Habitat suitability model of Agarwood in a changing climate

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Abstract. Agarwood is a resin produced from several types of trees that are infected. The high demand for agarwood causes CITES in 2004 to include this in appendix II, meaning that the agarwood trading is determined by quota. The Global Climate Change Model (GCM) predicts that by the end of the 21st century, compared with the pre-1980s, global warming will lead to an increase in average temperatures of 3-4 °C, a decrease in rainfall 30-40%, significant changes in seasons and severe weather events. When there are changes in these climate variables, the habitat value for the area will also change. This study aims to develop a species distribution model of \textit{Aguilaria malaccensis} based on naturalised distribution to project the potential distribution of \textit{A. malaccensis} throughout Indonesia under current climate conditions and to assess the sensitivity of this distribution to climate change. The Biodiversity and Climate Change Virtual Laboratory application was used for this analysis. The distribution of \textit{A. malaccensis} looks to be changing where in the year 2050 the decline in the number of locations estimated to be suitable for \textit{A. malaccensis} habitat will experience a significant decline such as distribution on the islands of Kalimantan, Bali, Lombok, and Timor. The opposite pattern is found in the pattern of prediction of its distribution on Sumatra and Sumba. On both of these islands, the number of suitable habitat prediction locations for \textit{A. malaccensis} will increase by 2050. This study has an important implication on the agarwood, where it emphasizing that conservation (both in-situ and ex-situ) of \textit{A. malaccensis} agarwood is needed.

1. Introduction
Agarwood (\textit{Gaharu}) and sandalwood (\textit{Cendana}) are forest products that are widely used because of its fragrance. Many assume that agarwood and sandalwood are produced from the same plant [1]. Sandalwood is produced from sandalwood trees (\textit{Santalum album}) from the Santalaceae tribe, while agarwood is a non-timber forest product produced from several species of trees from several species of the Thymelaceae family such as \textit{Aguilaria malaccensis} Lam. and \textit{Gyrinops versteegii} (Gilg) Domke. Agarwood is a resin or a kind of sap that is produced from several species of trees (producing agarwood) that are infected. Agarwood, which is also widely known as \textit{gaharu}, \textit{gubal} agarwood, \textit{karas}, \textit{mengkaras}, \textit{pious}, \textit{guru}, \textit{sigsigi}, aloeswood, \textit{oud}, and eaglewood have long been used in traditional Chinese medicine.

The history of gaharu or agarwood/ aloe trade has been around for centuries. Since the 3rd century AD, China has been regularly importing agarwood from the Malay Peninsula and other regions [2]. India and its neighbors have also been known as agarwood/ gaharu producing countries [2]. Meanwhile, the trade of agarwood from Indonesia had begun in the 5\textsuperscript{th} century AD. However, this trade began to bloom in the 15\textsuperscript{th} century AD at that time, relations between China and Northern
Kalimantan were well established [3]. The agarwood trade continued during the reign of the Netherlands (from the 18th century until the beginning of the 19th century) and then the trade continued to the present [2]. Aloe's trade also in the past carried out traditionally by residents who live near forest areas in Sumatra and Kalimantan, to meet their daily needs subsistence.

Until now agarwood with those traded in Indonesia is almost all obtained from natural forests such as in Sumatra, Kalimantan, Papua, Nusa Tenggara, Sulawesi, and Maluku. The high demand for agarwood causes many agarwood seekers to spread to the remaining natural forests in Indonesia [4]. Although not all agarwood-producing trees in nature produce agarwood sapwood, the search and harvest of agarwood-producing trees are increasingly intensive. In 2004 CITES-listed this species in appendix II meaning that the agarwood/gaharu trading system was determined by a quota. There are several species of agarwood trees found in Indonesia, namely Gyrinops spp. and Aquilaria spp., where both types of plants are very popular and have been cultivated.

The Global Climate Change Model (GCM) predicts that in the early 22nd century or end of 21st century, compared with pre-1980s, global warming will lead to an increase in average temperatures of 3-4 °C, a decrease in rainfall 30-40%, significant changes in seasons and severe weather events [5]. At a local scale, the majority of species and ecological communities live in bioclimatic niches that can be defined, where habitat values are mainly controlled by a set of variable climate parameters including rainfall and temperature [6]. Once there are changes in these climate variables, habitat values for the area will also alter [7]. For that reason, understanding how species and communities respond to these changes is not a trivial task. Therefore, this study aims to develop a species distribution model of Aquilaria malaccensis based on naturalized distribution to project the potential distribution of A. malaccensis throughout Indonesia under current climate conditions and to assess the sensitivity of this distribution to climate change.

2. Methods

This research was conducted in 2019. The research was carried out at the Spatial Ecology Laboratory, Plant Conservation Center of the “Eka Karya” Botanic Garden, Bali (LIPI). This study uses the apps developed by Griffith University Australia [8] to model habitat suitability of the Aquilaria malaccensis agarwood within Indonesia under current climate conditions. This modeling research uses the BCCVL application or the Biodiversity and Climate Change Virtual Laboratory [9]. Species occurrence data obtained from the GBIF (Global Biodiversity and Information Facility) database [10]. While climate data obtained from Worldclim current condition (1950-2000). Then selected variables as listed (table 1), based on monthly average data (1950 - 2000) available in WorldClim global climate data and CGIAR CSI (Consortium for Spatial Information) [11]. Prediction of climate change conditions in 2050 was done by using the IPSL-CM5A-LR RCP3D 2050-at 10’m-bioclim scenario as the prediction layer.

Species Distribution Model (SDM) analysis in this study uses the BCCVL application (http://www.bccvl.org.au/) [8], [12]. Species distribution modeling needs a species matrix as a variable response (Species occurrence) and an environmental matrix in this case climate as a predictor. BCCVL at present offers 17 different algorithms to execute species distribution models (e.g. profile models, statistical regression models, machine-learning models and geographical models). In this study, we use the MAXENT model to process SDM. The result of BCCVL is then processed using Arc Map 10.1. The main output of SDM is a map showing the prediction distribution of Aquilaria malaccensis. This prediction refers to the distribution of suitable habitats as defined by environmental variables (in this case the current climatic conditions). The second output is the response curve. The curve shows the relationship between the probability of a species and each of its environmental variables. The vigor of the model is evaluated using the AUC (Area under the Curve) of the ROC (Receiver-Operating Characteristic) Curve. What needs to be considered for evaluating the model is the value in the area under the curve (AUC). The author interprets the AUC score as follows: values above 0.9 are very good, good 0.9> AUC> 0.8, sufficient 0.8> AUC> 0.7, poor 0.7> AUC> 0.6, and fail 0.6> AUC> 0.5 [13].
Table 1. Several climate variables that used in the analysis.

| No. | Symbol | Information                                   |
|-----|--------|-----------------------------------------------|
| 1   | B01    | Annual Mean Temperature                      |
| 2   | B02    | Mean of monthly (max temp - min temp)        |
| 3   | B03    | Isothermality (BIO2/BIO7)                    |
| 4   | B04    | Temperature Seasonality (standard deviation) |
| 5   | B05    | Max Temperature of Warmest Month             |
| 6   | B06    | Min Temperature of Coldest Month             |
| 7   | B07    | Temperature Annual Range (BIO5-BIO6)         |
| 8   | B08    | Mean Temperature of Wettest Quarter          |
| 9   | B09    | Mean Temperature of Driest Quarter           |
| 10  | B10    | Mean Temperature of Warmest Quarter          |
| 11  | B11    | Mean Temperature of Coldest Quarter          |
| 12  | B12    | Annual Precipitation                         |
| 13  | B13    | Precipitation of Wettest Month               |
| 14  | B14    | Precipitation of Driest Month                |
| 15  | B15    | Precipitation Seasonality (Coefficient of Variation) |
| 16  | B16    | Precipitation of Wettest Quarter             |
| 17  | B17    | Precipitation of Driest Quarter              |
| 18  | B18    | Precipitation of Warmest Quarter             |
| 19  | B19    | Precipitation of Coldest Quarter             |
| 20  |        | Altitude                                     |
| 21  | Ai-yr  | Aridity per year                             |
| 22  | Pet-he_Yr | Evapotranspiri per year                   |

3. Results and discussion

The area below the receiver-operating curve (ROC-AUC) indicates the model's presentation measures (figure 1) [14]. The AUC test data (gray solid line) is 0.92, indicating that the MAXENT model has a 92% success rate and has a good match and is statistically significant (p <0.05) [15].

![Figure 1](image_url)

**Figure 1.** The ROC curve from the MAXENT analysis.

The potential distribution map modeled for *Aquilaria malaccensis* (figure 2) clearly illustrates various habitats potentially suitable for this species. Solid red indicates an area with a higher
likelihood of *A. malaccensis*. The distribution of *A. malaccensis* is seen to be changing, where by 2050 the number of locations estimated to be suitable for this species’ habitat will decrease significantly as well as its distribution on the islands of Kalimantan, Bali, Lombok and Timor (figure 2). The opposite pattern is found in the prediction pattern of distribution on the islands of Sumatra and Sumba. On these two islands, the number of habitat prediction locations suitable for *A. malaccensis* will increase by 2050.

![Figure 2](image)

**Figure 2.** Map of *Aquilaria malaccensis* habitat suitability models in Indonesia using the MAXENT method in BCCVL: (a) Current projection; and (b) Future projections.
Regarding species richness, especially for the eastern region where there is a significant decrease in the suitability of agarwood habitat, it can be seen in figure 3 below. The highest species of richness is predicted in 2050 to be on Sumba Island, as well as parts of Flores Island, East Nusa Tenggara.

![Figure 3. Prediction of the distribution of species richness of *Aquilaria malaccensis* in parts of Indonesia's East Nusa Tenggara in 2050.](image)

Regarding which environmental factors are used in this modeling analysis that has responses to species occurrence data can be seen in figure 4 below, namely the response curve for *A. malaccensis*. Agarwood, *A. malaccensis* responds to certain environmental layers, namely: Mean Diurnal Range (Mean of monthly (max temp - min temp), Mean Temperature of Wettest Quarter, Precipitation of Coldest Quarter, Aridity & Evapotranspiration. Agarwood, *A. malaccensis* in this modeling analysis can adapt to temperature ranges under conditions during the wet season at temperatures between 20-28°C, and in the coldest quarters with precipitation between 400-1,000 mm/year. Potential Evapotranspiration (PET) is a gauge of the ability of the atmosphere to be eliminated by water processes through Evapotranspiration (ET). For the potential for evapotranspiration (PET) agarwood curves are estimated to be suitable in areas with PET conditions of 1,200–1,600 mm/year, then the aridity index (AI) factor. Aridity is expressed as a common function of rainfall, temperature, and/or evapotranspiration potential (PET). Note that higher AI values represent more humid conditions; with lower AI values represent higher aridity. Aloes *A. malaccensis* is projected to be in the AI range/year between 0.5 - 3.5.

The islands of Bali, Lombok and Timor (three islands were based on modeling will experience a significant decrease in terms of decreasing number of locations thought to be suitable for *A. malaccensis* habitat) located west of the Wallacea line have many flora species as part of biodiversity. At present, a series of pressure is considered to threaten this diversity. On the other hand, humans rely on plants for wood, food, medicine, and more. To maintain availability, the practice of conservation
efforts is needed. Plant conservation can be classified as in-situ and ex-situ. Conservation of agarwood species from *A. malaccensis* is needed to preserve its endangered genetic material. In-situ and ex-situ conservation must be carried out to save the agarwood tree.

![Figure 4.](image)

For ex-situ conservation purposes where plant species are studied, propagated, and planted in a botanical garden, research on their ecology (relationships with environmental factors in their natural habitat) and also the selection of plus tree species of agarwood are needed [16]. Through this selection, it is hoped that the process of acclimation and propagation can be carried out effectively so that the ultimate goal of ex-situ conservation (i.e. replanting or enrichment of planting into its natural habitat) can be achieved. This study highlights some of the more important drivers determining the distribution of *A. malaccensis*. This driver provides insight into the abiotic conditions needed for plants to survive, given the temperature is expected to increase in global climate change [15], this increase could have a considerable impact on the distribution of agarwood species in the future. With climate and environmental variables such as air temperature, rainfall, evapotranspiration, and aridity that correlate with this model, so these four factors become important to focus on in maintaining their sustainability in nature through ex-situ conservation activities. In Kwazulu Natal in South Africa, the study of [15]
revealed that geological factors and altitude are the environmental factors most correlated with habitat selection of *Acacia nilotica* (a spiny acacia type which is one of the invasive foreign species in Indonesia). Global climate change seems to enlarge the potential distribution of *A. nilotica* in Indonesia, as explained by [7]. It is predicted by 2045, *A. nilotica* will likely spread to the eastern part of Indonesia. Likely, *A. malaccensis* will also suffer from global climate change because it is projected that there will be a decrease in the environmentally suitable range for this species by 2050.

4. Conclusion
This study estimates that geographical habitat shifts will occur. The new suitable habitat is predicted to be found mainly on Sumba Island and the central part of Papua. Thus, the protection of this region from habitat destruction and land-use change is needed to ensure that *A. malaccensis* can adapt to climate change. A limitation of this modeling is that it does not include factors such as poaching and other anthropogenic disturbances. Therefore, research on predictive modeling should also be supported by intensive field surveys including inventorying the anthropogenic disturbances, if it is to be implemented into policy. Further field surveys are needed to validate the predictions of this study. It is also recommended to get more co-occurrence data or density data of a species in a location that has been geo-referenced or equipped with geographical coordinates to further strengthen the prediction results obtained.

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