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MODELLING THE POTENTIAL DISTRIBUTIONS OF SAWO KECIK (*MANILKARA KAUKI* (L.)) DUBARD USING MAXENT TO SUPPORT CONSERVATIONS OF HISTORICAL AND CULTURAL VEGETATIONS IN DAERAH ISTIMEWA YOGYAKARTA PROVINCE

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ANDRI WIBOWO
Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Indonesia. Kampus UI Gedung E Level 2, Jln. Lingkar Kampus Raya, Pondok Cina, Beji, Depok 16424, Indonesia.
Email: awbio2021c@gmail.com. https://orcid.org/0000-0001-7787-5735.

ATUS SYAHBUDIN
Faculty of Forestry, Universitas Gadjah Mada. Jln. Agro, Bulaksumur, Sleman, 55281, Yogyakarta, Indonesia. https://orcid.org/0000-0002-8614-1925.

ADI BASUKRIADI
Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Indonesia. Kampus UI Gedung E Level 2, Jln. Lingkar Kampus Raya, Pondok Cina, Beji, Depok 16424, Indonesia.

ERWIN NURDIN
Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Indonesia. Kampus UI Gedung E Level 2, Jln. Lingkar Kampus Raya, Pondok Cina, Beji, Depok 16424, Indonesia.

ABSTRACT
WIBOWO, A., SYAHBUDIN, A., BASUKRIADI, A. & NURDIN, E. 2023. Modelling the potential distributions of Sawo Kecik (*Manilkara kauki* (L.)) Dubard using MaxEnt to support conservations of historical and cultural vegetations in Daerah Istimewa Yogyakarta Province. *Reinwardtia* 22(1): 55–67. — Sawo kecik or *Manilkara kauki* (L.) Dubard, of the Sapotaceae family as it is formally known, is one of the species with significant cultural values in Yogyakarta Province (DIY) culture because it symbolizes social righteousness. In connection with this, Yogyakarta's municipal and district governments have been encouraged to plant sawo kecik. Despite these efforts, there is still a lack of knowledge regarding the possible range of this species, and this knowledge is essential to promoting the conservation of *M. kauki* in DIY. With the help of isothermality, precipitation of driest month, precipitation seasonality, precipitation of driest quarter, and precipitation of warmest quarter data, this study tries to simulate the probable distributions of *M. kauki* throughout cities and districts in DIY. The model estimated 1,275 km^2 of DIY areas was suitable for *M. kauki* that concentrated in the central parts, spanning from the west to the east of DIY. Yogyakarta City followed by Sleman District has the largest areas categorized from high to very high suitable for *M. kauki*. While, Gunung Kidul followed by Kulonprogo Districts have the largest areas categorized as low suitable. To conclude, *M. kauki* can adapt areas with moderate precipitation as low as 20 mm during driest month and as low as 100 mm during driest quarter. During warmest quarter, *M. kauki* requires precipitation with value of 700 mm. The conservation effort and *M. kauki* planting should then concentrate on Yogyakarta City and Sleman District since such locations are thought to have high appropriateness for the species.

Key words: Distributions, *Manilkara kauki*, *MaxEnt*, Yogyakarta.

ABSTRAK
WIBOWO, A., SYAHBUDIN, A., BASUKRIADI, A. & NURDIN, E. 2023. Pemodelan potensi distribusi Sawo Kecik (*Manilkara kauki* (L.)) Dubard dengan MaxEnt untuk konservasi vegetasi bernilai sejarah dan budaya di Provinsi Daerah Istimewa Yogyakarta. *Reinwardtia* 22(1): 55–67. — Sawo kecik, atau secara ilmiah dikenal sebagai *Manilkara kauki* (L.) Dubard, suku Sapotaceae merupakan salah satu spesies yang memiliki nilai budaya penting dalam kebudayaan Provinsi Daerah Istimewa Yogyakarta (DIY) karena mewakili kebaikan di tengah masyarakat. Terkait hal tersebut, pemerintah provinsi telah mendorong kota dan kabupaten di Yogyakarta untuk menanam sawo kecik. Meski demikian, informasi tentang potensi sebaran jenis ini masih terbatas dan informasi ini sangat penting untuk mendukung konservasi *M. kauki* di DIY. Penelitian ini bertujuan untuk memodelkan sebaran potensial *M. kauki* di kota dan kabupaten di DIY dengan menggunakan metode *Maximum Entropy* (MaxEnt) sebagai kebaruan dengan menggunakan isotermalitas, presipitasi bulan terkering, presipitasi musiman, presipitasi kuartal terkering, dan presipitasi kuartal terhangat variabel. Model memperkirakan wilayah DIY seluas 1.275 km^2 cocok untuk *M. kauki* yang terkonsentrasi di bagian tengah, membentang dari barat hingga timur DIY. Kota Yogyakarta diikuti Kabupaten Sleman memiliki wilayah terluas dengan kategori potensi sebaran tinggi hingga sangat tinggi yang cocok untuk *M. kauki*. Sedangkan Kabupaten Gunung Kidul yang diikuti Kabupaten Kulonprogo memiliki wilayah terluas dengan kategori potensi sebaran rendah. Disimpulkan bahwa *M. kauki* dapat beradaptasi di daerah dengan curah hujan sedang serendah 20 mm selama bulan terkering dan serendah 100 mm selama kuartal terkering. Pada kuarter terhangat, *M. kauki* membutuhkan presipitasi dengan nilai 700 mm. Kemudian untuk mencapai hasil yang optimal, upaya konservasi dan pena-

naman *M. kauki* sebaiknya difokuskan di Kota Yogyakarta dan Kabupaten Sleman karena daerah tersebut dianggap memiliki tingkat potensi sebaran yang tinggi.

Kata kunci: *Manilkara kauki*, MaxEnt, sebaran, Yogyakarta.

INTRODUCTION

Manilkara kauki (Dubard, 1915) or local name is known as sawo kecik belongs to the Sapotaceae family and is native from the Malay Peninsula to the Pacific. *Manilkara kauki* was introduced into the West Indies many years ago, they are rarely seen today (Govaerts, 2017). *M. kauki* grows on beaches in open forest, monsoon forest, vine thickets, and rain forest. This species has at least 11 synonyms. In Indonesia, *M. kauki* is distributed from Java, Bali, and the Papua Islands. Besides that, this species is also observed on the southern coast of Banyuwangi, the Jakarta coast, the Karimun Jawa islands, Bali, Sulawesi, Kagean, Weh Island, and in Nusa Tenggara with elevation limits of 300 m (Alrasyid, 1971). Research by Sudrajat and Megawati (2010) has reported *M. kauki* presences in Benoa, Mokmer, Kaliurang, Lembar, and Alas Purwo within elevation ranges of 1–332 m. This species is adapted to rainfall rate ranges of 1,500–4,488 mm.

Recent research has indicated potential distribution of *M. kauki*. Regarding this, several methods have been developed to model species distribution at spatial scale. One approach that has been used widely to model the potential spatial distributions of a species is known as Maximum Entropy (MaxEnt) modelling. This model has been used widely to estimate potential distributions of animal (Stephenson *et al*., 2022), including ticks (Sanchez *et al*., 2023), vegetation (Dong *et al*., 2023), and crops. In Indonesia, potential distribution modelling studies using MaxEnt has been developed for *Xanthomonas campestris* (Saputra *et al*., 2023) and *Indigofera tinctoria* along Citarum Watershed (Usmadi *et al*., 2021). Besides MaxEnt, there are a growing variety of methods for estimating habitat appropriateness, including geographical based methods (BIOCLIM, DOMAIN, BIOMAPPER), statistical based methods (generalized additive model/GAM, GLM), machine learning based methods (MaxEnt, Random Forest, Support Vector Machine/SVM), and deep learning based methods (Artificial Neuron Network/ANN). Each tool is unique, with its own set of pros and downsides. According to Marcer *et al*. (2013), among other things, MaxEnt is one of the most often used habitat suitability modeling tools. The need for only species presence data, the ability to run with a little amount of data, the high accuracy of prediction findings, the high reproducibility, and the ability to predict the most discriminating environmental parameters are all advantages of MaxEnt (Fois *et al*., 2018).

DI Yogyakarta (DIY) is one of the provinces in Indonesia that has promoted the cultivation and planting of *M. kauki*. According to Governor of DIY Circular No. 194/Kep/2015, entitled Designation of Wanadesa Locations in DIY Year of 2015, it has been ordered to plant *M. kauki* across 11 villages in Kulonprogo, Bantul, Sleman, and Gunung Kidul Districts. In Bantul District, *M. kauki* has been assigned as flag species as stated in Mayor of Bantul Circular No. 567/B/Kep/BT/1998. In DIY, *M. kauki* is among the trees that are selected to be planted inside Kraton (Widayatsari, 2002) because it has important philosophical and cultural values, especially for the Sultanate of Yogyakarta. *Manilkara kauki* is representing *sarwo bercik* value or social righteousness (Wastuty, 2007). Despite this progress, there is still limited information on where the potential distribution of *M. kauki* is located, mainly in DIY. This information is required in advance to guarantee and sustain *M. kauki* plantings. Here, this research aims to determine the potential distribution areas for *M. kauki* in DIY. The novelty of this research is the use of MaxEnt modeling to achieve accuracy in potential distributions. The results of this study will benefit the success of conservation of historical and cultural vegetation in DIY.

MATERIALS AND METHODS

The research was conducted on DIY Province. The study methodology followed methods developed by Semu *et al*. (2021), including species occurrence, environmental variables, and model evaluation. The method to estimate and model the potential distributions of *M. kauki* was comprises several steps (Fig. 1). It is started with the species occurrence recording and multicollinearity test to select relevant environmental variables.

Study sites

This research was conducted in one city (Kodya Yogyakarta) and four districts (Kab. Sleman, Kulonprogo, Bantul, Gunung Kidul) of DIY Province (Fig. 2). The geo-coordinates of DIY were 110.0°–110.9° east longitude (E) and 7.2°–8.3° south latitude (S). DIY is bordered by highlands in the north, hilly areas in the east and west, and sea and coastal areas in the south. The southern parts of DIY were karst areas characterized by limited surface water and experiencing dryness (Putra & Nur-

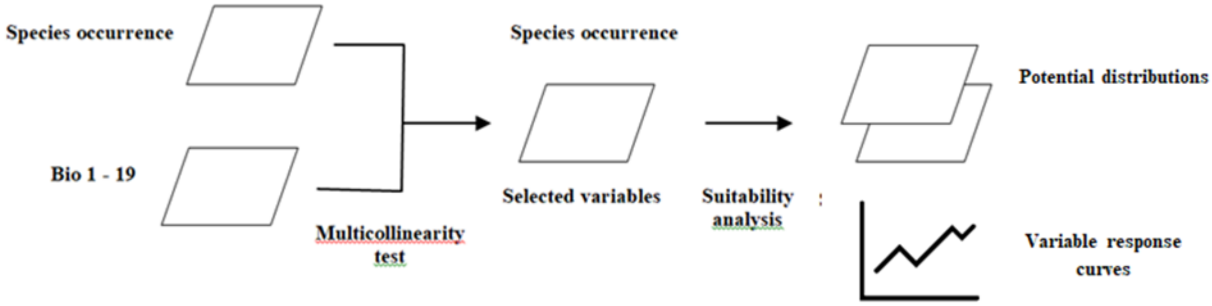

Fig. 1. A flowchart of the suitability analysis and geographical distribution modeling.

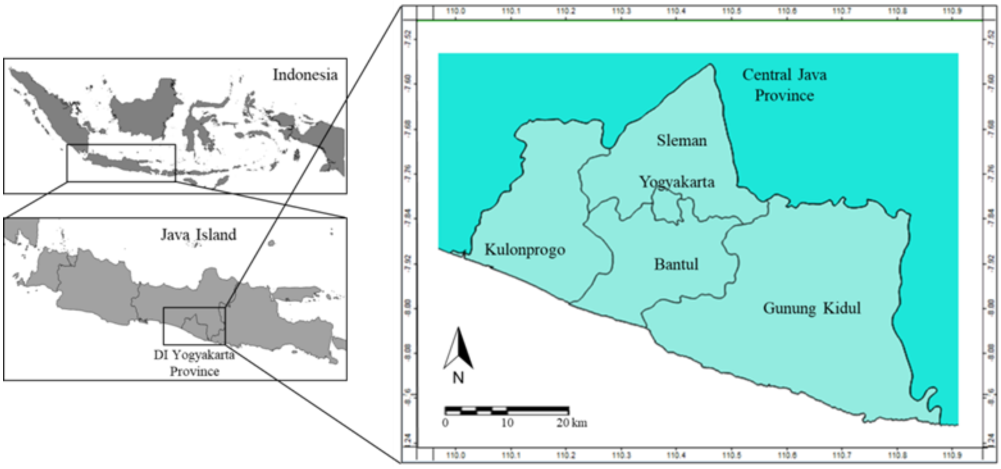

Fig. 2. Location map of the study sites in five districts within DIY Province, Indonesia

jani, 2021). The annual rainfall ranges of DIY are 718.0–2,992.3 mm/year. High rainfalls were observed in the northern parts of Sleman District. While low rainfalls were observed in the southern parts of Gunungkidul and Bantul districts, Sleman District has recorded rainfall rates up to 2,992.3 mm/year. While the lowest rainfalls with values of 197.6 mm/year were observed in the southern parts of Gunung Kidul District.

According to Hakim & Yuliah (2018), DIY is known for having a high diversity of vegetation. It was recorded that DIY has at least 805 plant species representing 110 families inhabiting terrestrial ecosystems, 12 families residing in aquatic ecosystems, and 4 families under protection. Among those species, at least 33 plant species are categorized as very rare, and *M. kauki* is included in that list. *M. kauki* is protected under Mayor of Bantul Circular No. 567/B/Kep/BT/1998. Among those species, there are 7 species that have cultural values, including *M. kauki*, which represents *sarwo becik* cultural values symbolizing social righteousness.

Manilkara kauki occurrence surveys and recordings

Explorations or field surveys combined with literature and database reviews were conducted to survey and record the presence of *M. kauki* in DIY from January to March 2023 covering Yogyakarta City, Kulonprogo, Sleman, Bantul, and Gunung Kidul Districts. The presence of *M. kauki* was recorded using direct visual observation or also known as visual encounter survey (VES) and a database (Tabel 1) provided and gathered from literature reviews sourced from journal articles and reports provided by government agencies, including the agency for agriculture and forestry at the Indonesian Ministry of Environment and Forestry. VES was implemented purposefully by visiting parks, household yards, and roadside areas where *M. kauki* may be planted. The sample size covered all trees planted. The geographical coordinates of *M. kauki* presences in the field were recorded using the Garmin Etrex 30 type Global Positioning System (GPS). The data were convert-

Table 1. Literature review source materials of *M. kauki* in Indonesian.

City/districts	Title	Authors	Year
Bantul	Laporan kinerja pengelolaan lingkungan hidup daerah Kabupaten Bantul	Dinas Lingkungan Hidup daerah Kabupaten Bantul	2016
Yogyakarta	Alternatif pohon buah untuk penghijauan permukiman perkotaan berdasarkan pendugaan tingkat keindahan dan pendapat masyarakat di Kelurahan Rejowinangun, Yogyakarta	Annisa, N. S., Irwan, R., S. N. Kurniasih, B. & Ambarwati, E.	2018
Kulonprogo, Gunung Kidul	Exploration and characterization of sapodilla (*Manilkara zapota* (l.) van Royen) in Daerah Istimewa Yogyakarta	Rozika, Murti, R. H. & Purwanti, S.	2013
Sleman	Kebun Raya Botani di Kabupaten Sleman	Jhonson	2019

ed to Microsoft Excel and saved in CSV format for use in MaxEnt habitat suitability modelling. The tree species identification guideline to determine *M. kauki* was based on identification keys (Backer & van den Brink, 1963; Partomihardjo *et al*., 2014).

Manilkara kauki environmental variables

This study included various environmental variables (Table 2) following Dong *et al*. (2023) and Arshad *et al.* (2022). For the recent time, bioclimatic variables (Bio 1–Bio 19) from the global climate database WordClim (www.worldclim.org, the new version 2.0) (Hijmans *et al*., 2005) have been employed extensively in habitat suitability modeling (Khanum *et al*., 2013) and are widely used in the Asian region (Rana *et al*., 2017).

Those environmental variables were chosen based on selection and utilization of environmental elements having a significant influence in order to obtain an accurate and informative habitat suitability model. Jackknife analysis was used to evaluate the contribution of each environmental variable to the resulting model. Some environmental variables resulted from Jackknife analysis were not used due to the lack of contribution to the model making (percent contribution = 0). Those environmental variables were variables with a small average contribution (< 6%) or permutation importance (< 6%) (Wei *et al*., 2018). The contribution percentage and permutation are two important factors for understanding and measuring the environmental variable's contribution as well as importance to the MaxEnt model.

Multicollinearity test

To establish a model that has better performance with fewer variables and to avoid collinearity between the variable, a multicollinearity test was performed using Pearson's correlation tests (Preau *et al*., 2018) on 19 environmental variables (Bio 1–Bio 19) (Table 2). The variables that have highly cross-correlated variables ($r^2 > 0.8$) were excluded and variables having $r^2 < 0.8$ were kept for further analysis for geographical distribution modeling. If multicollinearity occurs, then a variable is strongly correlated with other variables in the model, and its predictive power is unreliable and unstable (As'ary *et al*., 2023). Based on the multicollinearity test, the selected environmental variables to be used were Bio 3, 14, 15, 17, and 18.

Manilkara kauki suitability analysis

This study employed MaxEnt analysis using MaxEnt packages within R platform version 3.6.3 (Mao *et al*., 2022) to generate predicted suitability maps of *M. kauki* across DIY. Several R packages required to develop the suitability maps include library ("sp"), library ("dismo") (Khan *et al*., 2022), library ("maptools"), library ("rgdal") (Bivand *et al*., 2022), and library ("raster") (Lemenkova *et al*., 2020). The inputs for MaxEnt included 19 environmental variables (Bio 1–Bio 19).Within the model, the contribution and impact of each environmental variable on the *M. kauki* habitat suitability model were determined using a Jackknife test (Promnikorn *et al*., 2019), and the receiving operating curve (AUC) area was used to evaluate the performance model. AUC values range from 0 (least suitability) to 1, with a value less than 0.5 suggesting that the resulting model is no better than random and uninformative data and a value more than 1.0 showing that the resulting model is highly good and informative.

The prediction map resulting from MaxEnt models was imported into GIS for presentation and additional study (Hijmans *et al*., 2012). According to Wei *et al*. (2018), habitat suitability levels on the MaxEnt model map can be classified into five suitability level included 0: unsuitable, 1: low suitability, 2: medium suitability, 3: high suitability, 4: very high suitability.

Tabel 2. Variables used in this study

Variables	Sources	Format	Unit
Annual mean temperature (Bio 1)	www.worldclim.org	Image data in Raster	°C
Mean diurnal range (Bio 2) (mean of monthly (max temp - min temp))	www.worldclim.org	Image data in Raster	°C
Isothermality (Bio 3)*	www.worldclim.org	Image data in Raster	%
Temperature seasonality (Bio 4)	www.worldclim.org	Image data in Raster	°C
Max temperature of warmest month (Bio 5)	www.worldclim.org	Image data in Raster	°C
Min temperature of coldest month (Bio 6)	www.worldclim.org	Image data in Raster	°C
Temperature annual range (Bio 7)	www.worldclim.org	Image data in Raster	°C
Mean temperature of wettest quarter (Bio 8)	www.worldclim.org	Image data in Raster	°C
Mean temperature of driest quarter (Bio 9)	www.worldclim.org	Image data in Raster	°C
Mean temperature of warmest quarter (Bio 10)	www.worldclim.org	Image data in Raster	°C
Mean temperature of coldest quarter (Bio 11)	www.worldclim.org	Image data in Raster	°C
Annual precipitation (Bio 12)	www.worldclim.org	Image data in Raster	mm
Precipitation of wettest month (Bio 13)	www.worldclim.org	Image data in Raster	mm
Precipitation of driest month (Bio 14) *	www.worldclim.org	Image data in Raster	mm
Precipitation seasonality (Bio 15) *	www.worldclim.org	Image data in Raster	dimensionless
Precipitation of wettest quarter (Bio 16)	www.worldclim.org	Image data in Raster	mm
Precipitation of driest quarter (Bio 17) *	www.worldclim.org	Image data in Raster	mm
Precipitation of warmest quarter (Bio 18) *	www.worldclim.org	Image data in Raster	mm
Precipitation of coldest quarter (Bio 19)	www.worldclim.org	Image data in Raster	mm

*: selected variables based on multicollinearity test

Manilkara kauki model evaluation and validation

This study's model evaluation follows Reddy *et al.* (2015) and Song *et al.* (2023).

Area under the curve analysis (AUC) was used to examine the model. The MaxEnt model calculated the percentage contribution of each factor to the species distribution. The percentage contribution represents the value of each factor's contribution to the distributions of the species. The size of the receiver operating characteristic curve (ROC) and the area under the curve (AUC) were used to assess model prediction accuracy. The higher the AUC value, the greater the accuracy of the model's prediction outcomes, and the parameters of the MaxEnt model were selected in accordance with Zhao *et al.* (2018). AUC is an effective and efficient independent threshold index with the capacity of assessing the model's capacity to distinguish the presence and absence. AUC values are categorized in to five different classes based on performance. The performance classes are failing (0.5 to 0.6), bad (0.6 to 0.7), reasonable (0.7 to 0.8), good (0.8 to 0.9) and great (0.9 to 1). Models with values less than 0.5 indicates that the occurrence in the real-life scenario is rare or can be considered as a guesstimate (Shcheglovitova & Anderson, 2013). Jackknife was executed to systematically exclude each variable or evaluate the leading bioclimatic or topographic variables. Jackknife evaluates the leading variables in determining the potential distribution of species. The relationship between the selected environmental factors from 19 environmental variables and the potential habitat for the species is determined from the created response curve from the model (Vila *et al.*, 2012). The relative contributions in percentage of the each environmental variable to the MaxEnt model were calculated.

RESULTS

Manilkara kauki observed morphology

M. kauki common morphology was observed based on *M. kauki* occurrence surveys across DIY. The observed *M. kauki* has tree height ranges of 10–25 m.

Manilkara kauki occurrences

Manilkara kauki is mainly present (Fig. 2) between 110.2°–110.5° E and 7.68°–7.84° S in the central parts of DIY, with hilly areas in the east

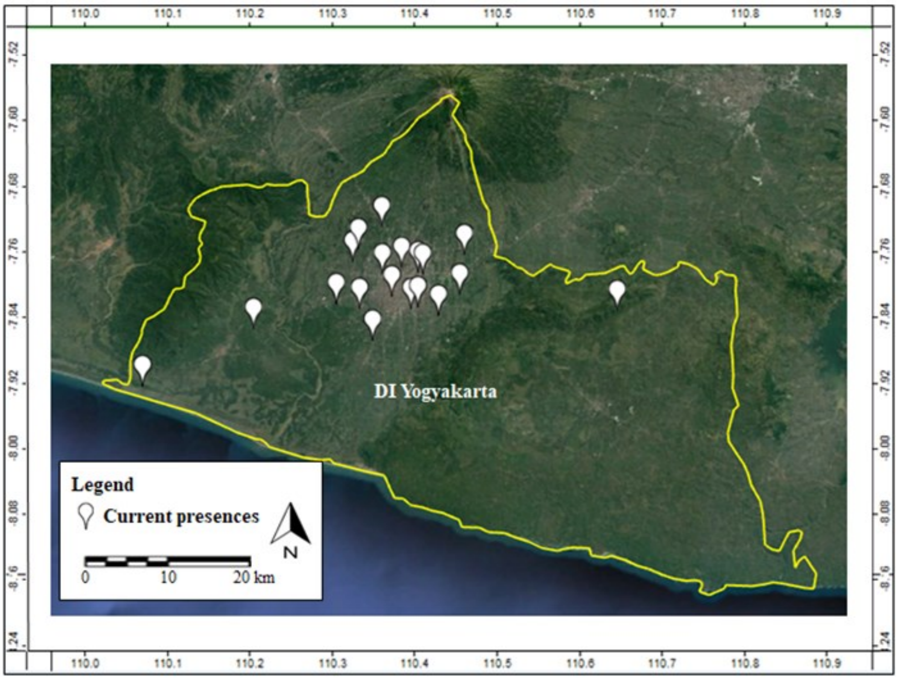

Fig. 3. Current presence records of *Manilkara kauki* across one city and four districts within DIY Province.

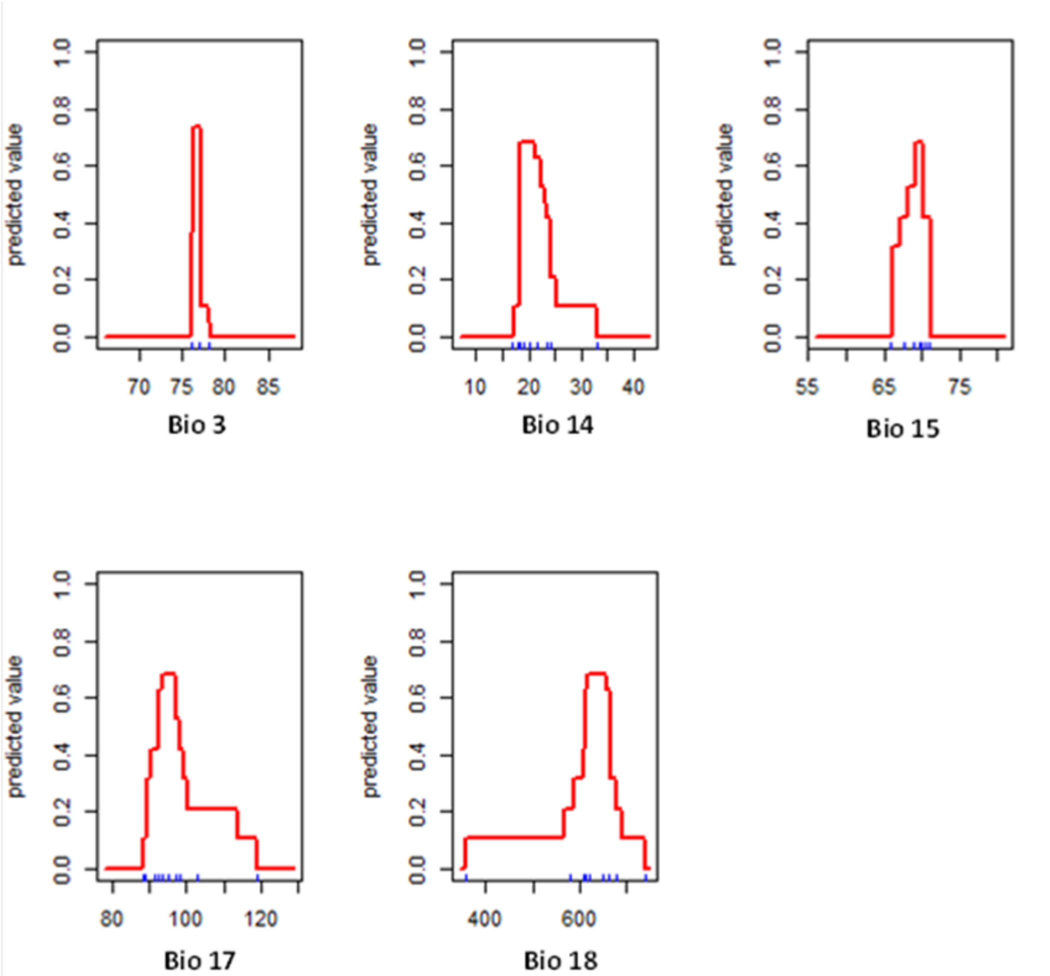

Fig 4. Response curves of suitability predicted values of *Manilkara kauki* with Bio 3: isothermality, Bio 14: precipitation of driest month, Bio 15: precipitation seasonality, Bio 17: precipitation of driest quarter, and Bio 18: precipitation of warmest quarter.

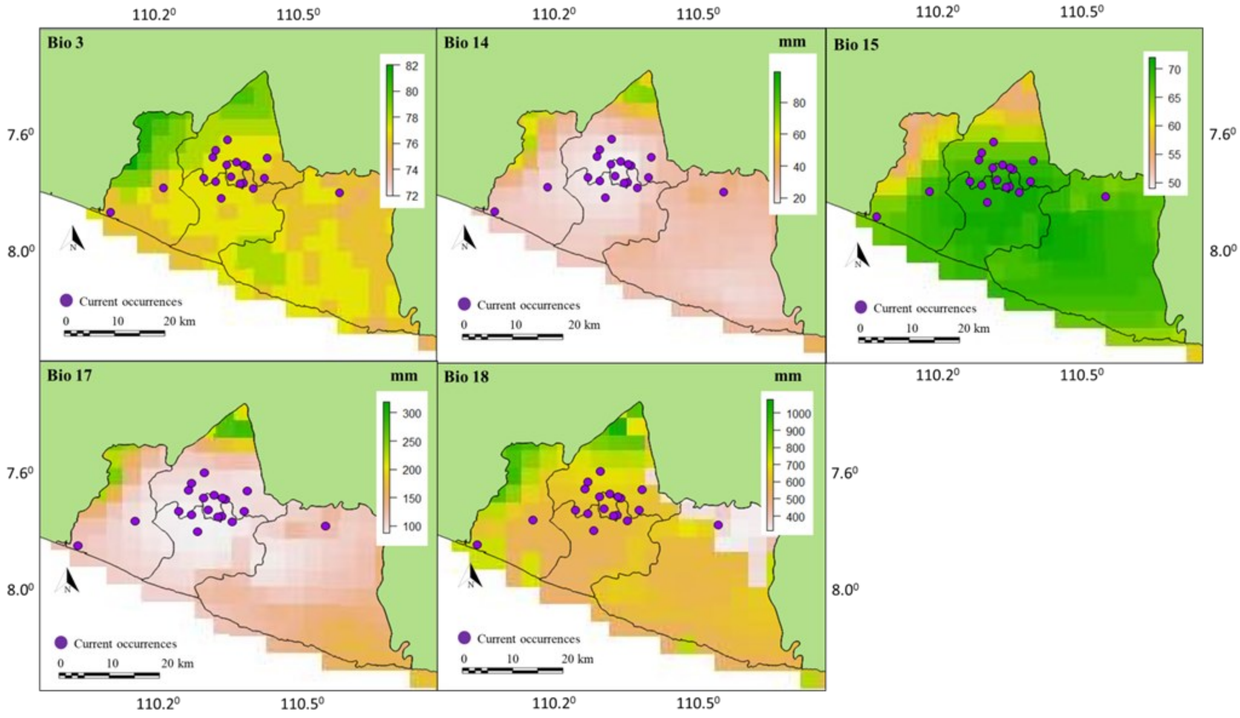

Fig. 5. Distributions of *Manilkara kauki* current presence records related to environmental variables including Bio 3: isothermality (%), Bio 14: precipitation of driest month (mm), Bio 15: precipitation seasonality (dimensionless), Bio 17: precipitation of driest quarter (mm), and Bio 18: precipitation of warmest quarter (mm) across one city and four districts within DIY Province, Indonesia.

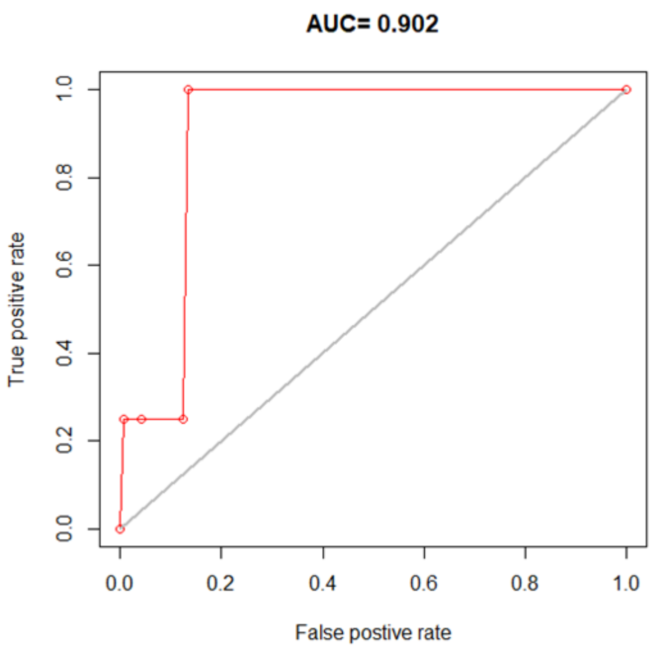

Fig. 6. The Receiver Operating Characteristic (ROC) curve result of the MaxEnt modelling.

and west according to the collected occurrence data and survey. In total, there were nineteen occurrences of *M. kauki* (Fig. 3), with 84.21% of occurrences dominating the central parts. Only one record near the coastal areas. *Manilkara kauki* occurs mostly in hilly areas and lowlands with altitude ranges of 33–176 m in DIY. *Manilkara kauki* was absent in near-coastal areas with an altitude less than 30 m.

Manilkara kauki response curves

Fig. 4 shows response curves of suitability predicted values of *M. kauki* potential distributions with Bio 3: isothermality, Bio 14: precipitation of driest month, Bio 15: precipitation seasonality, Bio 17: precipitation of driest quarter, and Bio 18: precipitation of warmest quarter. Among those environmental variables, significant responses were observed for isothermality, precipitation of driest month, and precipitation of driest quarter variables. *Manilkara kauki* responds immediately toward slight increases of those variables. This condition differs as can be seen for annual precipitation of warmest quarter. *Manilkara kauki* responds gradually toward this variable.

***Manilkara kauki* environmental variables**

Environmental variable spatial distributions related to the presence of *M. kauki* across DIY are available in Fig. 5. Those variables include isothermality, precipitation of driest month: precipitation seasonality, precipitation of driest quarter, and precipitation of warmest quarter. retrieved from the WordClim database. All variables were observed limit the distribution of *M. kauki* current presence. Coastal areas with low precipitation of warmest quarter < 700 mm has limited *M. kauki* distributions in here. While high isothermality with values of > 70% and low precipitation seasonality with values of < 60 has limited *M. kauki* distributions in hilly areas. *Manilkara kauki* can adapt areas with moderate precipitation as low as 20 mm during driest month and as low as 100 mm during driest quarter. During warmest quarter, *M. kauki* requires precipitation with value of 700 mm. *Manilkara kauki* was observed clustered near areas with high isothermality with values of > 76% covering north of Kulonprogo and Sleman Districts.

MaxEnt model evaluation and validation

Model evaluation and validation guarantees the reliability of the model and the reliability is expressed by the area under receiver-operating characteristic (ROC) curve (AUC) obtained by the accuracy test of the ROC curve analysis method. The AUC values were between 0 and 1 and divided into several value classes. When the AUC value was lower than 0.5, the model executed was considered poor than contingency. The MaxEnt model is more precise and descriptive when the AUC test value is closer to 1, indicating better discrimination. In this study, the AUC value showed that the MaxEnt model performed well with AUC value of 0.902 under the model at the current time (Fig. 6).This indicates that MaxEnt model has an accurate prediction on the potential distribution region of *M. kauki* in DIY.

***Manilkara kauki* MaxEnt model**

The MaxEnt species occurrence probability output raster for *M. kauki* was classified, mapped, and evaluated for land area calculation for each city and district considered suitable (Fig. 7). In total, there were estimated 1,275 km^2 of areas in DIY that considered suitable for *M. kauki* and falls into four suitability levels. The MaxEnt model classified the suitability levels into levels that vary in size among cities and districts. The most suitable habitats for *M. kauki* in DIY were estimated to be concentrated in the central parts, spanning from the west to the east of DIY Province. Kulonprogo, Bantul, Sleman districts and Yogyakarta City were observed as regions that have level 3 and level 4 suitabilities or are categorized as having high and very high suitabilities (Fig. 8). Level 1 and level 2 suitabilities, categorized as low and medium suitabilities, were observed in Gunung Kidul, followed by Kulonprogo, Bantul, and Sleman districts.

Each district and city across DIY has a different composition of potential suitable areas for *M. kauki* (Fig. 9). Areas of Yogyakarta City were dominated by high suitability, with similar compositions equaling 50% of total Yogyakarta City Areas. In Sleman, 10% of its areas were considered very suitable for *M. kauki*, and 20% were considered suitable. Almost all the areas in Gunung Kidul were considered to have low suitability for *M. kauki*, followed by Kulonprogo and Bantul Districts.

DISCUSSION

This is the first study, especially in Indonesia, to analyze the range expansions of *M. kauki* based on the MaxEnt species distribution model. To ensure the model's accuracy, the occurrence data and environmental variables have been carefully selected and validated. Model parameter optimization and evaluation for *M. kauki* were made using the AUC, and the AUC values indicated the high prediction accuracy of the MaxEnt model. Currently, in Indonesia, most studies of *M. kauki* were mostly focused and limited on taxonomy and morphological studies (Sofiyanti & Iriani, 2023) and *M. kauki* for absorbing CO_2 (Anggara & Rahmawati, 2021). Here, this study has expanded by estimating potential distributions of *M. kauki* at province scale.

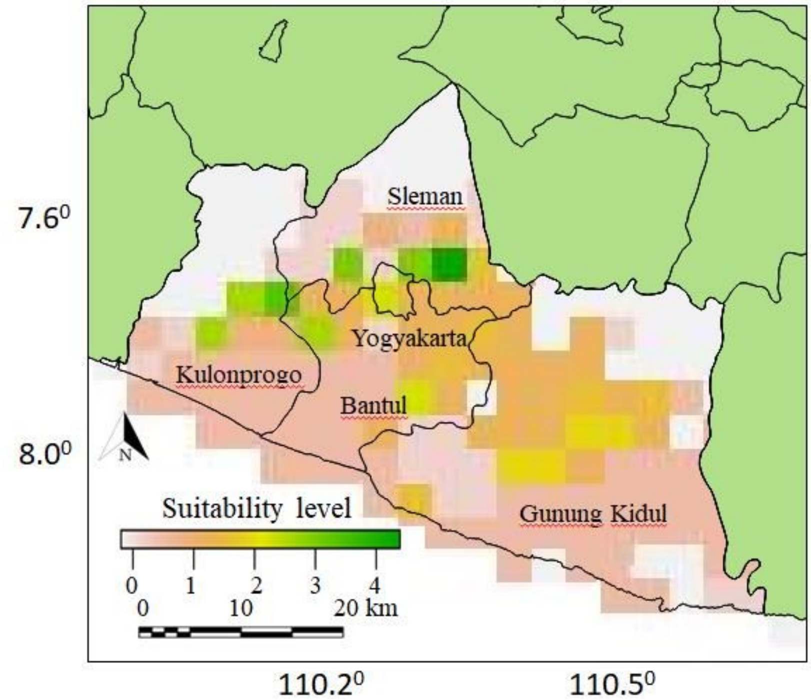

Fig.7. Distribution of potential suitable areas for *Manilkara kauki* across one city and four districts within DIY Province, Indonesia (Suitability level 0: unsuitable, 1: low suitability, 2: medium suitability, 3: high suitability, 4: very high suitability).

Manilkara kauki distributions on DIY were shown to be limited by coastal areas as can be seen in Gunung Kidul and Kulonprogo areas. This finding is quite contradicted with reports confirming potential distribution of *M. kauki* that also include coastal areas. The potential absences of *M. kauki* in coastal areas in Gunung Kidul and Kulonprogo areas can be related to the internal and external factor or environmental variables. As an internal variable the presences of *M. kauki* were determined by seed production during the first year and reproductive event during the second (Cruz-Rodríguez *et al*., 2009). As an external factor, soil fertility is one of the factors. While soils in Kulonprogo are classified as inceptisol soils. This kind of soil has N, P, and K nutrient deficits (Ciptaningrum, 2022) that limits the suitability of soils for *M. kauki.* The K deficit will limit the availability of soil pH, K total, K available nutrient, and led to K uptake by the plant (Abdillah *et al*., 2011). While according (Chakradhari *et al*., 2019), leaves, seed kernel, and seed coat of *Manilkara* Genus do have high level of K and this indicates the importance of K to determine the suitable habitats for *M. kauki* that in fact K was limited in the Kulonprogo areas and explain the low suitability of this area.

Besides K deficient, Kulonprogo is a coastal area where most of the soils comprise sandy soils (Sutardi, 2017). According to Hani *et al*. (2016), the sandy dominated soils in Kulonprogo were having deficient in NPK contents, C organic and also has low pH with ranges of 4.51–5.38. According to Falasca *et al*. (2016), species belong to Sapotaceae family require neutral soils with pH ranging from 6.5 to 7.5.

Based on the model, the hill central parts in Bantul, Sleman districts, and Yogyakarta City are considered as the most suitable. The elevation and precipitation of those areas were fulfilling the requirement for *M. kauki* to grow. The growth of *M. kauki* will reach its optimum results at the elevation ranges from 600 to 2,100 m above sea level (Pohlan *et al.,* 2000). While *Manilkara* genus belongs to Sapotaceae can tolerate dry climate, it requires from moderate to high rainfall with ranges of 1,000 to 4,000 mm. These suitable rainfalls can be observed in the Bantul, Sleman districts, and Yogyakarta City. In those areas the *M. kauki* can adapt areas with moderate precipitation as low as 20 mm during driest month and as low as 100 mm during driest quarter and those areas were considered suitable for *M. kauki* (Falasca *et al*., 2016).

Another variables that limit the distribution *M. kauki* is precipitation seasonality and isothermality. Precipitation seasonality (Souza *et al*., 2016) affects the soil moisture and potential distributions of *M. kauki* (Ayanlade *et al*., 2021). *M. kauki* was occurred near areas with high isothermality. According to (Huang *et al*., 2021), wide-range plant groups tended to occur in areas with higher tem-

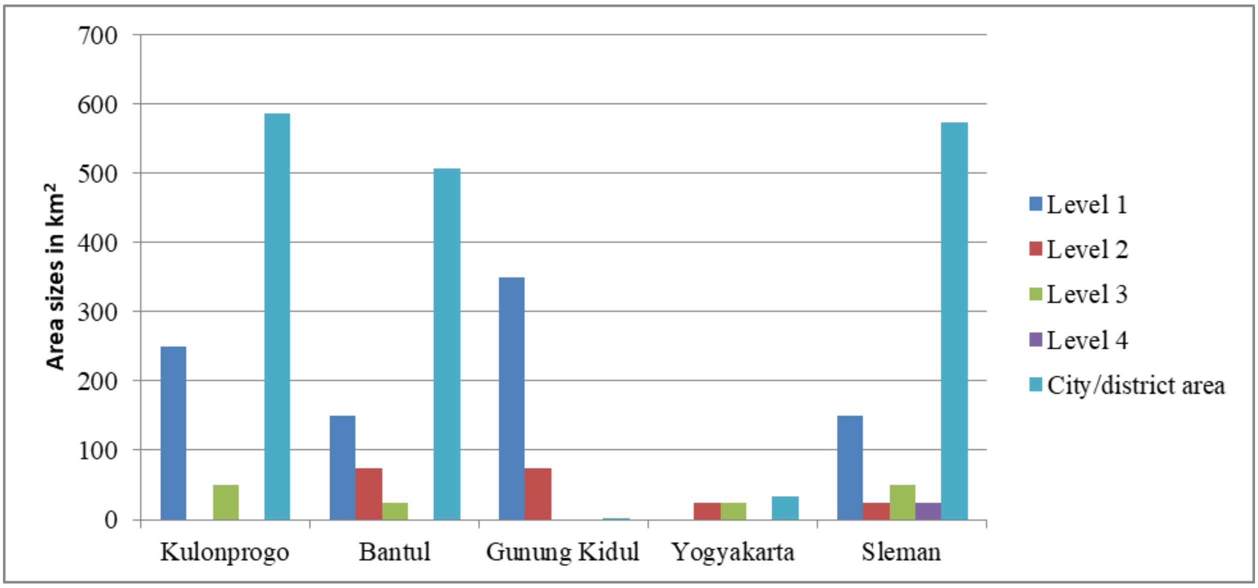

Fig.8. Distribution of potential suitable areas in km^2 for *Manilkara kauki* across one city and four districts within DIY Province, Indonesia related to district areas (Suitability level 1: low suitability, 2: medium suitability, 3: high suitability, 4: very high suitability).

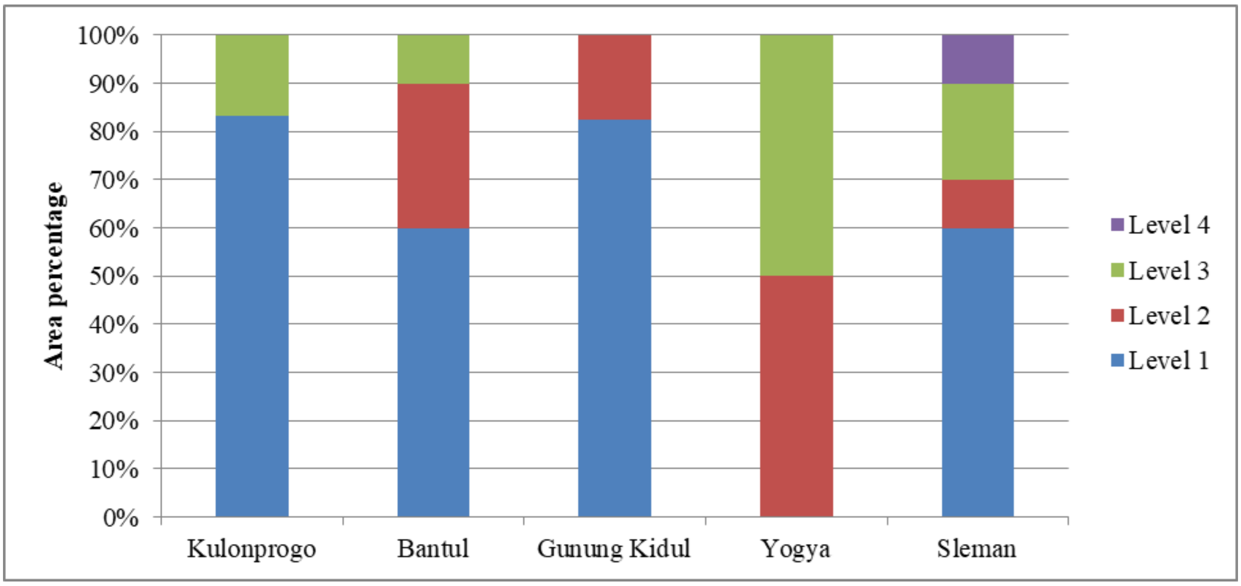

Fig.9. Percentages of potential suitable areasfor *Manilkara kauki* across one city and four districts within DIY Province, Indonesia (Suitability level 1: low suitability, 2: medium suitability, 3: high suitability, 4: very high suitability).

perature variability and isothermality.

CONCLUSION

DIY has considerably suitable areas for *M. kauki* sizing 1,275 km^2 of DIY areas. The suitable areas were increasing toward central parts of DIY and spanning from the west to the east of DIY. Yogyakarta City followed by Sleman district has the largest areas categorized from high to very high suitable for *M. kauki*. While, Gunung Kidul followed by Kulonprogo districts have the largest areas categorized as low suitable. To conclude, *M. kauki* can adapt areas with moderate precipitation as low as 20 mm during driest month and as low as 100 mm during driest quarter. During warmest quarter, *M. kauki* requires precipitation with value of 700 mm, Then for achieving optimum results, the conservation effort and planting of *M. kauki* should focus on Yogyakarta city and Sleman district since those areas considered has high suitability

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