Agr. Nat. Resour. 57 (2023) 343–352

AGRICULTURE AND NATURAL RESOURCES

Journal homepage: http://anres.kasetsart.org

Research article

Diversity, ecology and habitat suitability of *Gigantochloa* in Central Sumatra

M Farid Syauqi[a,†], Tatik Chikmawati[b,*], Fitmawati[c,†], Nunik Sri Ariyanti[b,†]

[a] *Plant Biology Graduate Program, Department of Biology, Faculty Mathematics and Natural Science, IPB University, Bogor 16680, Indonesia*

[b] *Department of Biology, Faculty Mathematics and Natural Science, IPB University, Bogor 16680, Indonesia*

[c] *Department of Biology, Faculty Mathematics and Natural Science, Riau University, Pekanbaru 28293, Indonesia*

Article Info

Article history:
Received 21 July 2022
Revised 3 April 2023
Accepted 19 April 2023
Available online 30 April 2023

Keywords:
Bamboo diversity,
Distribution,
Endemic species,
Gigantochloa,
Habitat suitability

Abstract

Importance of the work: Sumatra Island, with 76 species of bamboo, is the center of bamboo biodiversity in Indonesia.

Objectives: *Gigantochloa* species diversity was investigated and environmental factors analyzed to create prediction maps of species distribution and habitat suitability.

Materials & Methods: The *Gigantochloa* samples were collected from various habitats in Central Sumatra. The horizontal distribution was mapped using the QGIS 3.20.2 software, while the vertical distribution was analyzed using the Past 4.03 software. Correlations between species and environmental factors were subjected to canonical correspondence analysis using the CANOCO 4.5 software and habitat suitability was analyzed using the MaxEnt package.

Results: Fourteen species of *Gigantochloa* were identified from Central Sumatra, one of which was *G. kuring*, which is endemic to Sumatra. *Gigantochloa* was distributed from the lowlands up to 1,367 m above sea level. The distribution of *Gigantochloa* was influenced mostly by soil pH, soil moisture, wind and light. Analysis using MaxEnt indicated habitat that was suitable for *Gigantochloa* in Central Sumatra, with an area under the curve value of 0.851. Mapping showed Central Sumatra had suitability levels of high (5.9%), moderate (8.1%), low (21.7) and unsuitable (64.7%). The endemic *G. kuring* had the highest habitat suitability in Jambi province.

Main Finding: The collected information could be used to determine the best locality for further investigation regarding the diversity and taxonomy of *Gigantochloa* and as basic data to determine appropriate strategies to protect *Gigantochloa* habitats, especially for endemic species.

† Equal contribution.

* Corresponding author.
E-mail address: tatikch@apps.ipb.ac.id (T. Chikmawati)

online 2452-316X print 2468-1458/Copyright © 2023. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/), production and hosting by Kasetsart University Research and Development Institute on behalf of Kasetsart University.

https://doi.org/10.34044/j.anres.2023.57.2.14

Introduction

Indonesia has 176 species of bamboo, of which 105 species are endemic (Widjaja, 2019). The species richness of bamboo in Indonesia may increase if more intensive exploration is carried out, especially on the many small islands in Indonesia (Widjaja, 2001a). Sumatra Island, which has about 76 species, is the center of bamboo biodiversity and has the largest number of endemic species in Indonesia (Widjaja, 2019). However, there are still many habitats in Sumatra where bamboo species have not been investigated; one such area is in Central Sumatra that includes three provinces: Riau, West Sumatra and Jambi. Central Sumatra potentially has high bamboo species diversity because it has many riverbanks and mountainous areas that could be suitable habitats for bamboo.

Many bamboo species are threatened due to deforestation or conversion of watershed land use into agricultural and residential land (Hakim et al., 2002). Based on data from the Ministry of Environment and Forestry (2019), deforestation in Sumatra is the second highest after Kalimantan and had the largest area of damage (89,700 ha) in 2017–2018. Currently, the central part of Sumatra is also experiencing deforestation and land conversion, causes forest area loss. This situation threatens the diversity of existing plants, especially bamboo species.

Species of the genus *Gigantochloa* are distinguished from those of *Dendrocalamus* based on several characteristics, such as erect culms with internodes at the base of the culm that are relatively longer, stamens that form tubes, green culm sheaths, the base of the culm has aerial roots and the culm sheaths have black hairs and small auricles (Widjaja, 1997). *Gigantochloa* distributes across South and Southeast Asia. Its species distribution in the west of Indonesia has been recorded in Manokwari (Irian Jaya) and on the Yapen Islands (Widjaja, 1997). Often, *Gigantochloa* is found along streams, in lowland humid tropical forests and in mountain forests below 1,500 m above sea level (asl), according to Clark et al. (2015).

Exploration of bamboo diversity has been carried out in the central part of Sumatra and its surroundings, where *Gigantochloa* has been found along the coast in the east in Riau province and throughout the highlands in the west in Bukit Barisan, Jambi province (Fitmawati et al., 2020). However, further exploration needs to be carried out more intensively in many areas to obtain information on species diversity and distribution and possibly to discover new species. In addition, the bamboo population in nature is declining due to habitat disturbance and the over-exploitation of uncultivated bamboo.

Gigantochloa conservation management requires data on not only species diversity and distribution but also environmental factors that have the most influence on its distribution. The distribution of plant species has been predicted using modeling produced by software such as the Maximum Entropy (MaxEnt) package (Yang et al., 2013). Such modeling can be used to determine potential habitats for plants based on environmental factors, thereby helping to improve conservation and cultivation efforts (Xu et al., 2018). MaxEnt is one of the best and most widely used software packages to generate habitat suitability models. It has several advantages, including requiring only the presence of type data, running using only small datasets, having high prediction accuracy and predicting the most influential environmental factors (Fois et al., 2018).

The aims of the current study were to reveal the species diversity of *Gigantochloa* in Central Sumatra, to analyze environmental factors that influence its existence, to draw a distribution map of the species and to predict areas in Central Sumatra with a high level of suitability for *Gigantochloa*.

Materials and Methods

Research time and study area

This research was carried out from August 2021 to July 2022. The exploration work was carried out in various bamboo habitats in Central Sumatra in Riau province, West Sumatra province and Jambi province. Central Sumatra covers approximately 177,000 km^2 and has suitable habitat for *Gigantochloa*, including lowlands, highlands and mountainous areas, especially on the Bukit Barisan plateau, which has a high diversity of plants (Fitmawati et al., 2020). Based on the vegetation types and altitudinal range, the Central Sumatra region can be divided into five natural habitats: coastal forest, lowland rainforest, highland forest, submontane forest and montane forest. Several large rivers run through the Central Sumatra Region, such as the Batanghari River upstream in West Sumatra and its estuary in Jambi, while the Kampar, Siak, Rokan and Indragiri Rivers flow through Riau province.

The specimens collected were prepared for the herbarium, identified and characterized at the Botanical Laboratory of FMIPA Riau University, Laboratory of Ecology and Plant Resources, Department of Biology, Indonesia. Herbarium specimens were deposited in Herbarium Bogoriense (BO), Indonesia.

Sampling, identification and observation of morphological characteristics

Sampling of *Gigantochloa* was carried out by exploring areas following the method of Rugayah et al. (2004). Samples collected for voucher specimens consisted of roots, culms, leaves, shoots, leaves and flowers (if available). Samples were documented in detail using a camera before being collected. Herbarium specimens were made according to the standard method (Djarwaningsih et al., 2002).

The coordinates of the location where each sample was found were recorded using a global positioning system unit (Garmin 64S). This information was used to produce a distribution map of each species. Observation of morphological characteristics and identification referred to several references in the literature (Widjaja, 1987, 1997, 2001a, b; Widjaja and Karsono, 2005). The important characteristics observed for identifying bamboo species were the color of the bamboo shoots; the branching system, the culm sheath (including auricle, blade, bristle and ligule) and the leaf (including auricle, bristle, ligule and leaf blade).

Environmental data collection

Environmental data were collected at the points where species of *Gigantochloa* were found, consisting of: soil moisture, soil pH, air temperature, air humidity, wind speed and light intensity. These data were measured using a 4-in-1 Lutron LM-8000 environmental measuring instrument (Lutron Electronic Enterprise Co., Ltd.; Taiwan), except for the soil moisture and pH, which were taken using a soil tester-type Fosmon 3-in-1 soil tester (Fosmon Inc.; USA).

Abiotic data (data on environmental physical factors) that may have been important in determining the survival of *Gigantochloa* were collected and used in the habitat suitability modelling. These data were obtained from the global climate database, WorldClim (latest version 2.0, available at www.worldclim.org), consisting of altitude and 19 bioclimatic variables: annual mean temperature (bio1), mean diurnal range (bio2), isothermality (bio3), temperature seasonality (bio4), maximum temperature of the warmest month (bio5), minimum temperature of the coldest month (bio6), annual temperature range (bio7), mean temperature of the wettest quarter (bio8), mean temperature of the driest quarter (bio9), mean temperature of warmest quarter (bio10), mean temperature of coldest quarter (bio11), annual precipitation (bio12), precipitation of wettest month (bio13), precipitation of driest month (bio14), precipitation seasonality (bio15), precipitation of wettest quarter (bio16), precipitation of driest quarter (bio17), precipitation of warmest quarter (bio18) and precipitation of coldest quarter (bio19). In addition, the analysis used land cover data and distances of *Gigantochloa* locations from rivers, obtained from the Geospatial Information Agency (http://tanahair.indonesia. go.id/portal-web).

Data analysis

The coordinates for each *Gigantochloa* location were transferred to Microsoft Excel (Microsoft Corp; USA) and saved in "CSV" format and then processed using the Quantum Geographic Information System (QGIS) software (Version 3.20.2; Free Software Foundation Inc.; USA) to construct a distribution map of *Gigantochloa* in Central Sumatra. Data on the altitudinal location of each species were processed using the Past software (Version 4.5; Natural History Museum.; Norway) to present the vertical distribution. Correlations between the presence of *Gigantochloa* and the environmental factors (soil moisture, soil pH, air temperature, humidity, wind speed and light intensity) were computed using principal component analysis using canonical correspondence analysis (CCA) in the CANOCO software (Version 4.5; Microcomputer Power Inc.; USA) and presented in graphical form.

The suitability of habitat for *Gigantochloa* was analyzed using the MaxEnt software (Version 3.4.3; Center for Biodiversity and Conservation (CBC) at the American Museum of Natural History; USA; Phillips et al., 2017) based on the presence of *Gigantochloa* and the bioclimatic variables that were used as predictors. All environment variables used the continuous format, except for land cover which used the categorical format in the main menu of the MaxEnt software. The jackknife test has been used to select the most influential bioclimatic variables for modelling (Worthington et al., 2016). This test determines the contribution of each variable, with variables having less than 6% contribution being omitted in the initial model (Wei et al., 2018). The selected variables were used to build the model distribution of suitable habitats for *Gigantochloa* in Central Sumatra.

Validation of the distribution model was performed based on the area under the curve (AUC) value produced by the MaxEnt software. The model is accepted when the AUC value meets the criteria of the receiver operating curve (ROC), which is the standard method for identifying the predictive accuracy of distribution models (Lobo et al., 2008). The AUC value ranges from 0 to 1, with values below 0.5 indicating inappropriate modelling, while values of 1 indicate excellent and informative modelling (Zhu et al., 2017). The distribution

models were relayed to create a map presenting the level of habitat suitability using the QGIS 3.20.2 software. The level of habitat suitability produced by MaxEnt can be divided into four categories: least (0–0.2), low (0.2–0.4), medium (0.4–0.6) and high (0.6–1), according to Wei et al. (2020).

Results and Discussion

Diversity of Gigantochloa in Central Sumatra

In total, 11 known species and three unknown species of *Gigantochloa* were identified from the sampling in the central part of Sumatra, namely *G. achmadii, G. apus, G. atroviolaceae, G. atter, G. hasskarliana, G. kuring, G. levis, G. nigrociliata, G. pruriens, G. scortechinii, G. serik* and three unknown species (*G.* sp1, *G.* sp2 and *G*, sp3), which could represent new species (Fig. 1). *G. kuring* is endemic to Sumatra; however, this species has only been recorded in Riau and Jambi provinces (Widjaja, 2019) and has been conserved *ex-situ* in the Bogor Botanical Gardens, Java and in the Eka Karya Bali Botanical Gardens, Bali (Widjaja, 1997). The main character that distinguishes *G. kuring* from others is its culms which have yellow strips, green shoots with yellow to pinkish stripes, low rim-like auricles of the culm leaf with long bristles, short ligule with short bristles and small and rounded leaf sheath auricles with the extension curved inward (Widjaja, 1997). The diversity of *Gigantochloa* species in Central Sumatra covers about 60% of the total species in Sumatra, as, based on the site https://powo.science.kew.org/, 31 species of *Gigantochloa* have been recorded in Indonesia, 23 of which were found in Sumatra (Widjaja, 1987, 1997, 2019).

Current distribution of Gigantochloa

Based on the horizontal distribution (Fig. 2A), the species diversity of *Gigantochloa* was mostly concentrated in the western part of the Central Sumatra area. Although several species have been found on other islands of Indonesia, several species have restricted distribution, being found only in one or two explored provinces; for example, *G. apus* and *G. levis,* which are found only in Riau province. *G. apus* is an introduced species to Sumatra; it was brought by a forestry team from IPB in 1970 and planted in a transmigration area in Riau Province (Widjaja, 1987). *G. kuring* is an endemic species to Sumatra, since it occurs only in the central part of Sumatra, especially in Jambi province (Widjaja, 2019).

Gigantochloa in Central Sumatra was found in lowlands up to 1,367 m asl, as shown in Fig 2B. This result was consistent with another report that *Gigantochloa* was found from lowlands to highlands in the Malesian region (Widjaja, 1987). Some species of *Gigantochloa* in the central part of Sumatra, such as *G. hasskarliana, G. apus,* and *G. levis,* were found only in lowlands (0–150 m asl), while other species were distributed further up to the highlands. *Gigantochloa atter* could be found at the highest altitude (up to 1,367 m asl). The highest distribution of *G. atter* was in Nagari Aie Dingin, Lembah Gumanti district, Solok regency, West Sumatra province. *Gigantochloa atter* usually occurs in lowlands in the altitude range 15–756 m asl in Lombok (Damayanto et al., 2020). The distribution of *G. atter* in the highlands (up to 1,367 m asl) in Solok regency is related to human activities, where this species has been used for agricultural tools, bridges and building temporary houses in gardens (Widjaja, 1987).



Fig. 1 *Gigantochloa* identified from Central Sumatra: (A) *G. achmadii*; (B) *G. apus*; (C) *G. atroviolacea*; (D) *G. atter*; (E) *G. hasskarliana*; (F) *G. kuring*; (G) *G. levis*; (H) *G. nigrociliata*; (I) *G. pruriens*; (J) *G. scortechinii*; (K) *G. serik*; (L) *G.* sp1; (M) *G.* sp2; (N) *G.* sp3

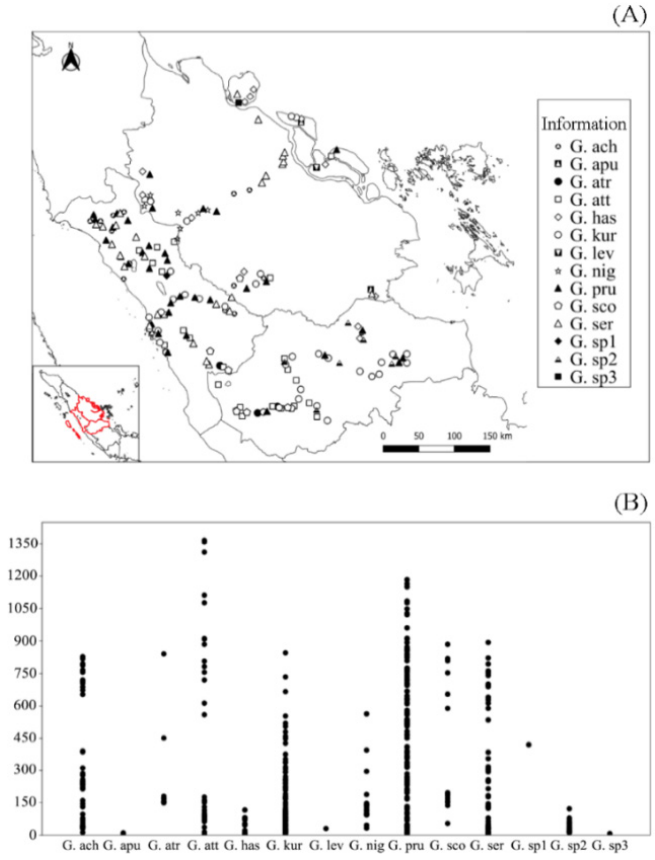


Fig. 2 Distribution of *Gigantochloa* in Central Sumatra: (A) horizontal distribution; (B) vertical distribution, where the legend entries G. ach = *G. achmadii*; G. apu = *G. apus*; G. atr = *G. atroviolacea*; G. att = *G. atter*; G. has = *G. hasskarliana*; G. kur = *G. kuring*; G. lev = *G. levis*; G. nig = *G. nigrociliata*; G. pru = *G. pruriens*; G. sco = *G. scortechinii*; G. ser = *G. serik*; *G*. sp1 = *G*. sp1; *G*. sp2 = *G*. sp2 and *G*. sp3 = *G*. sp3

Environmental factors of Gigantochloa in Central Sumatra

Environmental factors are the most important variables determining the presence of *Gigantochloa* in Central Sumatra, as shown in the CCA in Fig. 3. Table 1 shows the environmental factors in the three provinces of Central Sumatra. The environmental factors show that Central Sumatra is a suitable habitat for *Gigantochloa*. According to Takano et al. (2017), bamboo is scarcely found at temperatures below 20 °C. *Gigantochloa* in Central Sumatra grows in habitats that have neutral soil acidity (pH 7). On the other hand, Shi et al. (2020) suggested that *Gigantochloa* is also able to grow in acid soil.

The CCA results showed that the soil pH, soil moisture, wind speed and light intensity were positively correlated with the presence of *Gigantochloa* species, especially *G. atter, G. scortechinii, G. kuring, G. pruriens, G. achmadii, G. atroviolacea* and *G. serik*. Light intensity has an important role in plant growth and development since it influences the basic processes of photosynthesis, respiration and transpiration (Clark et al., 2015). It may also affect plant morphology and anatomy (Banik, 2015). *Gigantochloa*, which grow in the shade, has wider leaves, a thinner epidermis and more stomata (Legi et al., 2021).

Based on the CCA, the presence of *G. scortechini* and *G. kuring* was strongly influenced by soil moisture. Soil moisture may affect the growth of the rhizomes and shoots. Banik (2015) reported that bamboo rhizomes were shorter in size and abnormally shaped when grown on low-permeability soils.

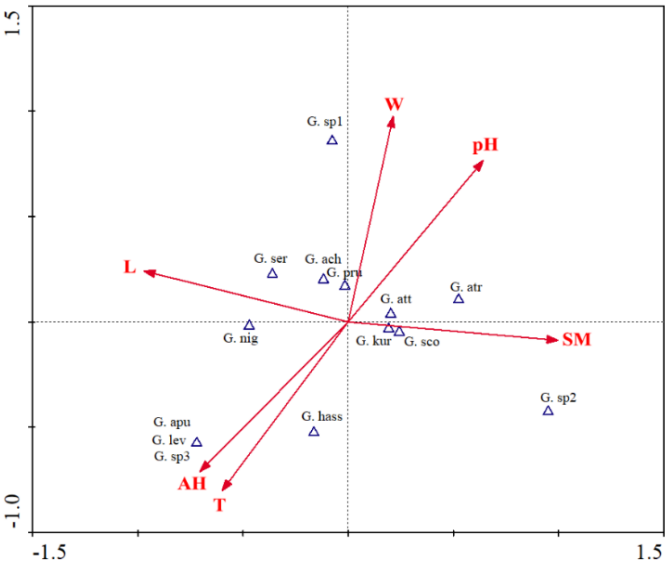


Fig. 3 Canonical correspondence analysis plot showing influence of main environmental factors (red arrows) with presence of *Gigantochloa,* where L = light intensity; W = wind speed; pH = soil pH; SM = soil moisture; T = temperature; AH = air humidity; triangular symbols shows species: G. ser = *G. serik*; G. ach = *G. achmadii*; G. pru = *G. pruriens*; G. att = *G. atter*; G. atr = *G. atroviolacea*; G. kur = *G. kuring*; G. sco = *G. scortechinii*; G. hass = *G. hasskarliana*; G. lev = *G. levis*; G. apu = *G.apus*; G. nig = *G. nigrociliata*; G. sp1 = *G*. sp1; G.sp2 = *G*. sp2; G. sp3 = *G*. sp3

Table 1 Environmental factors in three provinces of Central Sumatra (West Sumatra, Riau, and Jambi)

Province	Light intensity (lux)	Air humidity (%)	Temperature (°C)	Wind speed (m/s)	Soil pH	Soil moisture (%)
West Sumatra	1569.92	64.35	28.49	0.14	7.48	4.96
Riau	1689.02	69.00	29.43	0.05	7.24	4.68
Jambi	1113.60	64.92	28.75	0.08	7.43	5.63

Habitat modeling of Gigantochloa in central Sumatra

Model performances

The performance of each habitat model generated by the MaxEnt analysis was tested based on the AUC value. According to Swets (1988), a model is acceptable if AUC ≥ 0.5, while a model is unacceptable if AUC < 0.5. Furthermore, the value can be categorized into 0.5 ≤ AUC < 0.7 = sufficient accuracy, 0.7 ≤ AUC < 0.9 = good accuracy and AUC ≥ 0.9 = high accuracy. For *Gigantochloa* in Central Sumatra, the habitat model predicted AUC = 0.851 (Fig. 4), indicating that this habitat model was acceptable and its accuracy was in the good category. Thus, the selected environmental variable had a very good correlation with the *Gigantochloa* distribution and the habitat model generated for *Gigantochloa* by MaxEnt could be applied to predict the area whose environment resembled that for the natural habitat of *Gigantochloa*.

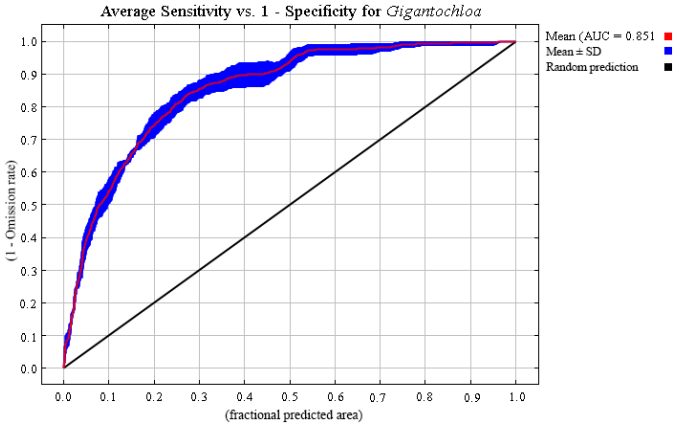


Fig. 4 Area under the curve (AUC) plots used to develop *Gigantochloa* habitat suitability model

Environmental variables are important factors affecting the regeneration, growth and distribution of plant populations (Zhang et al., 2018). Each variable has a different level of contribution in developing the habitat suitability model. From the 21 environmental variables used in the initial modelling, only 4 had contributing levels above 6%: land cover, precipitation in the warmest quarter, distance from river, and temperature seasonality. Consequently, these variables were used to build the model distribution of suitable habitats for *Gigantochloa* in Central Sumatra. Based on the percentage levels of contribution in Table 2, land cover played a major role in predicting the suitability of *Gigantochloa* habitat as land cover change greatly affected the distribution of *Gigantochloa.*

The results of the jackknife test can be used to determine the environmental variables having the greatest influence on the distribution of species and thus having potential for use as predictors of species distribution (Yang et al., 2013). The jackknife test was conducted to test the effect of environmental variables in 3 scenarios: 1) considering all variables; 2) considering individual variables; and 3) by excluding certain variables. The results of the jackknife test showed that four variables had the greatest influence on the distribution model of *Gigantochloa* in Central Sumatra (Fig. 5), with land cover being the key variable for predicting *Gigantochloa* habitat suitability, followed by temperature seasonality, precipitation in the warmest quarter and distance from rivers.

Responses of variable to suitability

Environmental variables were closely related to the potential distribution of plants at a location. Fig. 6 shows the relationship between the environmental variables in the response curve generated by MaxEnt and the possible distribution of *Gigantochloa* in Central Sumatra. These curves show the quantitative relationships between environmental variables and the logistical probability of existence (also known as habitat suitability), based on an understanding of the ecological niche of the species (Yi et al., 2016). In the current study, the response curves were used to investigate the relationships between species habitat suitability and environmental variables, as applied by Takano et al. (2017) for *Phyllostachys edulis*.



Fig. 5 Jackknife test showing importance of variables for predicting suitable habitat for *Gigantochloa*, where bio18 = precipitation in warmest quarter, bio4 = temperature seasonality, dis_riv = distance from river and land_cov = land cover

Table 2 Percentage contributions and permutation importance of predictor environmental variables in MaxEnt model

Variable	Contribution (%)	Permutation importance (%)
Land cover	55	56
Precipitation in warmest quarter	16	6
Distance from rivers	15	13
Temperature seasonality	13	26

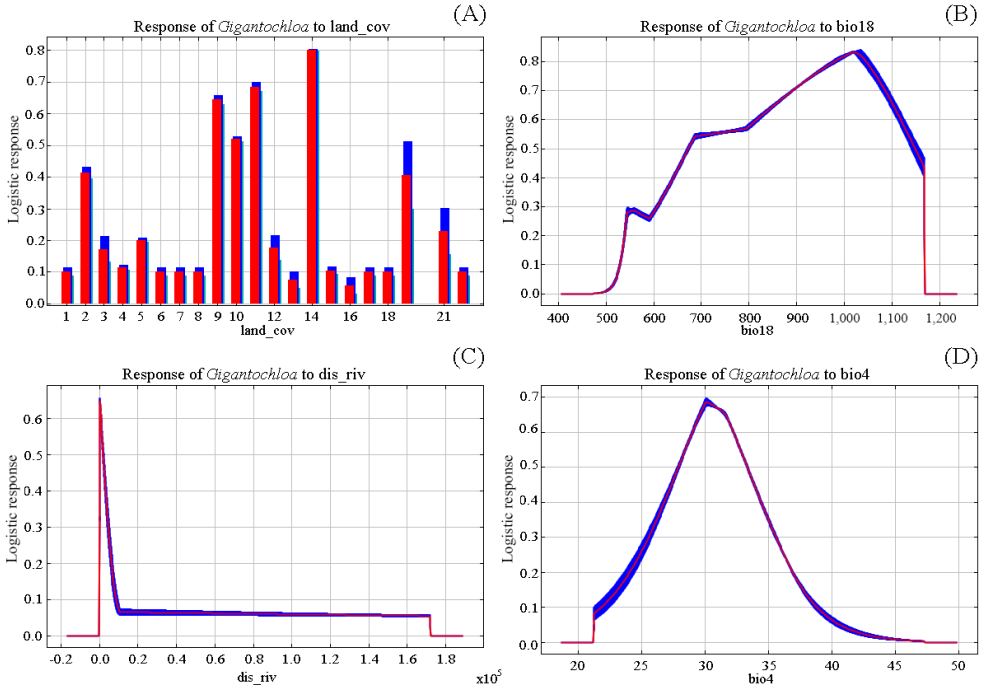


Fig. 6 Response curves of *Gigantochloa* to environmental variables, red color shows mean of 10 running MaxEnt replicates and blue area mean ± one standard deviation, where: (A) land cover, where 1 = primary dryland forest, 2 = scrubland, 3 = open forest, 4 = secondary dryland forest, 5 = plantations, 6 = primary mangrove forest, 7 = primary swamp forest, 8 = plantation forest, 9 = dry land agriculture, 10 = mixed dry land agriculture, 11 = rice fields, 12 = mining, 13 = swamp scrub, 14 = residential areas, 15 = secondary mangrove forest, 16 = secondary swamp forest, 17 = ponds, 18 = airports/harbors, 19 = transmigration, 20 = grasslands, 21 = bodies of water, 22 = swamps; (B) precipitation in warmest quarter; (C) distance from river; (D) temperature seasonality

Based on the response curve of *Gigantochloa* to land cover in Fig. 6A, *Gigantochloa* was found mostly in residential areas, dry land agriculture and rice fields because it is often cultivated for many benefits (Widjaja, 2019). In addition, the presence of *Gigantochloa* in bush areas, transmigration areas, water bodies and even mining areas indicated that *Gigantochloa* is a cultivated bamboo genus that can live in various areas (Widjaja and Karsono, 2005). Response curve to warmest quarter precipitation in Fig. 6B shows that *Gigantochloa* is abundant in areas with rainfall in the warmest quarter in the range of 700–1,180 mm. This result supported Shi et al. (2020), who reported that a rainfall range of 500–1,000 mm had potential as bamboo habitat. The response curve to the distance from the river in Fig. 6C showed that *Gigantochloa* was mostly found within 0–150 m of a river. According to Damayanto et al. (2020), the area along the river is the natural habitat of *Gigantochloa*, which is related to the fibrous root system that grows tightly and spreads, so that the culms can stand firmly and can bind into the soil well (Clark et al., 2015). The response curve to temperature seasonality in Fig. 6D showed that *Gigantochloa* may be found in habitats with a temperature range of 26–34 °C. Temperature is a very important environmental factor in influencing the distribution of a plant because it affects the speed of metabolic processes, especially photosynthesis and plant respiration (Zhong et al., 2010).

Prediction of potential distribution of Gigantochloa in Central Sumatra

The current study was the first to predict the potential distribution of *Gigantochloa* in Central Sumatra based on the habitat suitability model generated using MaxEnt. Habitat suitability has been classified into four classes: unsuitable, low suitability, medium suitability and high suitability (Wei et al., 2020). *Gigantochloa* has a high chance of occupying an area with a high level of habitat suitability. The central part of Sumatra has sites with 5.9% highly suitable, 8.1% moderately suitable, 21.7% low suitability and 64.7% unsuitable for *Gigantochloa* (Fig. 7).

The area with a high level of suitability was concentrated in the western part of Central Sumatra, along the Bukit Barisan plateau (Fig. 7). The eastern part of Central Sumatra (Riau province) had a few areas of low suitability and

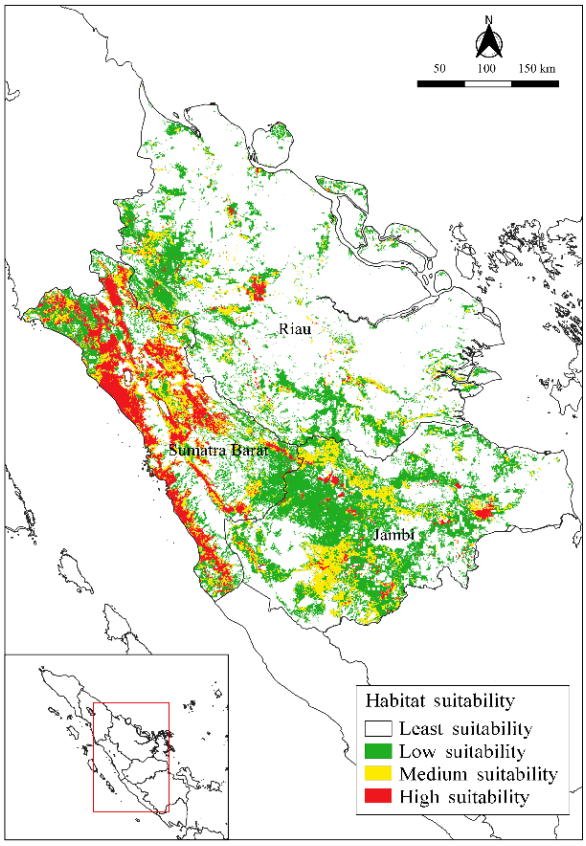


Fig. 7 Predicted distribution of habitat suitability for *Gigantochloa* in Central Sumatra generated using MaxEnt modelling

more widespread unsuitable areas for *Gigantochloa*, suggesting that finding *Gigantochloa* in the eastern part of Central Sumatra would be challenging. However, if a more intensive exploration were to be carried out, *Gigantochloa* might be found in the east region (Riau province), though this region was classified as having low habitat suitability. Nonetheless, this area has environmental conditions that would be suitable for the growth of *Gigantochloa* species, although less than other areas with a higher level of habitat suitability. According to Fitmawati et al. (2020), *Gigantochloa* could still grow in soil with a pH in the range 5.0–6.0.

Sumatra has several endemic *Gigantochloa* species, such as *G. calcicola, G. hirtinoda, G. kuring, G. longiprophylla, G. magenta, G. membranoidea, G. papyracea, G. pubipetiolata*, *G. tementosa,* and *G. velutina* (Widjaja, 2019). However, based on the current study in Central Sumatra, only one endemic species was found, namely *G. kuring.*

Based on the habitat suitability map modeled using Maxent, Fig. 8 shows that the Jambi region has a high level of habitat suitability for *G. kuring*, which is commonly found on the Batanghari riverbanks in Jambi province. This result was consistent with Widjaja (1997), who found *G. kuring* in several districts in Jambi province, such as Bungo, Tebo, Batanghari, Tanjung Jabung, and Bangko districts, all of which are crossed by the Batanghari River.

Several areas in West Sumatra also have high habitat suitability for *G. kuring*, such as Sijunjung, Lima Puluh Koto, Solok, South Solok, Payakumbuh and Pesisir Selatan districts, indicating that these areas have the same environmental conditions as the natural habitat of *G. kuring*. In contrast, it is extremely difficult to find *G. kuring* in its natural habitat in Riau province due to its overexploitation by local communities with no accompanying conservation efforts for this species (Fitmawati et al., 2020).

Based on the habitat suitability prediction map, *G. kuring* is likely to have a high endemicity level because only a few areas were predicted to be suitable for *G. kuring.* This is a concern regarding maintaining the *G. kuring* population in the wild. *G. kuring* is more at risk of extinction than other species, so the conservation of this species needs to be prioritized.

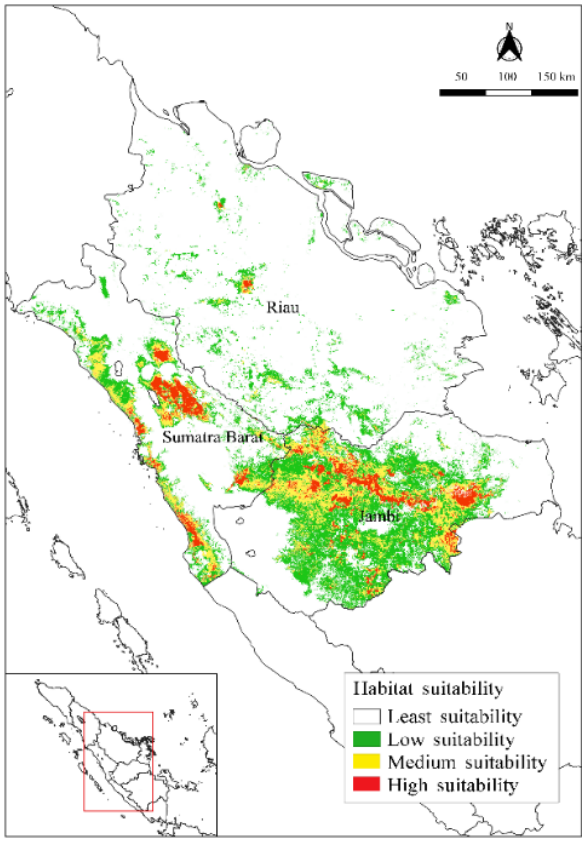


Fig. 8 Predicted distribution of habitat suitability for *G. kuring* in Central Sumatra generated using MaxEnt modelling

The MaxEnt model produced a predictive map of the distribution of suitable habitats for *Gigantochloa* species and identified the environmental variables that had the greatest influence on the distribution of *Gigantochloa*. This information could be used as a reference in managing and selecting areas and setting priorities for conserving *Gigantochloa* species and habitats in Central Sumatra.

Conflict of Interest

The authors declare that there are no conflicts of interest.

Acknowledgements

Mr Syafroni Pranata, Mr Aldo Aldafi, Mr Fajri Febrian, Mr Aulia Putra and Mr Zulamri provided field assistance. Professor Dr Elizabeth Anita Widjaja provided valuable advice and suggestions.

References

Banik, R.L. 2015. Bamboo silviculture. In: Liese, W., Kohl, M. (Eds.) Bamboo. Tropical Forestry, Vol. 10. Springer Cham. Switzerland, pp. 113–174. doi.org/ 10.1007/978-3-319-14133-6_5

Clark, L.G., Londono, X., Ruiz-Sanchez, E. 2015. Bamboo taxonomy and habitat. In: Liese, W., Kohl, M. (Eds.). Bamboo. Tropical Forestry, Vol. 10. Springer Cham. Hamburg, Germany, pp. 1–30. doi.org/10.1007/978-3-319-14133-6_1

Damayanto, I.P.G.P., Rustiami, H., Miftahudin, Chikmawati, T. 2020. A synopsis of Bambusoideae (Poaceae) in Lombok, Indonesia. Biodiversitas 21: 4489–4500. doi.org/10.13057/biodiv/d211004

Djarwaningsih, T., Sunarti, S., Kramadibrata, K. 2002. Guidelines for Processing and Management of Herbarium Materials and Integrated Pest Control at Herbarium Bogoriense. Puslitbang Biologi LIPI. Bogor, Indonesia. [in Indonesian]

Fitmawati, Saputri, N.A., Hartanto, S., et al. 2020. Diversity and utilization of bamboo (Bambusoidae) in five islands around Riau province, Indonesia. Sabrao J. Breed. Genet. 52: 177–190.

Fois, M., Cuena, L.A., Fenu, G., Bacchetta, G. 2018. Using species distribution models at a local scale to guide poorly known species: Review, methodological issues and future directions. Ecol. Model. 385: 124–132. doi.org/10.1016/j.ecolmodel.2018.07.018

Hakim, L., Nakagoshi, N., Isagi, Y. 2002. Conservation ecology of *Gigantochloa manggong*: An endemic bamboo at Java, Indonesia. J. Inter. Coop. Dev. 9: 1–16.

Legi, A., Septianingrum, P., Katipah, Verolina, M., Aulya, N.R., Supriyantin. 2021. Characteristic of several types of bamboo in Bogor Botanicals garden, Indonesia. In: Proceedings of Biology Education. 4: 21–35. doi.org/10.21009/pbe.4-1.3 [in Indonesian]

Lobo, J.M., Jiménez-Valvered, V.A., Real, R. 2008. AUC: A misleading measure of the performance of predictive distribution models. Glob. Ecol. Biogeogr. 17: 145–151. doi.org/10.1111/j.1466-8238.2007.00358.x

Ministry of Environment and Forestry. 2019. Indonesia's deforestation in 2017–2018. Jakarta: Directorate of Forest Resources Inventory and Monitoring, Directorate General of Forestry Planning and Environmental Management, Ministry of Environment and Forestry. Jakarta, Indonesia.

Phillips, S.J., Anderson, R.P., Dudik, M., Schapire, R.E., Blair, M.E. 2017. Opening the black box: An open-source release of Maxent. Ecography 40: 887–893. doi.org/10.1111/ecog.03049

Rugayah, Widjaja, E.A., Praptiwi. 2004. Guidelines for Collecting Data on Flora Diversity. Puslit-LIPI. Bogor, Indonesia. [in Indonesian]

Shi, P., Preisler, H.K., Quinn, B.K., et al. 2020. Precipitation is the most crucial factor determining the distribution of moso bamboo in Mainland China. Glob. Ecol. Conserv. 22: e00924. doi.org/10.1016/j.gecco.2020.e00924

Swets, J.A. 1988. Measuring the accuracy of diagnostic systems. Science 240: 1285–1293. doi.org/10.1126/science.3287615

Takano, K.T., Hibino, K., Numata, A., Oguro, M., Aiba, M., Shiogama, H., Takayubu, I., Nakashizuka, T. 2017. Detecting latitudinal and altitudinal expansion of invasive bamboo *Phyllostachys edulis* and *Phyllostachys bambusoides* (Poaceae) in Japan to project potential habitats under 1.5 °C–4.0 °C global warming. Ecol. Evol. 7: 9848–9859. doi.org/10.1002/ece3.3471

Wei, B., Wang, R., Hou, K., Wang, X., Wu, W. 2018. Predicting the current and future cultivation regions of *Carthamus tinctorius* L. using maxent model under climate change in China. Glob. Ecol. Conserv. 16: e00477. doi.org/10.1016/j.gecco.2018.e00477

Wei, J., Kai, H., Yunyun, L., Jiufeng, W. 2020. Predicting the potential distribution of the vine mealybug, *Planococcus ficus* under climate change by MaxEnt. Crop Prot. 137: 105268. doi.org/10.1016/j.cropro.2020.105268

Widjaja, E.A. 1987. A revision of Malesian *Gigantochloa* (Poaceae-Bambusoideae). Reinwardtia 10: 291–380.

Widjaja, E.A. 1997. New taxa in Indonesian bamboos. Reinwardtia 11: 57–152.

Widjaja, E.A. 2001a. Identification of Bamboo Species in the Lesser Sunda Islands. Puslitbang Biologi-LIPI. Bogor, Indonesia. [in Indonesian]

Widjaja, E.A. 2001b. Identification Key of Bamboo Species in Java. Puslitbang Biologi-LIPI. Bogor, Indonesia. [in Indonesian]

Widjaja, E.A., Karsono, K. 2005. Bamboo diversity in Sumba Island. Biodiversitas 6: 95–99. doi.org/10.13057/biodiv/d060205

Widjaja, E.A. 2019. The spectacular Indonesian bamboos. PT. Gudang Garam. Jakarta, Indonesia

Worthington, T.A., Zhang, T., Logue, D.R., Mittelstet, A.R., Brewer, S.K. 2016. Landscape and flow metrics affecting the distribution of a federally-threatened fish: Improving management, model fit, and model transferability. Ecol. Model. 342: 1–18. doi.org/10.1016/j.ecolmodel.2016.09.016

Xu, X., Zhang, H., Yue, J., Xie, T., Xu, Y., Tian, Y. 2018. Predicting shifts in the suitable climatic distribution of walnut (*Juglans regia* L.) in China: Maximum entropy model paves the way to forest management. Forests 9: 103. doi.org/10.3390/f9030103

Yang, X.Q., Kushwaha, S.P.S., Saran, S., Xu, J., Roy, P.S. 2013. Maxent modeling for predicting the potential distribution of medicinal plant *Justicia adhatoda* L. in Lesser Himalayan foothills. Ecol. Eng. 51: 83–87. doi.org/10.1016/j.ecoleng.2012.12.004

Yi, Y.J., Cheng, X., Yang, Z.F., Zhang, S.H. 2016. Maxent modeling for predicting the potential distribution of endangered medicinal plant (*H. riparia* Lour) in Yunnan. China Ecol. Eng. 92: 260–269. doi.org/10.1016/j.ecoleng.2016.04.010

Zhang, X., Li, G., Du, S. 2018. Simulating the potential distribution of *Elaeagnus angustifolia* L. based on climatic constraints in China. Ecol. Eng. 113: 27–34. doi.org/10.1016/j.ecoleng.2018.01.009

Zhong, I., Ma, Y.M., Salama, M.S., Su, Z. 2010. Assessment of vegetation dynamics and their response to variations in precipitation and temperature in the Tibetan Plateau. Clim. Change. 103: 519–535. doi.org/10.1007/s10584-009-9787-8

Zhu, G.P., Gariepy, T.D., Haye, T., Bu, W.J. 2017. Patterns of niche filling and expansion across the invaded ranges of *Halyomorpha halys* in North America and Europe. J. Pest Sci. 90: 1045–1057. doi.org/10.1007/s10340-016-0786-z