Modeling the plantation area of geographical indication product under climate change: Salak Pondoh Sleman (Salacca edulis cv Reinw)

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Abstract. As a geographical indication product, Salak Pondoh Sleman can only be cultivated in certain regions, to get fruit with distinctive characteristics. The risk of climate change in the future, therefore, can have an impact both on the possessed characteristics and on the grown area, both directly affecting the amount of product availability in the market. This study aims to generate a spatial model on the probability of Salak Pondoh Sleman plantation distribution under climate change. IP (IPSL-CM5A-LR) model in RCP45 was used to project the temperature and precipitation in 2050. Modeling the probability of plantation distribution was done by ArcMap 10.3 and Maximum Entropy (MaxEnt) software. Based on the developed model, Salak Pondoh Sleman is vulnerable to the climate change effect, indicated by the smaller probability of distribution of the Salak Pondoh Sleman planting area in 2050. The decrease in a suitable grown-area and required risk mitigation are discussed further in this paper.

1. Introduction
Climate change is a global phenomenon triggered by rising atmospheric average temperatures along with the increase in greenhouse gases in the atmosphere. The change refers to changes in climatic conditions that can be identified from changes in averages or variability in their properties over a long period, usually decades or longer, either due to natural variability or anthropogenic sources. The Earth’s surface temperature has increased by 0.85 °C (0.65 to 1.06 °C) from 1880 to 2018 and will remain to increase to 1.5 °C from 2030 to 2052 [1]. Meanwhile, the Indonesian territory has undergone a temperature increase of 0.76 °C in the last 100 years [2]. The global temperature changes have an impact on climate change, such as changes in rain patterns that leads to erratic weather, as well as rising and decreasing rainfall in some regions. The impact of variability and climate change will be even worse for the highly vulnerable agricultural sector [3,4].

In the last decade, climate change has influenced the success of agricultural cultivation, especially in the growth, development, and production of horticultural commodities [4]. The success of agricultural cultivation can be done by determining the optimal location of the plantation area. The determination suggests that the unsuitable cultivation area of specific crops in a particular region was closely related to climate and soil conditions [5]. Plants, in a short time, will become unproductive when they are forced to grow in an inappropriate location, unless there is an improvement effort, for example, input technology [6]. Climate changes occurring in different vegetation zones have different
impacts on the horticulture distribution and on its reproductive success. These changes may convert some of these areas from suitable to unsuitable and vice-versa.

Research related to the effect of climate change on the probability of Salak Pondoh Sleman plantation distribution has not been done before. Salak Pondoh Sleman is a superior local agricultural product in Sleman Regency. A superior local product is a product that has the potential to be developed in a region using their local natural and human resources as well as earning income for the community and the government [7]. The superiority of Salak Pondoh Sleman is indicated by the high percentage of the commodity yield when compared with other commodities in Sleman Regency, which was 41.63% in 2017 and increased to 53.49% in 2018 [8]. Furthermore, the superior product is also a competitive, market-oriented, and environmentally friendly product in order to create a competitive advantage to face global competition [7]. In addition, Salak Pondoh Sleman is claimed to have a distinctive flavor that distinguishes it from similar cultivar planted in other regions. The sweet-tasted and crunchy texture are the inherent characteristics in the Salak Pondoh Sleman [9]. The inherent characteristics were evidenced by the issuance of the geographical indication certificate since 2013. This certificate indicates that the product has distinctive characteristics that cannot be found in another region due to its geographical conditions, or the culture of the local community, or a combination of both [10].

The objective of this study is to perform a spatial model on the probability of Salak Pondoh Sleman plantation distribution under the risk of climate change. We used Species Distribution Models (SDMs) to identify changes in land suitability, both from suitable area to unsuitable area and vice versa. Combination of the Geographical Information System and Maxent model were used for projecting the probability of the land suitability in 2050 in the climate change scenario.

2. Materials and methods

2.1. Study Area

The plantation area of Salak Pondoh Sleman (Salacca edulis cv Reinw) is located in Sleman Regency, Special Region of Yogyakarta, Indonesia. The study was conducted in the area with the highest yields, i.e., Tempel, Turi, and Pakem subdistricts. Besides, these three subdistricts were also the registered area of geographical indications of Salak Pondoh Sleman. All the data compilation and spatial analyses were carried out in 2019.

2.2. Species presence records

The presence data used in this study is the presence of Salak Pondoh Sleman plants. The data was determined based on the Sleman Regency land-use map in 2015. A total of 9,729 points were collected as data for the presence of Sleman Pondoh Salak plants (figure 1).
2.3. Environmental variable

Bioclimatic data at 2.5-minute spatial resolution were used as current global climate conditions, while future climate conditions projections were carried out using Representative Concentration Pathways 4.5 (RCP 4.5) in 2050 (table 1). Selection for 2050 was due to the availability of bioclimatic data projection according to the IPCC report. We used 22 bioclimatic variables (average temperature and precipitation in 1970 – 2000 as current condition and average temperature and precipitation in 2041 – 2061 as a prediction in 2050), which were obtained from the WordClim database respectively [11,12]. Later, General Circulation Models (GCM), IPSL-CM5A-LR, were selected for both current and future bioclimatic data. The IPSL-CM5A-LR was the most recent GCM climate projections that are used in the Fifth Assessment IPCC report, which has been extensively used to perform future climate predictions. This model includes an interactive carbon cycle, a representation of tropospheric and stratospheric chemistry, and comprehensive representation of aerosols. This model also represents the key dynamical, physical, and biogeochemical processes relevant to the climate system [13]. The entire environmental variable was extracted from 13 coordinates, as a representation of the climate stations, for the climate data interpolation in order to obtain the spatial climate coverage of the observed region.

| Code | Environmental variables                                      | Unit     | % contribution |
|------|-------------------------------------------------------------|----------|----------------|
| bio1 | Annual Mean Temperature                                     | °C       | 0.0            |
| bio2 | Mean Diurnal Range (Mean of monthly (max temp - min temp)) | °C       | 5.3            |
| bio3 | Isothermality (bio2/bio7) (x100)                            |          |                |
| bio4 | Temperature seasonality (standard deviation x 100)          | C of V   | 11.7           |
| bio5 | Max Temperature of Warmest Month                            | °C       |                |
| bio6 | Min Temperature of Coldest Month                            | °C       |                |
| bio7 | Temperature of Annual Range (bio5 – bio6)                  | °C       |                |
| bio8 | Mean temperature of Wettest Quarter                        | °C       | 11.0           |
| bio9 | Mean Temperature of Driest Quarter                         | °C       | 38.6           |
| bio10| Mean Temperature of Warmest Quarter                        | °C       |                |
| bio11| Mean Temperature of Coldest Quarter                        | °C       |                |
| bio12| Annual Precipitation                                        | mm       | 0.9            |
| bio13| Precipitation of Wettest Month                             | mm       | 27.8           |
2.4. Maximum entropy (MaxEnt) model

The Maximum Entropy (MaxEnt) model has been used as the Species Distribution Models (SDMs) approach, both for animals and plants [14–17]. The main principle of MaxEnt is to estimate the distribution probability of a species from its subject distribution (pixels) opportunities that have maximum entropy and estimate the value of other pixels in the study area [18,19]. The MaxEnt distribution model only uses presence data, which further known as sample (including the environmental variables), to estimate the probability distribution around [19]. This study used 75% and 25% of training and test data points, respectively. The relative importance of each environmental predictor for the probability model of Salak Pondoh Sleman plantation distribution was assessed using the percent contribution of Jackknife test [18].

Maxent output was an HTML format file which contains a summary of the spatial prediction model for the plantation distribution of Salak Pondoh Sleman in Tempel, Turi, and Pakem subdistricts. This information was based on the Area Under Curve (AUC) value, which represents the model performance and the environmental variables that contribute to the model. The prediction model, thus, converted into raster format to be analyzed in ArcGIS software in order to determine the suitable or unsuitable area for Salak Pondoh Sleman plantation. The threshold value was required to distinguish regions based on its predicted land suitability, where values below the threshold were an unsuitable area for Salak Pondoh Sleman plantation and vice versa.

2.5. Performance and evaluation

This phase aims to determine the composition of the data in a model with optimal performance values. The evaluation was done by testing the model, using training data, to measure the model performance. The results were indicated by the AUC value, which can be categorized as good with a value close to 1 [19]. The generated AUC graph was obtained by plotting the true positive predictions (sensitivity) against the false positive predictions (1-specificity) [14].

3. Result and discussion

The prediction model of Salak Pondoh Sleman plantation area was built using maximum entropy modeling to identify contributed environmental factors on the probability of Salak Pondoh Sleman plantation distribution and predict the future Salak Pondoh Sleman plantation distribution in Sleman Regency, Special Region of Yogyakarta, Indonesia.

3.1. Model performance and evaluation

Model performance and evaluation in predicting plantation area distribution of Salak Pondoh Sleman in Sleman Regency were showed in the Receiver Operating Characteristic (ROC) curve. The model performance was indicated by the AUC value. The value, which was generated from available presence data, was categorized into four groups, i.e., low (ranged from 0.60 to 0.70); moderate (ranged from 0.71 to 0.80); good (ranged from 0.81 to 0.90), and high-performance (more than 0.91) [20]. The AUC value in this study was 0.709, which indicates a moderate performance of the model (figure 2).

3.2. Analysis of environmental variable contributions

The output of Maxent model was environmental variables which considered essential and contributed to the result of its prediction model. Analysis of the variables contribution was carried out on two
outputs, i.e. environmental variables based on its percentage contribution (table 1) and environmental variables which considered significant based on the jack-knife test results (figure 3).

The jackknife test results show environmental variables that affected both individually (with only variable) and without variables. This test was carried out on the used training data to build predictive models. The result (figure 3), shows that the temperature variables were the highest environmental variable that will give the highest value to the model. The result also denotes that the temperature variables were the effective single variable (only using one variable) in the prediction model of Salak Pondoh Sleman plantation area distribution.

Based on the analysis of the chosen environmental variable that influences the distribution of Salak Pondoh Sleman plantation area in this model, the mean temperature of the quarter variable (bio9) has the highest contribution, with the percentage of 38.6%. The precipitation of the wettest month variable (bio13) was 27.8 %, variable with the second highest contribution to the Salak Pondoh Sleman plantation area. The third variable was the temperature seasonality (bio4), contributed by 11.7%. The remaining variables were the mean temperature of the wettest quarter variable (bio8), the mean variable diurnal range variable (bio2), and the precipitation of wettest quarter variable (bio16), contributed by 11%, 5.3%, and 3.9%, respectively. Furthermore, considering probabilities of temperature variables, the mean temperature of driest quarter range (bio9) of Salak Pondoh Sleman was 17.41 to 24.88°C, the precipitation of wettest month (bio13) ranged from 385.24 to 505.01 mm. The temperature seasonality (bio4) was approximately ranged from 44.15 to 52.23 °C, while the mean temperature of the wettest quarter (bio8) was ranged from 17.76 to 25.65 °C. In addition, the range of mean variable diurnal (bio2) varied from 8.53 to 9.4 °C, whereas the precipitation of wettest quarter (bio16) varied from 1,070.51 to 1,435.00 °C. Therefore, these six variables were chosen as the most influential environment variable on the probability of Salak Pondoh Sleman plantation area distribution (figure 4). The other variables, such as annual precipitation variable (bio12), precipitation of quarter variable (bio17), precipitation of month variable (bio14), precipitation seasonality variable (bio15), and annual mean temperature variable (bio1), have a smaller percentage contribution (less than 1), thus, the variables were not used in the model (table 1).
3.3. Current and future prediction of Salak Pondoh Sleman plantation area distribution

Based on the AUC value representing the model performance, the response curve, and the contribution variables analysis, the prediction of the Salak Pondoh Sleman plantation area distribution can be spatially described (figure 5). The result shows a color gradation with a range of 0 - 1 indicating the probability of Salak Pondoh Sleman plantation distribution. The lower the predicted value, the lower the probability of Salak Pondoh Sleman plantation distribution [15][17].

Figure 5 depicts a MaxEnt prediction model of classified Salak Pondoh Sleman plantation area based on its land suitability. Therefore, the suitable and unsuitable distribution area for Salak Pondoh Sleman plantation in Sleman Regency can be distinguished. In the current prediction model, the most suitable area for Salak Pondoh Sleman plantation distribution is located in Turi. The finding is in accordance with Badan Pusat Statistik (Statistics Indonesia, BPS) data which showed that Turi was the biggest Salak Pondoh Sleman producer in Sleman Regency (4,789.5 tons in 2017) [10].

Since Salak Pondoh Sleman farming is the main economic activity in the three selected areas, it is important to note that predicted changes in the suitable plantation area may impact the lifestyle of the communities. The future land suitability of Salak Pondoh Sleman plantation in 2050 was predicted to experience a shift (figure 5b and 5d). Turi, as the current highest Salak Pondoh Sleman producer, will face a decreased land suitability. The decreased land suitability was also predicted to occur in Tempel. On the contrary, Pakem was predicted to experience an increase in the suitable area for Salak Pondoh Sleman plantation and predicted to become the highest area of Salak Pondoh Sleman in Sleman Regency in 2050. However, the presence of Mount Merapi National Park located in the northern part of Pakem should be respected. As protected forest areas, land conversion in the region is prohibited [21,22]. With the decline in land suitability in Turi, as the current highest producer of Salak Pondoh Sleman, it will have an impact on the decreased quantity of Salak Pondoh Sleman in 2050, although the results show an increase in land suitability in Pakem.

Mitigation against the risk of decreasing yield of Salak Pondoh Sleman products, therefore, needs to be done, with the consideration to the geographical indication status on Salak Pondoh Sleman as well as an indigenous product of Sleman Regency. The Sleman Regency Government has implemented a standardization policy for Salak Pondoh Sleman cultivation as an effort to its uniformity and maintains the quality and quantity of produced Salak Pondoh Sleman. In addition, the expansion of irrigated areas was a possible strategy to alleviate yield reductions due to climate change [23,24]. The strategy was supported by the model built in this study, which predicted to have a high rainfall (bio 13 dan bio 16), exceeding the range of agroclimatic suitability for Salak Pondoh Sleman cultivation (figure 4). The implementation of water resource management, such as rain harvesting and irrigation system, were able to minimize the depreciation of agricultural land [24], increased cropping intensity and water use efficiency [23]. Furrow irrigation technique has been used by the farmers, but still unable to irrigate the plantation in the region. The technique is also the recommended irrigation techniques by the government as an effort to mitigate the risks of climate change [25]. As the irrigation system improved, water availability will be assured, and farmers were able to monitor the water usage as needed. Consequently, reliance on the season uncertainty, in this case, the rainy season, in fulfilling the water needs for the Salak Pondoh Sleman cultivation was dispensable. Salak Pondoh
Sleman is a plant that requires plenty of water [9], so the management of water resources is required. In addition, rain harvesting system is a system based on the shelter of excess water in the rainy season and capitalize on it for the dry season [26]. Farmers of Salak Pondoh Sleman can utilize water storage gained from the rainy season and use it in the dry season. The Government of Sleman Regency, in the future, needs to consider water management approach in their agricultural policies, especially as an effort to maintain the quality and suitable area of Salak Pondoh Sleman.

Figure 5. Ecological niche modeling of Salak Pondoh Sleman plantation distribution and habitat suitability in 2050: (A) and (C), the occurrence probability of Salak Pondoh Sleman plantation in current condition and predicted 2050, respectively; (B) and (D), the habitat suitability area of Salak Pondoh Sleman in current condition and predicted 2050, respectively.

4. Conclusion
The model generated in this study was a predictive model with a moderate performance in obtaining predictive values that affect the distribution of Salak Pondoh Sleman plantation in Sleman Regency. This prediction model was also built on assumptions or predictions about the affected factors for the distribution of Salak Pondoh Sleman plantation area. However, the predicted current results for the distribution of Salak Pondoh Sleman plantation were quite accurate, following its conformity with the reality in the field. The future projection output for Salak Pondoh Sleman plantation distribution in this study can be used as a consideration or a useful approach in policy determination. According to approach and models used in this study, Salak Pondoh Sleman plantation area in 2050 was predicted to experience a shift in land suitability, with a tendency to the decreased land area compared with current condition. The generated model in this study may provide relevant elements for management practice and mitigation strategies of current and future land use in Sleman Regency. The government's policy efforts to maintain the quantity and quality of Salak Pondoh Sleman products need to be done, considering that these products cannot be found in other regions, as well as it is a flagship product of Sleman Regency.

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