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Suitability habitat model of *Mangifera rufocostata* under different climatic and environmental conditions

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Abstract. *Fitriani A, Arifin YF, Hatta GM, Wahdah R, Payung D. 2022. Suitability habitat model of* Mangifera rufocostata *under different climatic and environmental conditions. Biodiversitas 23: 4570-4577. Mangifera rufocostata* Kosterm is known as a medicinal plant for antidiabetic. Therefore, intensive use of the bark of this plant results in a significant decline in the plant population which can eventually cause the plant to become extinct. This study aimed to determine the potentially suitable cultivation region of *M. rufocostata* using Maximum Entropy (MaxEnt) modelling. Twenty-three environmental variables including bioclimatic, soil type, slope, altitude, and solar radiation have been used for the development of distribution modeling. The results showed that precipitation seasonality, precipitation, mean temperature, and solar radiation are important variables in the development of the habitat suitability model. Suitable habitat locations for *M. rufocostata* include the Hulu Sungai Tengah, Hulu Sungai Selatan and Hulu Sungai Utara Regency, South Kalimantan Province, Indonesia. The MaxEnt model provided an area under curve (AUC) value of 0.959, indicating that MaxEnt is accurate and informative for the prediction of habitat suitability of *M. rufocostata*. The results indicate that this suitability prediction model may be applied used for future management, monitoring, cultivation and conservation of *M. rufocostata*.

Keywords: Antidiabetic, climatic variables, conservation, rare species, suitability model

INTRODUCTION

Mangifera rufocostata Kosterm or *asam kiat* (Sumatra) and *asam tandui* or *tandui* (Kalimantan) are rare plants in Indonesia. This plant belongs to the *Anacardiaceae* family, which consists of more than 500 species and 64 genera. *M. rufocostata* is known as a non-timber forest product, especially used as a medicinal plant. The bark of *M. rufocostata* is generally utilized by the community as antidiabetic medicine (Kulkarni and Rathod 2018; Vasudea et al. 2015). Continuous removal of the bark will result in the death of this plant, while the cultivation of this plant has not yet been carried out by the community. Moreover, *M. rufocostata* is also cut down by residents because of the large diameter of the trunk for the high value of wood (Rajan and Hudedamani 2019).

Mangifera rufocostata is a tree with a height between 45 to 53 m, has a branch free of 30 m, and belongs to the genus *Mangifera*, in which the distribution area of this plant includes Peninsular Malaysia, Sabah, Sumatra and Kalimantan (Kostermans and Bompard 2012; Kuhn et al. 2019). However, Vasudea et al. (2015) reported that *M. rufocostata* is no longer found in Malaysia. *Mangifera rufocostata* grows well in tropical climate areas that have high humidity and shady locations, such as lowland dipterocarp forests and areas along watersheds or in swampy areas (Lim 2012). This species flowers and bears fruit outside the main season for other *Mangifera* species (Bompard 1995; Das et al. 2018), so the availability of seeds of this plant for cultivation is difficult to obtain. The results of observations made at Telaga Langsat Sub-district, Hulu Sungai Selatan Regency, South Kalimantan, Indonesia, which is one of the locations with a high population of *M. rufocostata* showed that this plant population is critical, because the population decreased from 10 trees in 2010 to 4 trees in 2014 (Rafieq and Fakhrina 2015). The International Union for Conservation Nature (IUCN) included *M. rufocostata* in the Redlist Vulnerable Category, indicating that this plant is in a critical condition and it is estimated that the population of this plant has declined significantly in the next 10 years.

Prediction of the distribution of a species or biodiversity in an area is a very crucial action in environmental conservation and restoration planning, and for that, various species distribution modeling techniques have been developed. Maximum entropy (MaxEnt) is the modeling or projection of the potential distribution of species using biophysical and bioclimatic parameters (Zhang et al. 2018a; Ab Lah et al. 2021). Habitat suitability estimates generated using MaxEnt vary from low to high suitability (Boral and Moktan 2021), with attributes that include continuous probability results and can be used with small sample sizes (Anand et al. 2021). The results of the research above indicate that MaxEnt has the potential to be used in modeling the distribution of a species in an area.

Habitat suitability modeling could help determine potential sites for the conservation and cultivation of a species (Xu et al. 2018), especially in areas with different climatic and environmental conditions. Climatic and environmental factors play a very significant role in determining the habitat of a species (Moura et al. 2016; Rellstab et al. 2016). Although MaxEnt has been used in research on the distribution of *Mangifera* habitat in an area (da Silva Sobrinho et al. 2019), the distribution of *M. rufocostata* under different climatic and environmental conditions is poorly understood. Thus, the purpose of this study was to model the habitat distribution of *M. rufocostata* using MaxEnt based on different climatic and environmental conditions. Habitat suitability modeling is useful for understanding environmental factors that affect the distribution of the species *M. rufocostata*, thereby helping to improve conservation and cultivation efforts.

MATERIALS AND METHODS

Data of species occurrence

Exploration or field observation was carried out in three regencies, namely: Balangan Regency, Hulu Sungai Tengah Regency and Hulu Sungai Selatan, Province of South Kalimantan, Indonesia (Figure 2). The selection of study areas was carried out on the basis of information from the conservation officers and community who knew about the existence of *M. rufocostata*. The population of *M. rufocostata* based on information from the community and conservation officers, has decreased very significantly in the last ten years, and only 13 plants were found in the study areas. Observations on climatic and environmental conditions were carried out around the location where *M. rufocostata* grew. The results showed that the location where *M. rufocostata* grown in Balangan Regency located at 29-75 m above sea level with farm land-use, the light intensity of 327-667 lux, the temperature of 28-29ºC, moisture of 100%, soil texture varied from sandy loam to clay, and soil pH of 6.03-6.53. Growth areas of *M. rufocostata* in Hulu Sungai Tengah Regency were shrubs situated at 60-76 m above sea level, had a light intensity of 245-324 lux, the temperature of 26-27ºC, moisture of 84-85%, different soil textures from sandy clay loam to clay loam, and soil pH of 5.74-5.90. Meanwhile, land uses varied from shrubs to the secondary forest with an altitude of 8-131 m above sea level, the light intensity of 100-602 lux, the temperature of 25-30ºC, moisture of 81-100%, soil texture in the range of sandy clay loam to clay, and soil pH of 4.48-6.78 were growth areas of *M. rufocostata* in Hulu Sungai Selatan Regency. Geographical coordinates of this plant were recorded using a Garmin Etrex 30 GPS type Global Position System (GPS), then the data were used for habitat suitability modeling.

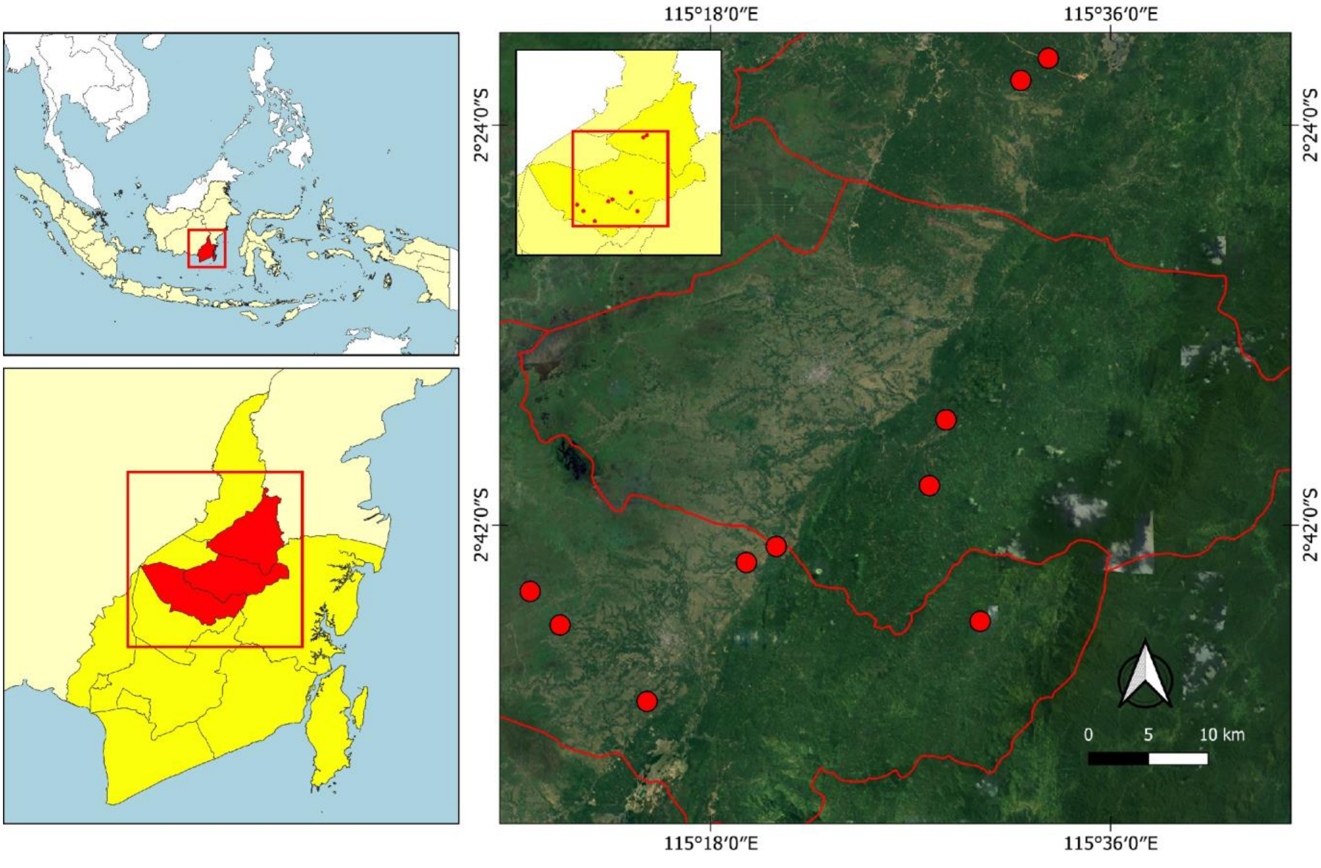

Figure 1. Study areas of suitability habitat model development for *Mangifera rufocostata*

Environmental variables

This study employed 22 environmental variables consisting of variables of bioclimatic, soil type, slope, altitude, and solar radiation (Table 1). Bioclimatic variables and solar radiation were downloaded from the WordClim global climate database (www.worldclim.org), and altitude data were downloaded from the WordClim Site based on a digital altitude model. This database has been widely used in modeling habitat suitability (Baek et al. 2019; Khanum et al. 2013). Kalimantan soil types are collected from the site Indonesia-geospatial.com, while slope data of Kalimantan was obtained from www.fao.org. The data were then processed and combined using ArcGIS Version 10.3, where all the data used in this study had a grid resolution of 30 arc seconds (1 km) (Fick and Hijmans 2017).

The results of a previous study showed that the use of environmental variables that have a large influence results in accurate and informative modeling results, and the Jackknife test was used to evaluate the contribution of each variable to the model (Worthington et al. 2016). Wei et al. (2018) suggest focusing on the variables with the highest contribution or permutation importance for habitat model development and leaving the environmental variables with a small mean contribution (<6%) or permutation importance (<6%). Contribution percentage and permutation are two important factors in understanding and measuring the contribution of environmental variables and the importance of the model. Results of Jackknife's analysis showed that 18 environmental variables were not used because of the lack of contribution to the modeling (percent contribution = 0). Therefore, the environmental variables used in the final run of the habitat suitability model for *M. rufocostata* were srad_7 (solar radiation in July), bio_15 (precipitation seasonality), bio_2 (mean temperature) and bio_17 (precipitation).

Species distribution modelling

This study used MaxEnt Version 3.4.1 (Phillips et al. 2017)) to develop a predictive suitability map for *M. rufocostata*. This software is obtained from https://biodiversityinformatics.amnh.org/open_ source/maxent/. Meanwhile, the contribution and importance of each environmental variable to the habitat suitability model of *M. rufocostata* were evaluated by the Jackknife test (Wei et al. 2018), and the receiver operating curve area (AUC) was used to evaluate the performance model. AUC values range from 0 (lowest fit) to 1 (maximum fit) (Zhu et al. 2017). An AUC value lower than 0.5 indicates that the resulting model is not better than random and uninformative data, while a value of 1.0 indicates that the resulting model is very good and informative (Swets 1988). Furthermore, the results of the analysis of the MaxEnt model to predict the suitability of *M. rufocostata* (range 0-1) were imported into Diva GIS Software Version 7.5 for further display and analysis (Hijmans et al. 2005). The level of habitat suitability on the model map generated from MaxEnt could be grouped into 4 classes, namely least suitable (0.0- 0.2), low suitability (0.2-0.4), moderate suitability (0.4-0.6), and high suitability (0.6 -1.0) (Ji et al. 2020; Team 2007).

RESULTS AND DISCUSSION

Results of MaxEnt modelling

The results of the study showed that areas were suitable for *M. rufocostata* habitats distributed spread in the Hulu Sungai Regency (Figure 2). *Mangifera rufocostata* grows well in Hulu Sungai Tengah Regency and Hulu Sungai Utara Regency with a habitat class of 0.6-1.0, while this plant was modeled to grow with a habitat class of 0.4-1.0 in Hulu Selatan Regency (Figure 2). Balangan Regency is predicted to have a relatively low *M. rufocostata* growing habitat class compared to other areas, which have a habitat class of 0.2-0.6 (Figure 2). *Mangifera rufocostata* is known as an annual plant that belongs to the *Anacardiaceae* family. *M. rufocostata* grows well in wet lowlands with good drainage in the forests of Sumatra and Kalimantan up to an altitude of 1000 m above sea level (Kostermans and Bompard 2012). The habitat of *M. rufocostata* has not yet been identified in detail, so the habitat of this plant mostly uses the habitat of *Mangifera indica* as a reference.

Table 1. Environmental variables used in the first run of the distribution model

Abbreviation	Description
Srad_7*	Solar Radiation in July
Bio_1	Annual Mean Temperature
SoilTypes	Soil Type in Kalimantan
GloSlope	Global Slope
Bio_2*	Mean Diurnal Range (Mean of monthly (max temp - min temp)
Bio_3	Isothermally (P2/P7) (*100)
Bio_4	Temperature Seasonality (standard deviation *100)
Bio_5	Max Temperature of Warmest Month
Bio_6	Min Temperature of Coldest Month
Bio_7	Temperature Annual Range (P5-P6)
Bio_8	Mean Temperature of Wettest Quarter
Bio_9	Mean Temperature of Driest Quarter
Bio_10	Mean Temperature of Warmest Quarter
Bio_11	Mean Temperature of Coldest Quarter
Bio_12	Annual Precipitation
Bio_13	Precipitation of Wettest Month
Bio_14	Precipitation of Driest Month
Bio_15*	Precipitation Seasonality (Coefficient of Variation)
Bio_16	Precipitation of Wettest Quarter
Bio_17*	Precipitation of Driest Quarter
Bio_18	Precipitation of Warmest Quarter
Bio_19	Precipitation of Coldest Quarter

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

Mangifera indica L. grows and produces very well in the cold or dry period prior to flowering, with abundant soil moisture and moderately hot temperatures (30-33°C) (Laxman et al. 2016). Hulu Sungai Regency has high precipitation (annual precipitation > 3000 mm) and is in the Oldeman climate zone type C2, which indicates that the study area has a wet month period of 5-6 months (monthly precipitation >200 mm) and a dry month period of 2-3 months (Noor et al. 2016). Thus, Hulu Sungai Regency has high habitat suitability for the growth of *M. rufocostata*. This is consistent with observations during the field surveys that *M. rufocostata* grows well in areas with land use varying from shrubs to secondary forests with temperatures of 25-30oC and moisture of 80-100%.

Contribution of environmental factors in the development of model

The contribution of environmental variables in the development of a habitat suitability model was quantified through the Jackknife test. The results of the Jackknife test on modeling are depicted in Figure 3. The results of the Jackknife test show that the environmental variables that contribute to the construction of the habitat suitability model were bio_15 (precipitation seasonality), bio_2 (mean temperature), bio_17 (precipitation) and srad_7 (solar radiation in July). The contribution of variables in developing the habitat suitability model is shown in Table 2.

Environmental variables are considered important factors for supporting plant cultivation and conservation management (Sun et al. 2013; Velazco et al. 2019). Bio_15 (precipitation seasonality, 44.5%), bio_17 (precipitation, 6.3%), and bio_2 (mean temperature 16.2%) affects the average temperature of the environment (Table 2). The results of this study are in line with Zhang et al. (2018b) which reported that climatic factors are very important in influencing plant regeneration, growth, and distribution. The environmental variable of Srad_7 (solar radiation in July) with a contribution of 26.6% plays an important role in plant growth. Solar radiation is absorbed by plants for the process of photosynthesis to form carbohydrates. The canopy of vegetation plays a role in reflecting, absorbing and transmitting incoming solar radiation (Verstraete 1987). The thickness of the canopy layer reduces solar radiation reaching the forest floor (Durand et al. 2021), so that the small size of *M. rufocostata* growing under the shade could develop properly. Among all variables, bio_15 (precipitation seasonality) is the most important predictor which contributes 44.5% to the development of a predictor model for the suitability of the habitat and has a major influence on plant distribution. The contribution of precipitation seasonality in the development of habitat suitability of plants is also reported in previous studies. For example, Akhter et al. (2017) reported the role of precipitation seasonality in the rapid assessment of habitat distribution of *Mangifera sylvatica* Roxb in Bangladesh using MaxEnt modelling. Precipitation seasonality is a climatic variable that plays an important role in predicting the potential distribution of *Homonoia riparia* Lour (endangered medicinal plant) in Yunnan, China using MaxEnt modelling (Yi et al. 2016). A study conducted by Asanok et al. (2020) demonstrated that habitat suitability modeling is helpful for increasing understanding of the relationship between plants and their respective habitats by including current location, microclimate, topographic, and edaphic factor data. Although this model produces a good habitat distribution for *M. rufocostata*, the role of other factors other than climatic data such as soil characteristics, land uses, and geology, really need to be integrated into the modeling to obtain more accurate and reliable predictions for future plant growth.

Habitat characteristics based on variable response curves

The interpretation of habitat characteristics from the modeling results could be seen through the response curve of environmental variables to the presence of *M. rufocostata* (Figure 4). Figure 4 shows that temperature is an environmental factor affecting the flowering process of *M. rufocostata*. The response curve showed that *M. rufocostata* might develop well at a temperature of 24-27 ºC, in line with several previous research results that which that mangoes (a similar family with *M. rufocostata*) require a temperature tolerance of 25-32ºC for the flowering process (Datta 2013; Suwardike et al. 2018). Mango may grow well in tropical areas in which temperature fluctuations are not too firm every season. The results showed that the suitable habitat for *M. rufocostata* is influenced by temperature, rainy season, rainfall and solar radiation. Sunlight affects plant growth to carry out the process of photosynthesis. Photosynthesis is the process of converting light energy into chemical energy. The rate of plant growth is controlled by the amount of light intensity received by plants. *M. rufocostata* is the same as mango (*M. indica*) belonging to the *Anacardiaceae* family, which could be classified as the C3 group of plant, which is capable of photosynthesis at low leaf temperatures (Théry 2001). Maximum photosynthesis (P_{max}) of mango is obtained when receiving light at 20% of the full exposure in the canopy (Taiz and Zeiger 2010). In addition, the results of research conducted by Li et al. (2019) showed that *M. indica* had normal photosynthesis at 45-77% soil water content.

The temperature has a close relationship with rainfall and humidity. Eccel (2012) suggested that high rainfall results in low temperatures and high humidity. The length of the rainy day will be related to the reception of sunlight that plants require for plant growth. Wang et al. (2009) suggested that sunlight affects the process of photosynthesis, opening and closing of stomata and chlorophyll synthesis. Rainfall and rainy days are part of the microclimate that *M. rufocostata* requires to develop satisfactorily. The rainfall required for mango growth is in the range of 250-3000 mm year^{-1} (Makhmale et al. 2016).

Evaluation of model performance

The results of the model performance evaluation are represented in the area under the curve (AUC) value. Based on the AUC value, the habitat suitability model of *M. rufocostata* is classified as a good category because the value was in the range of 0.8-0.9 (AUC = 0.959) with a standard deviation of 0.5. This indicates that the habitat suitability model could provide information on the distribution of the suitability habitat of *M. rufocostata* at the study site. The habitat of *M. rufocostata* based on the results of this prediction model has a high correlation with the location of the original litter habitat. The black line on the receiver operator characteristic (ROC) curve indicates that the AUC is a random model, if the blue line (test data) is below the black line curve (random model) then the model's performance is poor (Figure 5). On the other hand, if the blue line is above the black line, the better the model's performance in predicting the presence of the sample in the data (Phillips et al. 2017).

The results of field observation showed that *M. rufocostata* was most commonly observed in the Hulu Sungai Tengah Regency, Hulu Sungai Selatan Regency and Hulu Sungai Utara Regency. This is in accordance with the map of the suitability of *M. rufocostata* habitat modeling developed using MaxEnt. Environmental factors such as solar radiation, mean temperature, and precipitation contribute greatly to the distribution of *M. rufocostata*. Research on modeling the habitat suitability of *M. rufocostata* using MaxEnt provides very significant information for the cultivation and conservation management of this rare plant. The distribution map of the habitat suitability of *M. rufocostata* may assist researchers and conservators in determining either in-situ or ex-situ conservation or cultivation locations for this plant. Sites with a high degree of suitability should be maintained and prioritized for the conservation and cultivation of *M. rufocostata*.

Table 2. Contribution of variables in developing the habitat suitability model for *Mangifera rufocostata*

Environmental variables	Contribution (%)	Permutation importance (%)
Bio_15 (precipitation seasonality)	44.5	41.0
Bio_2 (mean temperature)	16.2	7.2
Bio_17 (precipitation)	6.3	0.0
Srad_7 (solar radiation in July)	26.6	49.0

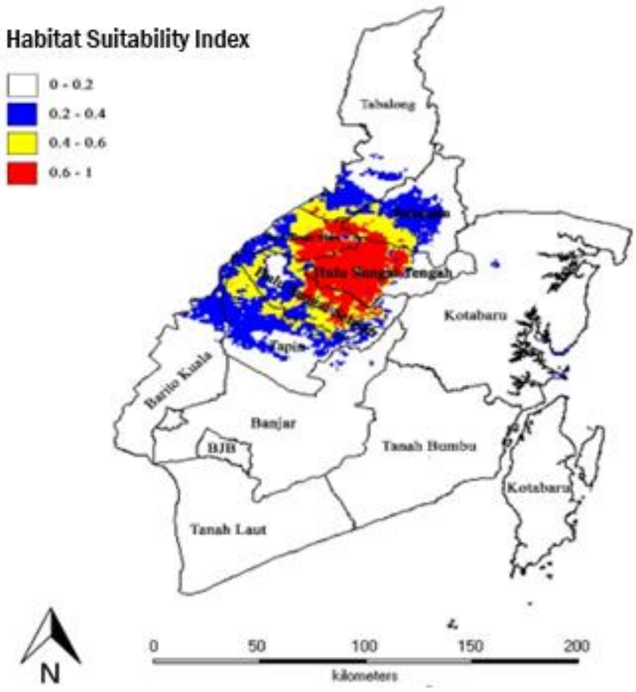

Figure 2. Map of suitable habitat for *Mangifera rufocostata*

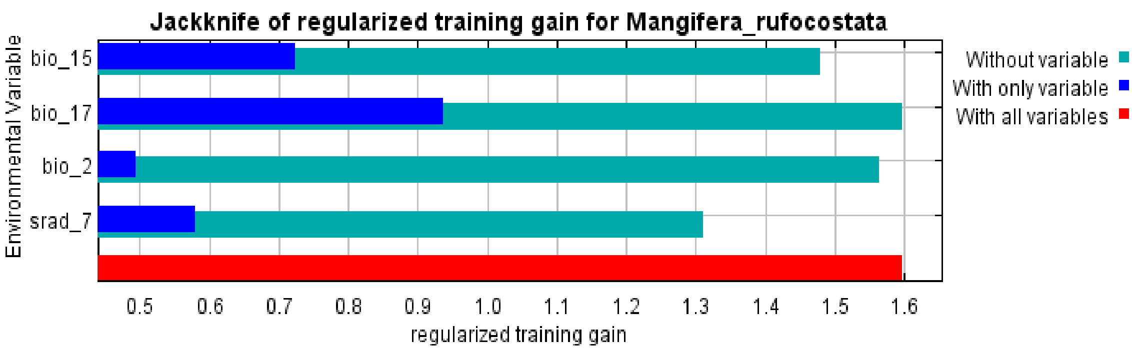

Figure 3. Result of Jackknife test on the development of the habitat suitability model for *Mangifera rufocostata*

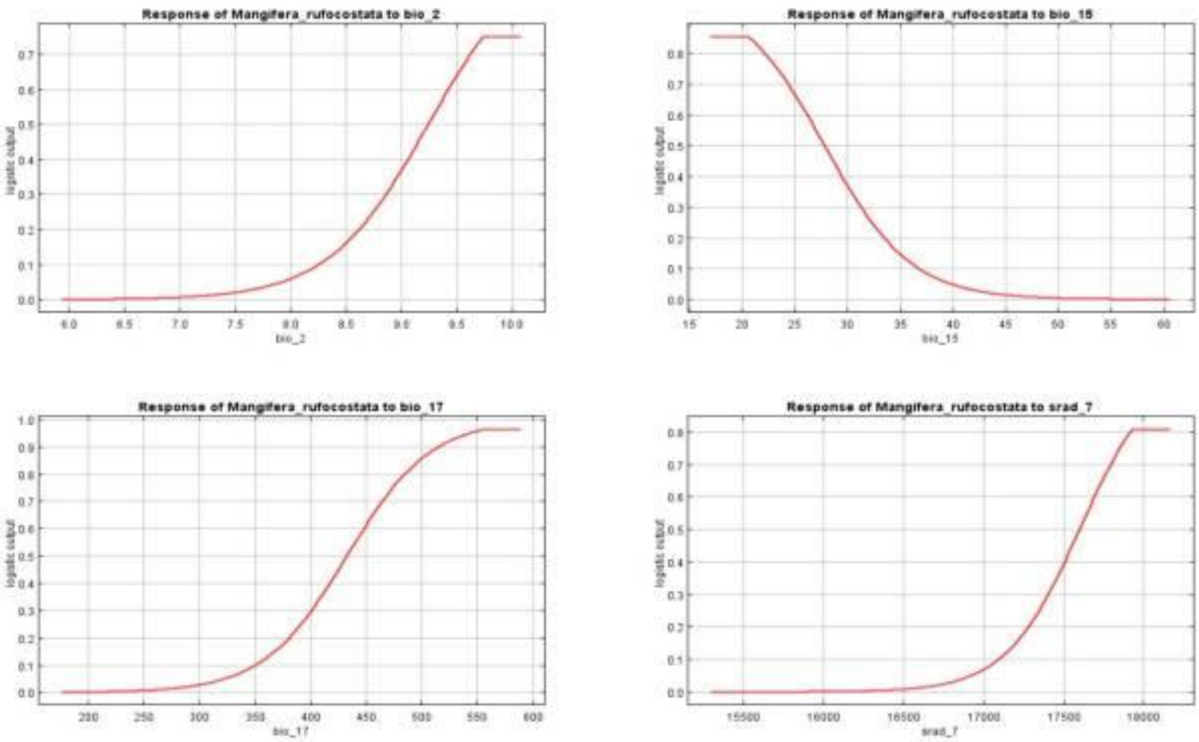

Figure 4. Response of environmental variables (bio_2=mean temperature, bio_15= precipitation seasonality, bio_17= precipitation, srad_7=solar radiation) to the presence of *Mangifera rufocostata*

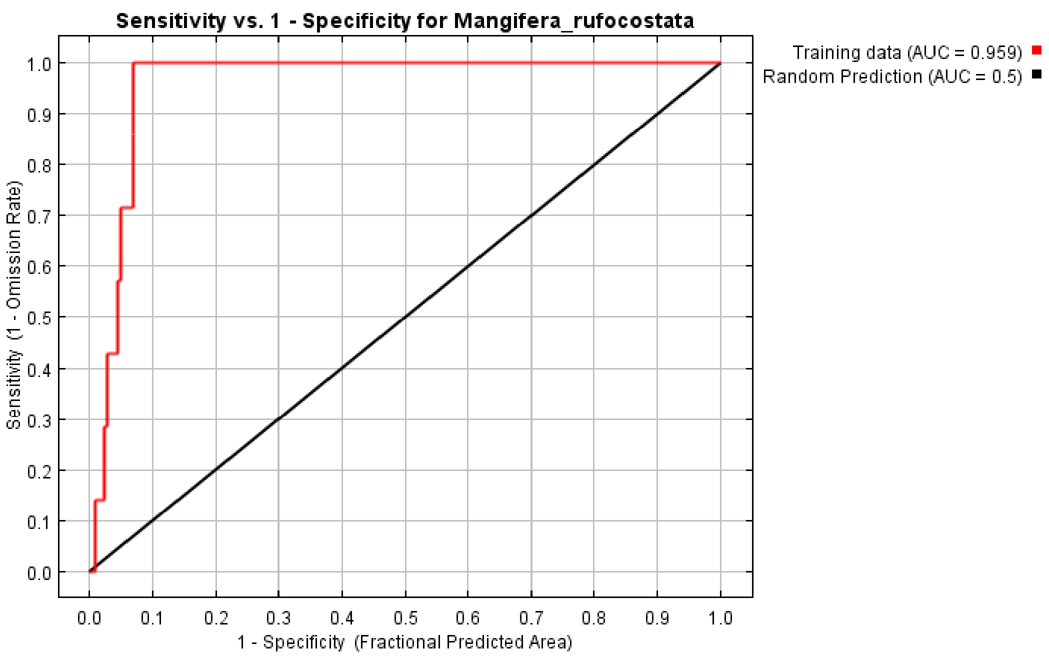

Figure 5. The area under the curve (AUC) for habitat suitability modelling of *Mangifera rufocostata*

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