in this study we could still find these species in montane area.

The highest deforestation activity occurred in lowland area. For example, Riau contributed 46% of total Sumatran forest degradation between 1990 to 2010, and remaining primary forest is located in upland mostly in Aceh (40%) followed by West Sumatra (15%) and Bengkulu (12%) (Margono et al. 2012). A study by Dwiyahreni et al. (2021) showed in 2012 and 2017 Tesso Nilo National Park lost 47% of total forest cover while Kerinci Seblat National Park only lost 1.96%. However, the upland in Sumatra is not completely safe from forest cover loss. The road constructions also play important role in driving deforestation. The Trans-Sumatra road development would pass several important ecosystems like northern boundary of Kerinci Seblat National Park and northeast flank of Gunung Leuser National Park. These protected areas are expected to be negatively impacted by road development (Sloan et al. 2019).

The first step for the conservation is to understand the relationship between the geographical distribution of taxa and the environmental conditions. Then, we need to assess the predicted distribution areas for collecting the current population data (Mir et al. 2020; Kaky et al. 2020). The predicted areas from MaxEnt can be applied easily to help identify important suitability areas specifically in Sumatra where conservation efforts need to be executed at broad scale. Our field survey into two predicted areas successfully confirmed the model is fairly accurate. The promising areas with a presence probability greater than 80% would be a base for a quantifiable assessment (Figure 4). This assessment can help the protection and restoration efforts for the endangered plants to be more scientific and cost-effective (Gillenwater et al. 2006). The spatial distribution model has directed us to understand better the potential habitat of both the *Castanopsis* species studied. The suitable area must be protected for reforestation and a future reintroduction to reserve the associated habitat. The predicted geographical map can analyze tree distribution data, potential habitat, and disturbance risks (Kamyo and Asanok 2020).

We propose combining the ex-situ conservation with reintroduction to multiply the individuals before their release to the natural habitat. The botanical garden would be a proper place for ex-situ conservation (Widyatmoko 2019). North Sumatra and West Sumatra have the highest value for suitable habitat for establishing an ex-situ conservation strategy. There are four botanical gardens in Sumatra, Solok Botanical Garden, Samosir Botanical Garden, Sriwijaya Botanical Garden and Bukit Sari Botanical Garden. Solok Botanical Garden was found to be located in suitable areas for these endangered plants, giving us the benefit of focusing on the growing population in the natural region. The botanical garden with suitable environmental conditions can use its financial resources and limited land more efficiently (Volis 2017). Solok botanical garden can focus on conservation of living collection *Castanopsis*. Eco-regional climatic conditions are important for living collection of plant species. However, it's ineffective in creating a living collection if these conditions are expected to become unsuitable. After identifying current suitable habitat, future work can be conducted with MaxEnt to identify the areas where the habitat remains suitable over time, e.g., year 2080 (Volis 2017). Therefore, all stakeholder groups need to develop protocols to equally and fairly share species and habitat management costs. Practically, the majority of actions will be governed by national policies. Hence, all management actions should be developed and implemented in association with appropriate monitoring programs where possible, which may be strategically the best way to increase their number of occurrences and reverse trend of their declining populations.

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