Predicting the current potential geographical distribution of Baccaurea (*B. lanceolata* and *B. motleyana*) in South Kalimantan, Indonesia

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Gunawan Gunawan <gunawan@ulm.ac.id>

[biodiv] Submission Acknowledgement

Ahmad Dwi Setyawan <support@mail.smujo.id> Sun, Nov 27, 2022 at 9:36 PM
To: Gunawan Gunawan <gunawan@ulm.ac.id>

Gunawan Gunawan:

Thank you for submitting the manuscript, "MaxEnt Modeling for Predicting the Current Potential Geographical Distribution of Baccaurea (B. lanceolata and B. motleyana) in South Kalimantan, Indonesia " to Biodiversitas Journal of Biological Diversity. With the online journal management system that we are using, you will be able to track its progress through the editorial process by logging in to the journal web site:

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Gunawan Gunawan, Anwar Khoerul, Gafur Abdul, RAUDATUL HILALIYAH, AZMIL AQILATUL WARO, NUR HIKMAH, MUHAMMAD ERWANSYAH, SAKINAH SAKINAH, DIAN SUSILAWATI, RATNA DWI LESTARI, DINDA TRIANA:

We have reached a decision regarding your submission to Biodiversitas Journal of Biological Diversity, "MaxEnt modeling for predicting the current potential geographical distribution of baccaurea (B. lanceolata and B. motleyana) in South Kalimantan, Indonesia".

Our decision is: Revisions Required

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MaxEnt modeling for predicting the current potential geographical distribution of Baccaurea (*B. lanceolata* and *B. motleyana*) in South Kalimantan, Indonesia

Abstract. *Baccaurea lanceolata* and *B. motleyana* are an underutilized species of Kalimantan fruit tree, but are potential source for food and medicine. However, little is known about the occurrences and potential geographical distribution of *B. lanceolata* and *B. motleyana*. This study aimed to predict the potential geographical distribution of *B. lanceolata* and *B. motleyana* using MaxEnt, and understand the key factors which influenced their distribution. Occurrence data include 57 for *B. lanceolata* and 87 for *B. motleyana* were collected from field surveys and with 19 bioclimatic variables, solar radiation, altitude, and slope were used to model their distribution. Jackknife test was used to evaluate the importance of the environmental variables for predictive modeling. The area under curve (AUC) values of *B. lanceolata* and *B. motleyana* were 0.927 and 0.851, indicating that the model is a good and informative model for species distribution of these species. The models for *B. lanceolata* suggest that the distribution is mainly influenced by altitude, temperature seasonality, precipitation of the wettest month, and precipitation of the driest quarter. Temperature, annual range, precipitation of the wettest month, precipitation of the coldest quarter, and solar radiation in July were the key environmental factors influencing the distribution of *B. motleyana*. The potential geographic distribution of *B. lanceolata* and *B. motleyana* can be useful information to help researcher in restoration and conservation planning.

Keywords: *Baccaurea motleyana*, *Baccaurea lanceolata*, MaxEnt, habitat suitability, species distribution.

Abbreviations (if any): AUC_ Area Under Curve, MaxEnt_Maximum Entropy

Running title: Predicting potential geographic distribution for *Baccaurea lancelata* and *Baccaurea lanceolata*

INTRODUCTION

Genus *Baccaurea* is a group of plants that produce fruit, but its existence is not as popular as that of other fruit plants. In addition to using the fruit as fresh fruit and wood as building materials, members of the genus *Baccaurea* have been used by the community as medicinal plants to treat several diseases, including constipation, swelling of the eyes, arthritis, abdominal pain, and facilitating menstruation and urination (Usha *et al*. 2014; Ullah *et al*. 2012; Goyal *et al*. 2014; Lim 2012; Gunawan *et al*. 2016).

Baccaurea lanceolata as locally known as "Limpasu" and *Baccaurea motleyana* as locally known as "Rambai" are two species from the genus *Baccaurea* Family Phyllanthaceae that have great potential as a medicinal ingredient. Antioxidant activity test with three methods (DPPH, ABTS, and FRAP) on the pericarp, fruit, flesh, and seeds of *B. lanceolata* showed high antioxidant activity, with the highest activity found in the flesh of the fruit (Bakar *et al*. 2014). Zamzani and Triadisti (2021) revealed that *B. lanceolata* has high antioxidant activity. The ethanol extract of spleen fruit was the most active extract against bacteria (Fitriansyah et al. 2018; Gallapathie 2018). Local communities in South Kalimantan used the extract fruit of Limpasu as cosmetics as sunscreen. Fruit of *B. Lanceolata* also contains fenol, flavonoids, antosianin, and karotenoid (Bakar *et al*. 2014). *Baccaurea motleyana* has high antioxidant activity containing phenolic, flavonoid, and anthocyanin compounds, secondary metabolite compounds derived from sugar metabolism. Fitri *et al*. (2016) revealed that *B. motleyana* fruit contains phenols and flavonols and has lipid peroxidation activity. Rambai fruits have relatively low amounts of fats, organic acids, phenolics, and antioxidants compared to many other familiar fruits. Rambai tree parts were found to exhibit antidiabetic, antibacterial, and skincare properties (Prodhan & Mridu 2021).

Although *B. lanceolata* and *B. motleyana* have high utility value, habitat loss and population declines of these species continue to occur. Little is known about the occurrence of *B. lanceolata* and *B. motleyana* and its adaptability different climate and edaphic conditions in South Kalimantan. Tha last publication by Haegens (2000) stated *B. lanceolata* and *B. motleyana* were found in Borneo. Agricultural clearing, forest fires, illegal logging, forest conversion, increasing human population, and mining are important factors causing decreasing plant populatian and biodiversity loss. Budiharta et al.

2011 state that in Kalimantan region, habitat loss of many tree species are caused by continuous illegal logging, development of human settlements, agriculture, perennial crops, and timber plantations. Besides that environmental degradation caused by various anthropogenic activities, climate change also harms current plant diversity (Belgacem et al. 2008). Climate change is also known as one of the most important factors influencing the geographic distribution of plant species (Forman 1964). Detailed information about the regional distribution of a plant is needed for their restoration and habitat conservation. Furthermore, information about a plant's distribution is important in determining the population, taxonomic variation, habitat suitability, and potential utilization. Studying the current and potential distribution of species and examining the key environmental factors that affect their growth can help us to understand the overall distribution patterns of species.

The Species Distribution Model (SDM) is a general approach for investigating the potential distribution of species and suitable habitats in the environment. It is widely used for broad applications in ecology, biogeography, and conservation biology. A number of SDMs have been developed to estimate the suitable areas for specific species according the specific algorithms, including Maximun Entropy (Phillips et al. 2006; Martinez-Minaya et al. 2018). MaxEnt is a niche modeling program based on environmental variables and species occurrence data, which is integrated by machine learning and the principle of maximum entropy to predict the potential distribution of species (Elith et al. 2011). The MaxEnt program has been used extensively to predict species distribution, which has also been employed by studies in South Asia (Pradhan 2015), including Indonesia (Setyawan et al. 2017, 2020a, 2020b, 2021; Gunawan et al. 2021a, 2021b; Usmadi et al. 2021; Harapan et al. 2022). Compared to other SDMs programs, MaxEnt can produce better models, because MaxEnt can create models only with occurrence data (Elith et al. 2011; Jackson and Robertson 2011; Kalboussi and Achour 2017), and it have the ability to run with a small amount of data (Fois et al. 2018; Preau et al. 2018). Furthermore, the results are highly accurate and highly reproducible (Fourcade et al. 2014).

The aim of this study was to predict the current potential distribution of *B. lanceolata* and *B. motleyana* in South Kalimantan, Indonesia and to identify the key factors include climatic and topography responsible for the distribution of these species. We expect the results of this study to provide information regarding the potential distribution of *B. lanceolata* and *B. motleyana* in Kalimantan, and identify the currently suitable areas for conservation and cultivation.

MATERIALS AND METHODS

Study area and species occurrence data

The study was conducted in South Kalimantan which consists of 13 districts, which has approximately 34.744 km^2 of land area. The geographic scope of this study includes the area of approximately 1º 21' 49" LS – 1º 10' 14" LS and 114º 19' 33" BT – 116º 33' 28". Authors collected the occurrence data of *B. lanceolata* and *B. motleyana* from local communities and forestry services (Figure 1.)

The explorative field survey was carried out according to the previous research method conducted by Rugayah et al. (2004). The field study period was from February to June 2022. Plant samples were collected and herbarium specimens were deposited in Bio-systematic laboratory Lambung Mangkurat University, South Kalimantan. Using Garmin 64s GPS series, we collected 57 occurrences points of *B. lanceolata* and 87 occurrences points of *B. motleyana* which were found distributed in South Kalimantan. All coordinates from the field survey were converted to decimal degrees and imported into Microsoft Excel, and then saved as CSV format. The coordinate data were used to describe the distribution of *B. macrocarpa* in the province of South Kalimantan using the DIVA Gis 7.5 software (Figure 2.) and is used as input data for habitat suitability modeling using MaxEnt.

Climatic variables

For this study, we used 19 bioclimatic variables (11 temperature and 8 precipitation variables), solar radiation (12 months), altitude, and geoslope were downloaded and assessed (Tabel 1). Bioclimatic variable were extracted from WorldClim (https://www.worldclim.org) (Hijsmans 2020). Slope variable was downloaded from www.fao.org. In addition, a raster file of digital elevation models based on the altitude data was also downloaded from the WordClim website. They were generated through interpolation of average monthly climate data from weather stations at 30 arc seconds (*1 km) spatial resolution (Ficks and Hijmans 2017). All predictor variables layers were in GeoTIFF format, QuantumGis ver 2.8.10 was used to convert bioclimatic variables and environmental layers into an ASCII format for use in MaxEnt (Setyawan et al. 2020a).

Species distribution model requires selecting and using environmental factors with a major influence to the model (Worthington et al. 2016) and with minimal inter-correlation (Pradhan 2016, 2019) to get an accurate and informative model. The variable selection was done with two-pronged approach. i) Firstly, Variance Inflation Factor (VIF) analysis was carried out across all bioclimatic variables in R platform. The pair wise VIF values of bioclimatic variables were assessed and those variables were screened whose pair wise VIF was <10. ii) Secondly, screened bioclimatic variables along with another environmental factor like solar radiation were put to Jackknife test evaluation for assessment of the contribution of each environmental variable to the resulting model.

The contribution percentage and permutation are two important factors for understanding and measuring the environmental variable's contribution as well as importance to the model. According to the Jackknife test evaluation of the contribution of each environmental variable to the resulting model, twelve environmental variables were not used, eleven of them due to the lack of contribution to the model making 0% percent contribution and bio 8 due to co linearity with bio 10 through VIF value of 63.8 (Pradhan 2016, 2019), and as well exclusion of bio 8 led to increase in regularized training gain. Besides that variables with a small average contribution (<6%) or permutation importance (<6%) were not used due to lack of contribution to the models (Wei et al. 2018). Therefore, the final environmental variables used in *B. lanceolata* species distribution model map for the current period were alt (altitude), bio 4 (temperatur seasonality), bio 13 (Precipitation of wettest month), bio 17 (Precipitation of driest quarter), whereas the final environmental variables for *B. motleyana* were bio 7 (Temperature annual range), bio 13 (Precipitation of wettest month), bio 19 (Precipitation of coldest quarter), srad 7 (Solar radiation in July). Variables that considered affecting to the distribution of these species, i.e, land use, human disturbances, species dispersal or biotic interaction change were not included to the model because the availability of these data were limited.

Species distribution modeling

We used MaxEnt version 3.4.1 (Phillips et al. 2017) to predict the current potential geographic distribution of *B. lanceolata* and *B. motleyana* in South Kalimantan. The software was downloaded from https://biodiversityinformatics.amnh.org / open_source / maxent / and can be extracted freely for scientific research. In our predicted models, default setting was used in MaxEnt model (Abdelaal et al. 2019). We employed 10 replicates and the average of probability for habitat suitability of *B. lanceolata* and *B. motleyana* in South Kalimantan (Hoveka et al. 2016). The bootstrap method was implemented with 10 repeats, a maximum of 5000 iteration, and default selected parameters (Yan et al. 2020). Models resulting from MaxEnt were evaluated; the accuracy and quality of the model used the Area Under the Curve (AUC) scores of Receiver Operating Curve (ROC) analysis. The scores of AUC ranged from 0.5 to 1. An AUC score of 0.5 indicated the model prediction did not perform better than random expectation, while a score of 1.0 shows the resulting model is very good and informative (Swets 1988). We also performed the Jacknife test. A Jackknife analysis was used to calculate the contribution the variables for the model prediction for *B. lanceolata* and *B. motleyana*. Jackknife analysis is also carried out to determine the dominant variables that determine the potential distribution of species (Yang et al. 2013). In addition, we used respond curves that produced by MaxEnt analysis to know the relationship between the habitat suitability of *B. lanceolata* and *B. motleyana* and environmental factors.

The results of Maxent's analysis for *B. lanceolata* and *B. motleyana* were imported into DIVA GIS software version 7.5 (Hijmans et al. 2012) for visualization and further data analysis. The species distribution model map resulted from MaxEnt has suitability levels that can be grouped into 4 classes, namely, least suitable (0.0-0.2), low suitability (0.2-0.4), medium suitability (0.4-0.6), and high suitability (0.6-1.0) (IPCC 2007; Wei et al. 2020).

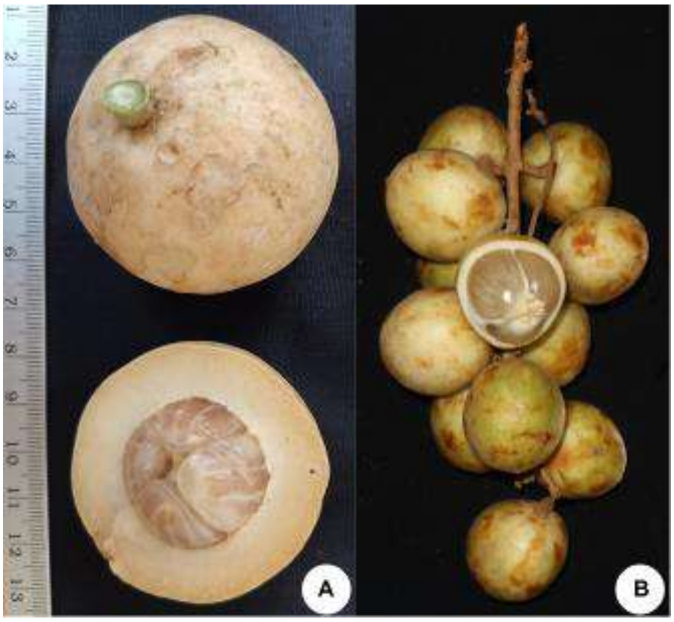

Figure 1. Fruit of Baccaurea species. A. *Baccaurea lanceolata*, B. *Baccaurea motleyana*

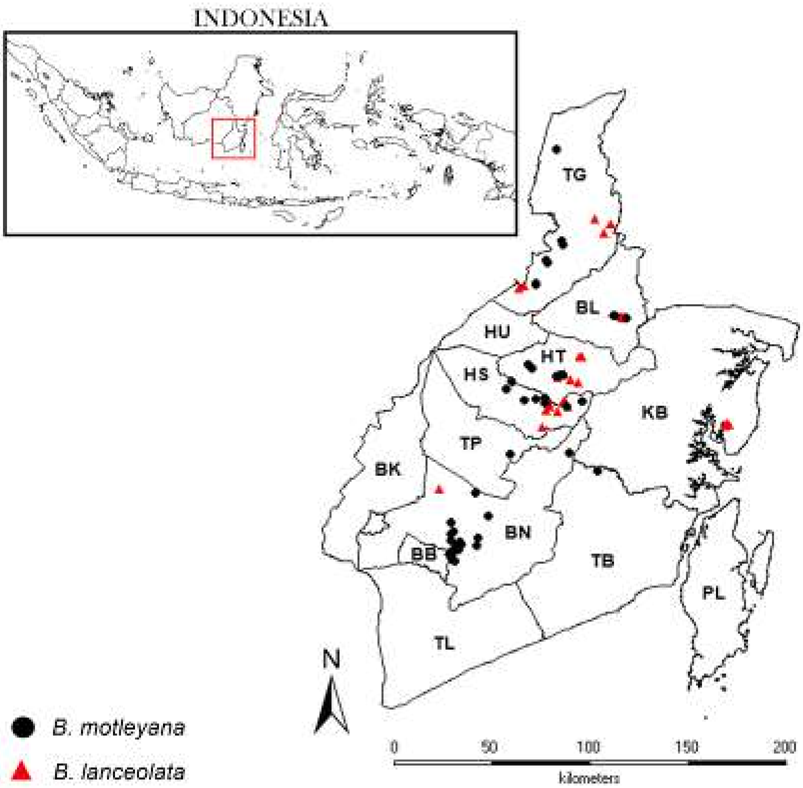

Figure 2. Current distibutions of *B. Lanceolata* and *B. motleyana* in South Kalimantan obtained from field survey. TL = Tanah Laut; TB = Tanah Bumbu; PL = Pulau Laut; BB = Banjar Baru; BN = Banjar; BK = Barito Kuala; TP = Tapin; KB = Kota Baru; HS = Hulu Sungai Selatan; HT = Hulu Sungai Tengah; HU = Hulu Sungai Utara; BL = Balangan; TG = Tabalong.

Table 1. Description environmental variables used for MaxEnt model prediction for *B. lanceolata* and *B. motleyana*

Code	Parameter	Unit
alt	Altitude	m
srad	Solar radiation (12 month)	w/m^2
gloslope	Slope	%
bio 1	Mean annual temperature	°C
bio 2	Mean diurnal range (max temp - min temp)	°C
bio 3	Isothermality	°C
bio 4	Temperatur seasonality	°C
bio 5	Maximum temperature of warmest month	°C
bio 6	Minimum temperature of coldest month	°C
bio 7	Temperature annual range	°C
bio 8	Mean temperature of wettest quarter	°C
bio 9	Mean temperature of driest quarter	°C
bio 10	Mean temperature of driest quarter	°C
bio 11	Mean temperature of coldest quarter	°C
bio 12	Annual precipitation	mm
bio 13	Precipitation of wettest month	mm
bio 14	Precipitation of driest month	mm
bio 15	Precipitation seasonality	mm
bio 16	Precipitation of wettest quarter	mm
bio 17	Precipitation of driest quarter	mm
bio 18	Precipitation of warmest quarter	mm
bio 19	Precipitation of coldest quarter	mm

RESULTS AND DISCUSSION

Model performance

Many researchers use the area under the curve (AUC) statistic to evaluate the final model (Setyawan et al. 2017, 2020a, 2020b, 2021; Pradan 2015; Gunawan et al. 2021a; Gunawan et al. 2021b; Romadlon et al. 2021; Shao et al. 2022). Model performance was classified as failing (0.5-0.6), poor (0.6-0.7), fair (0.7-0.8), good (0.8-0.9), and excellent (0.9-1) (Araujo et al. 2005). The model output by MaxEnt provided satisfactory results with the AUC training value for *B. lanceolata* 0.926 and for *B. Motleyana* AUC value is 0.851, which are higher than 0.5 of a random model. The final model indicated good model and had high accuracy for species distribution model (Figure 3). This indicated that the environmental variables were well selected to predict the current potential geographic distribution of *B. lanceolata* and *B. motleyana*. In this study, we determine the key environmental variable based on their contributions to the modeling process. The Jacknife test was conducted to show the influence of each environmental variable in the building the model (Figure 3).

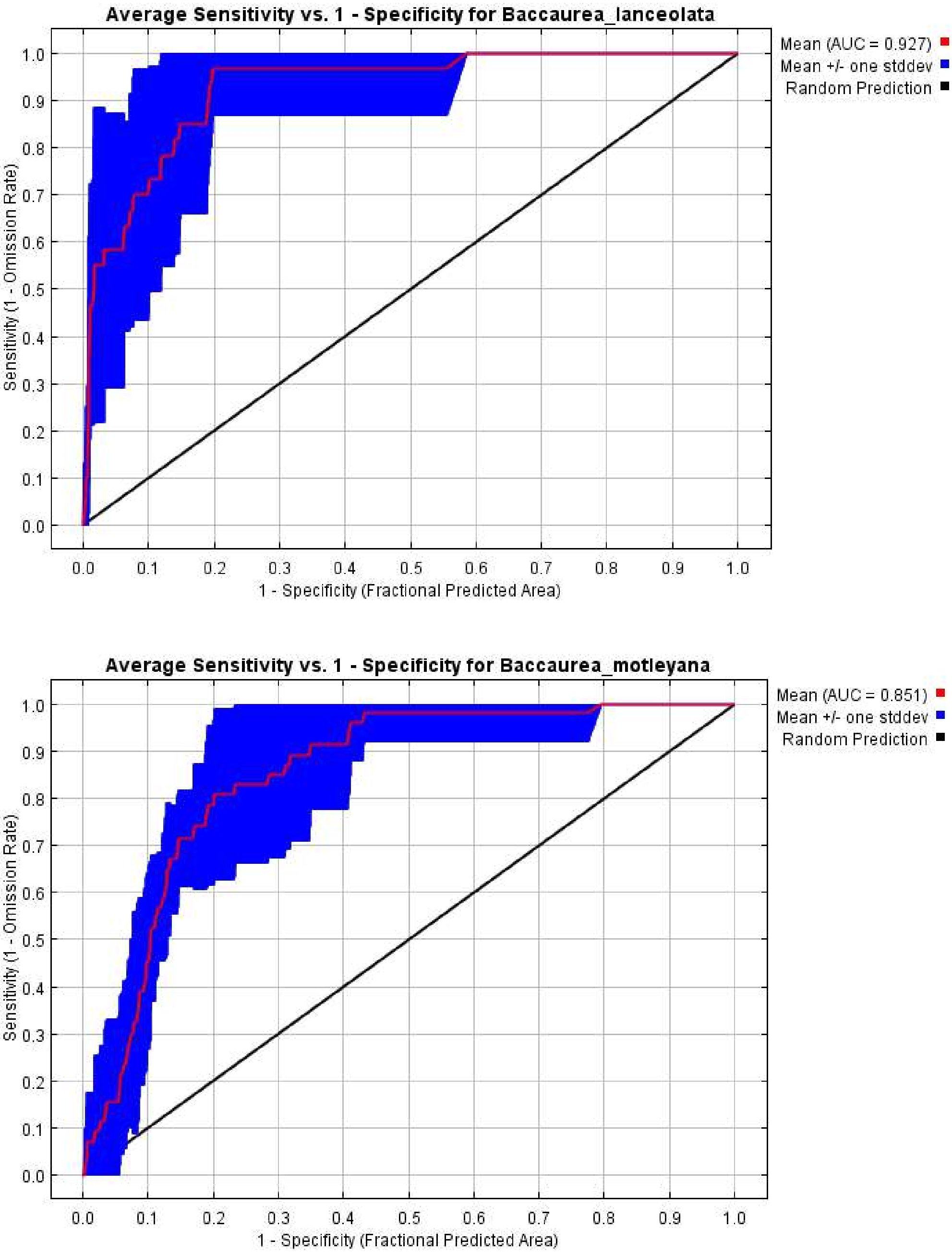

Figure 3. Result of area under the receiver operating characteristics curve (ROC-AUC) analyses for a MaxEnt model of habitat suitability for *Baccaurea lanceolata* and *Baccaurea motleyana*.

Altitude, temperature, and precipitation were the most important environmental for *B. lanceolata*, while for *B. motleyana* were temperature, precipitation, and solar radiation (Table 2). Altitude was the highest contributing influencing the predicticted distribution for *B. lanceolata* with ranging from 0 – 200 m asl with peak at ~180 m asl. Environmental variable with the great influence on predicted distribution for *B. motleyana* was temperature annual range, with the optimum temperature annual range condition between 9^{o}C and 11.5 ^{o}C. Analysis of environmental variables contributions is different between species, so that the different species have different species distribution model.

Table 2. Environmental variable contribution for *B. lanceolata* (Bl) and *B. motleyana* (Bm).

Code	Environmental variable	Contribution (%)	
		Bl	**Bm**
alt	Altitude	24.4	-
bio 4	Temperatur seasonality	15.7	-
bio 7	Temperature annual range	-	34.6
bio 13	Precipitation of wettest month	10.6	15
bio 17	Precipitation of driest quarter	22.2	-
bio 19	Precipitation of coldest quarter	-	7.3
srad 7	Solar radiation in July	-	10.7

Variables' response curves

The response curves were presented to show relationship between the probability of *B. lanceoalata* and *B. motleyana* distribution with environmental variables can be seen in the response curve generated by the Maximum Entropy model. Response curves show the quantitative relationship between environmental variables and the logistic probability of presence and they deepen the understanding of the ecological niche of the species (Yi et al. 2016). Species response curves also show biological tolerances for target species and habitat preferences (Gebrewahid et al. 2020). The response curves of *B. lanceolata* and *B. motleyana* to four environmental variables are illustrated in Figures 4A and 4B.

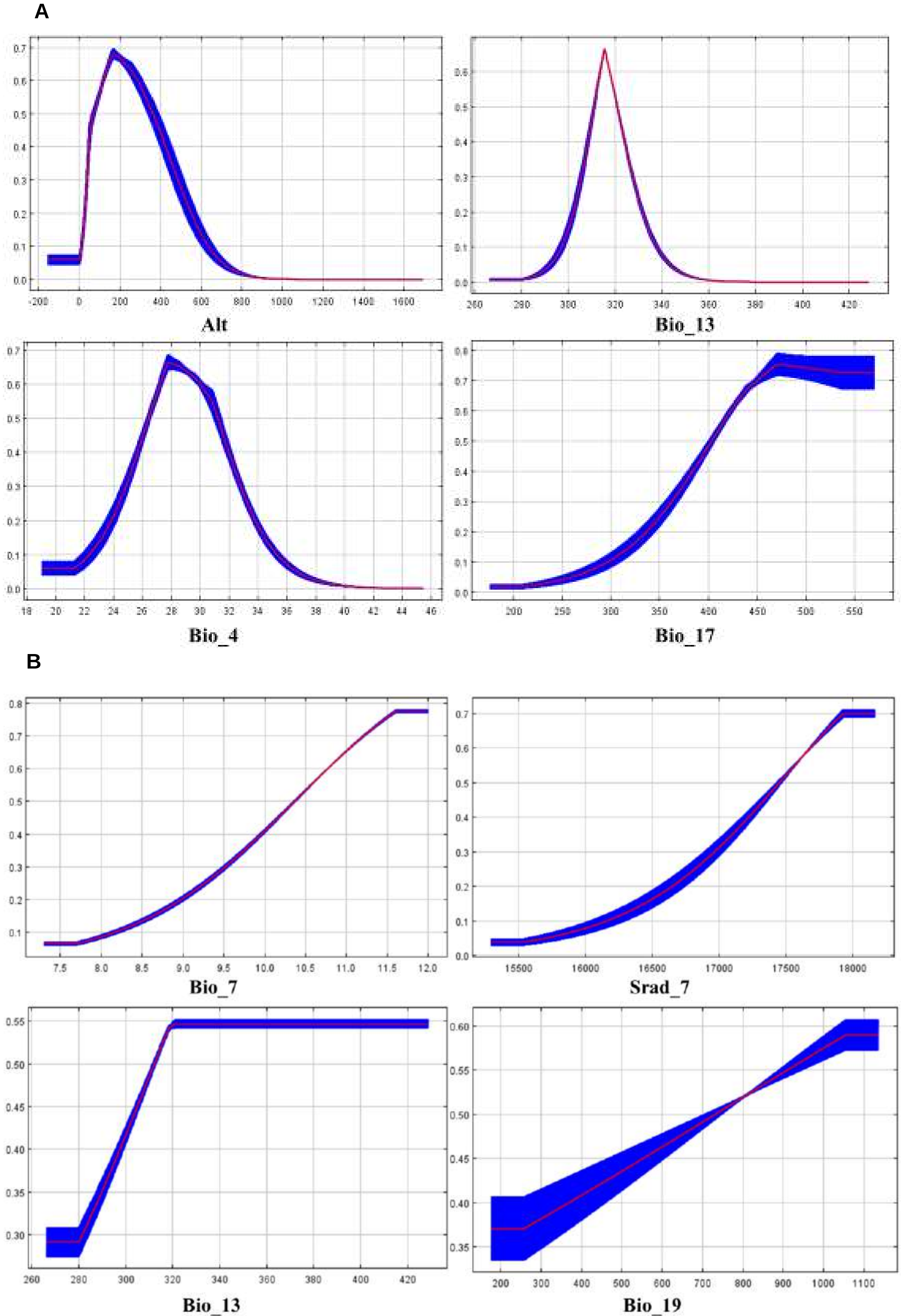

Figure 4. Response curves to four key environmental variables. A. response curve for *B. lanceolata*: Alt: Altitude; Bio 13: Precipitation of wettest month; Bio 4: Temperature seasonality; Bio 17: Precipitation of driest quarter. B. response curve for *B. motleyana*. Bio 7: Temperature annual range; Srad 7: Solar radiation in July; Bio 13: Precipitation of wettest month; Bio 19: Precipitation of coldest quarter. The curves show the mean response of the 10 replicate MaxEnt runs (red) and the mean +/- one standard deviation (blue, two shades for categorical variables)

The response curves of *B. lanceolata* to four environmental variables are show in Figure 4A. Based on the response curves, the suitable altitude range (Alt) of *B. lanceolata* ranged from 0 – 200 m asl with a peak at ~180 m asl. The next important environmental variable was the precipitation of wettest month (bio 13) which showed 300-320 mm, with peak at ~319 mm. The response curve of bio 4 showed that the suitable temperature seasonality ranged from 22 ºC - 28 ºC and peaked at ~27.5ºC. The optimal precipitation of the driest quarter which showed a range of 250 - 500 mm and a peak at ~425 mm required by *B. lanceolata* was indicated by the response curve of bio 17. The response curves of *B. motleyana* to four environmental variables are show in Figure 4B. According to the response curve, the optimum temperature annual range (bio 7) for *B. motleyana* ranged between 9ºC and 11.5 ºC. The next important environmental variable for *B. motleyana* was solar radiation in July (srad 7) which showed the range 16000-18000 w/m2, with a peak at ~17687 w/m2. The optimal precipitation of the wettest month which showed a range of 290 - 320 mm and a peak at ~310 mm required by *B. motleyana* was indicated by the response curve of bio 13. The response curve of bio 19 showed that the suitable precipitation of the coldest month (bio 19) ranged from 300 - 1100 mm and peaked at ~1090 mm.

The results of the model showed that as altitude, temperature, solar radiation, and precipitation were the dominant environmental variables for habitat suitability of *B. lanceolata* and *B. motleyana*. Geographical variables such as altitude are often having correlation with local precipitation and temperature (Austin 2002; Korner 2007). Temperature has an important role to maintain the humidity in the local region by regulation evapotranspiration level. Solar radiation is the main source of energy for organism in ecosystem. Solar radiation affects the plant's physiological processes, especially in plant growth and development. Solar radiation also affected climate, plant growth and evolution, vegetation distribution, and succession, and productivity in the forest ecosystem (Jordan et al. 2005; Li et al. 2011; Fyllas et al. 2017). Climates have significant role in the distribution of plant species (Svenning and Sandel 2013). Precipitation is one of the environmental variables has important role for habitat suitability of *B. lanceolata* and *B. motleyana.* Precipitation plays a major role as an element in plant development (Dasci at al. 2010).

The previous research on species *Baccaurea* (Gunawan et al. 2021a; 2021b) also revealed that altitude, temperature, solar radiation, and precipitation were also influenced in distribution range. This shows that environmental variables such as altitude, temperature, solar radiation, and precipitation play an important role in *Baccaurea* habitat. Climatic factors such as temperature and precipitation were affecting the distribution (Belguidum et al 2021). Zhang et al. 2018, also state that climatic factors were crucial factors that affect plant regeneration, growth, and the spread of its populations.

Prediction current potential distribution

Baccaurea is an underutilized plant, but this fruit has benefits as a source of medicinal ingredients and as well as important ecological functions such as the fruits are eaten by many bird species, but also by rodents, deer, and monkeys (Rijksen 1978). Little is known about the existence and distribution of *B. lanceolata* and *B. motleyana* in South Kalimantan. The model prediction of the potential distribution of *B. lanceolata* and *B. motleyana* was created based on the observed occurrences and current climate conditions. The maps of species distribution model produced by MaxEnt and categorized into four suitability classes between 0 to 1 are presented in Figure 5.

The greatest concentration of highly suitable areas for *B. lanceolata* (IHS 0.6-1) was mainly predicted in six districts (*kabupaten*): BN (Banjar), HS (Hulu Sungai Selatan), HT (Hulu Sungai Tengah), BL (Balangan), PL (Pulau Laut), and TG (Tabalong). Other locations that have highly and medium habitat suitability (IHS 0.4-0.6) were BN (Banjar), BL (Balangan), TG (Tabalong), TB (Tanah Bumbu), and PL (Pulau Laut). The lowly suitable habitat (IHS 0.2-0.4) was predicted in a part of TG (Tabalong), BL (Balangan), PL (Pulau Laut), TB (Tanah Bumbu), and BN (Banjar). The least levels of habitat suitability for *B. lanceolata* (IHS 0.0-0.2) were predicted in TL (Tanah Laut), BB (Banjarbaru), BK (Barito Kuala), TP (Tapin), a part of HU (Hulu Sungai Utara), HT (Hulu Sungai tengah), PL (Pulau Laut) and TB (Tanah Bumbu).

The greatest concentration of highly suitable areas for *B. motleyana* (IHS 0.6-1) was mainly predicted in nine districts (*kabupaten*): TG (Tabalong), BL (Balangan), HT (Hulu Sungai Tengah), HU (Hulu Sungai Utara), HS (Hulu Sungai Selatan), BN (Banjar), BB (Banjarbaru), and BK (Barito Kuala). Other locations that have highly and medium habitat suitability (IHS 0.4-0.6) were a part of TG (Tabalong), BL (Balangan), HT (Hulu Sungai Tengah), HU (Hulu Sungai Utara), TP (Tapin), BN (Banjar), BK (Barito Kuala), TL (Tanah Laut), and KB (Kota Baru). The lowly suitable habitat (IHS 0.2-0.4) was predicted most of a part of BK (Barito Kuala), TL (Tanah Laut), TB (Tanah Bumbu), and KB (Kota Baru). The least levels of habitat suitability for *B. lanceolata* (IHS 0.0-0.2) were predicted in BK (Barito Kuala), TL (Tanah Laut), TB (Tanah Bumbu), KB (Kota Baru), and PL (Pulau Laut).

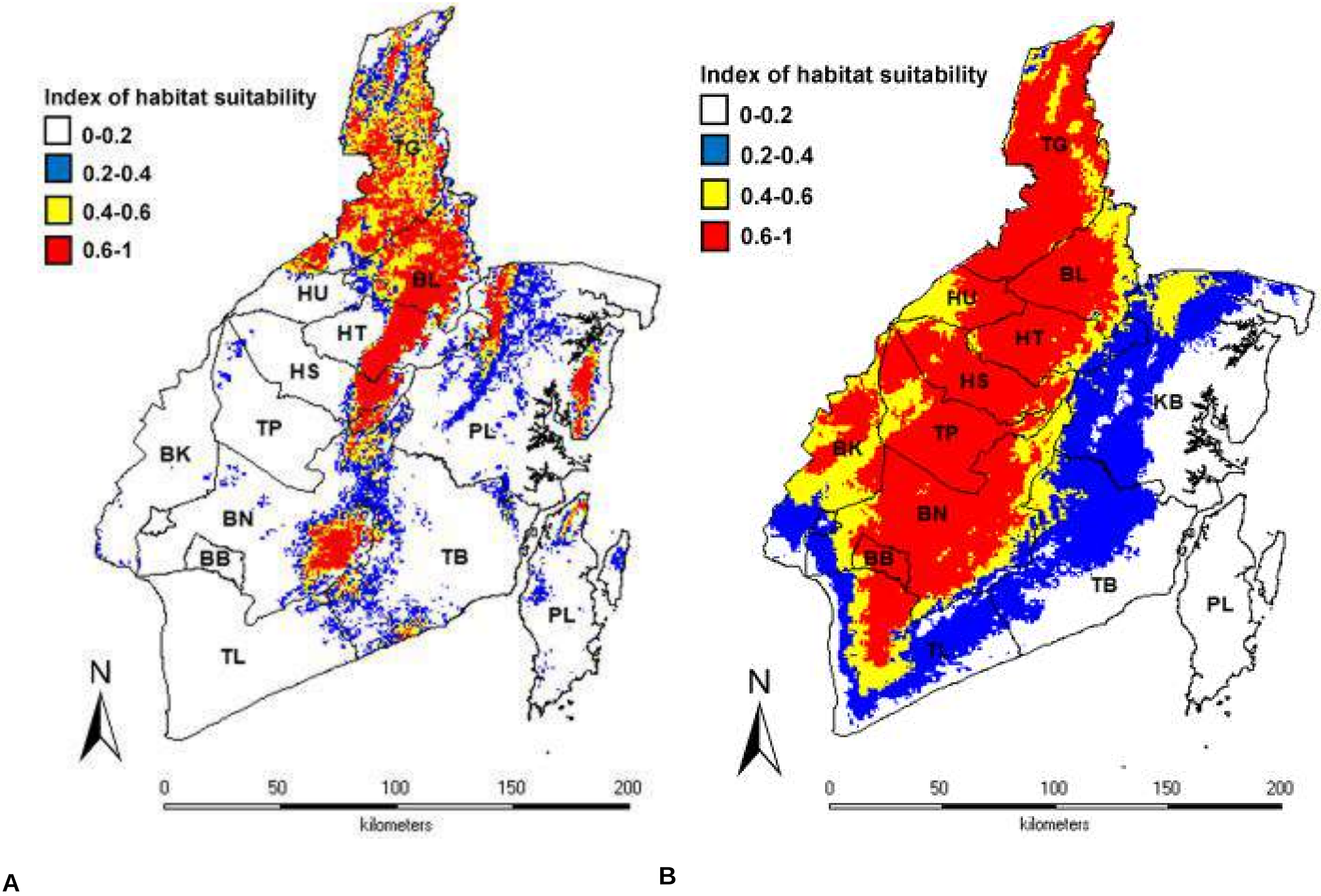

Figure 5. Map of potential current habitat suitability according to occurrence records in South Kalimantan. A. *Baccaurae lanceolata*. B. *Baccaurea motleyana*. TL = Tanah Laut; TB = Tanah Bumbu; PL = Pulau Laut; BB = Banjar Baru; BN = Banjar; BK = Barito Kuala; TP = Tapin; KB = Kota Baru; HS = Hulu Sungai Selatan; HT = Hulu Sungai Tengah; HU = Hulu Sungai Utara; BL = Balangan; TG = Tabalong.

The MaxEnt models under current climate conditions show that *B. lanceolata* distribution ranges are more influenced by altitude, temperature (seasonal temperature), and precipitation (driest month and driest quarter). Whereas *B. motleyana* distribution range was more influenced by temperature (temperature annual range), solar radiation (solar radiation in July), and precipitation (precipitation of wettest month and precipitation of the coldest quarter). Temperature, solar radiation, precipitation and soil properties are an important factor that influence of plant species distribution (Hemp 2006).

In addition to environmental variables, species distribution and modeling may also be influenced by biotic factors, speciation mechanisms and dispersal ability (Kaky et al. 2020). *Baccaurea lanceolata* has a narrower habitat suitability area compared to *B. motleyana* based on MaxEnt's final model. Based on field observations, *B. lanceolata* is often found at an altitude of 110–150 m a.s.l. This has a positive correlation with environmental factors that have a large influence on the model produced by MaxEnt, as indicated by response curve that is altitude.

Despite the fact that the genus Baccaurea is underutilized by local communities, it has great potential as a source of medicinal ingredients (Gunawan et al. 2016). SDMs can provide a new understanding of the ecological conditions required by *B. lanceolata* and *B. motleyana*, and also identify conservation areas for both species. The distribution and presence of *B. lanceolata* and *B. motleyana* in South Kalimantan are not well known. Therefore, habitat suitability distribution maps of *B. lanceolata* and *B. motleyana* are valuable resources for researchers and conservationists in determining locations for the conservation or cultivation of these plants. In the case of Indonesia, especially in the Kalimantan region, continuous illegal logging, settlement development, agriculture, annual crops, and timber plantations have been causing habitat loss for many tree species (Budiharta et al. 2011). As a result, rather than being converted to plantations or settlements, sites with a high degree of suitability are retained or prioritized, allowing for the conservation and cultivation of these plants.

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Gunawan Gunawan, Anwar Khoerul, Gafur Abdul, RAUDATUL HILALIYAH, AZMIL AQILATUL WARO, NUR HIKMAH, MUHAMMAD ERWANSYAH, SAKINAH SAKINAH, DIAN SUSILAWATI, RATNA DWI LESTARI, DINDA TRIANA:

We have reached a decision regarding your submission to Biodiversitas Journal of Biological Diversity, "MaxEnt modeling for predicting the current potential geographical distribution of baccaurea (B. lanceolata and B. motleyana) in South Kalimantan, Indonesia".

Our decision is: Revisions Required

Reviewer A:
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MaxEnt modeling for predicting the current potential geographical distribution of Baccaurea (*B. lanceolata* and *B. motleyana*) in South Kalimantan, Indonesia

Abstract. *Baccaurea lanceolata* and *B. motleyana* are an underutilized species of Kalimantan fruit tree, but are potential source for food and medicine. However, little is known about the occurrences and potential geographical distribution of *B. lanceolata* and *B. motleyana*. This study aimed to predict the potential geographical distribution of *B. lanceolata* and *B. motleyana* using MaxEnt, and understand the key factors which influenced their distribution. Occurrence data include 57 for *B. lanceolata* and 87 for *B. motleyana* were collected from field surveys and with 19 bioclimatic variables, solar radiation, altitude, and slope were used to model their distribution. Jackknife test was used to evaluate the importance of the environmental variables for predictive modeling. The area under curve (AUC) values of *B. lanceolata* and *B. motleyana* were 0.927 and 0.851, indicating that the model is a good and informative model for species distribution of these species. The models for *B. lanceolata* suggest that the distribution is mainly influenced by altitude, temperature seasonality, precipitation of the wettest month, and precipitation of the driest quarter. Temperature, annual range, precipitation of the wettest month, precipitation of the coldest quarter, and solar radiation in July were the key environmental factors influencing the distribution of *B. motleyana*. The potential geographic distribution of *B. lanceolata* and *B. motleyana* can be useful information to help researcher in restoration and conservation planning.

Keywords: *Baccaurea motleyana*, *Baccaurea lanceolata*, MaxEnt, habitat suitability, species distribution.

Abbreviations (if any): AUC_ Area Under Curve, MaxEnt_Maximum Entropy

Running title: Predicting potential geographic distribution for *Baccaurea lancelata* and *Baccaurea lanceolata*

INTRODUCTION

Genus *Baccaurea* is a group of plants that produce fruit, but its existence is not as popular as that of other fruit plants. In addition to using the fruit as fresh fruit and wood as building materials, members of the genus *Baccaurea* have been used by the community as medicinal plants to treat several diseases, including constipation, swelling of the eyes, arthritis, abdominal pain, and facilitating menstruation and urination (Usha *et al.* 2014; Ullah *et al.* 2012; Goyal *et al*. 2014; Lim 2012; Gunawan *et al.* 2016).

Baccaurea lanceolata as locally known as “Limpasu” and *Baccaurea motleyana* as locally known as “Rambai” are two species from the genus *Baccaurea* Family Phyllanthaceae that have great potential as a medicinal ingredient. Antioxidant activity test with three methods (DPPH, ABTS, and FRAP) on the pericarp, fruit, flesh, and seeds of *B. lanceolata* showed high antioxidant activity, with the highest activity found in the flesh of the fruit (Bakar *et al.* 2014). Zamzani and Triadisti (2021) revealed that *B. lanceolata* has high antioxidant activity. The ethanol extract of spleen fruit was the most active extract against bacteria (Fitriansyah et al. 2018; Gallapathie 2018). Local communities in South Kalimantan used the extract fruit of Limpasu as cosmetics as sunscreen. Fruit of *B. Lanceolata* also contains fenol, flavonoids, antosianin, and karotenoid (Bakar *et al*. 2014). *Baccaurea motleyana* has high antioxidant activity containing phenolic, flavonoid, and anthocyanin compounds, secondary metabolite compounds derived from sugar metabolism. Fitri *et al*. (2016) revealed that *B. motleyana* fruit contains phenols and flavonols and has lipid peroxidation activity. Rambai fruits have relatively low amounts of fats, organic acids, phenolics, and antioxidants compared to many other familiar fruits. Rambai tree parts were found to exhibit antidiabetic, antibacterial, and skincare properties (Prodhan & Mridu 2021).

Although *B. lanceolata* and *B. motleyana* have high utility value, habitat loss and population declines of these species continue to occur. Little is known about the occurrence of *B. lanceolata* and *B. motleyana* and its adaptability different climate and edaphic conditions in South Kalimantan. Tha last publication by Haegens (2000) stated *B. lanceolata* and *B. motleyana* were found in Borneo. Agricultural clearing, forest fires, illegal logging, forest conversion, increasing human population, and mining are important factors causing decreasing plant populatian and biodiversity loss. Budiharta et al.

2011 state that in Kalimantan region, habitat loss of many tree species are caused by continuous illegal logging, development of human settlements, agriculture, perennial crops, and timber plantations. Besides that environmental degradation caused by various anthropogenic activities, climate change also harms current plant diversity (Belgacem et al. 2008). Climate change is also known as one of the most important factors influencing the geographic distribution of plant species (Forman 1964). Detailed information about the regional distribution of a plant is needed for their restoration and habitat conservation. Furthermore, information about a plant's distribution is important in determining the population, taxonomic variation, habitat suitability, and potential utilization. Studying the current and potential distribution of species and examining the key environmental factors that affect their growth can help us to understand the overall distribution patterns of species.

The Species Distribution Model (SDM) is a general approach for investigating the potential distribution of species and suitable habitats in the environment. It is widely used for broad applications in ecology, biogeography, and conservation biology. A number of SDMs have been developed to estimate the suitable areas for specific species according the specific algorithms, including Maximun Entropy (Phillips et al. 2006; Martinez-Minaya et al. 2018). MaxEnt is a niche modeling program based on environmental variables and species occurrence data, which is integrated by machine learning and the principle of maximum entropy to predict the potential distribution of species (Elith et al. 2011). The MaxEnt program has been used extensively to predict species distribution, which has also been employed by studies in South Asia (Pradhan 2015), including Indonesia (Setyawan et al. 2017, 2020a, 2020b, 2021; Gunawan et al. 2021a, 2021b; Usmadi et al. 2021; Harapan et al. 2022). Compared to other SDMs programs, MaxEnt can produce better models, because MaxEnt can create models only with occurrence data (Elith et al. 2011; Jackson and Robertson 2011; Kalboussi and Achour 2017), and it have the ability to run with a small amount of data (Fois et al. 2018; Preau et al. 2018). Furthermore, the results are highly accurate and highly reproducible (Fourcade et al. 2014).

The aim of this study was to predict the current potential distribution of *B. lanceolata* and *B. motleyana* in South Kalimantan, Indonesia and to identify the key factors include climatic and topography responsible for the distribution of these species. We expect the results of this study to provide information regarding the potential distribution of *B. lanceolata* and *B. motleyana* in Kalimantan, and identify the currently suitable areas for conservation and cultivation.

MATERIALS AND METHODS

Study area and species occurrence data

The study was conducted in South Kalimantan which consists of 13 districts, which has approximately 34.744 km^2 of land area. The geographic scope of this study includes the area of approximately 1º 21' 49" LS – 1º 10' 14" LS and 114º 19' 33" BT – 116º 33' 28". Authors collected the occurrence data of *B. lanceolata* and *B. motleyana* from local communities and forestry services (Figure 1.)

The explorative field survey was carried out according to the previous research method conducted by Rugayah et al. (2004). The field study period was from February to June 2022. Plant samples were collected and herbarium specimens were deposited in Bio-systematic laboratory Lambung Mangkurat University, South Kalimantan. Using Garmin 64s GPS series, we collected 57 occurrences points of *B. lanceolata* and 87 occurrences points of *B. motleyana* which were found distributed in South Kalimantan. All coordinates from the field survey were converted to decimal degrees and imported into Microsoft Excel, and then saved as CSV format. The coordinate data were used to describe the distribution of *B. macrocarpa* in the province of South Kalimantan using the DIVA Gis 7.5 software (Figure 2.) and is used as input data for habitat suitability modeling using MaxEnt.

Climatic variables

For this study, we used 19 bioclimatic variables (11 temperature and 8 precipitation variables), solar radiation (12 months), altitude, and geoslope were downloaded and assessed (Tabel 1). Bioclimatic variable were extracted from WorldClim (https://www.worldclim.org) (Hijsmans 2020). Slope variable was downloaded from www.fao.org. In addition, a raster file of digital elevation models based on the altitude data was also downloaded from the WordClim website. They were generated through interpolation of average monthly climate data from weather stations at 30 arc seconds (*1 km) spatial resolution (Ficks and Hijmans 2017). All predictor variables layers were in GeoTIFF format, QuantumGis ver 2.8.10 was used to convert bioclimatic variables and environmental layers into an ASCII format for use in MaxEnt (Setyawan et al. 2020a).

Species distribution model requires selecting and using environmental factors with a major influence to the model (Worthington et al. 2016) and with minimal inter-correlation (Pradhan 2016, 2019) to get an accurate and informative model. The variable selection was done with two-pronged approach. i) Firstly, Variance Inflation Factor (VIF) analysis was carried out across all bioclimatic variables in R platform. The pair wise VIF values of bioclimatic variables were assessed and those variables were screened whose pair wise VIF was <10. ii) Secondly, screened bioclimatic variables along with another environmental factor like solar radiation were put to Jackknife test evaluation for assessment of the contribution of each environmental variable to the resulting model.

The contribution percentage and permutation are two important factors for understanding and measuring the environmental variable's contribution as well as importance to the model. According to the Jackknife test evaluation of the contribution of each environmental variable to the resulting model, twelve environmental variables were not used, eleven of them due to the lack of contribution to the model making 0% percent contribution and bio 8 due to co linearity with bio 10 through VIF value of 63.8 (Pradhan 2016, 2019), and as well exclusion of bio 8 led to increase in regularized training gain. Besides that variables with a small average contribution (<6%) or permutation importance (<6%) were not used due to lack of contribution to the models (Wei et al. 2018). Therefore, the final environmental variables used in *B. lanceolata* species distribution model map for the current period were alt (altitude), bio 4 (temperatur seasonality), bio 13 (Precipitation of wettest month), bio 17 (Precipitation of driest quarter), whereas the final environmental variables for *B. motleyana* were bio 7 (Temperature annual range), bio 13 (Precipitation of wettest month), bio 19 (Precipitation of coldest quarter), srad 7 (Solar radiation in July). Variables that considered affecting to the distribution of these species, i.e, land use, human disturbances, species dispersal or biotic interaction change were not included to the model because the availability of these data were limited.

Species distribution modeling

We used MaxEnt version 3.4.1 (Phillips et al. 2017) to predict the current potential geographic distribution of *B. lanceolata* and *B. motleyana* in South Kalimantan. The software was downloaded from https://biodiversityinformatics.amnh.org / open_source / maxent / and can be extracted freely for scientific research. In our predicted models, default setting was used in MaxEnt model (Abdelaal et al. 2019). We employed 10 replicates and the average of probability for habitat suitability of *B. lanceolata* and *B. motleyana* in South Kalimantan (Hoveka et al. 2016). The bootstrap method was implemented with 10 repeats, a maximum of 5000 iteration, and default selected parameters (Yan et al. 2020). Models resulting from MaxEnt were evaluated; the accuracy and quality of the model used the Area Under the Curve (AUC) scores of Receiver Operating Curve (ROC) analysis. The scores of AUC ranged from 0.5 to 1. An AUC score of 0.5 indicated the model prediction did not perform better than random expectation, while a score of 1.0 shows the resulting model is very good and informative (Swets 1988). We also performed the Jacknife test. A Jackknife analysis was used to calculate the contribution the variables for the model prediction for *B. lanceolata* and *B. motleyana*. Jackknife analysis is also carried out to determine the dominant variables that determine the potential distribution of species (Yang et al. 2013). In addition, we used respond curves that produced by MaxEnt analysis to know the relationship between the habitat suitability of *B. lanceolata* and *B. motleyana* and environmental factors.

The results of Maxent's analysis for *B. lanceolata* and *B. motleyana* were imported into DIVA GIS software version 7.5 (Hijmans et al. 2012) for visualization and further data analysis. The species distribution model map resulted from MaxEnt has suitability levels that can be grouped into 4 classes, namely, least suitable (0.0-0.2), low suitability (0.2-0.4), medium suitability (0.4-0.6), and high suitability (0.6-1.0) (IPCC 2007; Wei et al. 2020).

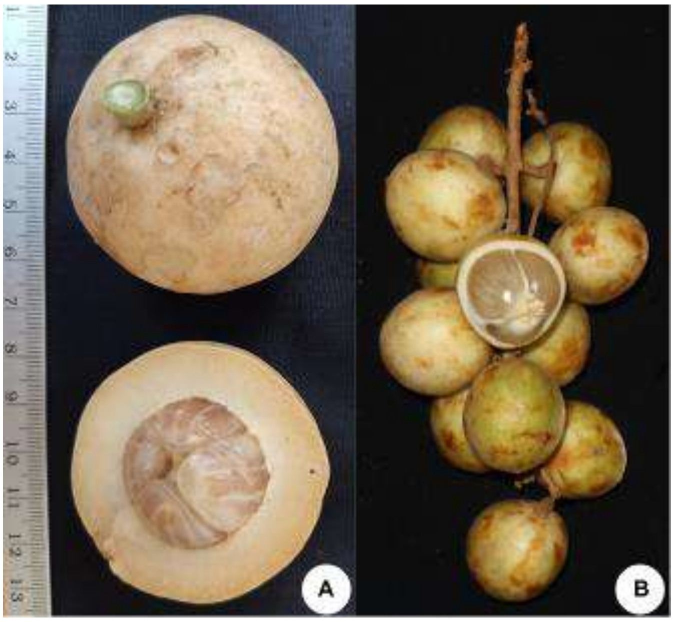


Figure 1. Fruit of Baccaurea species. A. *Baccaurea lanceolata*, B. *Baccaurea motleyana*

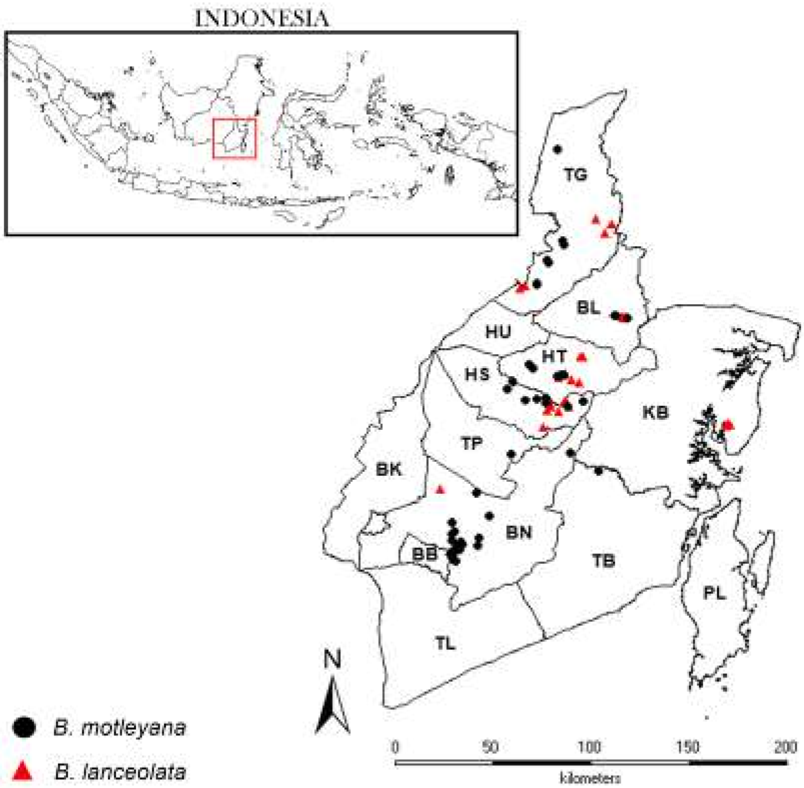


Figure 2. Current distibutions of *B. Lanceolata* and *B. motleyana* in South Kalimantan obtained from field survey. TL = Tanah Laut; TB = Tanah Bumbu; PL = Pulau Laut; BB = Banjar Baru; BN = Banjar; BK = Barito Kuala; TP = Tapin; KB = Kota Baru; HS = Hulu Sungai Selatan; HT = Hulu Sungai Tengah; HU = Hulu Sungai Utara; BL = Balangan; TG = Tabalong.

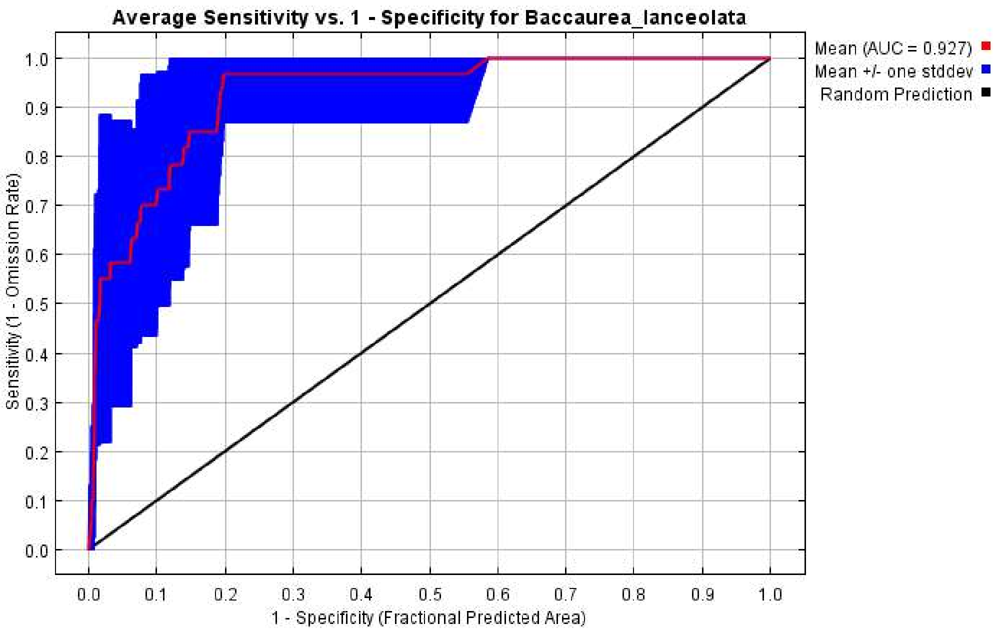
Table 1. Description environmental variables used for MaxEnt model prediction for *B. lanceolata* and *B. motleyana*

Code	Parameter	Unit
alt	Altitude	m
srad	Solar radiation (12 month)	w/m^2
gloslope	Slope	%
bio 1	Mean annual temperature	ºC
bio 2	Mean diurnal range (max temp - min temp)	ºC
bio 3	Isothermality	ºC
bio 4	Temperatur seasonality	ºC
bio 5	Maximum temperature of warmest month	ºC
bio 6	Minimum temperature of coldest month	ºC
bio 7	Temperature annual range	ºC
bio 8	Mean temperature of wettest quarter	ºC
bio 9	Mean temperature of driest quarter	ºC
bio 10	Mean temperature of driest quarter	ºC
bio 11	Mean temperature of coldest quarter	ºC
bio 12	Annual precipitation	mm
bio 13	Precipitation of wettest month	mm
bio 14	Precipitation of driest month	mm
bio 15	Precipitation seasonality	mm
bio 16	Precipitation of wettest quarter	mm
bio 17	Precipitation of driest quarter	mm
bio 18	Precipitation of warmest quarter	mm
bio 19	Precipitation of coldest quarter	mm

RESULTS AND DISCUSSION

Model performance

Many researchers use the area under the curve (AUC) statistic to evaluate the final model (Setyawan et al. 2017, 2020a, 2020b, 2021; Pradan 2015; Gunawan et al. 2021a; Gunawan et al. 2021b; Romadlon et al. 2021; Shao et al. 2022). Model performance was classified as failing (0.5-0.6), poor (0.6-0.7), fair (0.7-0.8), good (0.8-0.9), and excellent (0.9-1) (Araujo et al. 2005). The model output by MaxEnt provided satisfactory results with the AUC training value for *B. lanceolata* 0.926 and for *B. Motleyana* AUC value is 0.851, which are higher than 0.5 of a random model. The final model indicated good model and had high accuracy for species distribution model (Figure 3). This indicated that the environmental variables were well selected to predict the current potential geographic distribution of *B. lanceolata* and *B. motleyana*. In this study, we determine the key environmental variable based on their contributions to the modeling process. The Jacknife test was conducted to show the influence of each environmental variable in the building the model (Figure 3).



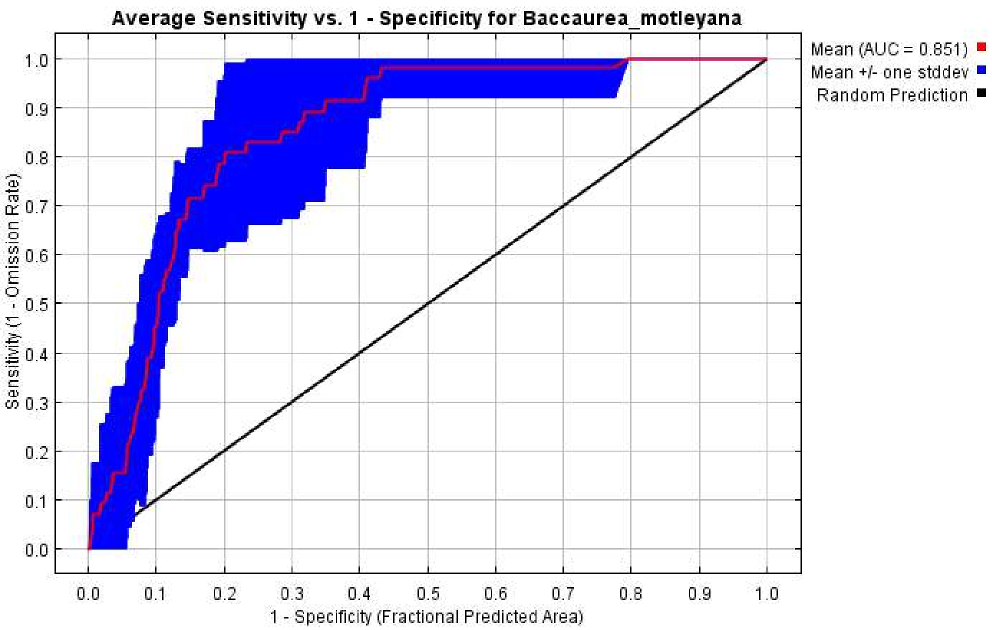


Figure 3. Result of area under the receiver operating characteristics curve (ROC-AUC) analyses for a MaxEnt model of habitat suitability for *Baccaurea lanceolata* and *Baccaurea motleyana*.

Altitude, temperature, and precipitation were the most important environmental for *B. lanceolata*, while for *B. motleyana* were temperature, precipitation, and solar radiation (Table 2). Altitude was the highest contributing influencing the predicticted distribution for *B. lanceolata* with ranging from 0 – 200 m asl with peak at ~180 m asl. Environmental variable with the great influence on predicted distribution for *B. motleyana* was temperature annual range, with the optimum temperature annual range condition between 9ºC and 11.5 ºC. Analysis of environmental variables contributions is different between species, so that the different species have different species distribution model.

Table 2. Environmental variable contribution for *B. lanceolata* (Bl) and *B. motleyana* (Bm).

Code	Environmental variable	Contribution (%)	
		Bl	**Bm**
alt	Altitude	24.4	-
bio 4	Temperatur seasonality	15.7	-
bio 7	Temperature annual range	-	34.6
bio 13	Precipitation of wettest month	10.6	15
bio 17	Precipitation of driest quarter	22.2	-
bio 19	Precipitation of coldest quarter	-	7.3
srad 7	Solar radiation in July	-	10.7

Variables' response curves

The response curves were presented to show relationship between the probability of *B. lanceoalata* and *B. motleyana* distribution with environmental variables can be seen in the response curve generated by the Maximum Entropy model. Response curves show the quantitative relationship between environmental variables and the logistic probability of presence and they deepen the understanding of the ecological niche of the species (Yi et al. 2016). Species response curves also show biological tolerances for target species and habitat preferences (Gebrewahid et al. 2020). The response curves of *B. lanceolata* and *B. motleyana* to four environmental variables are illustrated in Figures 4A and 4B.

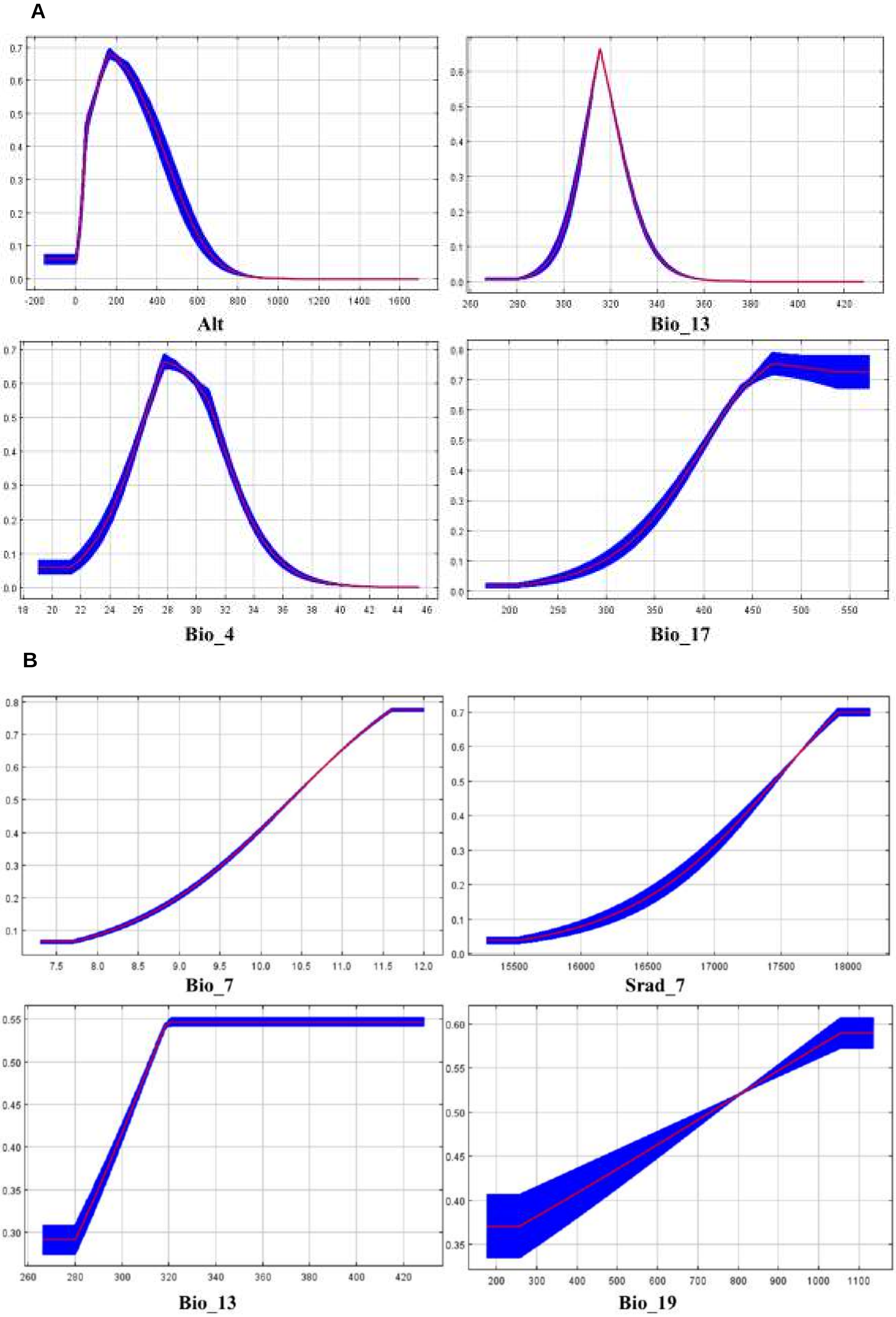


Figure 4. Response curves to four key environmental variables. A. response curve for *B. lanceolata*: Alt: Altitude; Bio 13: Precipitation of wettest month; Bio 4: Temperature seasonality; Bio 17: Precipitation of driest quarter. B. response curve for *B. motleyana*. Bio 7: Temperature annual range; Srad 7: Solar radiation in July; Bio 13: Precipitation of wettest month; Bio 19: Precipitation of coldest quarter. The curves show the mean response of the 10 replicate MaxEnt runs (red) and the mean +/- one standard deviation (blue, two shades for categorical variables)

The response curves of *B. lanceolata* to four environmental variables are show in Figure 4A. Based on the response curves, the suitable altitude range (Alt) of *B. lanceolata* ranged from 0 – 200 m asl with a peak at ~180 m asl. The next important environmental variable was the precipitation of wettest month (bio 13) which showed 300-320 mm, with peak at ~319 mm. The response curve of bio 4 showed that the suitable temperature seasonality ranged from 22 ºC - 28 ºC and peaked at ~27.5ºC. The optimal precipitation of the driest quarter which showed a range of 250 - 500 mm and a peak at ~425 mm required by *B. lanceolata* was indicated by the response curve of bio 17. The response curves of *B. motleyana* to four environmental variables are show in Figure 4B. According to the response curve, the optimum temperature annual range (bio 7) for *B. motleyana* ranged between 9ºC and 11.5 ºC. The next important environmental variable for *B. motleyana* was solar radiation in July (srad 7) which showed the range 16000-18000 w/m2, with a peak at ~17687 w/m2. The optimal precipitation of the wettest month which showed a range of 290 - 320 mm and a peak at ~310 mm required by *B. motleyana* was indicated by the response curve of bio 13. The response curve of bio 19 showed that the suitable precipitation of the coldest month (bio 19) ranged from 300 - 1100 mm and peaked at ~1090 mm.

The results of the model showed that as altitude, temperature, solar radiation, and precipitation were the dominant environmental variables for habitat suitability of *B. lanceolata* and *B. motleyana.* Geographical variables such as altitude are often having correlation with local precipitation and temperature (Austin 2002; Korner 2007). Temperature has an important role to maintain the humidity in the local region by regulation evapotranspiration level. Solar radiation is the main source of energy for organism in ecosystem. Solar radiation affects the plant's physiological processes, especially in plant growth and development. Solar radiation also affected climate, plant growth and evolution, vegetation distribution, and succession, and productivity in the forest ecosystem (Jordan et al. 2005; Li et al. 2011; Fyllas et al. 2017). Climates have significant role in the distribution of plant species (Svenning and Sandel 2013). Precipitation is one of the environmental variables has important role for habitat suitability of *B. lanceolata* and *B. motleyana.* Precipitation plays a major role as an element in plant development (Dasci at al. 2010).

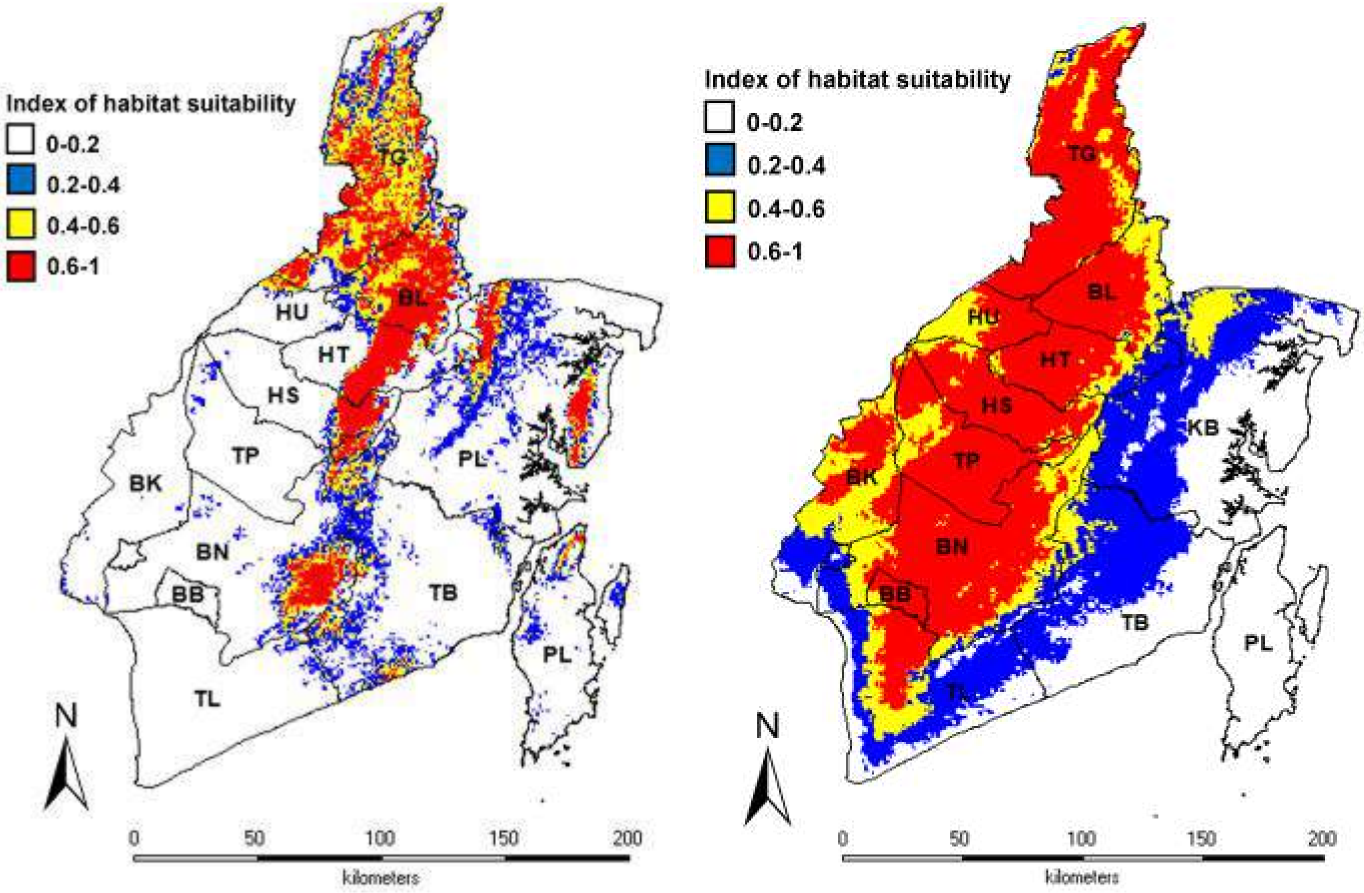
The previous research on species *Baccaurea* (Gunawan et al. 2021a; 2021b) also revealed that altitude, temperature, solar radiation, and precipitation were also influenced in distribution range. This shows that environmental variables such as altitude, temperature, solar radiation, and precipitation play an important role in *Baccaurea* habitat. Climatic factors such as temperature and precipitation were affecting the distribution (Belguidum et al 2021). Zhang et al. 2018, also state that climatic factors were crucial factors that affect plant regeneration, growth, and the spread of its populations.

Prediction current potential distribution

Baccaurea is an underutilized plant, but this fruit has benefits as a source of medicinal ingredients and as well as important ecological functions such as the fruits are eaten by many bird species, but also by rodents, deer, and monkeys (Rijksen 1978). Little is known about the existence and distribution of *B. lanceolata* and *B. motleyana* in South Kalimantan. The model prediction of the potential distribution of *B. lanceolata* and *B. motleyana* was created based on the observed occurrences and current climate conditions. The maps of species distribution model produced by MaxEnt and categorized into four suitability classes between 0 to 1 are presented in Figure 5.

The greatest concentration of highly suitable areas for *B. lanceolata* (IHS 0.6-1) was mainly predicted in six districts (*kabupaten*): BN (Banjar), HS (Hulu Sungai Selatan), HT (Hulu Sungai Tengah), BL (Balangan), PL (Pulau Laut), and TG (Tabalong). Other locations that have highly and medium habitat suitability (IHS 0.4-0.6) were BN (Banjar), BL (Balangan), TG (Tabalong), TB (Tanah Bumbu), and PL (Pulau Laut). The lowly suitable habitat (IHS 0.2-0.4) was predicted in a part of TG (Tabalong), BL (Balangan), PL (Pulau Laut), TB (Tanah Bumbu), and BN (Banjar). The least levels of habitat suitability for *B. lanceolata* (IHS 0.0-0.2) were predicted in TL (Tanah Laut), BB (Banjarbaru), BK (Barito Kuala), TP (Tapin), a part of HU (Hulu Sungai Utara), HT (Hulu Sungai tengah), PL (Pulau Laut) and TB (Tanah Bumbu).

The greatest concentration of highly suitable areas for *B. motleyana* (IHS 0.6-1) was mainly predicted in nine districts (*kabupaten*): TG (Tabalong), BL (Balangan), HT (Hulu Sungai Tengah), HU (Hulu Sungai Utara), HS (Hulu Sungai Selatan), BN (Banjar), BB (Banjarbaru), and BK (Barito Kuala). Other locations that have highly and medium habitat suitability (IHS 0.4-0.6) were a part of TG (Tabalong), BL (Balangan), HT (Hulu Sungai Tengah), HU (Hulu Sungai Utara), TP (Tapin), BN (Banjar), BK (Barito Kuala), TL (Tanah Laut), and KB (Kota Baru). The lowly suitable habitat (IHS 0.2-0.4) was predicted most of a part of BK (Barito Kuala), TL (Tanah Laut), TB (Tanah Bumbu), and KB (Kota Baru). The least levels of habitat suitability for *B. lanceolata* (IHS 0.0-0.2) were predicted in BK (Barito Kuala), TL (Tanah Laut), TB (Tanah Bumbu), KB (Kota Baru), and PL (Pulau Laut).



A B

Figure 5. Map of potential current habitat suitability according to occurrence records in South Kalimantan. A. *Baccaurae lanceolata*. B. *Baccaurea motleyana*. TL = Tanah Laut; TB = Tanah Bumbu; PL = Pulau Laut; BB = Banjar Baru; BN = Banjar; BK = Barito Kuala; TP = Tapin; KB = Kota Baru; HS = Hulu Sungai Selatan; HT = Hulu Sungai Tengah; HU = Hulu Sungai Utara; BL = Balangan; TG = Tabalong.

The MaxEnt models under current climate conditions show that *B. lanceolata* distribution ranges are more influenced by altitude, temperature (seasonal temperature), and precipitation (driest month and driest quarter). Whereas *B. motleyana* distribution range was more influenced by temperature (temperature annual range), solar radiation (solar radiation in July), and precipitation (precipitation of wettest month and precipitation of the coldest quarter). Temperature, solar radiation, precipitation and soil properties are an important factor that influence of plant species distribution (Hemp 2006).

In addition to environmental variables, species distribution and modeling may also be influenced by biotic factors, speciation mechanisms and dispersal ability (Kaky et al. 2020). *Baccaurea lanceolata* has a narrower habitat suitability area compared to *B. motleyana* based on MaxEnt's final model. Based on field observations, *B. lanceolata* is often found at an altitude of 110–150 m a.s.l. This has a positive correlation with environmental factors that have a large influence on the model produced by MaxEnt, as indicated by response curve that is altitude.

Despite the fact that the genus Baccaurea is underutilized by local communities, it has great potential as a source of medicinal ingredients (Gunawan et al. 2016). SDMs can provide a new understanding of the ecological conditions required by *B. lanceolata* and *B. motleyana*, and also identify conservation areas for both species. The distribution and presence of *B. lanceolata* and *B. motleyana* in South Kalimantan are not well known. Therefore, habitat suitability distribution maps of *B. lanceolata* and *B. motleyana* are valuable resources for researchers and conservationists in determining locations for the conservation or cultivation of these plants. In the case of Indonesia, especially in the Kalimantan region, continuous illegal logging, settlement development, agriculture, annual crops, and timber plantations have been causing habitat loss for many tree species (Budiharta et al. 2011). As a result, rather than being converted to plantations or settlements, sites with a high degree of suitability are retained or prioritized, allowing for the conservation and cultivation of these plants.

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We have reached a decision regarding your submission to Biodiversitas Journal of Biological Diversity, "MaxEnt modeling for predicting the current potential geographical distribution of baccaurea (B. lanceolata and B. motleyana) in South Kalimantan, Indonesia".

Our decision is: Revisions Required

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Predicting the current potential geographical distribution of Baccaurea (*B. lanceolata* and *B. motleyana*) in South Kalimantan, Indonesia

Abstract. *Baccaurea lanceolata* and *B. motleyana* are an underutilized species of Kalimantan fruit tree, but are potential source for food and medicine. However, little is known about the occurrences and potential geographical distribution of *B. lanceolata* and *B. motleyana*. This study aimed to predict the potential geographical distribution of *B. lanceolata* and *B. motleyana* using MaxEnt, and understand the key factors which influenced their distribution. In addition to 19 bioclimatic factors, occurrence data for 57 *B. lanceolata* and 87 *B. motleyana* were gathered from field surveys. Solar radiation, height, and slope were then utilized to estimate the distribution of these species. Jackknife test was used to evaluate the importance of the environmental variables for predictive modeling. The area under curve (AUC) values of *B. lanceolata* and *B. motleyana* were 0.927 and 0.851, indicating that the model is a good and informative model for species distribution of these species. The models for *B. lanceolata* suggest that the distribution is mainly influenced by altitude, temperature seasonality, precipitation of the wettest month, and precipitation of the driest quarter. Temperature, annual range, precipitation of the wettest month, precipitation of the coldest quarter, and solar radiation in July were the key environmental factors influencing the distribution of *B. motleyana*. The potential geographic distribution of *B. lanceolata* and *B. motleyana* can be useful information to help researcher in restoration and conservation planning.

Keywords: *Baccaurea motleyana, Baccaurea lanceolata,* MaxEnt, habitat suitability, species distribution.

Abbreviations (if any): AUC_ Area Under Curve, MaxEnt_Maximum Entropy

Running title: Predicting potential geographic distribution for *Baccaurea lancelata* and *Baccaurea lanceolata*

INTRODUCTION

Although the genus Baccaurea includes fruit-producing plants, its existence is not as well known as that of other fruit-producing plants. In addition to using the fruit as fresh fruit and wood as building materials, members of the genus *Baccaurea* have been used by the community as medicinal plants to treat several diseases, including constipation, swelling of the eyes, arthritis, abdominal pain, and facilitating menstruation and urination (Usha *et al*. 2014; Ullah *et al*. 2012; Goyal *et al*. 2014; Lim 2012; Gunawan *et al*. 2016).

Baccaurea lanceolata as locally known as “Limpasu” and *Baccaurea motleyana* as locally known as “Rambai” are two species from the genus *Baccaurea* Family, Phyllanthaceae that have great potential as a medicinal ingredient. Antioxidant activity test with three methods (DPPH, ABTS, and FRAP) on the pericarp, fruit, flesh, and seeds of *B. lanceolata* showed high antioxidant activity, with the highest activity found in the flesh of the fruit (Bakar *et al*. 2014). Zamzani and Triadisti (2021) revealed that *B. lanceolata* has high antioxidant activity. The ethanol extract of spleen fruit was the most active extract against bacteria (Fitriansyah et al. 2018; Gallapathie 2018). Local communities in South Kalimantan used the extract fruit of Limpasu as cosmetics as sunscreen. Fruit of *B. Lanceolata* also contains fenol, flavonoids, antosianin, and karotenoid (Bakar *et al*. 2014). *Baccaurea motleyana* has high antioxidant activity containing phenolic, flavonoid, and anthocyanin compounds, secondary metabolite compounds derived from sugar metabolism. Fitri *et al*. (2016) revealed that *B. motleyana* fruit contains phenols and flavonols and has lipid peroxidation activity. Rambai fruits have relatively low amounts of fats, organic acids, phenolics, and antioxidants compared to many other familiar fruits. Rambai tree parts were found to exhibit antidiabetic, antibacterial, and skincare properties (Prodhan & Mridu 2021).

Although *B. lanceolata* and *B. motleyana* have high utility value, habitat loss and population declines of these species continue to occur. Little is known about the occurrence of *B. lanceolata* and *B. motleyana* and its adaptability different climate and edaphic conditions in South Kalimantan. The latest publication by Haegens (2000) stated *B. lanceolata* and *B. motleyana* were found in Borneo. Agricultural clearing, forest fires, illegal logging, forest conversion, increasing human population, and mining are important factors causing decreasing plant population and biodiversity loss. Budiharta et al. (2011) state that in Kalimantan region, habitat loss of many tree species are caused by continuous illegal logging, development of human settlements, agriculture, perennial crops, and timber plantations. In addition to environmental degradation brought on by numerous human activities, climate change also threatens the diversity of the current plant species (Belgacem et al. 2008). Climate change is also known as one of the most important factors influencing the geographic distribution of plant species (Forman 1964). Detailed information about the regional distribution of a plant is needed for their restoration and habitat conservation. Furthermore, information about a plant's distribution is important in determining the population, taxonomic variation, habitat suitability, and potential utilization. Studying the current and potential distribution of species and examining the key environmental factors that affect their growth can help us to understand the overall distribution patterns of species.

The Species Distribution Model (SDM) is a general approach for investigating the potential distribution of species and suitable habitats in the environment. It is widely used for broad applications in ecology, biogeography, and conservation biology. A number of SDMs have been developed to estimate the suitable areas for specific species according the specific algorithms, including Maximun Entropy (Phillips et al. 2006; Martinez-Minaya et al. 2018). MaxEnt is one of the SDMs program based on environmental variables and species occurrence data, which is integrated by machine learning and the principle of maximum entropy to predict the potential distribution of species (Elith et al. 2011). The MaxEnt program has been used extensively to predict species distribution, which has also been employed by studies in South Asia (Pradhan 2015), including Indonesia (Setyawan et al. 2017, 2020a, 2020b, 2021; Gunawan et al. 2021a, 2021b; Usmadi et al. 2021; Harapan et al. 2022). Compared to other SDMs programs, MaxEnt can produce better models, because MaxEnt can create models only with occurrence data (Elith et al. 2011; Jackson and Robertson 2011; Kalboussi and Achour 2017), and it have the ability to run with a small amount of data (Fois et al. 2018; Preau et al. 2018). Furthermore, the results are highly accurate and highly reproducible (Fourcade et al. 2014).

The aim of this study was to predict the current potential distribution of *B. lanceolata* and *B. motleyana* in South Kalimantan, Indonesia and to identify the key factors include climatic and topography responsible for the distribution of these species. We expect the results of this study to provide information regarding the potential distribution of *B. lanceolata* and *B. motleyana* in Kalimantan, and identify the currently suitable areas for conservation and cultivation.

MATERIALS AND METHODS

Study area and species occurrence data

The study was conducted in South Kalimantan which consists of 13 districts, which has approximately 34.744 km^2 of land area. The geographic scope of this study includes the area of approximately 1º 21' 49" LS – 1º 10' 14" LS and 114º 19' 33" BT – 116º 33' 28". Authors collected the occurrence data of *B. lanceolata* and *B. motleyana* from local communities and forestry services (Figure 1.).The explorative field survey was carried out according to the previous research method conducted by Rugayah et al. (2004). The field study period was from February to June 2022. Plant samples were collected and herbarium specimens were deposited in Bio-systematic laboratory Lambung Mangkurat University, South Kalimantan. Using Garmin 64s GPS series, we collected 57 occurrences points of *B. lanceolata* and 87 occurrences points of *B. motleyana* which were found distributed in South Kalimantan. All coordinates from the field survey were converted to decimal degrees and imported into Microsoft Excel, and then saved as CSV format. The coordinate data were used to describe the distribution of *B. macrocarpa* in the province of South Kalimantan using the DIVA Gis 7.5 software (Figure 2.) and is used as input data for habitat suitability modeling using MaxEnt.

Climatic variables

For this study, we used 19 bioclimatic variables (11 temperature and 8 precipitation variables), solar radiation (12 months), altitude, and geo-slope were downloaded and assessed (Tabel 1). Bioclimatic variable were extracted from WorldClim (https://www.worldclim.org) (Hijsmans 2020). Slope variable was downloaded from www.fao.org (https://www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/harmonized-world-soil-database-v12/en/). In addition, a raster file of digital elevation models based on the altitude data was also downloaded from the WordClim website. They were generated through interpolation of average monthly climate data from weather stations at 30 arc seconds (*1 km) spatial resolution (Ficks and Hijmans 2017). All predictor variables layers were in GeoTIFF format, QuantumGis ver 2.8.10 was used to convert bioclimatic variables and environmental layers into an ASCII format for use in MaxEnt (Setyawan et al. 2020a).

Species distribution model requires selecting and using environmental factors with a major influence to the model (Worthington et al. 2016) and with minimal inter-correlation (Pradhan 2016, 2019) to get an accurate and informative model. The variable selection was done with two-pronged approach. i) Firstly, Variance Inflation Factor (VIF) analysis was carried out across all bioclimatic variables in R platform. The pair wise VIF values of bioclimatic variables were assessed and those variables were screened whose pair wise VIF was <10. ii) Secondly, screened bioclimatic variables along with another environmental factor such as solar radiation were put to Jackknife test evaluation for assessment of the contribution of each environmental variable to the resulting model.

The contribution percentage and permutation are two important factors for understanding and measuring the environmental variable's contribution as well as importance to the model. According to the Jackknife test evaluation of the contribution of each environmental variable to the resulting model, twelve environmental variables were not used, eleven of them due to the lack of contribution to the model making 0% percent contribution and bio 8 due to co linearity with bio 10 through VIF value of 63.8 (Pradhan 2016, 2019), and as well exclusion of bio 8 led to increase in regularized training gain. Besides that variables with a small average contribution (<6%) or permutation importance (<6%) were not used due to lack of contribution to the models (Wei et al. 2018). Therefore, the final environmental variables used in *B. lanceolata* species distribution model map for the current period were alt (altitude), bio 4 (temperature seasonality), bio 13 (Precipitation of wettest month), bio 17 (Precipitation of driest quarter), whereas the final environmental variables for *B. motleyana* were bio 7 (Temperature annual range), bio 13 (Precipitation of wettest month), bio 19 (Precipitation of coldest quarter), srad 7 (Solar radiation in July). Variables that considered affecting to the distribution of these species, i.e, land use, human disturbances, species dispersal or biotic interaction change were not included to the model because the availability of these data were limited.

Species distribution modeling

Several programs or algorithms have been developed to predict models of potential species distribution areas consisting of DOMAIN, Climatic Envelope (BIOCLIM), Generalized Linear Models (GLM), Artificial Neural Network (ANN), and Maximum Entropy (MAXENT). DOMAIN is a simple and straightforward model for modeling the distribution of plant species based on a range-standardized and point-to-point similarity matrix (Carpenter 1993). BIOCLIM is a climate-envelope model that has been widely used in species distribution modeling (Booth et al. 2014). BIOCLIM uses easy-to-understand algorithms and provides useful insight into methods and procedures of species distribution modeling (Hijmans and Graham 2006). GLM is a regression-based technique that is often used to predict biodiversity distribution (Guisan et al. 2017). Artificial Neural Network (ANN) is a machine learning approach that commonly tends to have better models' performance in predicting species distribution patterns. It is widely used in remote sensing image classification and ecological applications (Benediktsson et al. 1993). ANN works with both regression and classification, in addition, a continuous and categorical predictor can be used in this model. Each program has different theoretical foundations, required data, and analysis methods.

Several studies have shown that compared to other species distribution models, MaxEnt not only has good prediction and stability but also has the advantages of simple and fast operation, a small number of occurrences demanded (Yang et al. 2014; Beck et al. 2018; Song et al. 2020; Anand et al. 2021), and it works very well for presence-only data (Phillips et al. 2006). Maxent builds a prediction model based on the actual distribution points and environmental variables of the distribution area stored in the GIS and then Maxent will simulate the species distribution in the targeted location or region (Zhang et al. 2021).

We used MaxEnt version 3.4.1 (Phillips et al. 2017) to predict the current potential geographic distribution of *B. lanceolata* and *B. motleyana* in South Kalimantan. The software was downloaded from https://biodiversityinformatics.amnh.org /-open_source /-maxent / and can be extracted freely for scientific research. In our predicted models, default setting was used in MaxEnt model (Abdelaal et al. 2019). We employed 10 replicates and the average of probability for habitat suitability of *B. lanceolata* and *B. motleyana* in South Kalimantan (Hoveka et al. 2016). The bootstrap method was implemented with 10 repeats, a maximum of 5000 iteration, and default selected parameters (Yan et al. 2020). Models resulting from MaxEnt were evaluated; the accuracy and quality of the model used the Area Under the Curve (AUC) scores of Receiver Operating Curve (ROC) analysis. The scores of AUC ranged from 0.5 to 1. An AUC score of 0.5 indicated the model prediction did not perform better than random expectation, while a score of 1.0 shows the resulting model is very good and informative (Swets 1988). We also performed the Jackknife test. A Jackknife analysis was used to calculate the contribution the variables for the model prediction for *B. lanceolata* and *B. motleyana*. Jackknife analysis is also carried out to determine the dominant variables that determine the potential distribution of species (Yang et al. 2013). In addition, we used respond curves that produced by MaxEnt analysis to know the relationship between the habitat suitability of *B. lanceolata* and *B. motleyana* and environmental factors.

The results of Maxent's analysis for *B. lanceolata* and *B. motleyana* were imported into DIVA GIS software version 7.5 (Hijmans et al. 2012) for visualization and further data analysis. The species distribution model map resulted from MaxEnt has suitability levels that can be grouped into 4 classes, namely, least suitable (0.0-0.2), low suitability (0.2-0.4), medium suitability (0.4-0.6), and high suitability (0.6-1.0) (IPCC 2007; Wei et al. 2020).

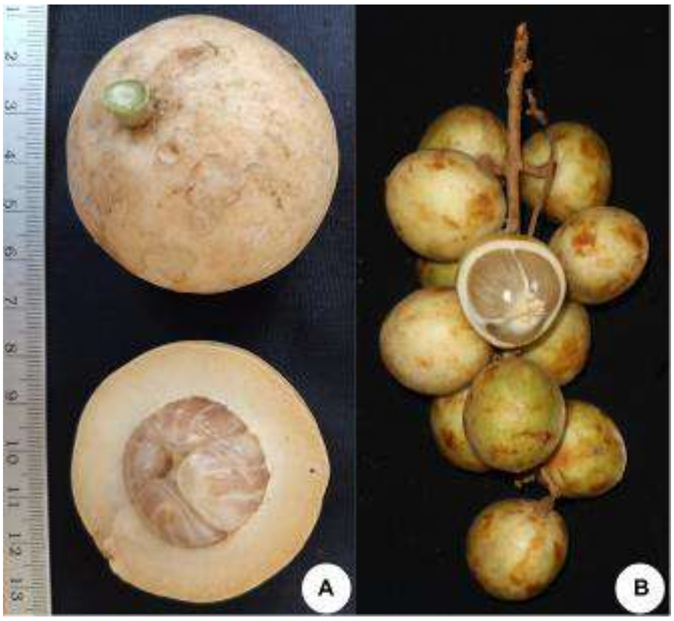


Figure 1. Fruit of Baccaurea species. A. *Baccaurea lanceolata*, B. *Baccaurea motleyana*

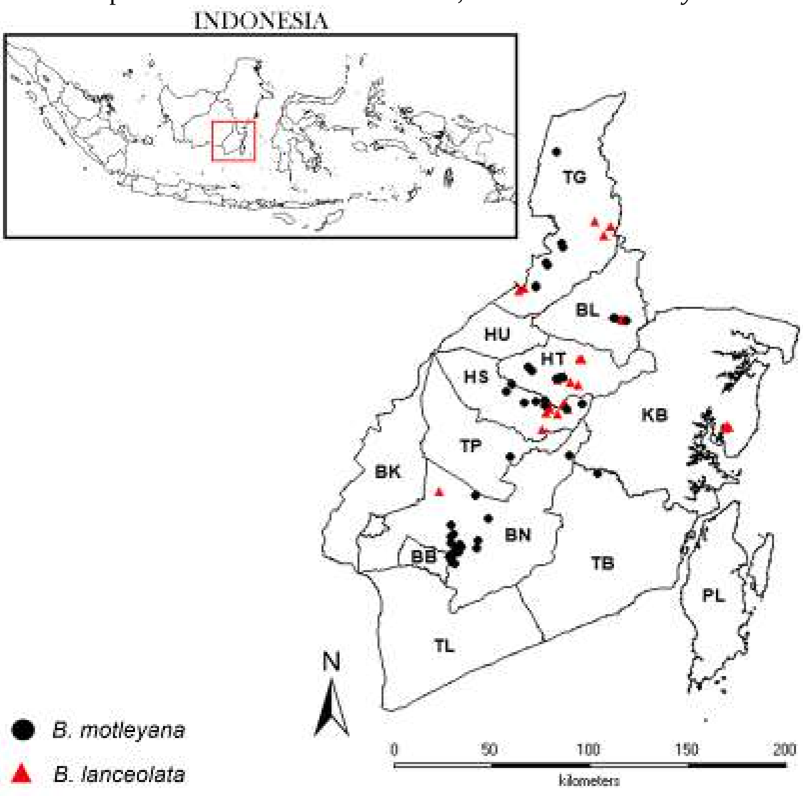


Figure 2. Current distributions of *B. Lanceolata* and *B. motleyana* in South Kalimantan obtained from field survey. TL = Tanah Laut; TB = Tanah Bumbu; PL = Pulau Laut; BB = Banjar Baru; BN = Banjar; BK = Barito Kuala; TP = Tapin; KB = Kota Baru; HS = Hulu Sungai Selatan; HT = Hulu Sungai Tengah; HU = Hulu Sungai Utara; BL = Balangan; TG = Tabalong.

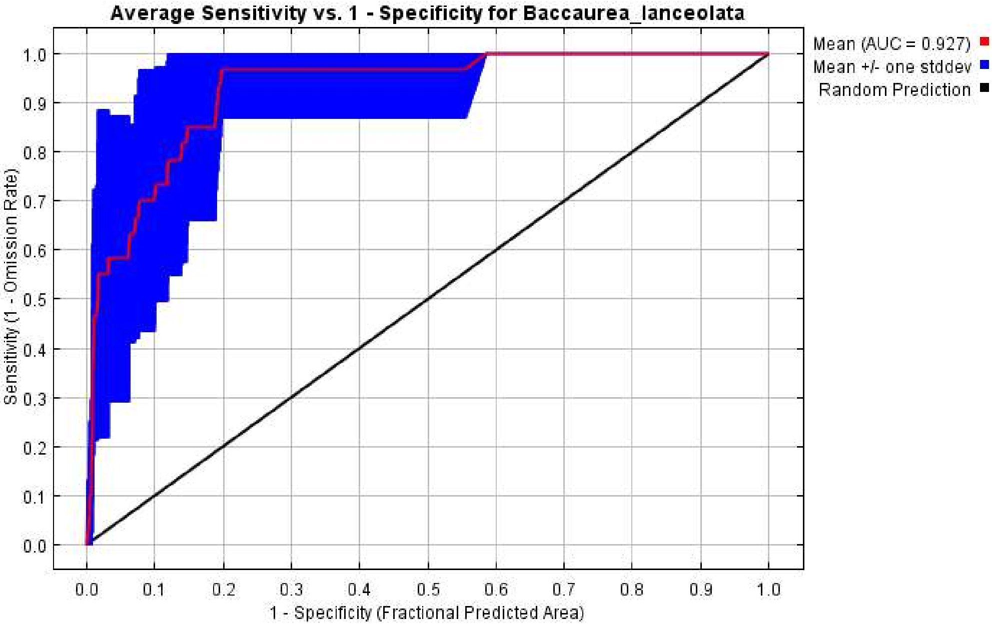
Table 1. Description environmental variables used for MaxEnt model prediction for *B. lanceolata* and *B. motleyana*

Code	Parameter	Unit
alt	Altitude	m
srad	Solar radiation (12 month)	w/m^2
gloslope	Slope	%
bio 1	Mean annual temperature	ºC
bio 2	Mean diurnal range (max temp - min temp)	ºC
bio 3	Isothermality	ºC
bio 4	Temperature seasonality	ºC
bio 5	Maximum temperature of warmest month	ºC
bio 6	Minimum temperature of coldest month	ºC
bio 7	Temperature annual range	ºC
bio 8	Mean temperature of wettest quarter	ºC
bio 9	Mean temperature of driest quarter	ºC
bio 10	Mean temperature of driest quarter	ºC
bio 11	Mean temperature of coldest quarter	ºC
bio 12	Annual precipitation	mm
bio 13	Precipitation of wettest month	mm
bio 14	Precipitation of driest month	mm
bio 15	Precipitation seasonality	mm
bio 16	Precipitation of wettest quarter	mm
bio 17	Precipitation of driest quarter	mm
bio 18	Precipitation of warmest quarter	mm
bio 19	Precipitation of coldest quarter	mm

RESULTS AND DISCUSSION

Model performance

Many researchers use the area under the curve (AUC) statistic to evaluate the final model (Setyawan et al. 2017, 2020a, 2020b, 2021; Pradan 2015; Gunawan et al. 2021a; Gunawan et al. 2021b; Romadlon et al. 2021; Shao et al. 2022). Model performance was classified as failing (0.5-0.6), poor (0.6-0.7), fair (0.7-0.8), good (0.8-0.9), and excellent (0.9-1) (Araujo et al. 2005). Our model output by MaxEnt provided satisfactory results with the AUC training value for *B. lanceolata* 0.926 and for *B. Motleyana* AUC value is 0.851, which are higher than 0.5 of a random model. The final model indicated good model and had high accuracy for species distribution model (Figure 3). This indicated that the environmental variables were well selected to predict the current potential geographic distribution of *B. lanceolata* and *B. motleyana*. In this study, we determine the key environmental variable based on their contributions to the modeling process. The Jacknife test was conducted to show the influence of each environmental variable in the building the model (Figure 3).



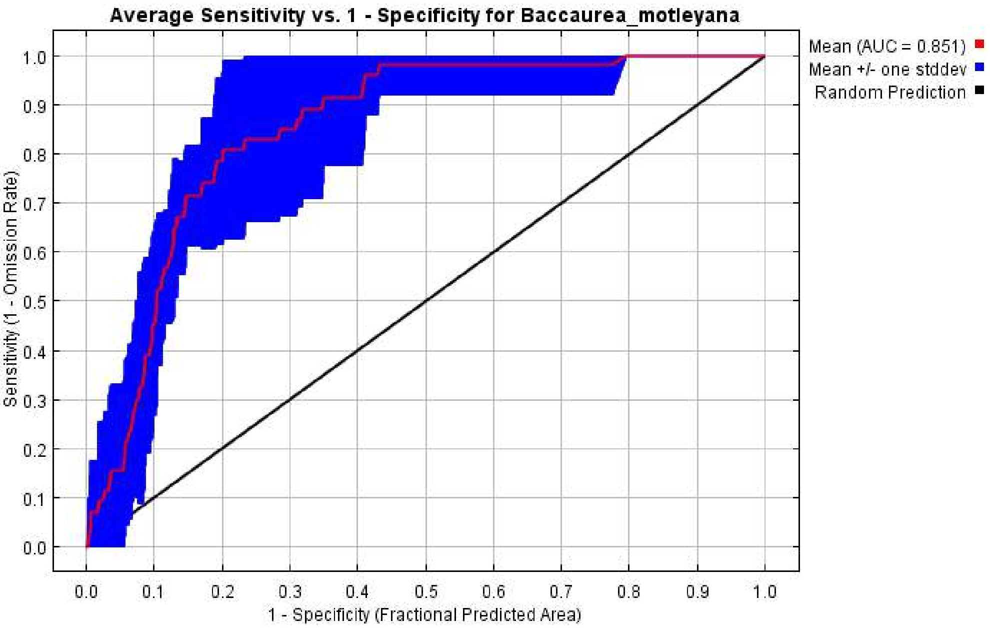


Figure 3. Result of area under the receiver operating characteristics curve (ROC-AUC) analyses for a MaxEnt model of habitat suitability for *Baccaurea lanceolata* and *Baccaurea motleyana*.

Altitude, temperature, and precipitation were the most important environmental for *B. lanceolata*, while for *B. motleyana* were temperature, precipitation, and solar radiation (Table 2). Altitude was the highest contributing influencing the predicticted distribution for *B. lanceolata* with ranging from 0 – 200 m asl with peak at ~180 m asl. Environmental variable with the great influence on predicted distribution for *B. motleyana* was temperature annual range, with the optimum temperature annual range condition between 9^{o}C and $11.5\,^{o}$C. Analysis of environmental variables contributions is different between species, so that the different species have different species distribution model.

Table 2. Environmental variable contribution for *B. lanceolata* (Bl) and *B. motleyana* (Bm).

Code	Environmental variable	Contribution (%)	
		Bl	**Bm**
alt	Altitude	24.4	-
bio 4	Temperature seasonality	15.7	-
bio 7	Temperature annual range	-	34.6
bio 13	Precipitation of wettest month	10.6	15
bio 17	Precipitation of driest quarter	22.2	-
bio 19	Precipitation of coldest quarter	-	7.3
srad 7	Solar radiation in July	-	10.7

Variables' response curves

The response curves were presented to show relationship between the probability of *B. lanceoalata* and *B. motleyana* distribution with environmental variables can be seen in the response curve generated by the Maximum Entropy model. Response curves show the quantitative relationship between environmental variables and the logistic probability of presence and they deepen the understanding of the ecological niche of the species (Yi et al. 2016). Species response curves also show biological tolerances for target species and habitat preferences (Gebrewahid et al. 2020). The response curves of *B. lanceolata* and *B. motleyana* to four environmental variables are illustrated in Figures 4A and 4B.

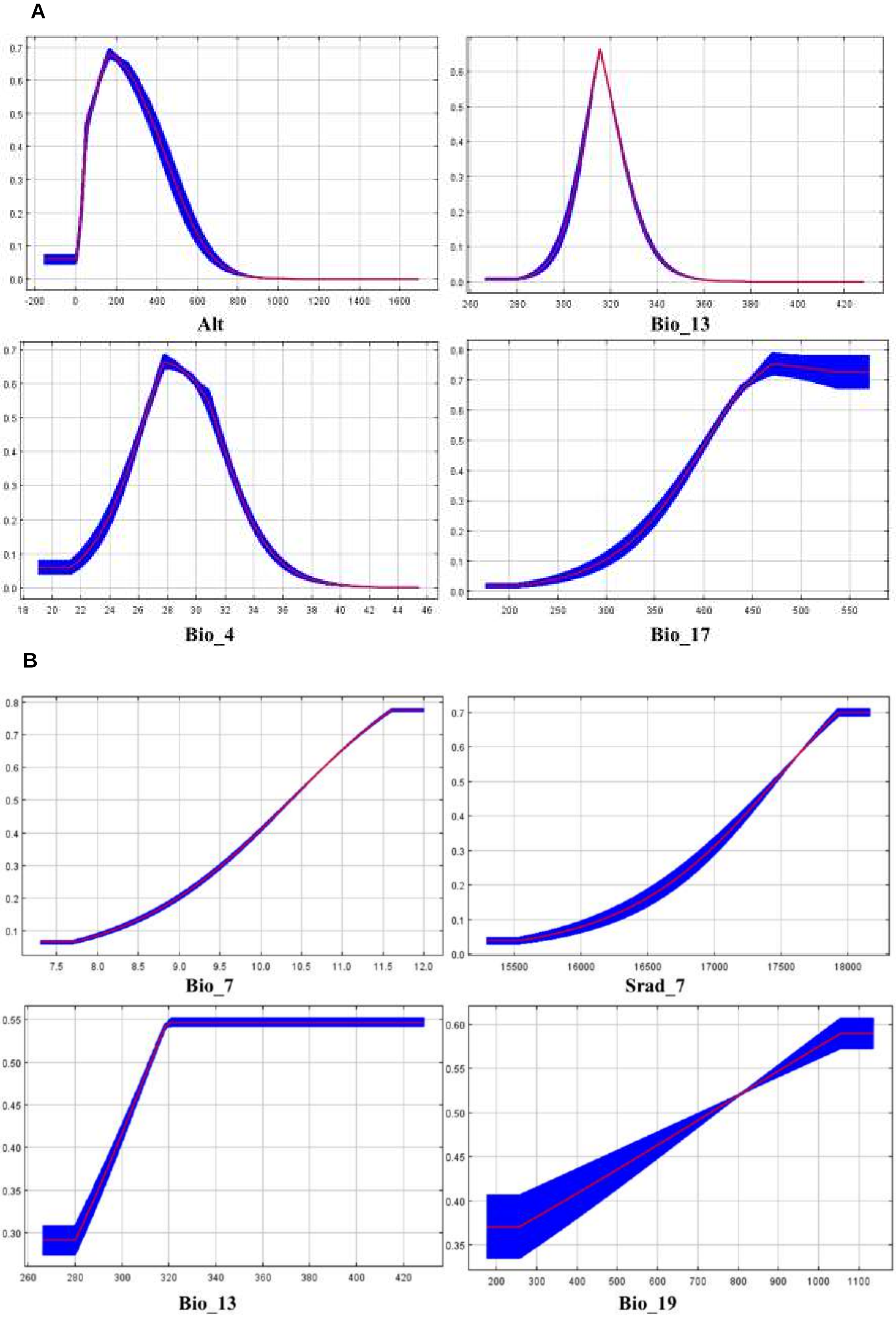


Figure 4. Response curves to four key environmental variables. A. response curve for *B. lanceolata*: Alt: Altitude; Bio 13: Precipitation of wettest month; Bio 4: Temperature seasonality; Bio 17: Precipitation of driest quarter. B. response curve for *B. motleyana*. Bio 7: Temperature annual range; Srad 7: Solar radiation in July; Bio 13: Precipitation of wettest month; Bio 19: Precipitation of coldest quarter. The curves show the mean response of the 10 replicate MaxEnt runs (red) and the mean +/- one standard deviation (blue, two shades for categorical variables)

The response curves of *B. lanceolata* to four environmental variables are show in Figure 4A. Based on the response curves, the suitable altitude range (Alt) of *B. lanceolata* ranged from 0 – 200 m asl with a peak at ~180 m asl. The next important environmental variable was the precipitation of wettest month (bio 13) which showed 300-320 mm, with peak at ~319 mm. The response curve of bio 4 showed that the suitable temperature seasonality ranged from 22 ºC - 28 ºC and peaked at ~27.5ºC. The optimal precipitation of the driest quarter which showed a range of 250 - 500 mm and a peak at ~425 mm required by *B. lanceolata* was indicated by the response curve of bio 17. The response curves of *B. motleyana* to four environmental variables are show in Figure 4B. According to the response curve, the optimum temperature annual range (bio 7) for *B. motleyana* ranged between 9ºC and 11.5 ºC. The next important environmental variable for *B. motleyana* was solar radiation in July (srad 7) which showed the range 16000-18000 w/m2, with a peak at ~17687 w/m2. The optimal precipitation of the wettest month which showed a range of 290 - 320 mm and a peak at ~310 mm required by *B. motleyana* was indicated by the response curve of bio 13. The response curve of bio 19 showed that the suitable precipitation of the coldest month (bio 19) ranged from 300 - 1100 mm and peaked at ~1090 mm.

The results of the model showed that as altitude, temperature, solar radiation, and precipitation were the dominant environmental variables for habitat suitability of *B. lanceolata* and *B. motleyana.* Geographical variables such as altitude are often having correlation with local precipitation and temperature (Austin 2002; Korner 2007). Temperature has an important role to maintain the humidity in the local region by regulation evapotranspiration level. Solar radiation is the main source of energy for organism in ecosystem. Solar radiation affects the plant's physiological processes, especially in plant growth and development. Solar radiation also affected climate, plant growth and evolution, vegetation distribution, and succession, and productivity in the forest ecosystem (Jordan et al. 2005; Li et al. 2011; Fyllas et al. 2017). Climates have significant role in the distribution of plant species (Svenning and Sandel 2013). Precipitation is one of the environmental variables has important role for habitat suitability of *B. lanceolata* and *B. motleyana.* Precipitation plays a major role as an element in plant development (Dasci at al. 2010).

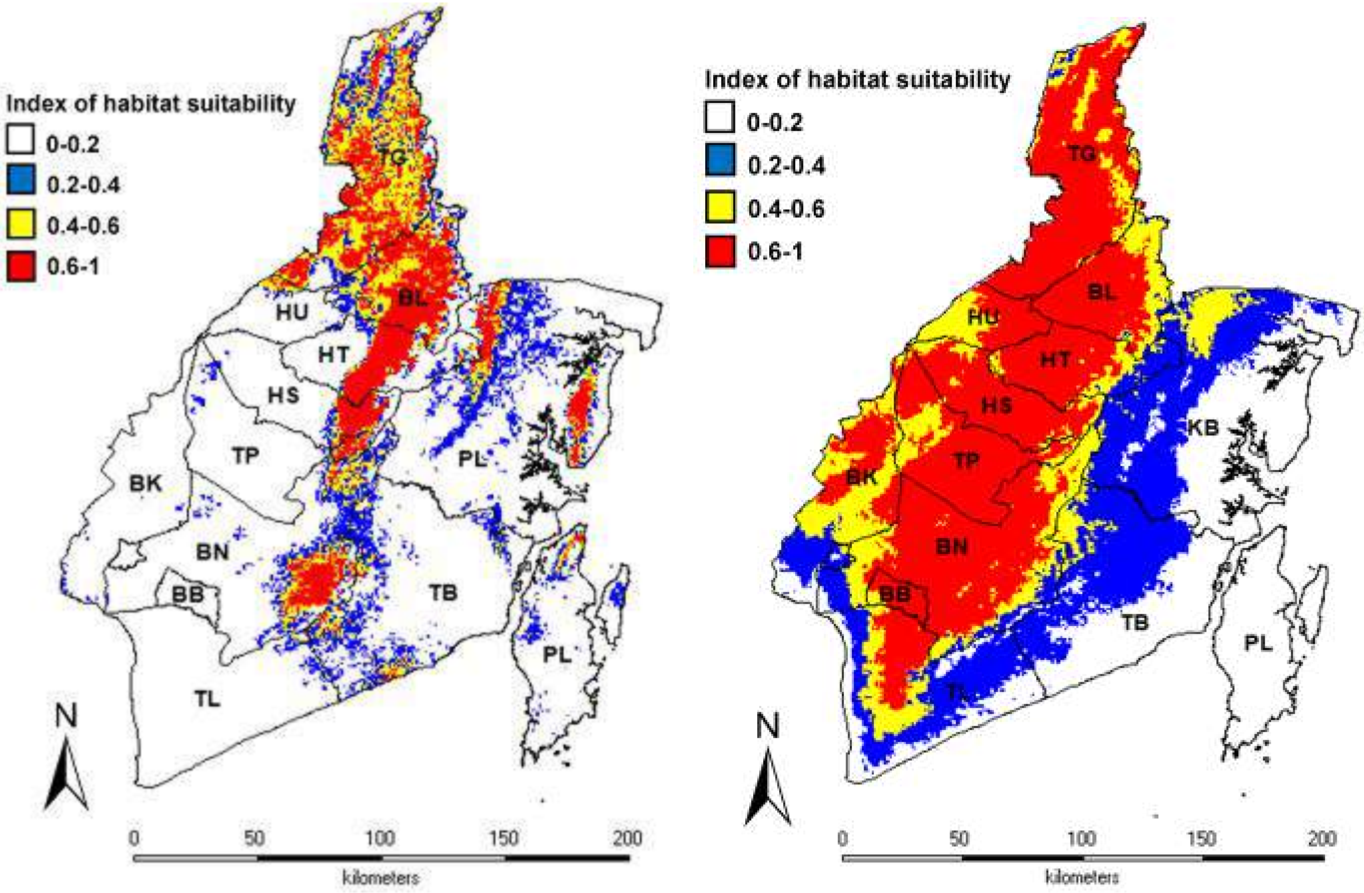
The previous research on species *Baccaurea* (Gunawan et al. 2021a; 2021b) also revealed that altitude, temperature, solar radiation, and precipitation were also influenced in distribution range. This shows that environmental variables such as altitude, temperature, solar radiation, and precipitation play an important role in *Baccaurea* habitat. Climatic factors such as temperature and precipitation were affecting the distribution (Belguidum et al 2021). Zhang et al. 2018, also state that climatic factors were crucial factors that affect plant regeneration, growth, and the spread of its populations.

Prediction current potential distribution

Baccaurea is an underutilized plant, but this fruit has benefits as a source of medicinal ingredients and as well as important ecological functions such as the fruits are eaten by many bird species, but also by rodents, deer, and monkeys (Rijksen 1978). Little is known about the existence and distribution of *B. lanceolata* and *B. motleyana* in South Kalimantan. The model prediction of the potential distribution of *B. lanceolata* and *B. motleyana* was created based on the observed occurrences and current climate conditions. The maps of species distribution model produced by MaxEnt and categorized into four suitability classes between 0 to 1 are presented in Figure 5.

The greatest concentration of highly suitable areas for *B. lanceolata* (IHS 0.6-1) was mainly predicted in six districts (*kabupaten*): BN (Banjar), HS (Hulu Sungai Selatan), HT (Hulu Sungai Tengah), BL (Balangan), PL (Pulau Laut), and TG (Tabalong). Other locations that have highly and medium habitat suitability (IHS 0.4-0.6) were BN (Banjar), BL (Balangan), TG (Tabalong), TB (Tanah Bumbu), and PL (Pulau Laut). The lowly suitable habitat (IHS 0.2-0.4) was predicted in a part of TG (Tabalong), BL (Balangan), PL (Pulau Laut), TB (Tanah Bumbu), and BN (Banjar). The least levels of habitat suitability for *B. lanceolata* (IHS 0.0-0.2) were predicted in TL (Tanah Laut), BB (Banjarbaru), BK (Barito Kuala), TP (Tapin), a part of HU (Hulu Sungai Utara), HT (Hulu Sungai tengah), PL (Pulau Laut) and TB (Tanah Bumbu).

The greatest concentration of highly suitable areas for *B. motleyana* (IHS 0.6-1) was mainly predicted in nine districts (*kabupaten*): TG (Tabalong), BL (Balangan), HT (Hulu Sungai Tengah), HU (Hulu Sungai Utara), HS (Hulu Sungai Selatan), BN (Banjar), BB (Banjarbaru), and BK (Barito Kuala). Other locations that have highly and medium habitat suitability (IHS 0.4-0.6) were a part of TG (Tabalong), BL (Balangan), HT (Hulu Sungai Tengah), HU (Hulu Sungai Utara), TP (Tapin), BN (Banjar), BK (Barito Kuala), TL (Tanah Laut), and KB (Kota Baru). The lowly suitable habitat (IHS 0.2-0.4) was predicted most of a part of BK (Barito Kuala), TL (Tanah Laut), TB (Tanah Bumbu), and KB (Kota Baru). The least levels of habitat suitability for *B. lanceolata* (IHS 0.0-0.2) were predicted in BK (Barito Kuala), TL (Tanah Laut), TB (Tanah Bumbu), KB (Kota Baru), and PL (Pulau Laut).



A B

Figure 5. Map of potential current habitat suitability according to occurrence records in South Kalimantan. A. *Baccaurae lanceolata*. B. *Baccaurea motleyana*. TL = Tanah Laut; TB = Tanah Bumbu; PL = Pulau Laut; BB = Banjar Baru; BN = Banjar; BK = Barito Kuala; TP = Tapin; KB = Kota Baru; HS = Hulu Sungai Selatan; HT = Hulu Sungai Tengah; HU = Hulu Sungai Utara; BL = Balangan; TG = Tabalong.

The MaxEnt models under current climate conditions show that *B. lanceolata* distribution ranges are more influenced by altitude, temperature (seasonal temperature), and precipitation (driest month and driest quarter). Whereas *B. motleyana* distribution range was more influenced by temperature (temperature annual range), solar radiation (solar radiation in July), and precipitation (precipitation of wettest month and precipitation of the coldest quarter). Temperature, solar radiation, precipitation and soil properties are an important factor that influence of plant species distribution (Hemp 2006).

In addition to environmental variables, species distribution and modeling may also be influenced by biotic factors, speciation mechanisms and dispersal ability (Kaky et al. 2020). *Baccaurea lanceolata* has a narrower habitat suitability area compared to *B. motleyana* based on MaxEnt's final model. Based on field observations, *B. lanceolata* is often found at an altitude of 110–150 m a.s.l. This has a positive correlation with environmental factors that have a large influence on the model produced by MaxEnt, as indicated by response curve that is altitude.

Despite the fact that the genus Baccaurea is underutilized by local communities, it has great potential as a source of medicinal ingredients (Gunawan et al. 2016). SDMs can provide a new understanding of the ecological conditions required by *B. lanceolata* and *B. motleyana*, and also identify conservation areas for both species. The distribution and presence of *B. lanceolata* and *B. motleyana* in South Kalimantan are not well known. Therefore, habitat suitability distribution maps of *B. lanceolata* and *B. motleyana* are valuable resources for researchers and conservationists in determining locations for the conservation or cultivation of these plants. In the case of Indonesia, especially in the Kalimantan region, continuous illegal logging, settlement development, agriculture, annual crops, and timber plantations have been causing habitat loss for many tree species (Budiharta et al. 2011). As a result, rather than being converted to plantations or settlements, sites with a high degree of suitability are retained or prioritized, allowing for the conservation and cultivation of these plants.

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Gunawan Gunawan, Anwar Khoerul, Gafur Abdul, RAUDATUL HILALIYAH, AZMIL AQILATUL WARO, NUR HIKMAH, MUHAMMAD ERWANSYAH, SAKINAH SAKINAH, DIAN SUSILAWATI, RATNA DWI LESTARI, DINDA TRIANA:

We have reached a decision regarding your submission to Biodiversitas Journal of Biological Diversity, "MaxEnt modeling for predicting the current potential geographical distribution of baccaurea (B. lanceolata and B. motleyana) in South Kalimantan, Indonesia".

Our decision is: Revisions Required

Reviewer A:

Please add in the discussion what if and how climate chnage scenario in the future would affect the distributin of these species. Please mark ALL chnages have been made based on my comments in a separate table and separate word file.

Recommendation: Revisions Required

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Predicting the current potential geographical distribution of Baccaurea (*B. lanceolata* and *B. motleyana*) in South Kalimantan, Indonesia

Abstract. *Baccaurea lanceolata* and *B. motleyana* are an underutilized species of Kalimantan fruit tree, but are potential source for food and medicine. However, little is known about the occurrences and potential geographical distribution of *B. lanceolata* and *B. motleyana*. This study aimed to predict the potential geographical distribution of *B. lanceolata* and *B. motleyana* using MaxEnt, and understand the key factors which influenced their distribution. In addition to 19 bioclimatic factors, occurrence data for 57 *B. lanceolata* and 87 *B. motleyana* were gathered from field surveys. Solar radiation, height, and slope were then utilized to estimate the distribution of these species. Jackknife test was used to evaluate the importance of the environmental variables for predictive modeling. The area under curve (AUC) values of *B. lanceolata* and *B. motleyana* were 0.927 and 0.851, indicating that the model is a good and informative model for species distribution of these species. The models for *B. lanceolata* suggest that the distribution is mainly influenced by altitude, temperature seasonality, precipitation of the wettest month, and precipitation of the driest quarter. Temperature, annual range, precipitation of the wettest month, precipitation of the coldest quarter, and solar radiation in July were the key environmental factors influencing the distribution of *B. motleyana*. The potential geographic distribution of *B. lanceolata* and *B. motleyana* can be useful information to help researcher in restoration and conservation planning.

Keywords: *Baccaurea motleyana*, *Baccaurea lanceolata*, MaxEnt, habitat suitability, species distribution.

Abbreviations (if any): AUC_ Area Under Curve, MaxEnt_Maximum Entropy

Running title: Predicting potential geographic distribution for *Baccaurea lancelata* and *Baccaurea lanceolata*

INTRODUCTION

Although the genus Baccaurea includes fruit-producing plants, its existence is not as well known as that of other fruit-producing plants. In addition to using the fruit as fresh fruit and wood as building materials, members of the genus *Baccaurea* have been used by the community as medicinal plants to treat several diseases, including constipation, swelling of the eyes, arthritis, abdominal pain, and facilitating menstruation and urination (Usha *et al*. 2014; Ullah *et al*. 2012; Goyal *et al*. 2014; Lim 2012; Gunawan *et al*. 2016).

Baccaurea lanceolata as locally known as "Limpasu" and *Baccaurea motleyana* as locally known as "Rambai" are two species from the genus *Baccaurea* Family, Phyllanthaceae that have great potential as a medicinal ingredient. Antioxidant activity test with three methods (DPPH, ABTS, and FRAP) on the pericarp, fruit, flesh, and seeds of *B. lanceolata* showed high antioxidant activity, with the highest activity found in the flesh of the fruit (Bakar *et al.* 2014). Zamzani and Triadisti (2021) revealed that *B. lanceolata* has high antioxidant activity. The ethanol extract of spleen fruit was the most active extract against bacteria (Fitriansyah et al. 2018; Gallapathie 2018). Local communities in South Kalimantan used the extract fruit of Limpasu as cosmetics as sunscreen. Fruit of *B. Lanceolata* also contains fenol, flavonoids, antosianin, and karotenoid (Bakar *et al*. 2014). *Baccaurea motleyana* has high antioxidant activity containing phenolic, flavonoid, and anthocyanin compounds, secondary metabolite compounds derived from sugar metabolism. Fitri *et al*. (2016) revealed that *B. motleyana* fruit contains phenols and flavonols and has lipid peroxidation activity. Rambai fruits have relatively low amounts of fats, organic acids, phenolics, and antioxidants compared to many other familiar fruits. Rambai tree parts were found to exhibit antidiabetic, antibacterial, and skincare properties (Prodhan & Mridu 2021).

Although *B. lanceolata* and *B. motleyana* have high utility value, habitat loss and population declines of these species continue to occur. Little is known about the occurrence of *B. lanceolata* and *B. motleyana* and its adaptability different climate and edaphic conditions in South Kalimantan. The latest publication by Haegens (2000) stated *B. lanceolata* and *B. motleyana* were found in Borneo. Agricultural clearing, forest fires, illegal logging, forest conversion, increasing human population, and mining are important factors causing decreasing plant population and biodiversity loss. Budiharta et al. (2011) state that in Kalimantan region, habitat loss of many tree species are caused by continuous illegal logging, development of human settlements, agriculture, perennial crops, and timber plantations. In addition to environmental degradation brought on by numerous human activities, climate change also threatens the diversity of the current plant species (Belgacem et al. 2008). Climate change is also known as one of the most important factors influencing the geographic distribution of plant species (Forman 1964). Detailed information about the regional distribution of a plant is needed for their restoration and habitat conservation. Furthermore, information about a plant's distribution is important in determining the population, taxonomic variation, habitat suitability, and potential utilization. Studying the current and potential distribution of species and examining the key environmental factors that affect their growth can help us to understand the overall distribution patterns of species.

The Species Distribution Model (SDM) is a general approach for investigating the potential distribution of species and suitable habitats in the environment. It is widely used for broad applications in ecology, biogeography, and conservation biology. A number of SDMs have been developed to estimate the suitable areas for specific species according the specific algorithms, including Maximun Entropy (Phillips et al. 2006; Martinez-Minaya et al. 2018). MaxEnt is one of the SDMs program based on environmental variables and species occurrence data, which is integrated by machine learning and the principle of maximum entropy to predict the potential distribution of species (Elith et al. 2011). The MaxEnt program has been used extensively to predict species distribution, which has also been employed by studies in South Asia (Pradhan 2015), including Indonesia (Setyawan et al. 2017, 2020a, 2020b, 2021; Gunawan et al. 2021a, 2021b; Usmadi et al. 2021; Harapan et al. 2022). Compared to other SDMs programs, MaxEnt can produce better models, because MaxEnt can create models only with occurrence data (Elith et al. 2011; Jackson and Robertson 2011; Kalboussi and Achour 2017), and it have the ability to run with a small amount of data (Fois et al. 2018; Preau et al. 2018). Furthermore, the results are highly accurate and highly reproducible (Fourcade et al. 2014).

The aim of this study was to predict the current potential distribution of *B. lanceolata* and *B. motleyana* in South Kalimantan, Indonesia and to identify the key factors include climatic and topography responsible for the distribution of these species. We expect the results of this study to provide information regarding the potential distribution of *B. lanceolata* and *B. motleyana* in Kalimantan, and identify the currently suitable areas for conservation and cultivation.

MATERIALS AND METHODS

Study area and species occurrence data

The study was conducted in South Kalimantan which consists of 13 districts, which has approximately 34.744 km^2 of land area. The geographic scope of this study includes the area of approximately 1º 21' 49" LS – 1º 10' 14" LS and 114º 19' 33" BT – 116º 33' 28". Authors collected the occurrence data of *B. lanceolata* and *B. motleyana* from local communities and forestry services (Figure 1.).The explorative field survey was carried out according to the previous research method conducted ~~by Rugayah~~by Rugayah et al. (2004). The field study period was from February to June 2022. Plant samples were collected and herbarium specimens were deposited in Bio-systematic laboratory Lambung Mangkurat University, South Kalimantan. Using Garmin 64s GPS series, we collected 57 occurrences points of *B. lanceolata* and 87 occurrences points of *B. motleyana* which were found distributed in South Kalimantan. All coordinates from the field survey were converted to decimal degrees and imported into Microsoft Excel, and then saved as CSV format. The coordinate data were used to describe the distribution of *B. macrocarpa* in the province of South Kalimantan using the DIVA Gis 7.5 software (Figure 2.) and is used as input data for habitat suitability modeling using MaxEnt.

Climatic variables

For this study, we used 19 bioclimatic variables (11 temperature and 8 precipitation variables), solar radiation (12 months), altitude, and geo-slope were downloaded and assessed (Tabel 1). Bioclimatic variable were extracted from WorldClim (https://www.worldclim.org) (Hijsmans 2020). Slope variable was downloaded from www.fao.org (https://www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/harmonized-world-soil-database-v12/en/). In addition, a raster file of digital elevation models based on the altitude data was also downloaded from the WordClim website. They were generated through interpolation of average monthly climate data from weather stations at 30 arc seconds (*1 km) spatial resolution (Ficks and Hijmans 2017). All predictor variables layers were in GeoTIFF format, QuantumGis ver 2.8.10 was used to convert bioclimatic variables and environmental layers into an ASCII format for use in MaxEnt (Setyawan et al. 2020a).

Species distribution model requires selecting and using environmental factors with a major influence to the model (Worthington et al. 2016) and with minimal inter-correlation (Pradhan 2016, 2019) to get an accurate and informative model. The variable selection was done with two-pronged approach. i) Firstly, Variance Inflation Factor (VIF) analysis was carried out across all bioclimatic variables in R platform. The pair wise VIF values of bioclimatic variables were assessed and those variables were screened whose pair wise VIF was <10. ii) Secondly, screened bioclimatic variables along with another environmental factor such as solar radiation were put to Jackknife test evaluation for assessment of the contribution of each environmental variable to the resulting model.

The contribution percentage and permutation are two important factors for understanding and measuring the environmental variable's contribution as well as importance to the model. According to the Jackknife test evaluation of the contribution of each environmental variable to the resulting model, twelve environmental variables were not used, eleven of them due to the lack of contribution to the model making 0% percent contribution and bio 8 due to co linearity with bio 10 through VIF value of 63.8 (Pradhan 2016, 2019), and as well exclusion of bio 8 led to increase in regularized training gain. Besides that variables with a small average contribution (<6%) or permutation importance (<6%) were not used due to lack of contribution to the models (Wei et al. 2018). Therefore, the final environmental variables used in *B. lanceolata* species distribution model map for the current period were alt (altitude), bio 4 (temperature seasonality), bio 13 (Precipitation of wettest month), bio 17 (Precipitation of driest quarter), whereas the final environmental variables for *B. motleyana* were bio 7 (Temperature annual range), bio 13 (Precipitation of wettest month), bio 19 (Precipitation of coldest quarter), srad 7 (Solar radiation in July). Variables that considered affecting to the distribution of these species, i.e, land use, human disturbances, species dispersal or biotic interaction change were not included to the model because the availability of these data were limited.

Species distribution modeling

Several programs or algorithms have been developed to predict models of potential species distribution areas consisting of DOMAIN, Climatic Envelope (BIOCLIM), Generalized Linear Models (GLM), Artificial Neural Network (ANN), and Maximum Entropy (MAXENT). DOMAIN is a simple and straightforward model for modeling the distribution of plant species based on a range-standardized and point-to-point similarity matrix (Carpenter 1993). BIOCLIM is a climate-envelope model that has been widely used in species distribution modeling (Booth et al. 2014). BIOCLIM uses easy-to-understand algorithms and provides useful insight into methods and procedures of species distribution modeling (Hijmans and Graham 2006). GLM is a regression-based technique that is often used to predict biodiversity distribution (Guisan et al. 2017). Artificial Neural Network (ANN) is a machine learning approach that commonly tends to have better models' performance in predicting species distribution patterns. It is widely used in remote sensing image classification and ecological applications (Benediktsson et al. 1993). ANN works with both regression and classification, in addition, a continuous and categorical predictor can be used in this model. Each program has different theoretical foundations, required data, and analysis methods.

Several studies have shown that compared to other species distribution models, MaxEnt not only has good prediction and stability but also has the advantages of simple and fast operation, a small number of occurrences demanded (Yang et al. 2014; Beck et al. 2018; Song et al. 2020; Anand et al. 2021), and it works very well for presence-only data (Phillips et al. 2006). Maxent builds a prediction model based on the actual distribution points and environmental variables of the distribution area stored in the GIS and then Maxent will simulate the species distribution in the targeted location or region (Zhang et al. 2021).

We used MaxEnt version 3.4.1 (Phillips et al. 2017) to predict the current potential geographic distribution of *B. lanceolata* and *B. motleyana* in South Kalimantan. The software was downloaded from https://biodiversityinformatics.amnh.org /open_source /maxent / and can be extracted freely for scientific research. In our predicted models, default setting was used in MaxEnt model (Abdelaal et al. 2019). We employed 10 replicates and the average of probability for habitat suitability of *B. lanceolata* and *B. motleyana* in South Kalimantan (Hoveka et al. 2016). The bootstrap method was implemented with 10 repeats, a maximum of 5000 iteration, and default selected parameters (Yan et al. 2020). Models resulting from MaxEnt were evaluated; the accuracy and quality of the model used the Area Under the Curve (AUC) scores of Receiver Operating Curve (ROC) analysis. The scores of AUC ranged from 0.5 to 1. An AUC score of 0.5 indicated the model prediction did not perform better than random expectation, while a score of 1.0 shows the resulting model is very good and informative (Swets 1988). We also performed the Jackknife test. A Jackknife analysis was used to calculate the contribution the variables for the model prediction for *B. lanceolata* and *B. motleyana*. Jackknife analysis is also carried out to determine the dominant variables that determine the potential distribution of species (Yang et al. 2013). In addition, we used respond curves that produced by MaxEnt analysis to know the relationship between the habitat suitability of *B. lanceolata* and *B. motleyana* and environmental factors.

The results of Maxent's analysis for *B. lanceolata* and *B. motleyana* were imported into DIVA GIS software version 7.5 (Hijmans et al. 2012) for visualization and further data analysis. The species distribution model map resulted from MaxEnt has suitability levels that can be grouped into 4 classes, namely, least suitable (0.0-0.2), low suitability (0.2-0.4), medium suitability (0.4-0.6), and high suitability (0.6-1.0) (IPCC 2007; Wei et al. 2020).

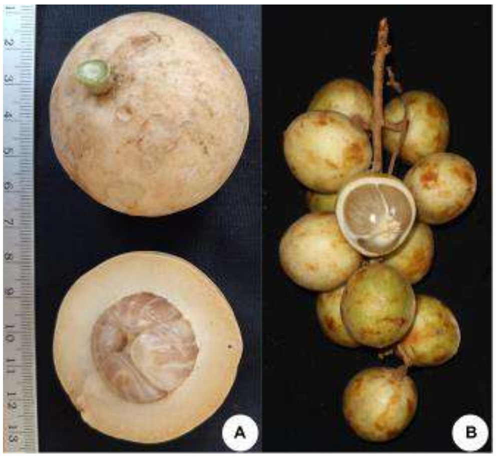


Figure 1. Fruit of Baccaurea species. A. *Baccaurea lanceolata*, B. *Baccaurea motleyana*

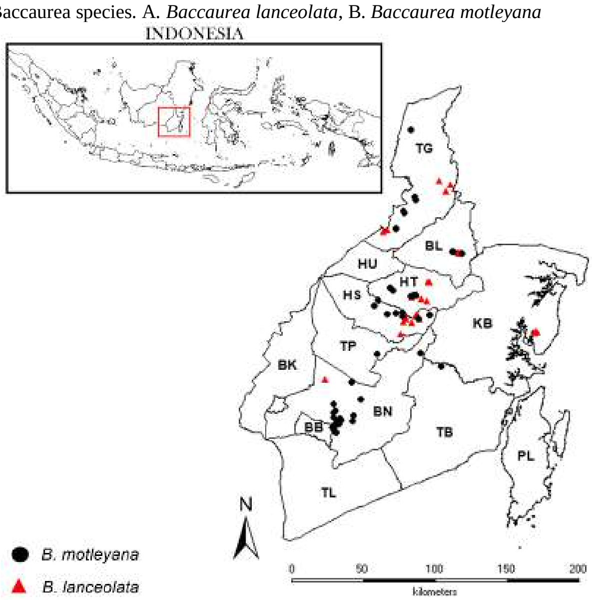


Figure 2. Current distributions of *B. Lanceolata* and *B. motleyana* in South Kalimantan obtained from field survey. TL = Tanah Laut; TB = Tanah Bumbu; PL = Pulau Laut; BB = Banjar Baru; BN = Banjar; BK = Barito Kuala; TP = Tapin; KB = Kota Baru; HS = Hulu Sungai Selatan; HT = Hulu Sungai Tengah; HU = Hulu Sungai Utara; BL = Balangan; TG = Tabalong.

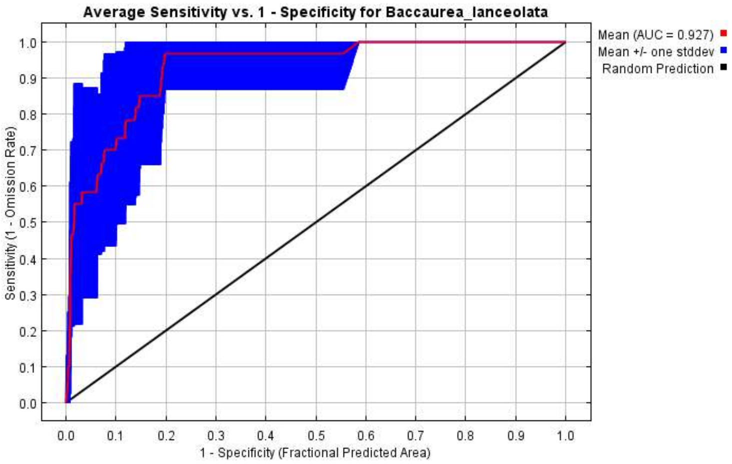
Table 1. Description environmental variables used for MaxEnt model prediction for *B. lanceolata* and *B. motleyana*

Code	Parameter	Unit
alt	Altitude	m
srad	Solar radiation (12 month)	w/m^2
gloslope	Slope	%
bio 1	Mean annual temperature	ºC
bio 2	Mean diurnal range (max temp - min temp)	ºC
bio 3	Isothermality	ºC
bio 4	Temperature seasonality	ºC
bio 5	Maximum temperature of warmest month	ºC
bio 6	Minimum temperature of coldest month	ºC
bio 7	Temperature annual range	ºC
bio 8	Mean temperature of wettest quarter	ºC
bio 9	Mean temperature of driest quarter	ºC
bio 10	Mean temperature of driest quarter	ºC
bio 11	Mean temperature of coldest quarter	ºC
bio 12	Annual precipitation	mm
bio 13	Precipitation of wettest month	mm
bio 14	Precipitation of driest month	mm
bio 15	Precipitation seasonality	mm
bio 16	Precipitation of wettest quarter	mm
bio 17	Precipitation of driest quarter	mm
bio 18	Precipitation of warmest quarter	mm
bio 19	Precipitation of coldest quarter	mm

RESULTS AND DISCUSSION

Model performance

Many researchers use the area under the curve (AUC) statistic to evaluate the final model (Setyawan et al. 2017, 2020a, 2020b, 2021; Pradan 2015; Gunawan et al. 2021a; Gunawan et al. 2021b; Romadlon et al. 2021; Shao et al. 2022). Model performance was classified as failing (0.5-0.6), poor (0.6-0.7), fair (0.7-0.8), good (0.8-0.9), and excellent (0.9-1) (Araujo et al. 2005). Our model output by MaxEnt provided satisfactory results with the AUC training value for *B. lanceolata* 0.926 and for *B. Motleyana* AUC value is 0.851, which are higher than 0.5 of a random model. The final model indicated good model and had high accuracy for species distribution model (Figure 3). This indicated that the environmental variables were well selected to predict the current potential geographic distribution of *B. lanceolata* and *B. motleyana*. In this study, we determine the key environmental variable based on their contributions to the modeling process. The Jacknife test was conducted to show the influence of each environmental variable in the building the model (Figure 3).



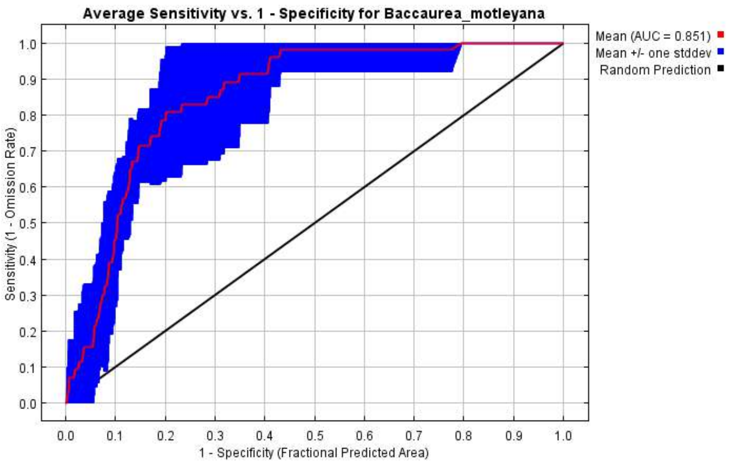


Figure 3. Result of area under the receiver operating characteristics curve (ROC-AUC) analyses for a MaxEnt model of habitat suitability for *Baccaurea lanceolata* and *Baccaurea motleyana.*

Altitude, temperature, and precipitation were the most important environmental for *B. lanceolata*, while for *B. motleyana* were temperature, precipitation, and solar radiation (Table 2). Altitude was the highest contributing influencing the predicticted distribution for *B. lanceolata* with ranging from 0 – 200 m asl with peak at ~180 m asl. Environmental variable with the great influence on predicted distribution for *B. motleyana* was temperature annual range, with the optimum temperature annual range condition between 9^{o}C and 11.5^{o}C. Analysis of environmental variables contributions is different between species, so that the different species have different species distribution model.

Table 2. Environmental variable contribution for *B. lanceolata* (Bl) and *B. motleyana* (Bm).

Code	Environmental variable	Contribution (%)	
		Bl	Bm
alt	Altitude	24.4	-
bio 4	Temperature seasonality	15.7	-
bio 7	Temperature annual range	-	34.6
bio 13	Precipitation of wettest month	10.6	15
bio 17	Precipitation of driest quarter	22.2	-
bio 19	Precipitation of coldest quarter	-	7.3
srad 7	Solar radiation in July	-	10.7

Variables' response curves

The response curves were presented to show relationship between the probability of *B. lanceoalata* and *B. motleyana* distribution with environmental variables can be seen in the response curve generated by the Maximum Entropy model. Response curves show the quantitative relationship between environmental variables and the logistic probability of presence and they deepen the understanding of the ecological niche of the species (Yi et al. 2016). Species response curves also show biological tolerances for target species and habitat preferences (Gebrewahid et al. 2020). The response curves of *B. lanceolata* and *B. motleyana* to four environmental variables are illustrated in Figures 4A and 4B.

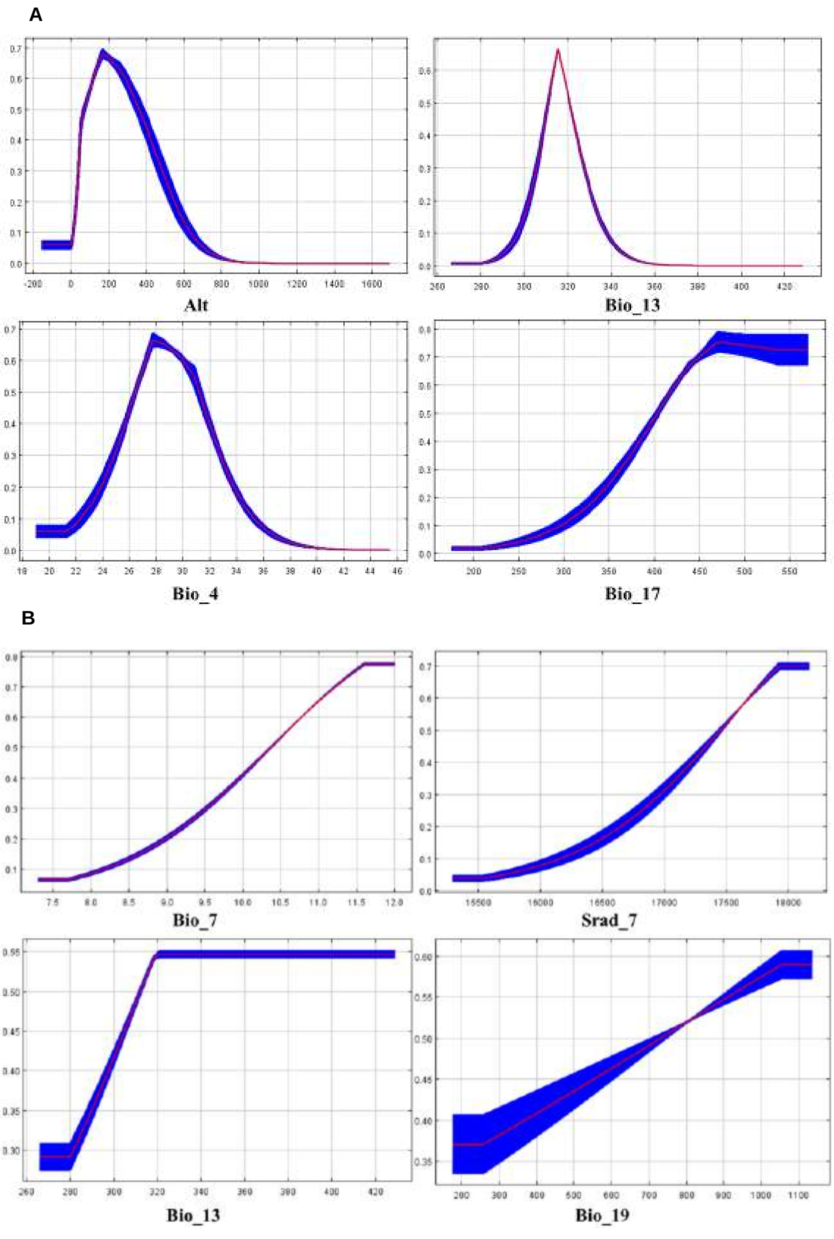


Figure 4. Response curves to four key environmental variables. A. response curve for *B. lanceolata*: Alt: Altitude; Bio 13: Precipitation of wettest month; Bio 4: Temperature seasonality; Bio 17: Precipitation of driest quarter. B. response curve for *B. motleyana*. Bio 7: Temperature annual range; Srad 7: Solar radiation in July; Bio 13: Precipitation of wettest month; Bio 19: Precipitation of coldest quarter. The curves show the mean response of the 10 replicate MaxEnt runs (red) and the mean +/- one standard deviation (blue, two shades for categorical variables)

The response curves of *B. lanceolata* to four environmental variables are show in Figure 4A. Based on the response curves, the suitable altitude range (Alt) of *B. lanceolata* ranged from 0 – 200 m asl with a peak at ~180 m asl. The next important environmental variable was the precipitation of wettest month (bio 13) which showed 300-320 mm, with peak at ~319 mm. The response curve of bio 4 showed that the suitable temperature seasonality ranged from 22 ^oC - 28 ^oC and peaked at ~27.5^oC. The optimal precipitation of the driest quarter which showed a range of 250 - 500 mm and a peak at ~425 mm required by *B. lanceolata* was indicated by the response curve of bio 17. The response curves of *B. motleyana* to four environmental variables are show in Figure 4B. According to the response curve, the optimum temperature annual range (bio 7) for *B. motleyana* ranged between 9^oC and 11.5 ^oC. The next important environmental variable for *B. motleyana* was solar radiation in July (srad 7) which showed the range 16000-18000 w/m2, with a peak at ~17687 w/m2. The optimal precipitation of the wettest month which showed a range of 290 - 320 mm and a peak at ~310 mm required by *B. motleyana* was indicated by the response curve of bio 13. The response curve of bio 19 showed that the suitable precipitation of the coldest month (bio 19) ranged from 300 - 1100 mm and peaked at ~1090 mm.

The results of the model showed that as altitude, temperature, solar radiation, and precipitation were the dominant environmental variables for habitat suitability of *B. lanceolata* and *B. motleyana*. Geographical variables such as altitude are often having correlation with local precipitation and temperature (Austin 2002; Korner 2007). Temperature has an important role to maintain the humidity in the local region by regulation evapotranspiration level. Solar radiation is the main source of energy for organism in ecosystem. Solar radiation affects the plant's physiological processes, especially in plant growth and development. Solar radiation also affected climate, plant growth and evolution, vegetation distribution, and succession, and productivity in the forest ecosystem (Jordan et al. 2005; Li et al. 2011; Fyllas et al. 2017). Climates have significant role in the distribution of plant species (Svenning and Sandel 2013). Precipitation is one of the environmental variables has important role for habitat suitability of *B. lanceolata* and *B. motleyana.* Precipitation plays a major role as an element in plant development (Dasci at al. 2010).

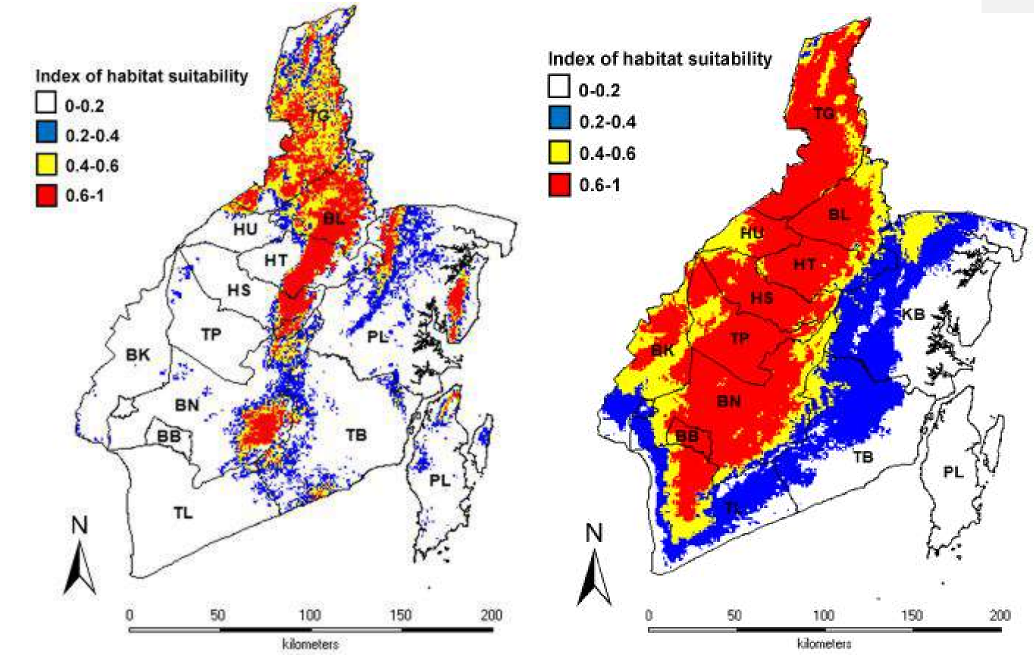
The previous research on species *Baccaurea* (Gunawan et al. 2021a; 2021b) also revealed that altitude, temperature, solar radiation, and precipitation were also influenced in distribution range. This shows that environmental variables such as altitude, temperature, solar radiation, and precipitation play an important role in *Baccaurea* habitat. Climatic factors such as temperature and precipitation were affecting the distribution (Belguidum et al 2021). Zhang et al. 2018, also state that climatic factors were crucial factors that affect plant regeneration, growth, and the spread of its populations.

Prediction current potential distribution

Baccaurea is an underutilized plant, but this fruit has benefits as a source of medicinal ingredients and as well as important ecological functions such as the fruits are eaten by many bird species, but also by rodents, deer, and monkeys (Rijksen 1978). Little is known about the existence and distribution of *B. lanceolata* and *B. motleyana* in South Kalimantan. The model prediction of the potential distribution of *B. lanceolata* and *B. motleyana* was created based on the observed occurrences and current climate conditions. The maps of species distribution model produced by MaxEnt and categorized into four suitability classes between 0 to 1 are presented in Figure 5.

The greatest concentration of highly suitable areas for *B. lanceolata* (IHS 0.6-1) was mainly predicted in six districts (*kabupaten*): BN (Banjar), HS (Hulu Sungai Selatan), HT (Hulu Sungai Tengah), BL (Balangan), PL (Pulau Laut), and TG (Tabalong). Other locations that have highly and medium habitat suitability (IHS 0.4-0.6) were BN (Banjar), BL (Balangan), TG (Tabalong), TB (Tanah Bumbu), and PL (Pulau Laut). The lowly suitable habitat (IHS 0.2-0.4) was predicted in a part of TG (Tabalong), BL (Balangan), PL (Pulau Laut), TB (Tanah Bumbu), and BN (Banjar). The least levels of habitat suitability for *B. lanceolata* (IHS 0.0-0.2) were predicted in TL (Tanah Laut), BB (Banjarbaru), BK (Barito Kuala), TP (Tapin), a part of HU (Hulu Sungai Utara), HT (Hulu Sungai tengah), PL (Pulau Laut) and TB (Tanah Bumbu).

The greatest concentration of highly suitable areas for *B. motleyana* (IHS 0.6-1) was mainly predicted in nine districts (*kabupaten*): TG (Tabalong), BL (Balangan), HT (Hulu Sungai Tengah), HU (Hulu Sungai Utara), HS (Hulu Sungai Selatan), BN (Banjar), BB (Banjarbaru), and BK (Barito Kuala). Other locations that have highly and medium habitat suitability (IHS 0.4-0.6) were a part of TG (Tabalong), BL (Balangan), HT (Hulu Sungai Tengah), HU (Hulu Sungai Utara), TP (Tapin), BN (Banjar), BK (Barito Kuala), TL (Tanah Laut), and KB (Kota Baru). The lowly suitable habitat (IHS 0.2-0.4) was predicted most of a part of BK (Barito Kuala), TL (Tanah Laut), TB (Tanah Bumbu), and KB (Kota Baru). The least levels of habitat suitability for *B. lanceolata* (IHS 0.0-0.2) were predicted in BK (Barito Kuala), TL (Tanah Laut), TB (Tanah Bumbu), KB (Kota Baru), and PL (Pulau Laut).



A **B**

Figure 5. Map of potential current habitat suitability according to occurrence records in South Kalimantan. A. *Baccaurae lanceolata*. B. *Baccaurea motleyana*. TL = Tanah Laut; TB = Tanah Bumbu; PL = Pulau Laut; BB = Banjar Baru; BN = Banjar; BK = Barito Kuala; TP = Tapin; KB = Kota Baru; HS = Hulu Sungai Selatan; HT = Hulu Sungai Tengah; HU = Hulu Sungai Utara; BL = Balangan; TG = Tabalong.

The MaxEnt models under current climate conditions show that *B. lanceolata* distribution ranges are more influenced by altitude, temperature (seasonal temperature), and precipitation (driest month and driest quarter). Whereas *B. motleyana* distribution range was more influenced by temperature (temperature annual range), solar radiation (solar radiation in July), and precipitation (precipitation of wettest month and precipitation of the coldest quarter). Temperature, solar radiation, precipitation and soil properties are an important factor that influence of plant species distribution (Hemp 2006).

In addition to environmental variables, species distribution and modeling may also be influenced by biotic factors, speciation mechanisms and dispersal ability (Kaky et al. 2020). *Baccaurea lanceolata* has a narrower habitat suitability area compared to *B. motleyana* based on MaxEnt's final model. Based on field observations, *B. lanceolata* is often found at an altitude of 110–150 m a.s.l. This has a positive correlation with environmental factors that have a large influence on the model produced by MaxEnt, as indicated by response curve that is altitude.

Despite the fact that the genus Baccaurea is underutilized by local communities, it has great potential as a source of medicinal ingredients (Gunawan et al. 2016). SDMs can provide a new understanding of the ecological conditions required by *B. lanceolata* and *B. motleyana*, and also identify conservation areas for both species. The distribution and presence of *B. lanceolata* and *B. motleyana* in South Kalimantan are not well known. Therefore, habitat suitability distribution maps of *B. lanceolata* and *B. motleyana* are valuable resources for researchers and conservationists in determining locations for the conservation or cultivation of these plants. In the case of Indonesia, especially in the Kalimantan region, continuous illegal logging, settlement development, agriculture, annual crops, and timber plantations have been causing habitat loss for many tree species (Budiharta et al. 2011). As a result, rather than being converted to plantations or settlements, sites with a high degree of suitability are retained or prioritized, allowing for the conservation and cultivation of these plants.

Commented [S1]: Please add in the discussion what if and how climate chnage scenario in the future would affect the distributin of these species. Please mark ALL chnages have been made based on my comments in a separate table and separate word file

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To: Gunawan Gunawan <gunawan@ulm.ac.id>, Anwar Khoerul <endrasance@yahoo.com>, Gafur Abdul <agafur@ulm.ac.id>, RAUDATUL HILALIYAH <raudatulhilaliyah3@gmail.com>, AZMIL AQILATUL WARO <azmilaqila68@gmail.com>, NUR HIKMAH <noorhikmah017@gmail.com>, MUHAMMAD ERWANSYAH <muhammaderwansyah5347@gmail.com>, SAKINAH SAKINAH <sakinahinah753@gmail.com>, DIAN SUSILAWATI <1911013120008@mhs.ulm.ac.id>, RATNA DWI LESTARI <1911013120007@mhs.ulm.ac.id>, DINDA TRIANA <dindatriana830@gmail.com>

Gunawan Gunawan, Anwar Khoerul, Gafur Abdul, RAUDATUL HILALIYAH, AZMIL AQILATUL WARO, NUR HIKMAH, MUHAMMAD ERWANSYAH, SAKINAH SAKINAH, DIAN SUSILAWATI, RATNA DWI LESTARI, DINDA TRIANA:

We have reached a decision regarding your submission to Biodiversitas Journal of Biological Diversity, "MaxEnt modeling for predicting the current potential geographical distribution of baccaurea (B. lanceolata and B. motleyana) in South Kalimantan, Indonesia".

Our decision is: Revisions Required

Reviewer A:
Recommendation: Accept Submission

Reviewer B:
Recommendation: Accept Submission

Biodiversitas Journal of Biological Diversity

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Climate has long been recognized as one of the factors that influence the distribution of plant speciesfactor influencing plant species' distribution (Forman 1964). One of the impacts of climate change on plant species is that plants may shift to higher elevations in response to which they are adapting (Parmesan 2006). In addition, the impact of climate change on plants is to affect the life cycle of plants, affect flowering time, and reproduction time, and ultimately can affect the diversity of plant species (Thuiler et al. 2008; Belgacem et al. 2008; Hilbish et al. 2010; Hill and Preston 2015). Climate For example, climate change affects the flowering and fruiting season of the genus Baccaurea. From the literature, it is knownThe literature shows that *Baccaurea Motleyana* flowers from January to May, August, October, and November. This species fruits in January, May, July to to September, November, and December (Haegens 2000). However, based on field observations, *B. motleyana* in South Kalimantan flowers in August and October, and fruits in September, November, and December. The flowering season of *B. lanceolata*, which should be March to December, according to Haegens (2000), based on observations in South Kalimantan, flowered from June to December. The fruiting season for *B. lanceolata* from observations, which is fruiting throughout the year, has not changed compared to Haegens (2000) literature, which is fruiting throughout the year.

Parmesan C. 2006. Ecological and evolutionary responses to recent climate change. Annu Rev Ecol Evol Syst 37: 367-669 DOI: 10.1146/annurev.ecolsys.37.091305.

Thuiller W, Albert C, Araujo MB, et al. 2008. Predicting global change impacts on plant species distribution: Future challenges. Perspectives in Plant Ecology, Evol Sys 9: 137-152. Doi:10.1016/j.ppees.2007.09.004

Belgacem OA, Salem BH, Bouaicha A, El-Mourid M. 2008. Communal rangeland rest in arid area, a tool for facing animal feed cost and drought mitigation: the case of Chenini Community, Southern Tunisia. J Biol Sci 8 (4): 822-825. DOI**:** 10.3923/jbs.2008.822.825

Hilbish TJ, Branmock PM, Jones KR, Smith AB, Bullock BN, Wethey DS. 2010. Historical changes in the distribution of invasive and endemic marine invertebrates are contrary to global warming prediction: the effects of decadal climate oscillations. J Biogeo 37: 423-431. DOI: 10.1111/j.1365-2699.2009.02218.x

Hill MO, Preston CD. 2015. Disappearance of boreal plants in southern Britain: habitat loss or climate change ?. Biol J Linn Soc 115 (3): 598-610. DOI: 10.1111/bij.12500

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Round 1 Round 2 Round 3 Round 4 Round 5 Round 6 Round 7

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