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Modeling potential distribution of *Baccaurea macrocarpa* in South Kalimantan, Indonesia

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Abstract. *Gunawan, Rizki MI, Anafarida O, Mahmudah N. 2021. Modeling potential distribution of* Baccaurea macrocarpa *in South Kalimantan, Indonesia. Biodiversitas 22: 3230-3236.* *Baccaurea macrocarpa* is fruit tree that has a potential source of food and medicine. However, little is known about the occurrences and potential distribution of *B. macrocarpa* mainly in South Kalimantan. This study is the first to predict the distribution of *B. macrocarpa* in South Kalimantan using maximum entropy (MaxEnt). Modeling included 102 occurrence records with 19 bioclimatic variables, solar radiation, altitude, and slope. Temperature, solar radiation, and precipitation were the key environmental factor influencing the distribution of *B. macrocarpa*. The district of HS (Hulu Sungai Selatan), HT (Hulu Sungai Tengah), HU (Hulu Sungai Utara), BL (Balangan), and TG (Tabalong) were predicted as highly suitable areas (IHS 0.6-1) for this species. The MaxEnt model performed better than the random method with an Area Under Curve (AUC) value of 0.817, indicating that the model is good and informative model for habitat suitability of *B. macrocarpa*. The predicted model we presented here can help habitat conservation, biodiversity conservation planning and monitoring, and cultivation in the future for *B. macrocarpa*.

Keywords: Biodiversity conservation, habitat suitability, MaxEnt, Phyllanthaceae, predictive modeling.

Abbreviations: AUC: Area Under Curve, MaxEnt: Maximum Entropy

INTRODUCTION

Habitat degradation and fragmentation, forest conversion, and increasing human population are seen as crucial factors causing species extinction in the world (Barnosky et al. 2011). In the case of Indonesia, mainly in Kalimantan region, habitat loss of many native species are caused by continuous illegal logging, development of human settlements, agriculture, perennial crop, and timber plantations (Budiharta et al. 2011). Habitat restoration is an effort that can be taken to rehabilitate species and conserve its habitat (Yang 2013). Detailed information about the regional distribution of a plant is needed for their rehabilitation. Species Distribution Models (SDMs) are widely used for broad application in ecology, biogeography, and conservation biology. SDMs are synonymous with the habitat suitability models, ecological niche models, and Climate Envelope Model (Yudaputra et al. 2019). Moreover, habitat suitability model can be used to determine precise location for conservation, monitoring and restoration of damaged habitat, and conservation management (Xu et al. 2018). SDMs use quantitative calculations to estimate the species geographic range based on occurrence records and concerned environmental conditions (Beck et al. 2014).

The maximum entropy-based general-purpose machine learning method (MaxEnt) is one of the SDMs algorithms that has been widely used to make predictive models of species distribution based only on presence data (Promnikorn et al. 2019), which has also been employed by studies in South Asia (Pradhan 2015), including Indonesia (Setyawan et al. 2017, 2020a, 2020b, 2021). MaxEnt can be used to predict suitable areas for occurrences by relating species existence and its biophysical environment to predict current distribution for species target (West et al. 2016).

Baccaurea macrocarpa is a fruit tree locally known as "Kapul" belonging to the family Phyllanthaceae and is distributed in Peninsular Malaysia, Sumatra, Borneo (Sarawak, Brunei, Sabah, West-, Central-, South- and East-Kalimantan), Ambon, and Irian Jaya (Haegens 2000). Local people in South Kalimantan use fresh fruits for consumption and wood as building materials. Hoe and Siong (1999) reported that proximate nutrient composition of *B. macrocarpa* arillode per 100 g consists of 127 kcal, moisture 66.6%, protein 1.5 g, fat 4.4 g, carbohydrates 27.9, dietary fiber 2.2 g, ash 0.9 g, P 54 mg, K 293 mg, Ca 10 mg, Mg 20 mg, Fe 20 mg, Mn 3 mg, Cu 7.3 mg, Zn 18.3 mg and vitamin C 0.1 mg. Pericarp of the fruit has one of the highest phytochemicals and strong antioxidant activity (Bakar et al. 2014). Pardede et al. (2020) also mentioned that these fruits contain alkaloids, saponins and flavonoids. Studies by Norhayati (2019) showed that fruits of *B. macrocarpa* have antibacterial activity for *Streptococcus sanguis*. In addition, the leaves of *B. macrocarpa* also contain antibacterial properties (Zamzani 2019).

Baccaurea macrocarpa has great potential as a medicinal ingredient. However, there is very little information about its distribution in Indonesia. This study is the first to reveal the distribution and identification of suitable areas of *B. macrocarpa* for cultivation and conservation in South Kalimantan, Indonesia. This information is useful for data collection of plant populations, a record of the flora diversity and habitat, as well as development for further conservation strategies. Xu et al. (2018) reported habitat suitability modeling is helpful in determination of the right locations for conservation and cultivation. In addition, such modeling is useful in understanding the environmental factors affecting *B. macrocarpa*'s distribution, thus, helping to improve conservation and cultivation programs. This study, therefore, aims to provide information regarding *B. macrocarpa* distribution in South Kalimantan, predict and identify the suitable habitat for conservation as well as cultivation, and identify important environmental factors related to its distribution.

MATERIALS AND METHODS

Study area and species occurrence data Study area

The study area consists of the entire province of South Kalimantan, Indonesia which has 13 districts covering approximately 34.744 km^2 of land area. The location was selected based on information from local communities about occurrence of *B. macrocarpa*. Explorative field surveys were carried out following the method of Rugayah et al. (2004). A total of 102 geographical coordinates of occurrence locations of *B. macrocarpa* were recorded from the survey using Garmin 64s GPS. The coordinates were imported into Microsoft Excel and saved in CSV format. The coordinate data was used to map the spatial distribution of *B. macrocarpa* in the province of South Kalimantan using the DIVA Gis 7.5 program (Figure 1) and it was used as input species presence data for habitat suitability modeling using MaxEnt version 3.4.1 (Phillips et al. 2017)

Climatic variables

For Habitat suitability modeling for *B. macrocarpa* in South Kalimantan, 19 bioclimatic variables (11 temperature based and 8 precipitation-based variables), solar radiation (12 months), altitude, and slope (Tabel 1) were downloaded and assessed. Raster files of bioclimatic variables and environmental variables were downloaded from WorldClim 2.0 datasets (http://www.worldclim.org) for the recent period (1970-2000). In addition, raster file of digital elevation model based on the altitude data was also downloaded from the WordClim website. Slope variable was downloaded from www.fao.org. The environmental variables used in the present study have been widely used to model habitat suitability (Evangelista et al. 2011; Sanchez et al. 2011; Khanum et al. 2013), including studies from Asian region (Xin et al. 2013; Pradhan 2016; Rana et al. 2017). All predictor variables were used at a spatial resolution of 30 arc-second (~1 km) (Ficks and Hijmans 2017). Processing of the raster files including cropping to the extent of study region and conversion of bioclimatic rasters into ASC format for use in MaxEnt were conducted using QuantumGis ver 2.8.10 (Setyawan et al. 2020a).

Figure 1. Current distributions of *B. macrocarpa* in South Kalimantan were obtained from field survey.

Table 1. Candidate environmental variables for use in MaxEnt models for *B. Macrocarpa*

Code	Parameter	Unit
Alt	Altitude	m
Srad*	Solar radiation (12 months)	w/m^2
GloSlope	Slope	%
Bio 1	Mean annual temperature	°C
Bio 2*	Mean diurnal range (max temp-min temp)	°C
Bio 3	Isothermality	%
Bio 4	Temperature seasonality	%
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	%
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

Note: (*) Asterisks indicated variables selected for use in MaxEnt models

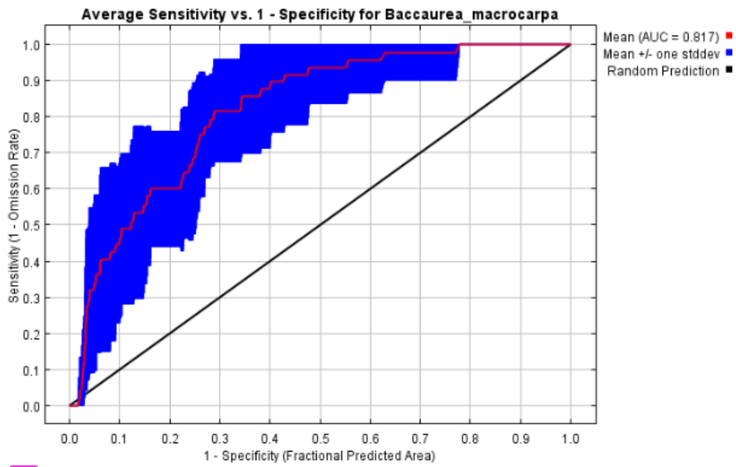

Figure 2. Result of area under the receiver operating characteristics curve (ROC-AUC) analyses for a MaxEnt model of habitat suitability for *Baccaurea macrocarpa*

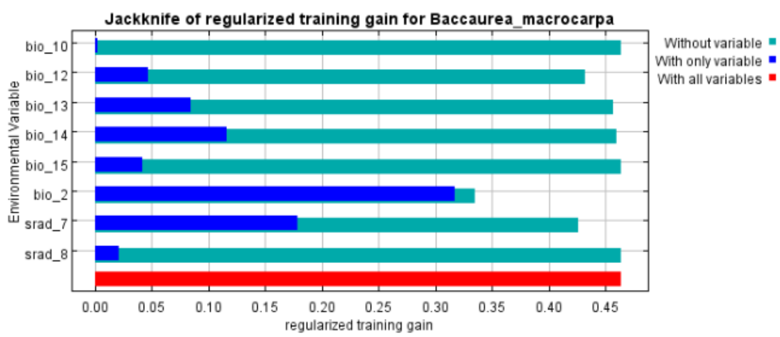

Figure 3. The jackknife test for evaluating the relative importance of environmental variables for *B. macrocarpa* in South Kalimantan. bio 10: Mean temperature of warmest quarter; bio 12: Annual precipitation; bio 13: Precipitation of wettest month; bio 14: Precipitation of driest month; bio 15: Precipitation seasonality; bio 2: Mean diurnal range; srad 7: Solar radiation in July; srad 8: Solar radiation in August.

In order to obtain an accurate and informative habitat suitability model, selecting and using environmental factors with a major influence to the model (Worthington et al. 2016) and with minimal inter-correlation (Pradhan 2016, 2019) are suggested. The variable selection was done with two-pronged approach. i) Firstly, Variance Inflation Factor (VIF) analysis was carried out across all the bioclimatic variables in R platform. The pairwise VIF values of bioclimatic variables were assessed and those variables were screened whose pairwise VIF was <10. ii) secondly, screened bioclimatic variables along with another environmental factor like solar radiation was 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 collinearity 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. Wei et al. 2018 suggested not to use environmental variables with a small average contribution (<6%) or permutation importance (<6%). Therefore, the final environmental variables used in *B. macrocarpa* habitat suitability map model for the current period were bio 10 (mean temperature of warmest quarter), bio 12 (annual precipitation), bio 13 (precipitation of wettest month), bio 14 (precipitation of driest month), bio

15 (precipitation seasonality), bio 2 (mean diurnal range), srad 7 (solar radiation in July) and srad 8 (solar radiation in August).

Modeling methodology

The habitat suitability of *B. macrocarpa* in South Kalimantan were generated using java based MaxEnt program (Phillips et al. 2017). The software was obtained from https://biodiversityinformatics.amnh.org/open_source/maxent/ and can be extracted freely for scientific research. We used MaxEnt in this study because of its advantages which include i) requirement of only species presence (or occurrence) data and environmental information (Elith et al. 2011), ii) the results are highly accurate and highly reproducible (Fourcade et al. 2014; Fois et al. 2018), iii) having option of evaluation of the importance of individual environmental variables using a built-in jackknife test, iv) ability to produce a spatially explicit habitat suitability map and species response curves to environmental variables and, v) having option to use both continuous and categorical data as input variables (Philips et al. 2006). In our study, the default setting was used in MaxEnt (Abdelaal et al. 2019). We employed 10 replicates and average of probability for habitat suitability (Hoveka et al. 2016). The Jackknife test was performed to assess the relative importance of each environmental variable to *B. macrocarpa* using a percent contribution (Phillips et al. 2006). To determine the accuracy and quality of the model prediction, we used the Area Under the Curve (AUC) of Receiving Operator Curve (ROC). The value of AUC ranges from 0.5 to 1. An AUC value of 0.5 indicated the model prediction did not perform better than random expectation, while a value of 1.0 shows the resulting model is very good and informative. In Maxent, Jackknife analysis is also carried out to determine the dominant environmental variables that determine the potential distribution of species (Yang et al. 2013). In addition, response curves were also used to investigate the relationship between the habitat suitability of the target species and environmental factors.

According to IPCC (2007) and Wei et al. (2020) habitat suitability levels on the model suitability map resulted from MaxEnt 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) and accordingly, the habitat suitability map for *B. macrocarpa* were categorized into said four categories. For further data analysis and visualization, the results of Maxent's analysis for *B. Macrocarpa* were imported into DIVA GIS software version 7.5 (Hijmans et al. 2012).

RESULTS AND DISCUSSION

Model performance

As per Swets (1988), value of AUC close to one indicates good model fit while AUC values of 0.5 or less may indicate a random model with low discrimination between presences and absences. The result of this study showed that the MaxEnt model for *B. macrocarpa* provided good results with an AUC value of 0.817 which was higher than AUC (0.5) of a random model (Figure 3). This indicated that the environmental variables were well selected to predict current potential distribution of *B. macrocarpa*. The key environmental variables were determined based on their contributions to the modeling process. The key environmental variables included bio 2 (mean diurnal range, 62.3%), srad 7 (solar radiation in July, 12.1%), bio 13 (Precipitation of wettest month, 8.8%), bio 14 (precipitation of driest month, 8.7%), bio 12 (precipitation seasonality, 7.2%), which together contributed 99.1% for prediction model of *B. macrocarpa*. The permutation importance values of the environmental variables were bio 2 (55.3%), srad 7 (18%), bio 13 (7.1%), and bio 12 (19.6%). The result of the Jackknife test of variables contribute to the prediction model are shown in Figure 4. The Jackknife test showed mean diurnal range (bio 2), solar radiation in July (srad 7), precipitation of driest month (bio 14), and precipitation of wettest month (bio 13) were the main variables.

Climatic conditions have an important role on the distribution of terrestrial plant and animal species (Aguirre-Gutierrez et al. 2015). The environmental variable with the highest training gain value was bio 2, which represents the mean diurnal range values in the range of 6.5 - 9.7 ºC in the area under study. The MaxEnt model showed predicted areas of potential distribution of *B. macrocarpa* close to the occurrence location of its natural habitat.

Variable's response to habitat suitability

MaxEnt generates response curves to illustrate how each variable affects the model prediction. The curves show the quantitative relationship between the logistic probability of presence and environmental variables, and they deepen the understanding of the ecological niche of a species (Ma and Sun 2018). Species response curves also show biological tolerances for target species and habitat preferences (Gebrewahid et al. 2020). The response curve of *B. macrocarpa* to four environmental variables are illustrated in Figure 5. Based on the response curves, the suitable mean diurnal range (bio 2) of *B. macrocarpa* ranged from 6.5 - 10 ºC with peak at ~9.7 ºC. The next important environmental variable for *B. macrocarpa* was solar radiation in July (srad 7) which showed range 16000-18000 w/m^2, with peak at ~17687 w/m^2. The response curve of bio 14 showed that the suitable precipitation of the driest month (bio 14) ranged from 80 - 180 mm and peaked at ~175mm. The optimal precipitation of the wettest month which showed range of 290 - 340 mm and peak at ~314 mm required by *B. macrocarpa* was indicated by the response curve of bio 13.

It is important to understand the ecological niche of the species for developing effective conservation strategies and planning cultivation and resource utilization of plants in the potential areas in future. Species distribution modeling provides valuable information about a target species. Our SDM result showed that the distribution of *B. macrocarpa* to be controlled by environmental variables mainly temperature (mean diurnal range), solar radiation, and precipitation (precipitation of driest month and precipitation of wettest month). Zhang et al. 2018 stated that the environmental variables to be one the most important factors that influence plant regeneration, growth and spread of its population. Key environmental variables such as precipitation and temperature need to be considered for conservation effort. Precipitation rather than temperature is suggested to often play a major role in controlling distribution, physiology, growth and mortality of plants (Vicento-serrano et al. 2010). Previous studies by Song et al. (2016) and Chen et al. (2017) also reported that precipitation was important factor in plant distribution. The present study showed that the temperature played an important role in limiting the distribution of *B. macrocarpa* than precipitation. Temperature is an important climatic factor that determines the phenology of important life cycle events, such as flowering in many plants (Shi et al. 2017) and also may have an indirect effect on plant growth (Doughty and Goulden 2008).

Other environmental variable which affected the distribution of *B. macrocarpa* was solar radiation. Recent study by Gunawan et al. (2021) highlighted solar radiation to play an important role in limiting the distribution of *B. angulata* in different months. Solar radiation provides energy for photosynthesis, and therefore growth of stem and shoot, seed germination, leaf expansion, flowering, fruiting, and other physiological and phenological functions of a plant (Gurjar et al. 2017). Haegens (2000) stated that in *B. macrocarpa* flowering and fruiting takes place throughout the year, but based on survey in South Kalimantan, the plant began flowering in May-July only.

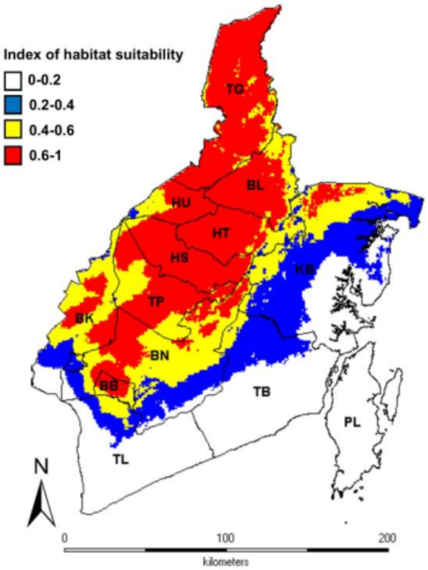

Figure 5. Map of potential current habitat suitability of *Baccaurea macrocarpa* according to occurrence records in South Kalimantan. TL: Tanah Laut; TB: Tanah Bumbu; PL: Pulau Laut; BB: Banjar Baru; BN: Banjar; BK: Barito Kuala; TP: Tapin; KB: Kota Baru; HS: Hulu Sungai Selatan; HT: Hulu Sungai Tengah;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

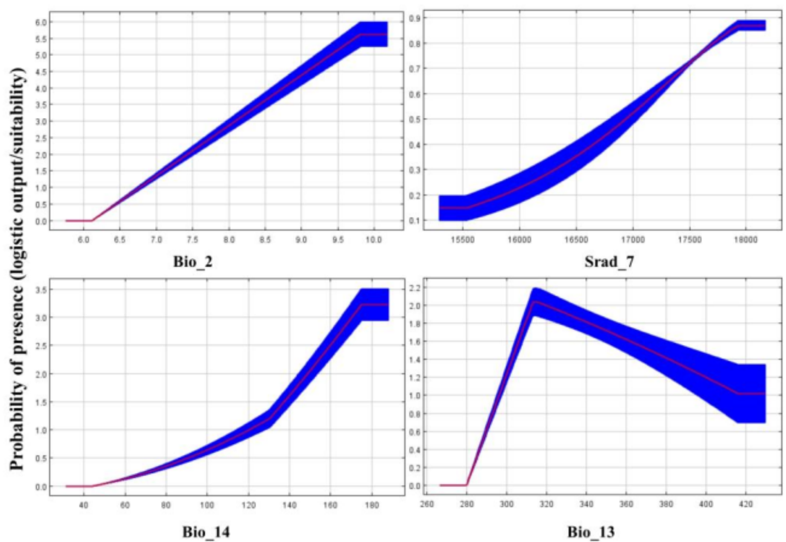

Figure 4. Response curve of *Baccaurea macrocarpa* to four key environmental variables. Bio 2: Mean diurnal range; srad 7: Solar radiation in July; bio 14: Precipitation of driest month; bio 13: Precipitation of wettest month. The curves show the mean response of the 10 replicate MaxEnt runs (red) and the mean +/- one standard deviation (blue, two shades for categorical variables).

Prediction of current potential distribution

Little is known about the existence and distribution of *B. macrocarpa* in South Kalimantan. This study is the first to explore the geographical distribution and predict suitability habitat of *B. macrocarpa* in South Kalimantan using MaxEnt. The model prediction of potential distribution of *B. macrocarpa* was created based on observed occurrences and current climate conditions. The map of the habitat suitability produced by MaxEnt and categorized into four suitability classes between 0 to 1 are presented in Figure 6.

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

Our result revealed, under current climatic conditions indicated that *B. macrocarpa* distribution range was more influenced by temperature (mean diurnal range), solar radiation, and precipitation (precipitation of driest month and precipitation of wettest month). *Baccaurea macrocarpa* is an underutilized plant, but its fruit has high potential to be developed as a food source and a medicinal bioresource. However, the habitat and population of *B. macrocarpa* are declining due to logging activities and conversion of forest to rubber and oil palm plantations. Previous studies reported that the MaxEnt model has been used widely to predict potentially suitable habitats in many species (Warren and Seifert 2011; Zhang et al. 2018). Species distribution modeling provided valuable information about habitat suitability and environmental condition. Information on the potential habitat distribution can help in planning land use management and prioritize sites for restoration of natural habitat for more effective conservation. More importantly, the present study confirmed that *B. macrocarpa* to be mainly distributed from 40 to 260 m asl. Notably, the size of potentially suitable habitat was significantly larger than the present occurrence of *B. macrocarpa* in South Kalimantan. Franklin (2009) stated that data on geographical distribution are important information needed for studying ecology, evolution and conservation of species.

Management implication

Information on the distribution and habitat suitability of a species is very important for decisions and actions towards management and conservation. The SDMs are novel machine learning methods that can generate such data, and MaxEnt is one of the best SDM algorithms today which is also used to identify environmental factors that affect the distribution of target species. This is for the first time that the species distribution model for *B. macrocarpa* was studied in South Kalimantan, Indonesia, categorizing habitat suitability into four levels (high, medium, low, and least). The data from this study can be used for conservation efforts of *B. macrocarpa* in South Kalimantan. Locations identified as having high suitability can be protected from deforestation and land conversion, and prioritized for conservation and cultivation of *B. macrocarpa*.

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