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PREDICTING THE FUTURE DISTRIBUTIONS OF ENDEMIC RATTAN *Calamus javensis* BLUME UNDER CLIMATE CHANGE SCENARIOS CMIP 5 RCP 8.5 IN 2050 AND 2070 IN WEST JAVA

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HIGHLIGHTS

- Information on how climate change can shape *Calamus javensis* distributions is still lacking
- The study used SDM with RCP 8.5 scenario for the years 2050 and 2070
- Suitable habitats for *C. javensis* are expected to decline by approximately 46.34%
- Suitable habitats for *C. javensis* are expected to be concentrated in western parts of West Java

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ABSTRACT

Calamus javensis is an endemic rattan plant found in West Java. However, information on how climate change can shape C. javensis distributions and how C. javensis can cope with climate change conditions is still lacking. This information is required considering that C. javensis is an endemic plant in West Java. Then, the purpose of this study is to model the climate change impact on future C. javensis distributions. The study used species distribution modeling (SDM) covering nine locations across West Java with RCP 8.5 representing the most pessimistic climate change scenario for the years 2050 and 2070. The results indicated that under the scenarios of climate change, the only suitable habitats for C. javensis are expected to be concentrated in western parts of West Java. Over time, as climate conditions change, the areas deemed very highly suitable for C. javensis are projected to decline. Specifically, from 2050 to 2070, suitable habitats for C. javensis are expected to decline by approximately 46.34%, decreasing from 1,025 km^2 to 550 km^2. The decline of suitable areas will affect both organisms and local communities that depend on rattan. In the future, it is recommended to focus conservation efforts on the western parts of West Java, as indicated by the model showing these areas as suitable amid climate change.

Keywords: climate change, habitat, rattan, RCP, West Java

INTRODUCTION

In Asia, rattans are the main lianas that live in and spread throughout tropical rainforests. In temperate climates and other tropical and sub-tropical locations, rattans do not grow natively. One of the most significant non-wood forest products used in Asia as a substitute for timber is rattan, which is classified under the Arecaceae/Palmae family and belongs to the Calamoideae subfamily. Climbing plants in the Arecaceae family of palms are commonly referred to as rattan. Rattan is crucial to the community's ability to sustain its livelihood, particularly for the local population that depends on and uses forest resources. In Indonesia, the harvests of rattan are 485.92 tonnes per year with the value of IDR 1,200 per ton (Rinekso *et al.* 2019). There are currently over 600 rattan species in the world, divided into 13 genera, and almost all of them are utilized by the local population, albeit only approximately 50 of them are valuable commercially (Meitram & Sharma 2005). Rattan inhabits a wide variety of habitats, including peat swamps, mixed deciduous forests, evergreen and dry evergreen forests, and areas up to 1,000 meters measured from the sea surface (Rozali *et al.* 2014). Rattans play a vital part in the physiognomy of the tropical rainforest in Indonesia, but the country's most valuable commercial rattan species are already vulnerable because of climate change. According to Zhang *et al.* (2024), high climate warming, equal to 3 - 4.5 °C, can lead to mass death of these plant groups.

The most varied genus in the Arecaceae family and among all climbing plant genera is *Calamus*. The Old World characterized by humid tropics, which include Africa, much of Asia, Australasia, and portions of the Pacific including Fiji, are habitat for *Calamus*. In southeast Asian dense-canopy forests, where their dominance is a notable feature of Asian liana ecosystems, the genus *Calamus* achieves its highest level of diversity. An Indonesian rattan species that is indigenous to West Java is *Calamus javensis* Blume (Arecaceae: Calamoideae) (Mogea 2004). In actuality, nine of the thirteen genera in the globe are found in Indonesia (Guzman 2015). According to the numbers of species of each genus, the orders are 15 species for Calamus, 4 species for *Daemonorops*, 2 species for *Korthalsia* and *Ceratolobus*, 1 species for *Plectocomia*, followed by *Retispatha, Plectocomiopsis, Pogonotium*, and *Myrialepis* are the nine genera in discussion. *Daemonorops* and *Calamus* were two of those genera that were known to have commercial value. Locally, *C. javensis* was referred to as *rotan lilin* by the native populations that used it in its endemic regions.

Large-scale species distribution patterns, mainly those classified as plants and medicinal herbs, have recently been affected by climate change and levels of greenhouse gas (Zhang *et al.* 2024). The Intergovernmental Panel on Climate Change (IPCC) developed a series of climatic scenarios known as the Representative Concentration Pathways (RCP) following these levels of greenhouse gas. RCP 8.5 is characterized by high fossil fuel consumption, a significant increase in methane emissions, and a slow rate of technological development to mitigate the climate change effects, with no plans to reduce emissions. Therefore, the climate scenario under RCP 8.5 pathway is deemed suitable for modeling the impact of climate change on species distribution, according to Doulabian *et al.* (2021).

The current study has emphasized the importance of species dispersion in modeling. As a result, numerous methods have been established to analyze the distribution of species on a geographic scale. One widely used technique is machine learning-based Species Distribution Modeling (SDM), which estimates the potential spatial distribution of various organisms, including crops (Dong *et al.* 2023), vegetation (Sánchez Pérez *et al.* 2023), animals (Stephenson *et al.* 2022), and ticks. SDMs employ a variety of methods to assess habitat suitability, including Biomapper, Bioclim, and Domain using a climatic approach, and MaxEnt (Maximum Entropy) using a machine learning approach. Statistical approaches are represented by Generalized Additive Models (GAM) and Generalized Linear Models (GLM). Each machine learning tool has its own unique set of advantages and disadvantages. Following Marcer *et al.* (2013), Species Distribution Modeling (SDM) is one of the most popular and effective methods to model habitat suitability. Some of the advantages of SDM, as noted by Fois *et al.* (2018), include the capacity to determine the environmental factors having significant contributions, high precision of predictive results, reproducibility, the requirement for only species presence data, and its effectiveness in estimating the potential spatial distribution even with limited data.

C. javensis is an endemic plant in West Java. In addition, *C. javensis* plays a significant role in supporting local communities and forest

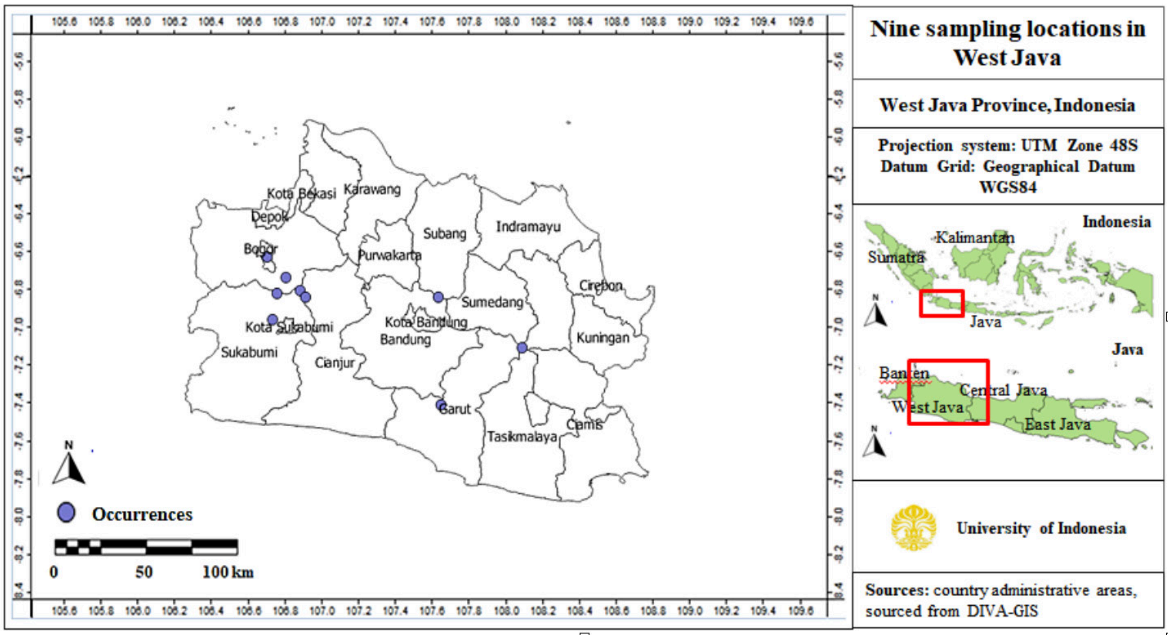

Figure 1 Nine sampling locations in West Java

conservation by supplying nontimber products (Rahim & Idrus 2019). While the information on how this species can cope with climate change and how climate change will limit the distribution of certain species is still lacking, this information is required in light of that *C. javensis* is an endemic plant in West Java. Then, this research sought to simulate the effects of climate change on future *C. javensis* distributions. The novelty of this study is using SDM and RCP 8.5 to simulate the effects of the most pessimistic climate change scenario.

MATERIALS AND METHODS

Study Area

The selected area of this study is in West Java Indonesia. West Java is divided into 18 districts and 9 cities (Fig. 1). Climate in West Java is varied following landscapes. The North and South of West Java were characterized by low land and coastal areas. While the central of West Java is characterized by mountainous areas. The lowest temperature is 9 °C and can reach 34 °C in the coastal regions. In the mountainous areas of West Java, the annual rainfall can range from 3,000 mm to 5,000 mm.

Survey on *Calamus javensis*

Survey activities were conducted over two months in 2024 at nine sampling locations throughout West Java (Fig. 1). The sampling sites were chosen based on the presence of natural habitats suitable for *C. javensis*. To document the presence of *C. javensis,* we utilized direct visual observation, known as the Visual Encounter Survey (VES), along with a database assembled from literature reviews, including scientific articles and official reports published by government organizations, such as the Indonesian Ministry of Environment and Forestry's agency for agriculture and forestry. VES was employed purposefully by surveying natural habitats including forests and plantations where *C. javensis* may grow. The surveys were established using ten plots randomly placed in each sampling location throughout West Java. Each plot measured 20 × 20 m, and it was divided into several square subplots. For detailed observation and recording of *C. javensis,* 20 × 20 m plots for adult rattan level, 10 × 10 m for pole level, 5 × 5 m for sapling level, and 2 × 2 m for rattan seedling level (Joshi *et al.* 2017). Global Positioning System (GPS) of Garmin Etrex 30 was utilized to retrieve the geocoordinate locations of *C. javensis* presences in the field. This information was saved in CSV format and then imported into Microsoft Excel for use in Species Distribution Modeling (SDM) habitat suitability analysis. Because presence-only data is widely available, a presence-only SDM was chosen rather than a generalized linear model (GLM). These methods are relatively easy to implement, requiring only the locations where a species has been observed, and can be useful when absence data is limited or unreliable (Leroy 2022). According to Jasni *et al.* (2007), the identification of *C. javensis* was based on specific identification keys using *C. javensis* diagnostic features, voucher specimens, and rattan taxonomist confirmation.

Table 1 Bioclimatic variables employed in this study

Variables	Sources	Format	Unit
Annual average temperature (Bio 1)*	www.worldclim.org	Data represented in raster format	^{0}C
Mean diurnal range (Bio 2) (mean of monthly (max temp - min	www.worldclim.org	Data represented in raster format	^{0}C
Isothermality (Bio 3)*	www.worldclim.org	Data represented in raster format	%
Seasonality of temperature (Bio 4)*	www.worldclim.org	Data represented in raster format	^{0}C
Warmest month maximum temperatu (Bio 5)	www.worldclim.org	Data represented in raster format	^{0}C
Coldest month minimum temperatur (Bio 6)	www.worldclim.org	Data represented in raster format	^{0}C
Annual range of temperature (Bio 7)	www.worldclim.org	Data represented in raster format	^{0}C
Wettest quarter average temperature (Bio 8)	www.worldclim.org	Data represented in raster format	^{0}C
Driest quarter average temperature (Bio 9)	www.worldclim.org	Data represented in raster format	^{0}C
Warmest quarter average temperatur (Bio 10)	www.worldclim.org	Data represented in raster format	^{0}C
Coldest quarter average temperature (Bio 11)*	www.worldclim.org	Data represented in raster format	^{0}C
Precipitation per year (Bio 12)*	www.worldclim.org	Data represented in raster format	mm
Wettest month rainfall (Bio 13)*	www.worldclim.org	Data represented in raster format	mm
Driest month rainfall (Bio 14)*	www.worldclim.org	Data represented in raster format	mm
Seasonality of rainfall (Bio 15)	www.worldclim.org	Data represented in raster format	dimension less
Wettest quarter rainfall (Bio 16)*	www.worldclim.org	Data represented in raster format	mm
Driest quarter rainfall (Bio 17)*	www.worldclim.org	Data represented in raster format	mm
Warmest quarter rainfall (Bio 18)*	www.worldclim.org	Data represented in raster format	mm
Coldest quarter rainfall (Bio 19)*	www.worldclim.org	Data represented in raster format	mm

Note: * = Some variables were selected based on multicollinearity tests including Bio 1, 2, 3, 4, 7, 11, 12, 13, 14, 16, 17, 18, and 19.

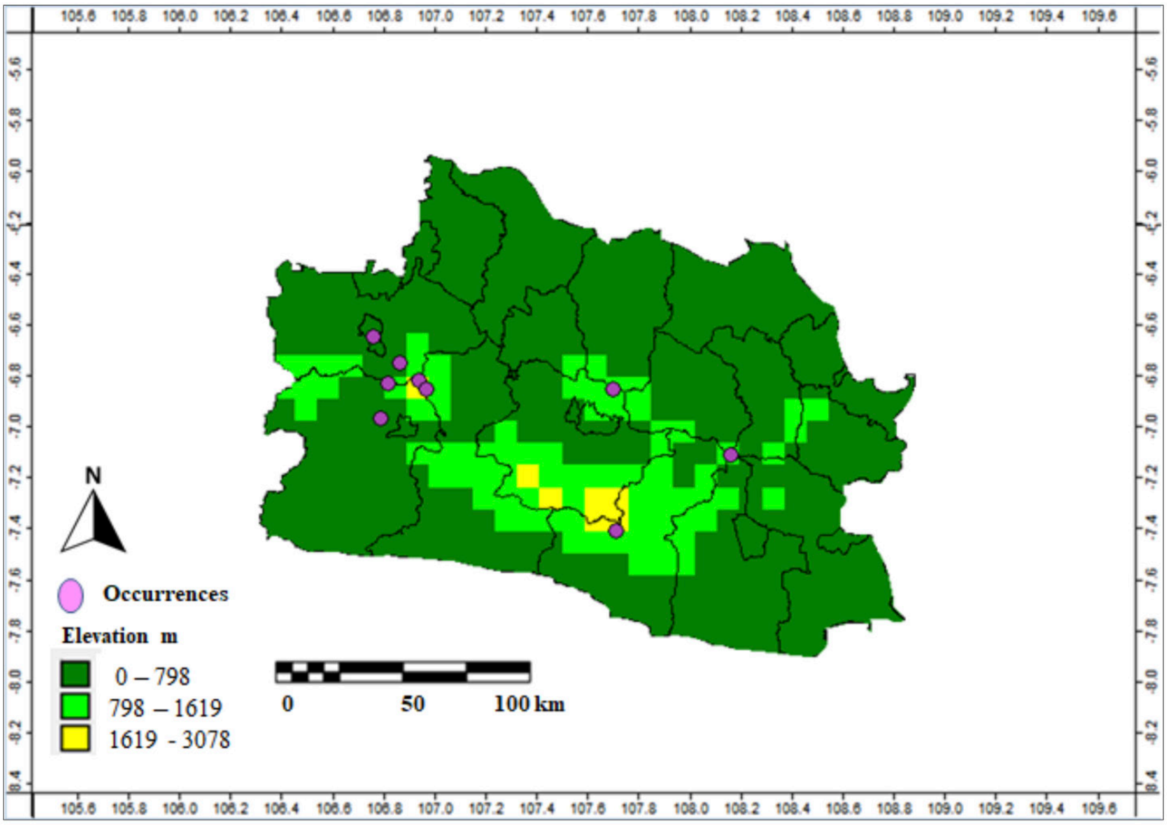

Figure 2 *Calamus javensis* occurrences related to elevation in West Java

Calamus javensis Bioclimatic Variables

This study examined a range of bioclimatic factors in line with the methods described by Dong *et al.* (2023) and Arshad *et al.* (2022) (Table 1). Particularly in Asia, as highlighted by Khanum *et al.* (2013) and Rana *et al.* (2017), bioclimatic variables (Bio 1 - Bio 19) from the global climate database WorldClim (www.worldclim.org, version 2.0) (Hijmans *et al.* 2005) have been widely utilized in modeling the habitat appropriateness at current time. The locality data of West Java was obtained from the WorldClim database by setting the region of interest.

The selection and analysis of environmental factors that significantly impacted the results led to the inclusion of specific bioclimatic variables, aimed at producing an informative and precise model of habitat suitability. A Jackknife analysis was conducted to assess each bioclimatic variable's contribution to the finished model. Several environmental factors identified in the Jackknife analysis were excluded from the model because they had no effect (0% contribution). Wei *et al.* (2018) noted that some bioclimatic variables exhibited minimal permutation relevance (less than 6%) or a low average contribution (also less than 6%). Therefore, two critical components for understanding and measuring the importance of bioclimatic variables used in developing the model of species distribution (SDM) are the percentage of contribution and permutation relevance.

Calamus javensis Suitability Analysis

This study utilized species distribution modeling using machine learning approach (SDM) techniques within R application version 3.6.3 to generate estimated suitable maps for *C. javensis* in West Java and its surrounding areas (Mao *et al.* 2013). The maps of suitability were created using various R packages, including sp, dismo (Khan *et al.* 2022), map tools, rgdal (Bivand 2022), and raster (Lemenkova 2020). Nineteen environmental variables (Bio 1 - Bio 19) served as inputs for the SDM. The area under the Receiver Operating Characteristic curve (AUC) was employed to evaluate the model's performance. Additionally, the Jackknife test was conducted to determine each environmental variable's contribution and impact on the habitat suitability model for *C. javensis* (Promnikorn *et al.* 2019). The AUC values below 0.5 indicate that the model has performance no better than random or contains vague data, while values above 0.5 suggest that the model is

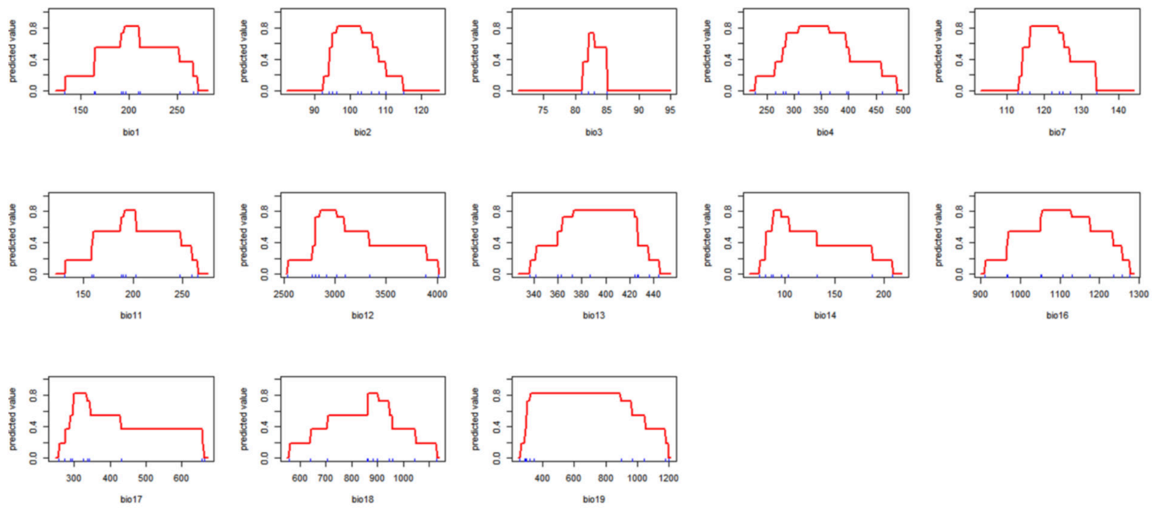

Figure 3 Response curves of *Calamus javensis* associated with bioclimatic variables in West Java

highly effective and precise. The AUC value has a range of 0 - 1, with 0 representing the lowest appropriateness and 1 the highest. Geographic Information Systems (GIS) were utilized to visualize and analyze the maps of prediction generated by the Species Distribution Models (SDM) (Hijmans *et al*. 2005). Based on Wei *et al.* (2018), five levels of habitat suitability can be identified on the SDM model map: 0 signifies unsuited, 1 indicates the suitability is low, 2 denotes the suitability is moderate, 3 represents the suitability is high, and 4 indicates the suitability is very high.

CMIP 5 Future Scenario

This investigation utilized two scenarios. The first scenario represents the current state in 2023, while the second scenario projects future conditions based on the RCP 8.5 projections from the Fifth Coupled Model Intercomparison Project (CMIP) for the years 2050 and 2070. The future scenario is based on the Intergovernmental Panel on Climate Change's Fifth Assessment Report (AR5) from 2008, which incorporates downscaled data from global climate models in CMIP5. The IPCC's 2014 AR5 report adopted several Representative Concentration Pathways (RCPs) for CMIP5, focusing on variations in levels of greenhouse gas instead of levels of emissions. This new method has replaced the previous projections from the Special Report on Emissions Scenarios (SRES), published in 2000 (van Vuuren *et al.* 2009). Based on the expected release of greenhouse gases shortly, these pathways outline four credible future climate scenarios for modeling and research. According to Weyant *et al.* (2009), the four Representative Concentration Pathways (RCPs), RCP2.6, RCP4.5, RCP6.0, and RCP8.5, are named according to their projected ranges of radiative forcing values in 2100 relative to pre-industrial levels (+2.6, +4.5, +6.0, and +8.5 W/m², respectively). To forecast the suitable habitat distributions of *C. javensis* for the years 2050 and 2070, this study employed the RCP8.5 models, which correspond to different climate change scenarios.

RESULTS AND DISCUSSION

Occurrences and Bioclimatic Variables of *Calamus javensis*

Our study showed a total of nine current occurrences of *C. javensis* across West Java (Fig. 2). At the current time, 33.33% of *C. javensis* occurrences were observed in highland landscapes. Those highland landscapes have elevations with a range of 1,619 - 3,078 m above sea level and are located in Garut and between Sukabumi and Cianjur. While 33.33% of *C. javensis* occurrences were observed in lowland landscapes at elevations having a range of 0 - 798 m above sea level. Then, in general, the preferred current habitats of *C. javensis* were dominated by highlands with an elevation range of 798 - 3,078 m above sea level. According to regions, *C. javensis* was very common in Bogor, Sukabumi and Cianjur in comparison to other regions.

The response curves of *Calamus javensis* associated with the chosen bioclimatic variables in West Java is presented in Figure 3, while Figure 4 shows numerous bioclimatic variables that have

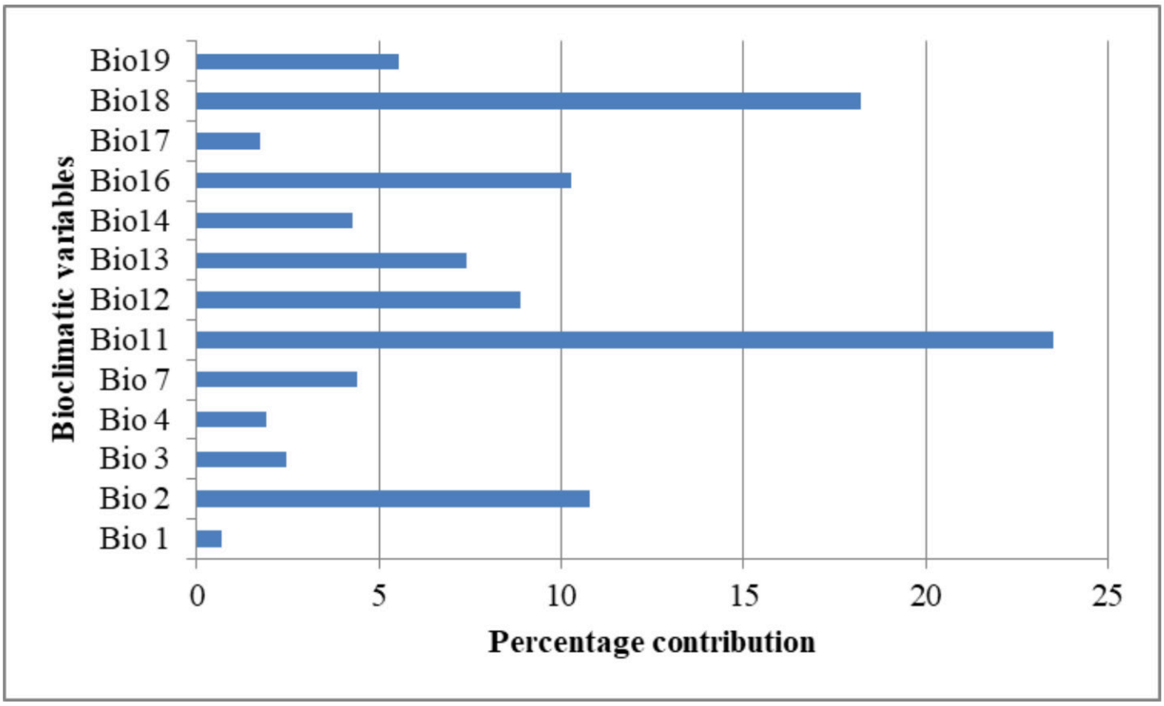

Figure 4 Percentage contribution of Calamus javensis related to bioclimatic variables in West Java

more contributions to the distributions of *C. javensis* in West Java. Those bioclimatic variables were Bio 11, 18, 2, and 16. Bio 11 which is the coldest quarter average temperature variable indicated that the *C. javensis* prefers habitats having temperature range from 12.5 °C to 24.0 °C (Fig. 3). In regard to precipitation, Bio 18 variable indicated that *C. javensis* prefers habitats which have precipitation of the warmest quarter from 70 mm to 105 mm. Meanwhile, Bio 2 variable indicated that the preferred temperature mean range is 9.0 - 11.5 °C. This narrow range of Bio 2 value is related to the endemism of C. javensis, which can only inhabit limited areas. The Bio 16 variable confirms that the preferred precipitation of the wettest quarter is from 100 mm to 120 mm. High rainfall preferences during the peak of rainy season indicates that the distribution of *C. javensis* is limited to the mountainous areas where heavy rainfall is common.

In our study, current distributions of *C. javensis* were widespread, from highlands in mountainous areas to the lowlands around Bogor. This is in agreement with the findings reported in the previous studies. In Cameroon, *Calamus* resides in elevation with a range of 400 - 1,000 m. In Malaysia, rattan species were recorded ending from an elevation of less than 300 m to 600 m. The rattan species reach high abundance at an elevation of 600 m. In Central Kalimantan, *C. javensis* was observed residing in the lowlands in the peatland areas (Fambayun *et al.* 2022). While *C. javensis* was known to be common in highlands, as reported on Mount Halimun, West Java (Watanabe *et al.* 2006), Kalima (2015) has reported that *C. javensis* can inhabit areas with an elevation as low as 2 m and as high as 1,200 m above sea level. In West Java, it is widely distributed in the high-elevation areas, including Halimun-Salak and Gede-Pangrango areas. Besides, *C. javensis* is also recorded in the lowland parks, including in Ujung Kulon. This documented distribution explained the current presence of *C. javensis* in Sukabumi and Cianjur as parts of the Halimun-Salak and Gede-Pangrango areas. The wide current distribution of *C. javensis* was related to the seed dispersion that was facilitated by birds and primates allowing wider distributions (Kalima 2022).

Current and Future Distributions of *Calamus javensis*

The model of *Calamus javensis* current distributions in West Java is presented in Figure 5. Based on the estimations, *C. javensis* was common in the southern regions of West Java, covering Cianjur, Sukabumi, Garut, Bandung, and Bogor Districts. Areas categorized as having very high potential suitability were mostly recorded in Cianjur. Meanwhile, areas classified as high suitability were mostly recorded in Sukabumi and Bandung and small parts in the Bogor bordering Sukabumi and Cianjur.

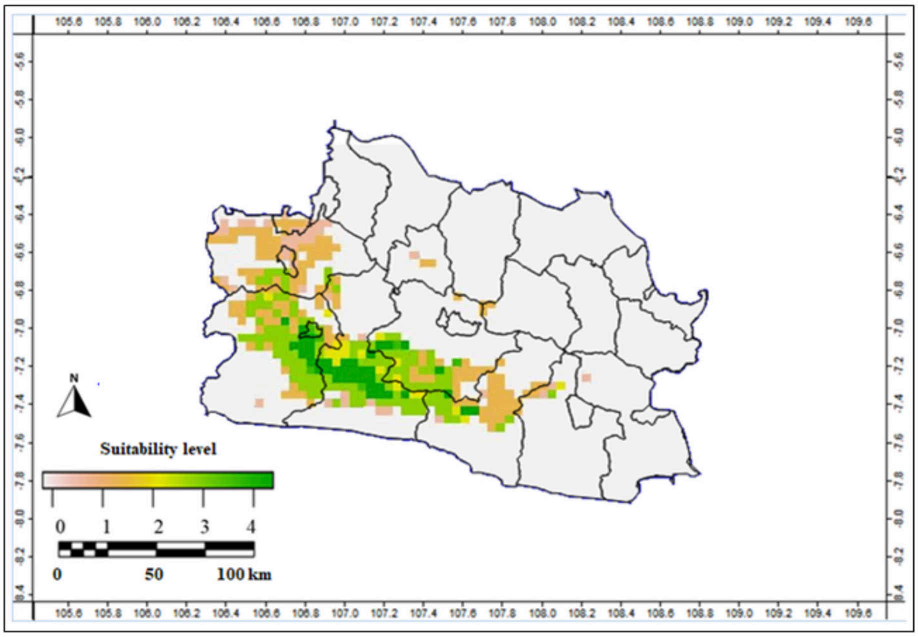

Figure 5 Model of *Calamus javensis* current distributions in West Java

Notes: Suitability level 0 = unsuitable; 1 = low suitability; 2 = medium suitability; 3 = high suitability; 4 = very high suitability.

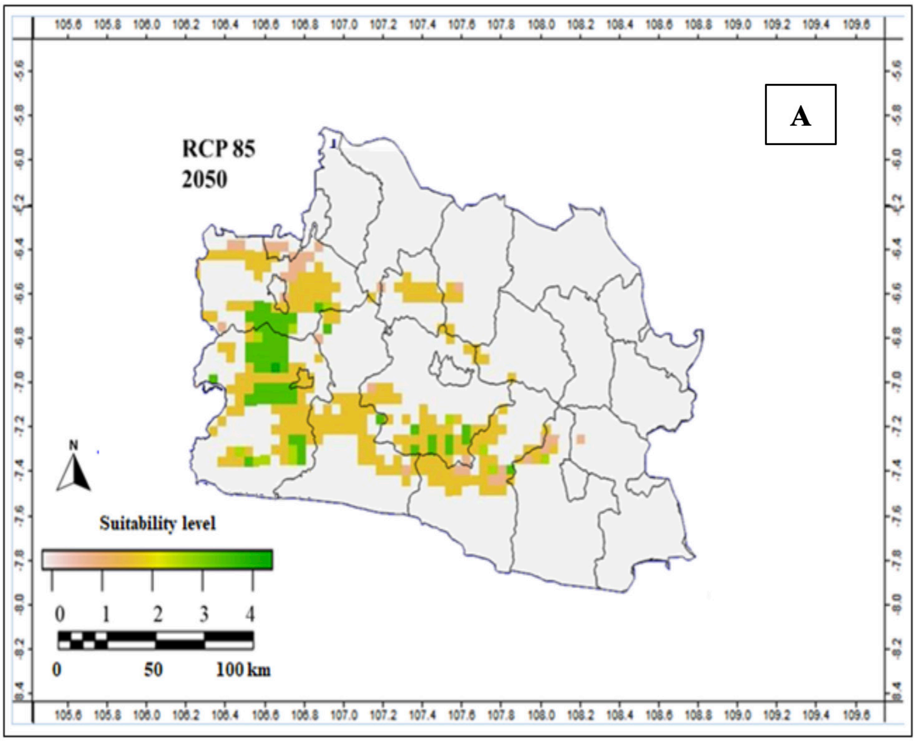

Figure 6 Model of *Calamus javensis* distributions in 2050 (A) and 2070 (B) related to RCP 8.5 scenario in West Java

Notes: Suitability level 0 = unsuitable; 1 = low suitability; 2 = medium suitability; 3 = high suitability; 4 = very high suitability.

Table 2 Comparisons of bioclimatic variables with other studies on *Calamus*

Species	Bioclimatic variable	Percentage contribution	Location	Source
C. lakshmanae	Annual precipitation Max temperature of warmest month	65.4 1.4	Western Ghats	Sreekumar & Sasi 2019
C. javensis	The mean temperature of the coldest quarter Precipitation of the warmest quarter	23.49 18.19	West Java	This study

The models of *Calamus javensis* distributions in West Java under RCP 8.5 climate change scenarios for years 2050 and 2070 are shown in Figure 6. Based on the estimations, it is observed that climate change has impacted the *C. javensis* distributions. According to the model, climate change has made suitable habitats for *C. javensis* in Cianjur, Garut, and Bandung disappear. The only remaining suitable habitats would probably be in Sukabumi. Within 20 years, between the year of 2050 and 2070, it is clear that the remaining suitable habitats for *C. javensis* classified as having very high suitability will be reduced by 46.34% from 1,025 to only 550 km^2 in 2070. Also, in 2070, it is predicted that *C. javensis* would possibly reside in southern parts of Sukabumi. This area is considered a novel area that has never been existed under the current *C. javensis* distributions. The novelty of these newly predicted areas is that the southern Sukabumi is a lowland and coastal area. Although the current distributions of *C. javensis* are mostly in highland areas, there is a possibility that this species would occupy coastal areas with low elevation. In South Kalimantan, Arifin (2008) observed that *C. javensis* was common in lowland forests and this supports the possibility of *C. javensis* to inhabit low coastal areas. In Malaysia, rattans were observed to reach high abundance in the offshore areas.

This study is the first to explore the potential dispersal of *C. javensis* in specific regions of Southeast Asia. It is comparable to similar habitat suitability studies implemented in other areas, such as Assam (Mehmud *et al.* 2022) and the Western Ghats in India (Sreekumar & Sasi 2019). The findings indicate that temperature and rainfall during the warmest quarter are significant bioclimatic variables affecting the distribution of this species. This aligns with previous research (Table 2). Sreekumar and Sasi (2019) noted that the dispersal of *Calamus* species is primarily affected by several factors, such as latitude, the driest quarter precipitation, total annual rainfall, and the coldest month minimum temperature. Overall, climate plays a more critical role than habitat or human effect in shaping the potential distributions of *Calamus* species. Most rattan species tend to prefer humid climates, making rainfall a key factor influencing the distribution at the landscape scale of these potential *Calamus* species.

This study confirmed that the climate change presented in the form of bioclimatic variables change the shape and alter the potential distribution area of the *Calamus*. Combined with the changes in climatic key variables, ranging from temperature to rainfall and seasonality, ongoing increments and changes in atmospheric greenhouse gases, mostly carbon dioxide (CO_2), influence and affect the growth and physiology of plants, including *Calamus*. Mainly in the tropics, increasing levels of CO_2 have the potential to increase the growing season leaf area. In addition, elevated CO_2 levels are associated with increased water use efficiency, increased photosynthesis rate, and increased root and stem growth of *Calamus*. It seems likely that elevated CO2 have a positive effect on the growth, development, and physiology of *Calamus*. This explained the presence of *Calamus* in the area that had never been recorded before, as reported in this study. While not all palm species benefit from the climate change effects, Buttler and Larson (2019) recorded that only one out of four species of palms are benefitted due to climate change. Others are remained stable and other are slightly increase. This condition is relevant to the condition and explains that the *Calamus* in this study has various reactions to the climate change effects.

Calamus is a plant that belongs to the Arecaceae family. The climate change influence on the dispersal and presence of species in the Arecaceae group, or palms, has been validated by earlier reports. Palms have been used as markers for the previous paleoclimate linked to the megathermal because of their sensitivity (Buttler & Larson 2019). For palm species, temperature combined with palm dispersal capacity regulates palm presence. Since the beginning of the Quaternary period in the western hemisphere, palms have been observed to exist and disappear, which also contributes to extinction. It is thought that the existence of climate oscillations is what caused these historical occurrences, which occurred about 2.6 million years ago.

Important details regarding *Calamus* management, cultivation, and conservation, primarily in West Java, are provided by the anticipated appropriate habitat for *Calamus* in the future. Commercial *Calamus* cultivations can be established and applied using the results. It has been noted that the *Calamus* continues to live in its current habitat and maintain its natural range. *Calamus* is spreading to the new habitat areas at the same time. This study suggests creating and maintaining natural corridors in conjunction with large-scale forestry-protected areas. In addition to this strategy, the establishment of germplasm banks is advised in order to manage and preserve these significant endemic rattan species mainly in West Java regions.

This study has succeeded in using 13 bioclimatic variables as the determinant factors that have effects on the dispersals of this certain species. In the future, the approach to the appropriate distribution of rattan is recommended to be developed by incorporating more determinant variables, including environmental variables and rattan seed dispersal facilitated by winds, birds and primates. Those variables are recommended to be incorporated with the edaphic, topographic, and even anthropogenic variables.

CONCLUSION

At the present time, it is estimated that *C. javensis* is widely distributed in the southern parts of West Java, with areas expanding from Garut in the east, Bandung in the central, and Cianjur and Sukabumi in the west. The climate change scenario with emissions of 8.5 W/m^2 is projected to reduce the current suitable habitats for *C. javensis* so that the only suitable habitats for *C. javensis* would be concentrated in Sukabumi. Within the time series and climate change scenarios, the potential habitats categorized as highly suitable for *C. javensis* are estimated to decline by around 46.34%, from 1,025 to only 550 km^2 in 2070.

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