The effect of climate and land cover changes on the distribution of *Actinodaphne areolata* Blume, an endemic and endangered species in Java, Indonesia

D. Usmadi[1*] and *R.* Cahyaningsih[2]

[1]National Research and Innovation Agency, Research Center for Ecology and Ethnobiology, Bogor, Indonesia, 16911
[2] National Research and Innovation Agency, Research Center for Plant Conservation, Botanic Gardens, and Forestry, Bogor, Indonesia, 16121

Abstract. *Actinodaphne areolata* Blume is an endemic plant in Indonesia. The minimal distribution makes this species threatened and even listed as endangered species by IUCN. Therefore, analyses of climate change and land cover change were conducted to predict the future species distribution and to determine conservation action for this species. The plant occurrences from GBIF online database and Naturalis herbarium data were collected and validated. The environmental variables used in the model were topography, vegetation, soil, and climate. All environmental variables were selected with the multicollinearity test. Prediction of future land cover using cellular automata and the future species distribution for 2050 (2041-2060) and 2070 (2061-2080) under the Representative Concentration Pathways 4.5 and 8.5 scenarios were simulated using maximum entropy (maxent). The resulting habitat suitability prediction model has an AUC value of more than 0.92, indicating an adequate model for predicting habitat suitability for *A. areolate*. Environmental variables that affect the presence of *A. areolata* are temperature seasonality (bio4) and land cover. Land cover and climate change were estimated to impact plant distribution in the future negatively. The suitable habitat for *A. areolata* will gradually decrease throughout the year, so it is necessary to designate priority areas for conserving this species.

1 Introduction

Actinodaphne aorelata Blume is an endemic plant to Java Island, Indonesia, and is included in *Actinodaphn*e genus, which has 121 relatives from the Lauraceae family [1]. The little-known information about *A. aorelata*, but is harvested for its timber [2]. The species grows naturally in forests and due to habitat decline is included as endangered species based on IUCN red list criteria.

People's activity has a more negative impact on their habitat. It impacts land use and cover change more than natural occurrences like rainfall, temperature, and soil texture [3]. It is

* Corresponding author: didi020@brin.go.id

notably due to rapid urbanization activity and land conversion to meet needs, including deforestation [4]. Moreover, various ecosystems are provided by land resources, which are essential for people's life [5]. Java island is a part of Sundaland that is severely threatened by climate change, mainly due to sea level rise and air temperature rise [6].

As a result of land cover and climate change, plant species would be susceptible to becoming extinct in Java [7]. Thus, conservation efforts for *A. aerolata* are critical. Through this study, we aim to estimate the future habitat suitability due to climate change and land cover changes on *A. areolata* Blume distribution to determine conservation efforts.

2 Materials and methods

2.1 Study area

The research was carried out on the Indonesian island of Java, which stretches from 5°55′-8°47′ S and 105°12′-114°36′ E. The study area's altitude ranges from sea level to 3,415 meters above sea level; the north and south areas are generally lowlands, while the central areas, which stretch east to west are highlands (mountains area).

2.2 Land use land cover change

The actual land cover used is in land cover in 2010, 2015, and 2020 resulting from Moderate Resolution Imaging Spectroradiometer (MODIS) land cover data downloaded from USGS (United States Geological Survey) Earth Explorer Website. The MCD12Q1 type and land cover classification type 1 (annual IGBP classification) were selected and used in these analyses, which we modified to make it simpler. Future land cover predictions in 2050 and 2070 were conducted using the MOLUSCE (Modules for Land Use Change Simulations) plugin version 3.0.13 included in QGIS 2.18.20 [8]. The driving factors in land cover change are elevation, distance from the roads, slope, and population. The logistic regression algorithm was used to create the transition potential model. The cellular automata simulation method was used for projecting land cover in 2020 based on actual land cover data from 2010, 2015, and transition potential modelling. Moreover, the projected land cover in 2020 is validated against the actual land cover in 2020. The Kappa statistic provided by the MOLUSCE model indicates its performance, are interpreted as follows: value ≤ 0.00 (poor), 0.00 - 0.20 (slight), 0.21 - 0.40 (fair), 0.41 – 0.60 (moderate), 0.61-0.80 (substantial), and 0.81-1.00 (almost perfect) [9].

2.3 Occurrences and environmental predictors

A. areolata occurrences were collected from GBIF online [10] and Naturalis Biodiversity Center (the Netherlands), totalling seven occurrences. The species distribution is determined by topography (elevation, slope, and aspect), vegetation (land cover), soil (soil type), and climate variables (bioclimatic). Elevation using the Shuttle Radar Topography Mission (SRTM) elevation data with a spatial resolution of 30 m. Slope and aspect are derived from the elevation data. Vegetation using MODIS land cover data with a spatial resolution of 500 m.

Soil types were obtained with a spatial resolution of 250 m from SoilGrids website [11]. Climate based on 19 WorldClim bioclimatic variables obtained from WorldClim website with a spatial resolution of 30 seconds (~1 km) [12]. All environmental spatial variables were resampled to a size of 1 km. To avoid multicollinearity between environmental variables, one variable with a Pearson correlation coefficient with other variables > 0.80 is not used in

estimating the model distribution [13]. This resulted in 7 environmental variables, namely bio4 (temperature seasonality), bio5 (max temperature of warmest month), bio15 (precipitation seasonality), bio19 (precipitation of coldest quarter), aspect, land cover, and soil type.

2.4 Species distribution modelling

A. areolata's current and future species distribution model is generated on the tool of maximum entropy (Maxent) version 3.4.4. [14]. Estimating future model species distribution based on land cover prediction data from MOLUSCE analysis and future bioclimatic data from the MRI-ESM2-0 climate model [15]. Future species distribution predictions are generated for 2050 (2041-2060) and 2070 (2061-2080) under the Representative Concentration Pathways (RCP) RCP 4.5 and RCP 8.5 scenarios [16].

The model performance was interpreted with AUC value from maxent analysis's result as 0.9-1 (excellent), 0.8-0.9 (good), 0.7-0.8 (fair), 0.6-0.7 (poor), and 0.5-0.6 (fail) [17]. Environmental variables predict the presence of this species using the Jackknife test [18]. For the analyses of current and future habitat suitability, the habitats of a species are divided into four categories: not suitable (≤0.10), low suitability (0.11-0.30), moderate suitability (0.31-0.70), and high suitability (≥0.71) [19].

3 Results and discussion

3.1 Analysis of spatiotemporal land cover change

Table 1 give statistics on land cover in Java at the time of the study, as well as annual temporal and spatial changes. Croplands is the most extensive land cover in Java, followed by woody savannas (tree cover 10-60%) and forests (tree cover >60%), with barren and wetlands being the lowest. Land cover in the form of woody savannas, wetlands, croplands, barren and water bodies has declined over the last decade (2010-2020). Woody savannas decreased from 40,386 km^2 to 37,917 km^2 (Table 1). Forests, grasslands, and urban and built-up lands have increased in the area over the last decade. Forests expanded by 2,370 km^2 at a rate of 1.37 percent per year. Grasslands are expanding by 115 km^2 at a rate of 0.90 percent per year. Urban and built-up lands expanded by 749 km^2 at a rate of 0.87 percent per year.

3.2 Analyses of future land cover prediction

The MOLUSCE model's forecast of land cover in 2020 was validated against the actual land cover of MODIS image data in 2020, generating an overall kappa statistic of 0.73. This value shows that the MOLUSCE prediction model is reliable enough to predict future land cover. According to the analysis of future land cover prediction results, the amount of land cover in 2050 and 2070 will expand in the form of forests and urban and built-up lands. The most significant growth was in forest land cover, which increased by 3,063 km^2 to 22,738 km^2 (2050) and by 4,088 km^2 to 23,762 km^2 (2070) (Table 1). The area of predicted land cover in the form of woody savannas, wetlands, croplands, barren, and water bodies will decrease compared to 2020. The most significant decline occurred in woody savannas, which decreased by -2,032 km^2 to 35,885 km^2 (2050), followed by a decrease of -3,043 km^2 to 34,874 km^2 (2070).

The habitat of *A. areolata* consists primarily of forests and some woody savannas. Future simulation results show that forests will continue to expand in 2050 and 2070, covering 18.10 percent of the island of Java in 2050 and 18.91 % in 2070. Meanwhile, woody savannas will

account for 28.56 % of the whole area of the island of Java in 2050 and 27.76 % in 2070. The center and southern regions of Java Island are dominated by forest cover and woody savannas.

Table 1. Land cover of Java Island. Actuals for 2010, 2015, and 2020 and predictions for 2050 and 2070 (km^2).

Land cover	2010	2015	2020	2050	2070
Forests	17,304	18,158	19,674	22,738	23,762
Woody savannas	40,386	38,972	37,917	35,885	34,874
Grasslands	1,276	1,496	1,391	439	422
Wetlands	1,131	1,201	1,064	992	978
Croplands	55,513	55,556	54,826	53,966	53,792
Urban and built-up lands	8,575	8,824	9,324	10,259	10,457
Barren	60	51	51	41	41
Water bodies	1,385	1,372	1,384	1,312	1,305

3.3 Model evaluation and importance variable analyses

The AUC training data is 0.956, and the AUC test data is 0.927, indicating that maxent's model is very reliable in predicting the occurrence of *A. areolata*. According to the model results, the highest contributions of biophysical variables in the maxent model are temperature seasonality (bio4) and land cover, with percentage contributions of 53.8% and 24.7%, respectively. Other biophysical variables, such as aspect, precipitation of coldest quarter (bio19), max temperature of warmest month (bio5), precipitation seasonality (bio15), and soil type, contribute a relatively small percentage to the maxent model (7%).

The jackknife test of variable importance analysis showed that the biophysical environment variable that most influenced the presence of *A. areolata* was temperature seasonality (bio4) (Fig. 1). Temperature seasonality has the highest gain value and is more important information than other variables. Other important biophysical environmental variables that determine the presence of *A. areolata* are land cover, max temperature of warmest month (bio5), and precipitation seasonality (bio15).

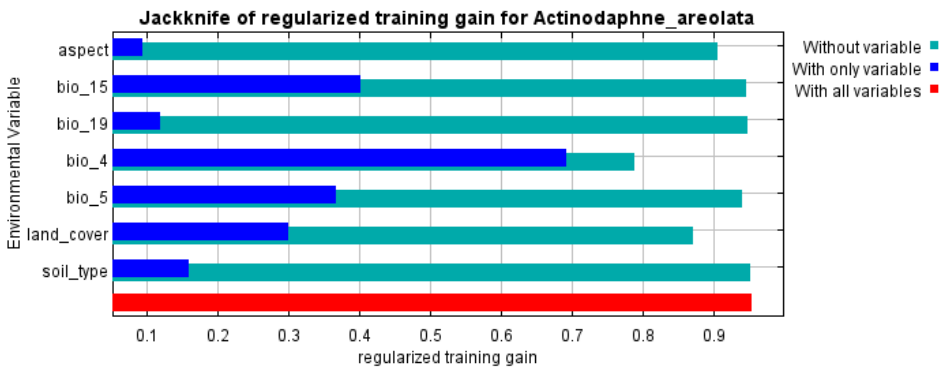


Fig. 1. Environmental variables that affect *A. areolata* occurrences.

3.4 Analyses of current and future habitat suitability

According to Table 2, the current high habitat suitability of *A. areolata* width is 8,794 km^2 or 7% of the total area of Java Island, while *A. areolata*'s moderate habitat suitability is 22,604 km^2 or 17.99% of the total area of Java Island. The habitat suitability of West Java Province and southern Banten Province is exceptional. Moderate habitat suitability is found

in the provinces of West Java, central and southern parts of Banten, Central Java, and slightly in the eastern part of East Java (Fig. 2).

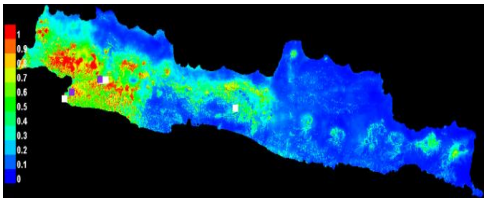
The results of future habitat suitability predictions due to land cover changes and climate change show that high suitability habitats for *A. areolata* have declined as greenhouse gas emissions have increased. The high suitability habitat for *A. areolata* in the RCP 4.5 scenario is 4,122 km^2 (2050) and 4,583 km^2 (2070). Meanwhile, the high suitability habitat for *A. areolata* in the RCP 8.5 scenario is 1,326 km^2 (2050) and 1,870 km^2 (2070).

The maxent model predicted that air temperature variables (bio4, bio5, and bio15) and land cover influenced the distribution of *A. areolata*. Looking at the existing habitat distribution and two climate change scenarios (RCP 4.5 and RCP 8.5), it is clear that a rise in greenhouse gas emissions, which produces an increase in air temperature, harms *A. areolata*'s distribution. The scenario with the highest level of greenhouse gas emissions (RCP 8.5) generates a faster rate of increase in air temperature than the scenario with the lowest level of greenhouse gas emissions (RCP 4.5). As a consequence, *A. areolata*'s suitable environment became more limited. Simultaneously, the area of high suitability habitat will drop in 2050 at RCP 4.5 by 3.28 % to 1.06 % at RCP 8.5, and in 2070 at RCP 4.5 by 3.65 % to 1.49 % at RCP 8.5.

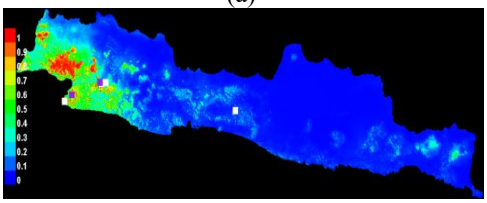
Climate change and changes in land cover will have an impact on the spread of *A. areolata* in the future. *A. areolata* will choose habitats that are comparable to the current conditions. Hence *A. areolata* will be found at higher elevations and in locations where the land cover is forest rather than woody savanna. This is how this species may adapt to survive in the presence of climate change and land changes.

Table 2. Prediction of current and future habitat suitability of *A. areolata* at RCP 4.5 and RCP 8.5.

Habitat suitability	Current		RCP 4.5				RCP 8.5			
	2020		2050		2070		2050		2070	
	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
Not suitable	57,983	46.15	94,282	75.05	91,241	72.63	102,138	81.30	105,807	84.22
Low	36,250	28.85	15,816	12.59	17,376	13.83	15,296	12.18	11,503	9.16
Moderate	22,604	17.99	11,411	9.08	12,431	9.90	6,870	5.47	6,452	5.14
High	8,794	7.00	4,122	3.28	4,583	3.65	1,326	1.06	1,870	1.49



(a)



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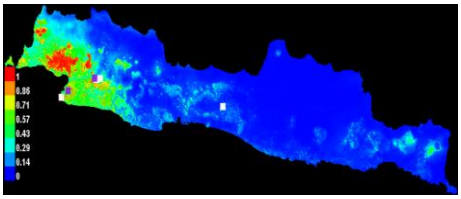

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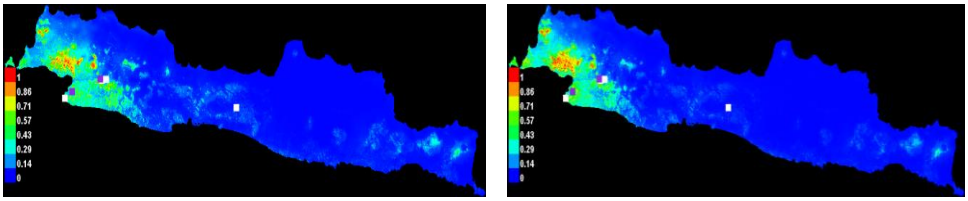

(d) (e)

Fig. 2. Prediction of habitat suitability from maxent model; current (a), RCP 4.5 in 2050 (b), RCP 4.5 in 2070 (c), RCP 8.5 in 2050 (d), RCP 8.5 in 2070 (e).

Conservation efforts need to be made to ensure the survival of this species in the future. *A. areolata* will have high habitat suitability in sites located in *in situ* conservation areas such as Mount Halimun Salak National Park and Mount Gede Pangrango National Park. However, some additional sites with high habitat suitability, such as Mount Pulosari, Mount Karang, and Mount Aseupan in Pandeglang Regency, Banten Province, do not have the status of a protected reserve. In order to preserve these habitats, it is necessary to establish protected areas, especially in places with high habitat suitability [20]. Moreover, other conservation efforts might include population monitoring, propagation, and reintroducing the species to its natural habitat. Reintroduction can take place in regions with high habitat suitability. Despite climate change and extensive land cover change on the island of Java, all of these measures are expected to be able to maintain the sustainability and population of these species in nature in the future.

4 Conclusion

In the future, changes in climate and land cover are likely to have a negative impact on plant distribution. Suitable habitat for *A. areolata* would gradually decrease over the year, and priority locations and conservation actions for this species have been identified. The species that have already grown in situ conservation areas should have active conservation effort, that is, monitoring. Otherwise, the area could be recommended for new potential in situ conservation establishment.

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