BIODIVERSITAS
Volume 26, Number 8, August 2025
Pages: 3952-3964

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d260825

Morphological diversity and habitat suitability modeling of *Oncosperma tigillarium* in coastal Riau, Indonesia

DETI NOVELA[1], TATIK CHIKMAWATI[2,♥], NINA RATNA DJUITA[2], FITMAWATI[3]
[1]Plant Biology Graduate Program, Department of Biology, Faculty of Mathematics and Natural Sciences, Institut Pertanian Bogor. Jl. Raya Dramaga Bogor 16680, West Java, Indonesia. Tel./fax.: +62-251-8622833, ♥email: tatikch@apps.ipb.ac.id
[2]Department of Biology, Faculty of Mathematics and Natural Sciences, Institut Pertanian Bogor. Jl. Raya Dramaga, Bogor 16680, West Java, Indonesia
[3]Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Riau. Jl. HR Soebrantas, Tampan, Pekanbaru 28293, Riau, Indonesia

Manuscript received: 14 June 2025. Revision accepted: 17 August 2025.

Abstract. *Novela D, Chikmawati T, Djuita NR, Fitmawati. 2025. Morphological diversity and habitat suitability modeling of* Oncosperma tigillarium *in coastal Riau, Indonesia. Biodiversitas 26: 3952-3964.* Land-use change and forest fires are major threats to the survival of *Oncosperma tigillarium* in the coastal areas of Riau, Indonesia. Scientific information on the species' morphological diversity, distribution, and habitat suitability remains limited, despite its significant ecological and economic value to local communities. Therefore, comprehensive research is urgently needed to support its conservation and sustainable use. This study aimed to assess the morphological diversity and model habitat suitability using the Maximum Entropy (MaxEnt) approach for *O. tigillarium* in the coastal areas of Riau Province. Morphological samples were collected from various coastal habitats and analyzed using Principal Component Analysis (PCA). Habitat suitability modeling was conducted based on 72 occurrence points and relevant environmental variables. The results revealed low qualitative morphological diversity, with notable differences in stem color, spine shape, and rachillae color during flowering and fruiting. PCA revealed three clusters based on quantitative variation, with PC1 and PC2 explaining 54.8% of total morphological variation. The MaxEnt model performed exceptionally well, with an Area Under Curve value of 0.993. Highly suitable habitats (IHS 0.6-1.0) were primarily located in Bengkalis. This area is highly suitable for the long-term conservation of *O. tigillarium.*

Keywords: Coastal Riau, habitat suitability modeling, MaxEnt, *Oncosperma tigillarium,* palm conservation

INTRODUCTION

Threats to plant diversity are increasing due to land-use changes and recurring fires, especially in tropical regions, such as Indonesia (Tawade et al. 2022). In coastal Riau, land clearing and peatland fires have degraded habitat quality and endangered endemic plant species (Fitmawati et al. 2022; Harrison et al. 2024). One species particularly affected by these environmental pressures is *Oncosperma tigillarium* (Jack) Ridl., commonly known as '*nibung*'. This coastal palm is predominantly distributed along the eastern coast of Sumatra, particularly in Riau Province (Hasanah et al. 2019). Morphologically, *O. tigillarium* is characterized by prominent spines covering much of the plant, a tall stem reaches 20-30 m with a brown to grey hue, and pinnately compound leaves. It produces yellow flowers and round fruits that turn black or purple upon ripening (Aisyah et al. 2023).

Oncosperma tigillarium holds considerable cultural and economic significance for coastal communities in Riau. Various parts of the plant are utilized, such as the roots are used for abdominal pain medication, the young shoots (called *umbut*) are consumed as food (Desti et al. 2024); the stems are valued for construction due to their resistance to saltwater and termites (Hasanah et al. 2019), Thorns used as ceremonial building nails in traditional rituals, the leaves are crafted into handicrafts, the flowers are used to impart fragrance to rice, and the fruits as a component in traditional betel chewing (Partomihardjo et al. 2020). However, the exploitative use of the species has led to a gradual decline in its population. In the absence of cultivation efforts, demand continues to rely entirely on wild populations. This practice constitutes a direct disturbance that threatens the species' survival, as it involves the removal of individual plants from their natural habitat for consumption or trade (Setiawan 2022).

The increasing pressure on the natural habitat of *O. tigillarium* has not been accompanied by sufficient information regarding its morphological variation, distribution, and habitat suitability. This lack of data poses a significant obstacle to the conservation and sustainable use of the species. Investigating morphological diversity is essential for understanding a species' potential for adaptation to varying environmental conditions and identifying superior genotypes suitable for domestication. Morphological traits may also reflect underlying genetic variability and ecological responses, thereby supporting informed conservation and breeding strategies. Therefore, comprehensive morphological data on *O. tigillarium* germplasm are crucial for the effective management of its conservation and genetic improvement.

Species Distribution Models (SDMs) are increasingly used in ecology, biogeography, and conservation to assess and predict the distribution of species under environmental threats, as demonstrated in studies on Arecaceae in Rio de Janeiro, Brazil (de Lima et al. 2022) and Mexico (Macedo-Santana et al. 2021). Maximum Entropy (MaxEnt) is one of the most widely used SDM models due to its ability to generate accurate predictions based on presence and environmental data and its reliability in projecting future species distributions to support conservation planning (Khwarahm 2020; Dai et al. 2022). MaxEnt enables identification of suitable habitats, providing a scientific basis for prioritizing *O. tigillarium* conservation in coastal Riau. Although MaxEnt is a popular and accurate method, it has several limitations, including sensitivity to sampling bias, low transferability between regions, and challenges in model evaluation and selection (Baldwin 2009). This study aimed to analyze the morphological diversity and model the habitat suitability of *O. tigillarium* along the Riau coastal region using the MaxEnt approach. The results are expected to provide a basis for understanding its morphology and potential distribution to support conservation efforts. This study represents the first spatial modeling study on *O. tigillarium* in Indonesia.

MATERIALS AND METHODS

Study area

Oncosperma tigillarium was collected from the study sites using purposive sampling, by directly visiting locations known to be centers of its distribution (Rugayah et al. 2004). The study was conducted in the coastal region of Riau Province, Indonesia, encompassing three districts: Bengkalis, Kepulauan Meranti, and Siak (Figure 1). The entire study area is not designated as a conservation area. Study sites were selected based on specimen records from the Herbarium Bogoriense (BO) in Bogor, Indonesia, literature review, and information provided by local communities familiar with *O. tigillarium*. Exploratory field surveys were carried out from July to August 2024. The exploration covered several villages, including Bantan Air, Bantan Tengah, Selat Baru, Jangkang, Deluk, Pambang, Melimau, and Makeruh in Bengkalis (BK) District; Mekar Delima and Dedap in Kepulauan Meranti (MR) District; Temusai in Siak (SK) District.

Procedures

Morphological character observation

The morphological characteristics of *O. tigillarium* observed in this study included roots, stems, and leaves (including leaf sheath, petiole, rachis, and leaflets), as well as inflorescence features (including floral bracts, peduncle, flower color, rachis and rachilla, and floral scent), fruits, and seeds. A total of 92 morphological characters (both vegetative and generative) of *O. tigillarium* were observed in this study. However, only 28 characters were used for the Principal Component Analysis (PCA), as these showed variation among individuals and were relevant for distinguishing morphological diversity (Supplementary Data). Morphological observations were conducted using standard descriptors and taxonomic references (Dransfield et al. 2008). Field observations were carried out on individuals growing in natural populations. Individuals were selected based on the presence of mature morphological structures to ensure accurate and reliable characterization. Observations were carried out on a minimum of three clumps of *O. tigillarium* at each sampling site, with morphological traits recorded from three individual plants within each clump.

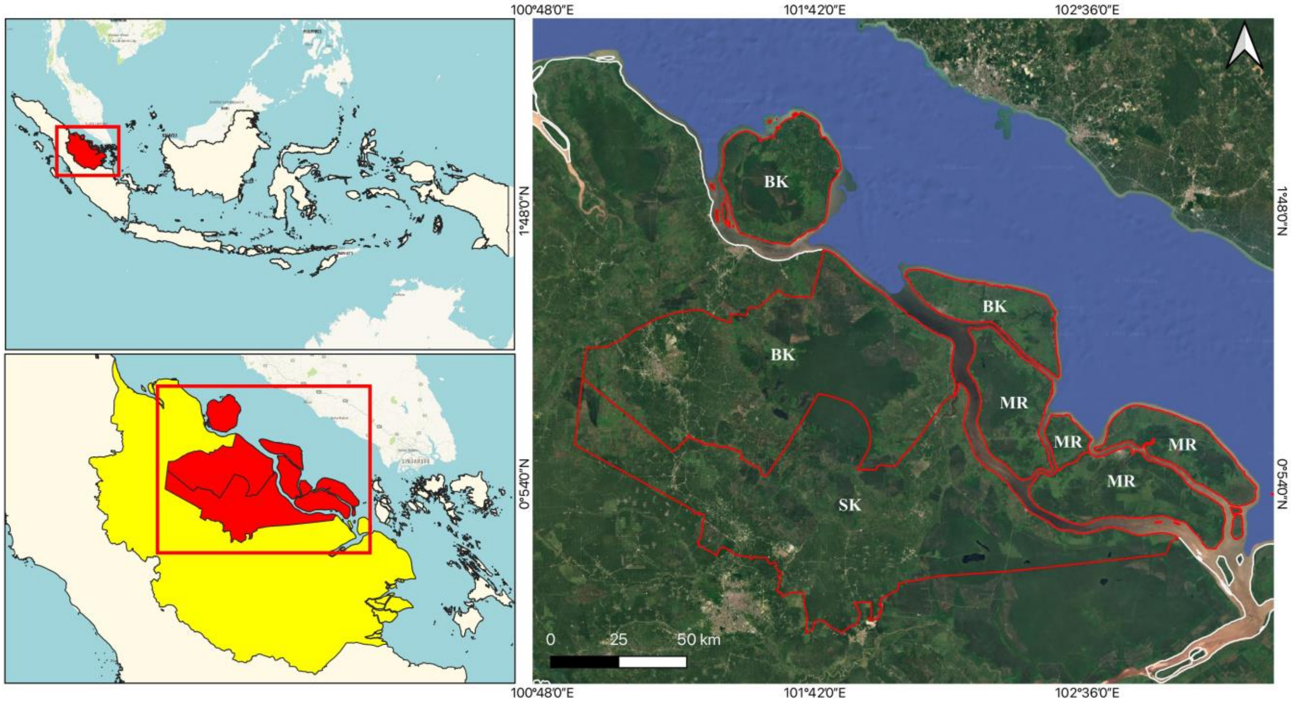

Figure 1. Research sites of *Oncosperma tigillarium* in coastal Riau Province, Indonesia: Bengkalis District (BK), Kepulauan Meranti District (MR), and Siak District (SK)

Species occurrence data and environmental variables

Species distribution modelling, including the MaxEnt approach, requires georeferenced presence data of the target species. In this study, the geographic coordinates (latitude and longitude) of *O. tigillarium* occurrence points were recorded in the field using a Global Positioning System (GPS). A total of 72 occurrence points were successfully documented during the field survey. The coordinate data were compiled in Microsoft Excel and saved in Comma-Separated Values (CSV) format. These data were then processed using Quantum Geographic Information System (QGIS) software version 3.34.3 to generate a distribution map of *O. tigillarium* along the coastal region of Riau Province. The occurrence points were also used as input presence data for habitat suitability modelling in MaxEnt version 3.4.4. Additionally, six environmental parameters supporting the growth of *O. tigillarium* were recorded, including air temperature, relative humidity, elevation, soil pH, soil type, and light intensity.

Environmental data (abiotic factors) that potentially influence the survival of *O. tigillarium* were collected and incorporated into the habitat suitability model. Twenty-two environmental variables were used, comprising 19 bioclimatic variables, monthly solar radiation, elevation, and distance to the coastline. All environmental data used in this study had a spatial resolution of 30 arc-seconds (approximately 1 km²) (Fick and Hijmans 2017). The 19 bioclimatic variables used were: Bio1: Annual Mean Temperature (°C), Bio2: Mean Diurnal Range (°C), Bio3: Isothermality (%), Bio4: Temperature Seasonality (%), Bio5: Max Temperature of Warmest Month (°C), Bio6: Min Temperature of Coldest Month (°C), Bio7: Annual Temperature Range (°C), Bio8: Mean Temperature of Wettest Quarter (°C), Bio9: Mean Temperature of Driest Quarter (°C), Bio10: Mean Temperature of Warmest Quarter (°C), Bio11: Mean Temperature of Coldest Quarter (°C), Bio12: Annual Precipitation (mm), Bio13: Precipitation of Wettest Month (mm), Bio14: Precipitation of Driest Month (mm), Bio15: Precipitation Seasonality (%), Bio16: Precipitation of Wettest Quarter (mm), Bio17: Precipitation of Driest Quarter (mm), Bio18: Precipitation of Warmest Quarter (mm), and Bio19: Precipitation of Coldest Quarter (mm).

Bioclimatic variables, solar radiation, and elevation data were obtained from the WorldClim database (https://www.worldclim.org/) for the most recent period. In addition, the coastal proximity variable (distance to the coastline) was derived from the official portal of the Indonesian Geospatial Information Agency (https://tanahair.indonesia.go.id/portal-web/). All environmental raster datasets were clipped to the study area's extent using QGIS version 3.43.3. The processed raster layers were then converted to ASCII format and stored in a dedicated folder for MaxEnt analysis.

Data analysis

Descriptive analysis was performed to summarize the morphological characters observed in *O. tigillarium*, including vegetative traits (roots, stems, and leaves) and generative traits (flowers, fruits, and seeds). These traits were first transformed into binary data to construct an accession matrix. A correlation test was conducted among variables before multivariate analysis to detect multicollinearity. Traits showing a high correlation coefficient ($r>0.9$) were excluded to avoid redundancy. Only variables with r between 0.3 and 0.9 were retained for further analysis. All procedures were carried out using RStudio version 2025.05.1. PCA was used to identify key morphological traits contributing to phenotypic variation, reduce dimensionality, and visualize groupings based on trait similarities, with variance proportions indicating trait influence (Jalil et al. 2020; Alarmelu and Hemaprabha 2023).

Habitat suitability for *O. tigillarium* was modelled using MaxEnt software version 3.4.4 (Phillips et al. 2017). This Java-based software was freely downloaded from the American Museum of Natural History's biodiversity informatics portal (https://biodiversityinformatics.amnh.org/) and utilized for scientific research purposes. The modelling process began by inputting species occurrence points into the 'samples' field and importing environmental factor maps into the 'environmental layers' field. All environmental variables were formatted as continuous raster data. The model was run using the default settings with 10 replicate runs (replicated run type: Bootstrap) to assess prediction stability and model robustness. A Jackknife test was conducted to identify variables that significantly contributed to the model and eliminate those with low importance. This step ensured that only the most relevant environmental variables were selected to generate an accurate and informative habitat suitability model (Worthington et al. 2016).

Based on the Jackknife analysis, 18 environmental variables were excluded due to their low contribution to the model. Following the criteria proposed by Wei et al. (2018), variables with contribution values and permutation importance less than 6% were removed during the preliminary filtering stage. These two metrics are crucial in assessing the contribution of each variable in shaping the model (Gunawan et al. 2021). The final model was constructed using the selected variables: srad3 (solar radiation in March), srad9 (solar radiation in September), srad12 (solar radiation in December), and bio14 (precipitation of the driest month).

Model validation was performed by evaluating the area under the receiver operating characteristic curve (AUC) generated by MaxEnt. The AUC represents the area under the Receiver Operating Characteristic (ROC) curve, which plots the relationship between sensitivity and specificity. Sensitivity indicates the model's ability to accurately predict the presence of *O. tigillarium*, while specificity measures its effectiveness in correctly identifying unsuitable areas (Hultera et al. 2020). AUC values range from 0 to 1, where values below 0.5 indicate poor model performance, and values approaching 1 suggest highly accurate and informative predictions (Wang et al. 2020). Habitat suitability levels were interpreted based on changes in color gradients from blue to red on the MaxEnt output map (Chen et al. 2024). For visualization and classification purposes, the maxent output was further processed using QGIS version 3.43.3 to reclassify habitat suitability levels into four categories: unsuitable habitat (0-0.2), low suitability (0.2-0.4), moderate suitability (0.4-0.6), and high suitability (0.6-1) (Wei et al. 2019).

RESULTS AND DISCUSSION

Oncosperma tigillarium diversity

Field observations of *O. tigillarium* along the coastal regions of Riau Province revealed a relatively low degree of morphological diversity. Most individuals exhibited highly uniform morphological characteristics, with only minor variation in quantitative traits. The limited variation observed was primarily related to stem color, spine morphology, and the color of rachillae during the flowering and fruiting stages. A detailed morphological depiction of *O. tigillarium* as documented in this study is presented in Figure 2.

Morphological characterization indicates that *O. tigillarium* is a tall, clustering palm species with each clump consisting of 5 to 30 individual stems. The stems are erect and cylindrical, ranging from 6 to 16 m in height and typically measuring between 5 and 18 cm in diameter. Variation in both the external and internal stem epidermis color was observed among the sampled accessions, which were categorized into three primary color types (Figure 3). Individuals with cream-colored outer stem bark generally exhibited similarly colored internal tissue. In contrast, stems with brown outer bark revealed orange-colored interiors, while those with grey outer bark had reddish-brown internal coloration. Notably, this variation in internal stem coloration has not been previously documented. Partomihardjo et al. (2020) reported that the external bark color of *O. tigillarium* ranged from pale grey to light brown.

Field observations revealed that cream-colored stems were predominantly observed in individuals from the Kepulauan Meranti District, where sandy clay soils are dominant. Conversely, populations from the Bengkalis and Siak Districts tended to exhibit brown to grey stems, typically associated with clay or humic peat soils. These variations in the stem are influenced by quantitative traits governed by multiple minor genes and are strongly affected by environmental factors (Ferita et al. 2015; Wulantika 2020). Evidence of environmental influence on stem coloration is also demonstrated in *Arenga pinnata* (Wurmb) Merr., which exhibited variation in bark color at different altitudes in Lareh Sago Halaban District-light brown at 900 m asl and grayish brown at 500-650 m asl (Hasibuan et al. 2023). Furthermore, a strong positive correlation was observed between stem color and the color of the abscission rings left by fallen leaf sheaths. For instance, stems with cream coloration typically exhibited similarly colored abscission rings, and this pattern was consistent across other color variants.

Figure 2. The appearance of *Oncosperma tigillarium*: A: Habit, B: Stem, C: Spine, D: Leaf sheath, E: Frond, F: Leaflet, G: Outer floral bract/prophyll (adaxial), H: Outer floral bract/prophyll (abaxial), I: Inner floral bract, J: Inflorescences, K: Rachillae, L: Portion of rachilla with triads (2 staminate flowers and 1 pistillate flower), M: Pistillate bud, N: Staminate flower, O: Immature fruit, P: Mature fruit, Q: Transverse section of fruit, R: Persistent calyx (adaxial), S: Persistent calyx (abaxial). Source: Bengkalis

Spines represent one of the most conspicuous forms of mechanical defense in various plant species. The presence of such structures is often interpreted as an adaptive trait, particularly in plant species exposed to high levels of herbivore pressure. Indeed, spiny plants are more frequently encountered in environments where intense grazing pressure (Goldel et al. 2016). In *O. tigillarium*, the stem surface is characteristically grooved and covered with black spines. Two distinct spine morphotypes were identified, namely elongated-flat and broad-flat types, both of which terminate in sharp points (Figure 3). The elongated-flat spines were generally thinner than the broad-flat type, with respective thicknesses of 0.5-1.0 mm and 1.3-1.6 mm. The elongated flat spines also exhibited greater lengths. According to Liu et al. (2021), longer spines are hypothesized to be more effective in deterring herbivores, while broader spines are believed to offer increased structural stability. The spine morphology of *O. tigillarium*, particularly in length, sharpness, and density, suggests that this species may occupy a high position within this defensive hierarchy.

The spines on *O. tigillarium* play an important ecological role in the plant's natural defense system. First, the sharp and dense spines along the trunk and leaf sheaths protect against herbivores such as wild boars by creating a physical barrier that limits access and reduces the likelihood of the plant being eaten. In a broader ecological context, spines also reflect an adaptation to harsh environments such as swamps and coastal forests, where environmental pressures and interspecies competition are high. These spines help the species withstand mechanical disturbances and competition in its natural habitat. Equally important, the spines protect young shoots and reproductive organs such as flowers and fruits, particularly during early growth, by preventing damage from external interaction. Altogether, these functions make the spines a vital component in the survival and regenerative success of *O. tigillarium* in its natural environment.

Oncosperma tigillarium exhibits a solitary inflorescence that emerges infrafoliarly (beneath the crown shaft). A noteworthy phenological observation in this study is the progressive color transformation of the rachillae during flower and fruit development (Figure 4). The rachillae are bright yellow at the time of prophyll dehiscence and flower emergence. As fruit development begins, the rachillae transition to green. During the young fruit stage, they display reddish-green coloration. As the fruits continue to mature, the rachillae gradually take on a reddish-brown hue with traces of yellow-green near the tips. At full fruit maturity, the fruits turn dark purplish-black, while the rachillae become reddish-brown. This consistent and predictable change in rachillae coloration throughout the reproductive stages has not previously been documented in *O. tigillarium*. This phenomenon may serve as a valuable visual phenological indicator, particularly for determining the optimal timing for fruit collection in seed management and conservation practices.

Field observations revealed that only a few mature fruits remained on the fruit clusters. This condition is due to the tendency of ripe fruits to detach from the rachillae and fall to the ground easily. As a result, only a few mature fruits were still attached at the time of observation. It suggests that the attachment between ripe fruits and their stalks is relatively weak, causing most fruits to drop before they can be directly observed or collected from the tree. This fruit drop is associated with a natural process known as abscission, which involves cell separation within a specialized Abscission Zone (AZ) at the base of the fruit (Patharkar and Walker 2019). This mechanism plays a critical role in seed dispersal, which is essential for the reproductive success of plants (Fooyontphanich et al. 2021).

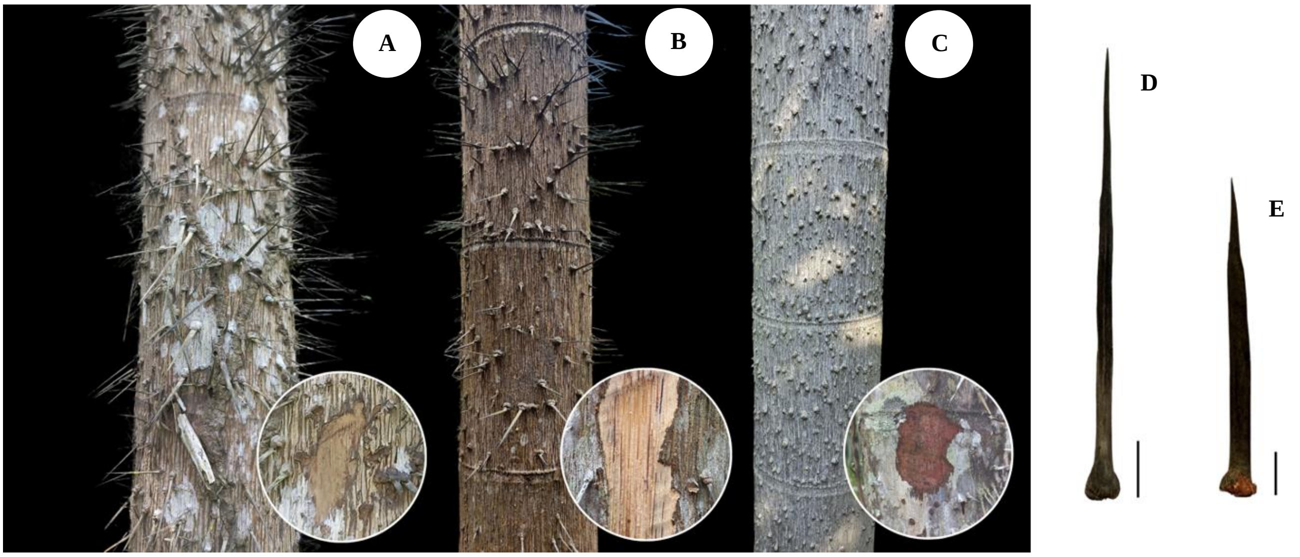

Figure 3. Color variation of the outer and inner bark, and morphological differences in thorn shape on the stem of *Oncosperma tigillarium* were observed in coastal Riau Province, Indonesia: A: Cream outer and inner bark, B: Brown outer bark, orange inner bark, C: grey outer bark, brownish red inner bark, D: Elongated flat thorn, E: Flared flat thorn. Scale: 1 cm. Source: All study sites

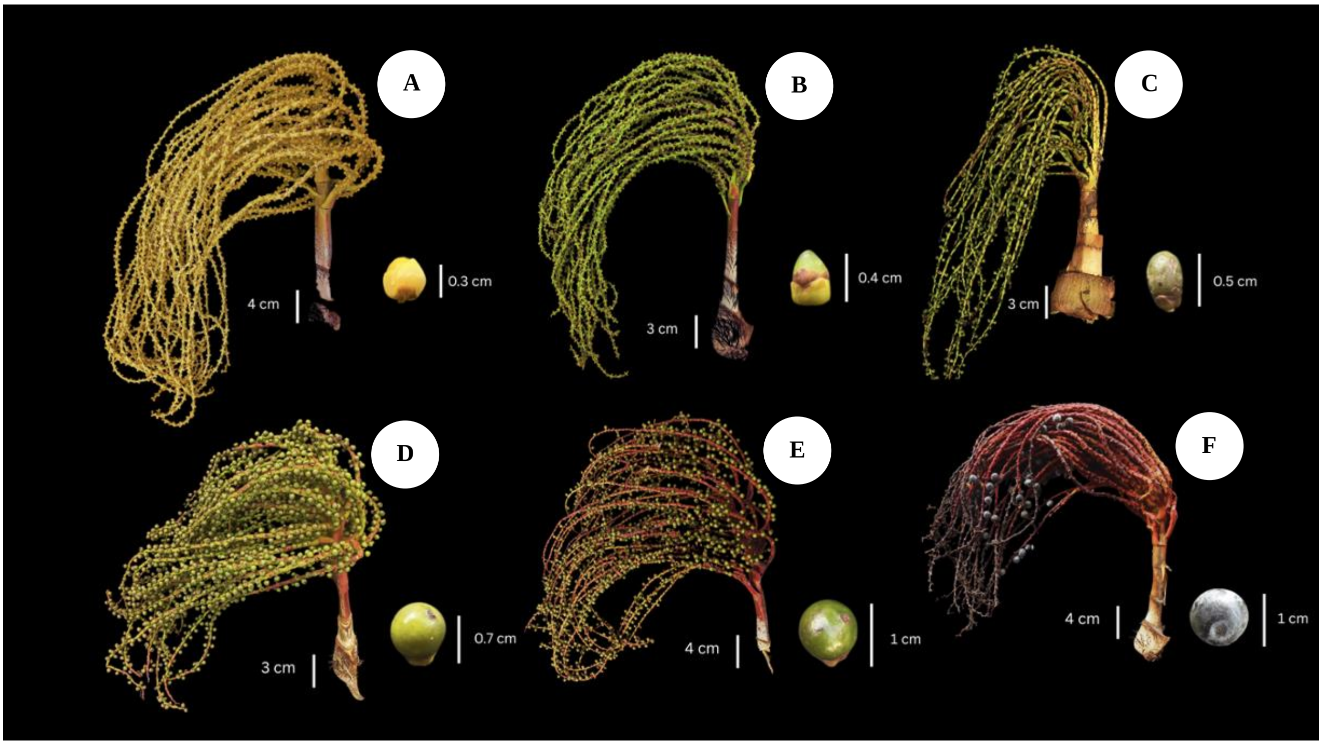

Figure 4. Changes in rachillae color during flower and fruit development: A: Flower phase, B-C: Early young fruit phase, D: Young fruit phase, E: Mature fruit phase, F: Ripe fruit phase. Source: All study sites

Principal component analysis of morphological variation

Principal Component Analysis (PCA) revealed that morphological variation among *O. tigillarium* individuals was primarily explained by two principal components, PC1 and PC2, which together accounted for 54.8% of the total morphological variation (Figure 5). PC1 contributed the most (48.6%) and strongly correlated with size-related morphological traits, particularly those associated with vegetative and reproductive structures. Traits with high loading values on PC1 (>0.7) included outer floral sheath length (0.87), rachis width (0.87), inner floral sheath width and length (0.83 and 0.80, respectively), rachis branch width (0.82), rachis branch length (0.80), prophyll stalk width (0.82), leaflet width (0.74), and rachillae length (0.74). These features reflect structural robustness and reproductive organ development, indicating that PC1 captures overall plant vigor and architectural growth. In contrast, PC2 explained 6.2% of the variation and captured more subtle morphological differences, especially related to defensive adaptation and organ spatial distribution. Traits contributing strongly to PC2 included spine shape on the stem (0.79), leaflet spacing (0.31), inner floral sheath length (0.30), and stem epidermis color (0.32). High loading values for these traits suggest that PC2 represents adaptive morphological responses to environmental factors, such as microhabitat variability.

The separation of individuals into three morphometric clusters based on the PCA plot suggests potential ecotypic adaptation. Cluster I consisted of individuals with intermediate PC1 scores, reflecting moderate organ sizes, and was generally found in lowland areas near coastal zones and rivers. Cluster II, located in the upper-left quadrant was characterized by distinctive spine morphology and smaller organ sizes. These individuals were found in mangrove forests, and their relatively small size is likely influenced by saline water inundation, which limits the availability of essential nutrients. Salinity stress has been shown to impede plant growth and reduce plant height (Hao et al. 2021). In contrast, Cluster III comprised individuals with high PC1 scores, indicating well-developed morphological structures and larger organ sizes. This group was typically found in rubber or oil palm plantations, as well as in coastal forest areas. These patterns indicate that local adaptation may be shaping morphological variation among populations. The findings underscore the importance of applying multivariate morphometric approaches to understand intraspecific morphological diversity. Identifying the dominant traits contributing to cluster separation provides a strong scientific foundation for conservation efforts, particularly for recognizing populations with unique morphological adaptations that may be vulnerable to habitat fragmentation or environmental disturbances.

The accessions of *O. tigillarium* from the coastal areas of Riau Province were classified into three groups based on their morphological characteristics. Each group possesses distinctive diagnostic traits that allow for accurate identification of individual accessions. These diagnostic traits were compiled into an identification key, while additional distinguishing characteristics were described in detail for each group.

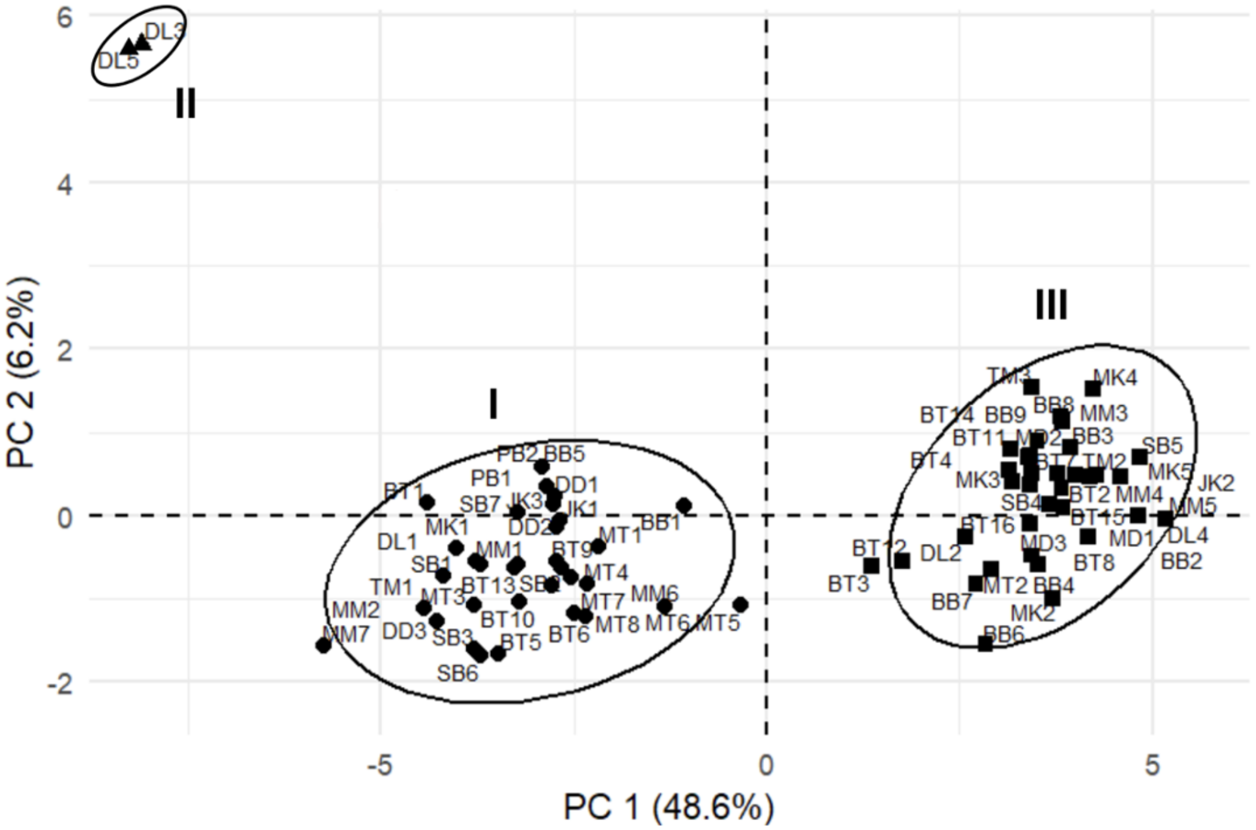

Figure 5. Principal Component Analysis (PCA) biplot based on morphological characters of *Oncosperma tigillarium* from the coastal region of Riau Province, Indonesia. Sample codes: Bantan Air (BB), Muntai (MT), Melimau (NG), Bantan Tengah (BT), Selat Baru (SB), Jangkang (JK), Pambang (PB), Dedap (DD), Makeruh (MK), Deluk (DL), Temusai (TM), and Mekar Delima (MD). Symbols represent clusters: circles (Cluster I), triangles (Cluster II), and squares (Cluster III)

Identification key for *O. tigillarium* accession groups:

1. a. Stem spine shape is flattened and wide; stem size is small with a circumference of 23-25 cm ....**Group II**
   b. Stem spine shape is flattened and elongated; stem size is medium to large with a circumference of 36-60 cm **2**
2. a. Leaf sheath length: 86-110 cm; petiole length: 16-20 cm; leaflet length: 80-96 cm; outer floral sheath length: 77-94 cm; inner floral sheath length: 76-87 cm ....**Group III**
   b. Leaf sheath length: 70-85 cm; petiole length: 13-15 cm; leaflet length: 61-78 cm; outer floral sheath length: 62-76 cm; inner floral sheath length: 58-75 cm ....**Group I**

Distribution and environmental factors of *O. tigillarium*

The distribution map of *O. tigillarium* across the coastal areas of Riau Province shows that this species is predominantly found in Bengkalis District, where 63 out of 72 recorded occurrence points (87.5%) were located. In comparison, only 6 points (8.3%) were recorded in Kepulauan Meranti District and 3 points (4.2%) in Siak District. These findings indicate a highly uneven distribution, with populations concentrated in Bengkalis and limited, scattered occurrences in the other two districts (Figure 6). Land-use change has been identified as a primary driver of shifts in plant distribution, particularly through the conversion of forested landscapes into agricultural or plantation areas (Gunawan et al. 2018). Such transformations lead to the fragmentation or complete loss of natural habitats essential for the survival of native species, such as *O. tigillarium*. Furthermore, environmental degradation, especially peatland fires, exacerbates habitat destruction and significantly impairs natural regeneration processes. These disturbances are particularly detrimental to palm species with slow growth and specialized habitat requirements.

The distribution pattern of *O. tigillarium* in coastal Riau is also influenced by a set of environmental variables, as presented in Table 1. Field observations and environmental data analysis indicate that the species predominantly inhabits lowland areas with elevations ranging from 4.5 to 87 m above sea level (asl). This distribution aligns with the ecological characteristics of *O. tigillarium*, which is typically found in coastal zones, swamps, and wetland ecosystems at low altitudes. This pattern contrasts with that of its close relative, *Oncosperma horridum* (Griff.) Scheff., which is commonly found in higher-elevation habitats. The bayas palm (*O. horridum*) grows on mountain slopes and hills at elevations reaching up to 1.000 m asl. (Aisyah et al. 2023).

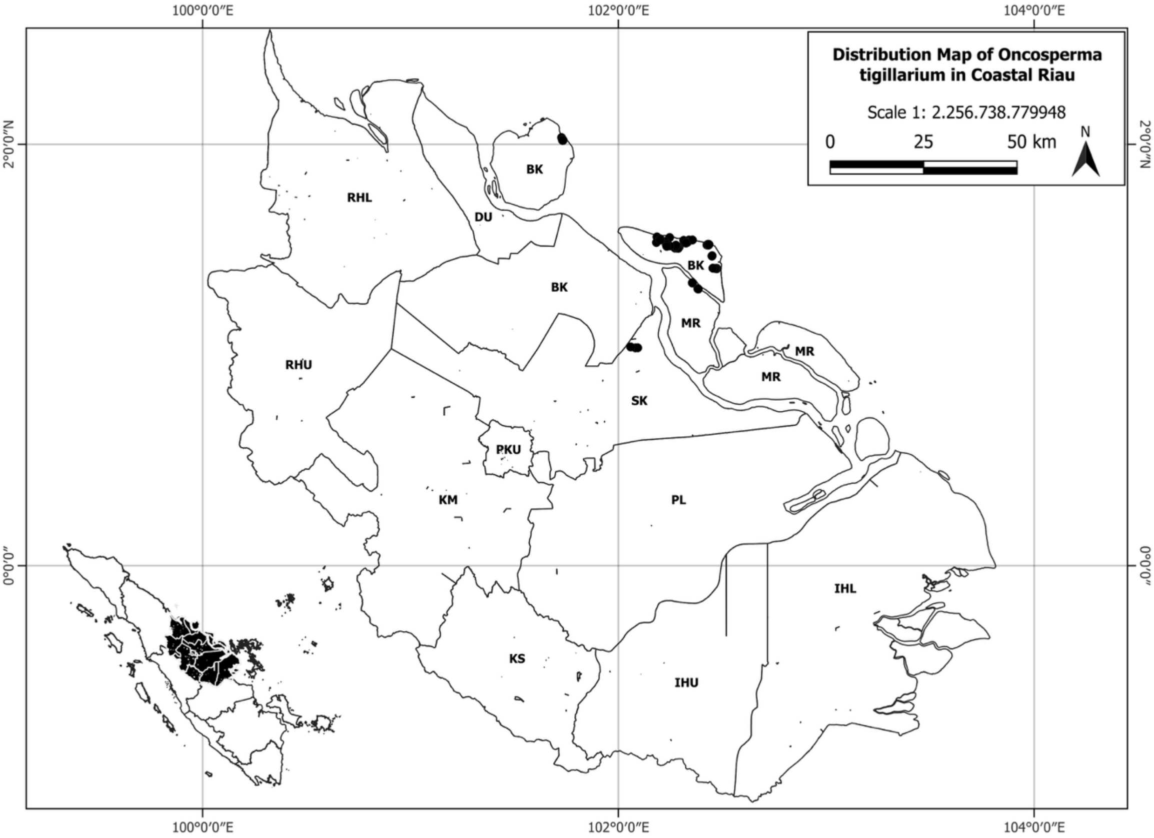

Figure 6. Distribution of *Oncosperma tigillarium* along the coastal Area of Riau Province, Indonesia. Black dots (*Oncosperma tigillarium*), BK (Bengkalis), DU (Dumai), MR (Meranti), SK (Siak), PL (Pelalawan), KS (Kuantan Singingi), IHL (Indragiri Hilir), IHU (Indragiri Hulu), RHL (Rokan Hilir), RHU (Rokan Hulu), KM (Kampar), PKU (Pekanbaru)

Elevation plays a crucial role in shaping the growth and distribution of plant species, primarily through its influence on microclimate parameters such as temperature and humidity (Negari et al. 2023). Generally, temperature decreases with increasing altitude at a rate known as the adiabatic lapse rate, which ranges from 6°C to 8°C for every 1.000 m of altitude increase (John et al. 2024). In the studied lowland coastal habitats, ambient temperatures ranged from 24.5°C to 41.7°C, while relative humidity levels fluctuated between 46.3% and 77.7%. These climatic conditions align with the thermal and hydric preferences of *O. tigillarium*, suggesting that such abiotic factors at least partially constrain the species' distribution.

Soil pH has emerged as a key environmental factor influencing the distribution of *O. tigillarium* in coastal Riau. Field data indicate that the species predominantly grows in soils with pH values ranging from 4.5 to 7.0 (Table 1), demonstrating its adaptability to slightly acidic to neutral soil conditions. Soil pH is closely linked to nutrient availability and soil microbial activity, both of which are essential for plant growth and survival (Penn and Camberato 2019; Mukrimin et al. 2021). In acidic soils, nutrient solubility and mobility are often limited, yet *O. tigillarium* appears capable of establishing and thriving in such conditions, possibly due to specific physiological traits or microbial associations that enhance nutrient uptake efficiency.

In terms of substrate preference, *O. tigillarium* was observed growing on various soil types, including clay, sandy clay, and a distinctive local soil known as '*kilang manis'* (Table 1). The latter is an early-stage decomposed peat soil commonly found in transitional wetland habitats. According to Rahayu et al. (2013), '*kilang manis'* habitats are characterized by seasonally or permanently waterlogged conditions, and are underlain by a stratified soil profile: a superficial peat layer (0-2 m) that transitions to clay at depths greater than 2 m. Peat types consist of Hemic, Sapric, Fibric, Mineral, and a combination of the four types (Fauziah et al. 2025). Hemic and sapric peat soils with depths of less than 200 cm, commonly found in Bengkalis District, are considered suitable for the cultivation of perennial crops (Agus et al. 2016).

Model performances and variable responses to *Oncosperma tigillarium* habitat suitability

The habitat suitability model for *O. tigillarium* in the coastal region of Riau Province yielded an AUC value of 0.993 (Figure 7), indicating excellent model performance. This high AUC score confirms that the selected environmental variables are strongly correlated with the current distribution of *O. tigillarium* and that the resulting model is sufficiently robust to identify environmentally suitable areas resembling the species' natural habitat (Pradhan and Setyawan 2021). However, an AUC value approaching 1 may also indicate a potential overfitting issue, where the model fits the current occurrence data too perfectly but has poor generalization ability to predict conditions beyond the training data. This possibility may be influenced by the uneven distribution of samples across locations, which depends on the natural population size in each area.

Environmental variables are critical determinants of plant regeneration, growth, and population distribution (Zhang et al. 2018). Although the initial model incorporated 22 environmental variables, only four exhibited a contribution rate above 6%, i.e., solar radiation in March, December, and September, along with precipitation of the driest month (Table 2). These variables also showed high values in permutation importance tests, further confirming their relevance in the final habitat suitability model. Among them, solar radiation in March (srad3) was the most influential. According to Zhou et al. (2022), solar radiation is one of the key drivers of plant growth, along with soil nutrients and other edaphic factors. To further assess the relative importance of each variable, the Jackknife test was employed, a method commonly used in MaxEnt modelling to evaluate the predictive power and contribution of each environmental variable (Romadlon et al. 2021). The results of the Jackknife analysis (Figure 8), also include regularized training gain scores, which reflect the unique influence of each variable while accounting for multicollinearity and standardizing variable effects (Zhao et al. 2024).

The Jackknife test for variable importance further clarifies the influence of individual environmental factors on the model. The test shows that the distribution of *O. tigillarium* is primarily influenced by solar radiation and rainfall (Figure 8). These results suggest that *O. tigillarium* is highly responsive to variation in light availability and seasonal water stress in its coastal habitat. The values presented in the jackknife test represent the average of several repetitions. This result highlights the ecological niche complexity of *O. tigillarium* and the importance of integrating various interacting environmental gradients to obtain accurate habitat suitability predictions. Among individual predictors, March solar radiation (srad3) yielded the highest increase when used alone, confirming its critical role in defining the ecological niche of this species. This significant influence underscores the crucial role of solar radiation in regulating the phenology, physiology, and spatial distribution of *O. tigillarium* within the Riau coastal landscape. These findings suggest that the distribution of *O. tigillarium* is not determined by a single dominant factor, but rather by a combination of environmental variables, particularly those related to solar radiation patterns and rainfall. These results provide valuable ecological insights that can guide future conservation and restoration efforts for this economically and ecologically important palm species.

Climatic conditions play a crucial role in determining the potential distribution of plant species within their natural habitats (Aguirre-Gutiérrez et al. 2015). In this study, the MaxEnt model generated response curves that illustrate the quantitative relationship between environmental variables and the logistic probability of *O. tigillarium* occurrence in the coastal region of Riau Province (Figures 9.A-C). These response curves reflect habitat suitability based on the ecological niche and provide information on the optimal environmental conditions for the growth and survival of *O. tigillarium* (Esfanjani et al. 2018; Ma and Sun 2018).

Table 1. Environmental conditions of the three research areas

Environmental parameters	**Sites**		
	Bengkalis	**Kepulauan Meranti**	**Siak**
Air temperature (°C)	24.5-41.7	32-37.8	34.7-36.7
Altitude (m asl)	4.7-87	7-13	5.5-8
Light intensity (lux)	63.9-18390	1960-19450	5850-13160
Soil pH	4.5-7.0	4.5-4.7	4.5-4.7
Type of soil	Clay-'Kilang manis'	Clay-sandy clay	Clay
Relative humidity (%)	46.3-77.7	54.4-71.55	66.2-65.95

Table 2. Percentage contribution and permutation importance of predictor environmental variables in the MaxEnt model

Variable	**Percentage contribution (%)**	**Permutation of interest (%)**
March solar radiation	66	9.5
December solar radiation	13.3	11.3
September solar radiation	12.6	57.3
Driest month rainfall	8.1	21.9

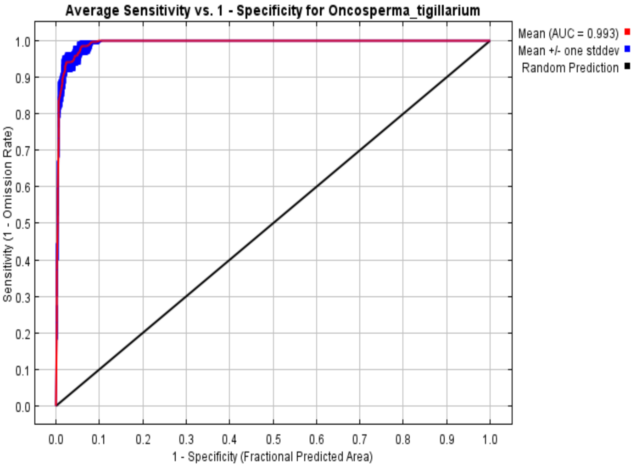

Figure 7. Results of the AUC curve in the *Oncosperma tigillarium* habitat suitability model using MaxEnt

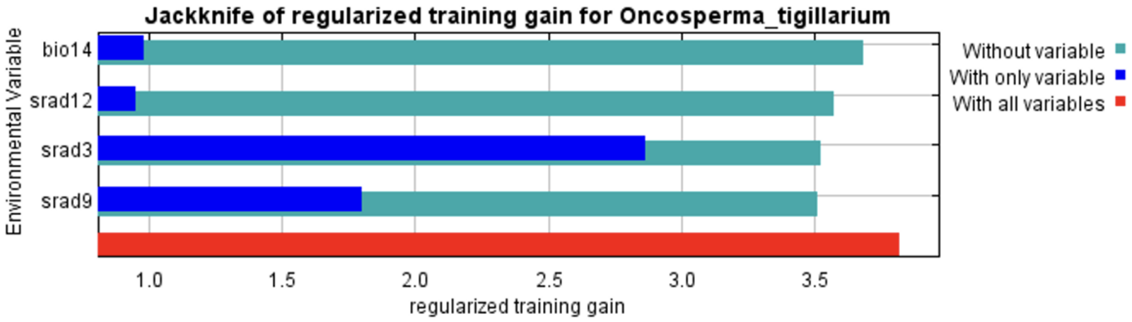

Figure 8. Jackknife test showing the importance of variables for predicting suitable habitat for *Oncosperma tigillarium*, srad3: solar radiation in March, srad12: solar radiation in December, srad9: solar radiation in September, and bio14: driest month rainfall

Understanding a species' environmental preferences is essential for designing effective conservation strategies, as well as for exploring its potential use in other suitable areas. The response curves for *O. tigillarium* habitat suitability indicate that the species exhibits specific tolerance thresholds to solar radiation levels, which vary seasonally. The optimal solar radiation values that support the presence of *O. tigillarium* are shown in Figure 9. Solar radiation regulates the induction and initiation of flowering in various plant species (Rezazadeh et al. 2018). Field observations further reveal that *O. tigillarium* requires sufficient sunlight exposure for flowering and does not thrive under shaded conditions. This finding aligns with Gurjar et al. (2017), who emphasized the role of solar radiation as a primary energy source for photosynthesis and its importance in a wide range of plant growth processes, including stem and shoot development, seed germination, leaf expansion, flowering, fruiting, and other physiological and phenological functions. Another significant environmental variable contributing to the *O. tigillarium* habitat suitability model is precipitation during the driest month (bio14) (Figure 9.D). This condition indicates that *O. tigillarium* prefers coastal regions with relatively high humidity, even during the driest part of the year. Many tropical palm species have low drought tolerance and rely on consistent water availability for survival in lowland tropical forests (Slik et al. 2015).

Potential distribution and conservation implications

Information regarding the presence and distribution of *O. tigillarium* in the coastal regions of Riau Province remains limited. The MaxEnt prediction model indicates that areas of high habitat suitability are primarily concentrated along the coastal zones of Bengkalis District (Figure 10). This region appears to offer environmental conditions that closely align with the ecological niche of *O. tigillarium*. Field observations corroborate the MaxEnt analysis, as numerous *O. tigillarium* individuals were recorded during exploration in this area. In contrast, the coastal region of Kepulauan Meranti District predominantly exhibits low suitability classes, with a significant portion of the area categorized as unsuitable. Nevertheless, *O. tigillarium* was still found in several low-suitability areas, albeit in small numbers. Its presence in these areas may be attributed to the species' ecological plasticity or broad environmental tolerance. Interestingly, the MaxEnt model predicts that the Siak District region is unsuitable for the *O. tigillarium* habitat. However, field surveys documented the species in a few locations, which may reflect remnant populations that have persisted despite substantial environmental changes. Local accounts indicate that *O. tigillarium* was once widely distributed in Siak. However, the expansion of oil palm plantations has led to a significant decline in its population, as such land-use changes are unsuitable for the continued existence of *O. tigillarium* habitats. Anthropogenic activities such as logging are suspected to contribute to the current distribution patterns of *O. tigillarium* (Antúnez et al. 2018; Bouderbala et al. 2023), given that this species has considerable economic value.

In addition to environmental factors, this study also highlights that social and cultural aspects influence the presence and conservation efforts of *O. tigillarium* in certain regions. In Bengkalis District, the population of *O. tigillarium* remains relatively high, not only due to favorable environmental conditions but also because of the species' economic and cultural value to the local community. In practice, residents of Bengkalis tend to preserve wild clumps of *O. tigillarium* during land-clearing activities due to the species' considerable economic value. The stems are sold for approximately IDR 330.000/7 *depa* (with one *depa* equivalent to 1.7 m). The harvesting of *O. tigillarium* is performed in a selective and controlled manner, with individuals only cutting the plants when they have a defined and purposeful use. In contrast, in regions outside Bengkalis District, *O. tigillarium* does not hold the same cultural or economic significance. In these areas, when land is converted into oil palm plantations, *O. tigillarium* is often perceived as a hindrance and is frequently removed. This divergence in the perception and treatment highlights the need for a conservation strategy that is both ecologically grounded and sensitive to local social contexts and cultural values. Integrating community perspectives and traditional practices into conservation planning can enhance the effectiveness and long-term sustainability of conservation efforts for species preservation.

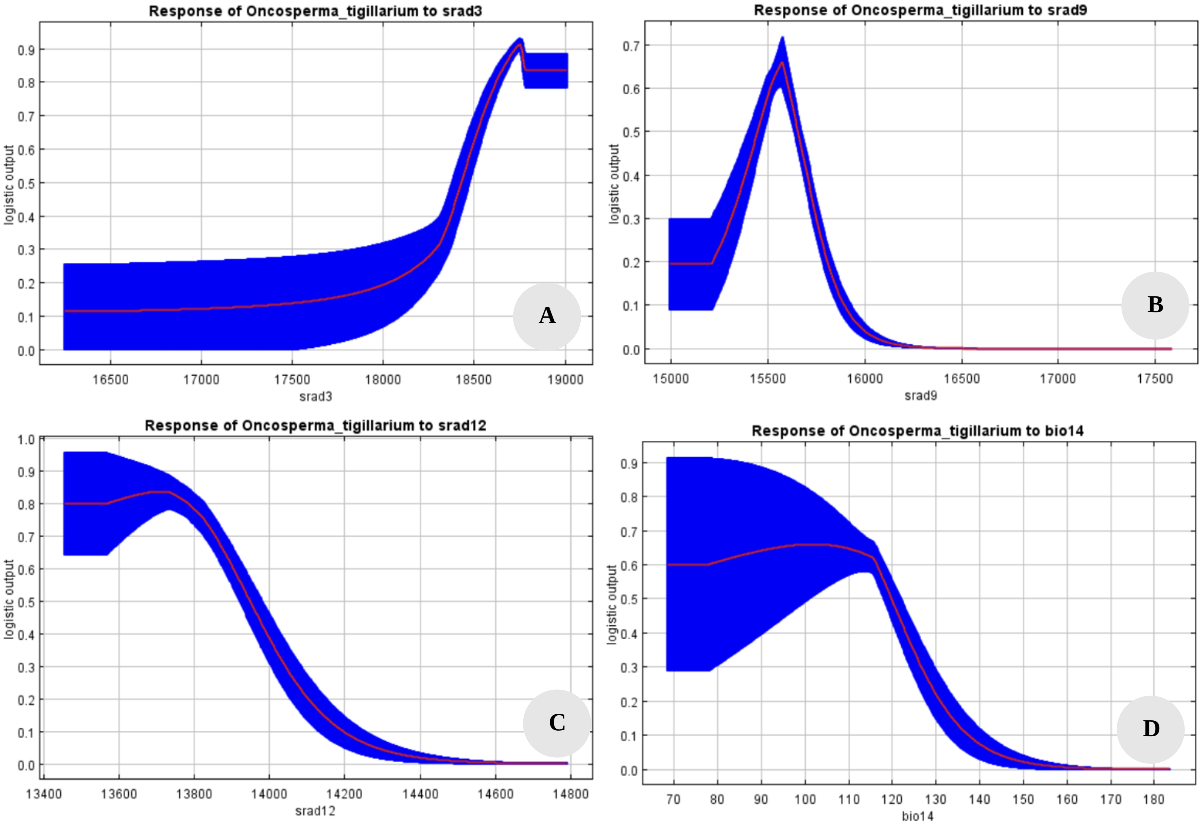

Figure 9. Response curves of the three main climate variables used in modeling habitat suitability of *Oncosperma tigillarium* in coastal Riau Province, Indonesia using MaxEnt: A: srad3 (March solar radiation), B: srad9 (September solar radiation), C: srad9 (September solar radiation), C: srad12 (December solar radiation), D: bio14 (driest month rainfall)

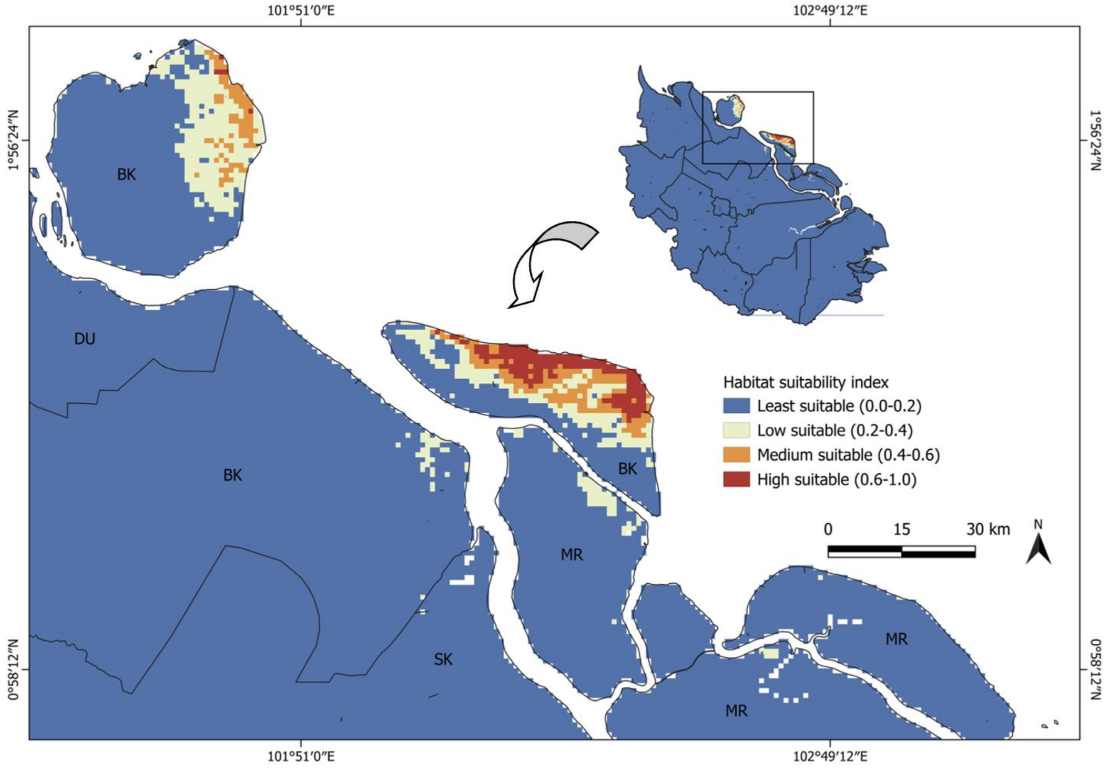

Figure 10. Map of current potential habitat suitability for *Oncosperma tigillarium* based on its occurrence records in Coastal Riau Province, Indonesia. BK (Bengkalis), DU (Dumai), MR (Meranti), SK (Siak)

The MaxEnt model successfully identified coastal areas in Riau Province with high habitat suitability. However, the absence of future projections remains a limitation that should be considered. These findings provide a scientific basis for developing both in situ and ex situ conservation strategies for *O. tigillarium*. In situ conservation should be prioritized in highly suitable zones, particularly in Bengkalis District, where natural populations are more likely to persist. For ex situ conservation, it is recommended to collect germplasm from various morphometric clusters and establish conservation plots outside the species' natural habitat. Reforestation efforts should focus on core areas using locally adapted seedlings. Active participation of coastal communities is essential to ensure the success of these strategies, especially given the long-standing traditional use of *O. tigillarium*. Integrating this species into coastal rehabilitation programs and spatial planning policies is strongly recommended to support its long-term conservation and sustainable use.

In conclusion, this study successfully assessed morphological diversity, modeled habitat suitability, and identified key environmental factors affecting the presence of *O. tigillarium* in coastal areas of Riau Province. Morphological variation observed was relatively low, especially in qualitative characters, with visible differences mainly in stem color, thorn shape, and rachillae color during flowering and fruiting. PCA separated the accessions into three distinct morphometric clusters. The distribution of *O. tigillarium* was found to be patchy, with the highest concentration in Bengkalis District. The MaxEnt habitat suitability model showed excellent prediction performance, with an AUC value of 0.993. Highly suitable habitats (IHS values 0.6-1.0) were mainly located in Bengkalis, where environmental conditions such as solar radiation and monthly rainfall were identified as key factors favoring the growth and persistence of this species. Priority for in situ conservation should be given to areas with high habitat suitability, especially in Bengkalis District.

ACKNOWLEDGEMENTS

We would like to express our sincere appreciation and gratitude to the Indonesia Endowment Fund for Education (LPDP), Ministry of Finance of the Republic of Indonesia, for providing financial support for this research. We also extend our thanks to all individuals and institutions who contributed to the success of this study.

REFERENCES

Aguirre-Gutiérrez J, Serna-Chavez HM, Villalobos-Arambula AR, Pérez de la Rosa JA, Raes N. 2015. Similar but not equivalent: Ecological niche comparison across closely related Mexican white pines. Divers Distrib 21: 245-257. DOI: 10.1111/ddi.12268.

Agus F, Anda M, Jamil A, Masganti. 2016. Indonesian Peatlands: Formation, Characteristics, and Potential. IAARD Press, Jakarta.

Aisyah BN, Syamsuardi, Nurainas. 2023. Morphological differentiation between nibung (*Oncosperma tigillarium* (Jack) Ridl), a mascot flora of Riau Province, and its closed related species, bayas (*Oncosperma horridum* (Griff) Scheffer). World J Adv Res Rev 18 (2): 621-626. DOI: 10.30574/wjarr.2023.18.2.0869.

Alarmelu S, Hemaprabha G. 2023. Principal component and cluster analyses based on morphological characterization in sugarcane. J Sugarcane Res 12 (1): 16-31. DOI: 10.37580/JSR.2022.1.12.16-31.

Antúnez P, Suárez-Mota ME, Valenzuela-Encinas C, Ruiz-Aquino F. 2018. The potential distribution of tree species in three periods of time under a climate change scenario. Forests 9 (10): 628. DOI: 10.3390/f9100628.

Baldwin RA. 2009. Use of maximum entropy modeling in wildlife research. Entropy 11 (4): 854-866. DOI: 10.3390/e11040854.

Bouderbala I, Labadie G, Be´land J-M, Tremblay JA, Boulanger Y, He´bert C, Desrosiers P, Allard A, Fortin D. 2023. Long-term effect of forest harvesting on boreal species assemblages under climate change. Plos Clim 2 (3): e0000179. DOI: 10.1371/ journal.pclm.0000179.

Chen J, Yin Y, Yu W, Tao W, Huang Y, Zhu B. 2024. Current and future distribution of *Camellia sinensis* in China estimated by MaxEnt. Hort-Sci 59 (2): 179-187. DOI: 10.21273/HORTSCI17390-23.

Dai X, Wu W, Ji L, Tian S, Yang B, Guan B, Wu D. 2022. MaxEnt model-based prediction of potential distributions of *Parnassia wightiana* (Celastraceae) in China. Biodivers Data J 10: 81073. DOI: 10.3897/bdj.10.e81073.

de Lima TM, Portela RDCQ, Mendes ETB, Oda GA. 2022. Species distribution modeling allied with land-use reveal priority sites and species for palm (Arecaceae) conservation in Rio de Janeiro, Brazil. Front For Glob Change 5: 928446. DOI: 10.3389/ffgc.2022.928446.

Desti D, Mastuti R, Azrianingsih R, Arumingtyas EL. 2024. Local uses and traditional knowledge of nibung (*Oncosperma tigillarium*) in Riau Province, Indonesia. Biodiversitas 25 (5): 2043-2050. DOI: 10.13057/biodiv/d250522.

Dransfield J, Uhl NW, Asmussen CB, Baker WJ, Harley MM, Lewis CE. 2008. Genera Palmarum: The Evolution and Classification of Palms. Kew Publishing, Royal Botanic Gardens, Kew.

Esfanjani J, Ghorbani A, Chahouki MAZ. 2018. MaxEnt modeling for predicting impacts of environmental factors on the potential distribution of *Artemisia aucheri* and *Bromus tomentellus-Festuca ovina* in Iran. Pol J Environ Stud 27(3): 1041-1047. DOI: 10.15244/pjoes/76496.

Fauziah, Hayati N, Prasetyo LB. 2025. Simulation of land use and land cover of peatland Bengkalis using QGIS. Intl J Inform Visual 9 (1): 57-64. DOI: 10.62527/joiv.9.1.2432.

Ferita I, Tawarati, Syarif Z. 2015. Identification and characterization of the enau plant (*Arenga pinnata*) in Gayo Lues. Proc Indonesia Biodivers Soc Nat Sem 1 (1): 31-37. DOI: 10.13057/psnmbi/m010105. [Indonesian]

Fick SE, Hijmans RJ. 2017. Worldclim 2: New 1-km spatial resolution climate surfaces for global land areas. Intl J Clim 37 (12): 4302-4315. DOI: 10.1002/joc.5086.

Fitmawati F, Desti D, Juliantari E, Novela D, Kapli H. 2022. Molecular phylogeny of nibung (*Oncosperma tigillarium* [Jack] Ridl.) inferred from *trnL-F* intergenic spacer sequences. SABRAO J Breed Genet 54 (1): 175-183. DOI: 10.54910/sabrao2022.54.1.16.

Fooyontphanich K, Morcillo F, Joët T, Dussert F, Serret J, Collin M, Amblard P, Tangphatsornruang S, Roongsattham P, Jantasuriyarat C, Verdeil JL, Tranbarger TJ. 2021. Multi-scale comparative transcriptome analysis reveals key genes and metabolic reprogramming processes associated with oil palm fruit abscission. BMC Plant Biol 21: 92. DOI: 10.1186/s12870-021-02874-1.

Goldel B, Araujo AC, Kissling WD, Svenning JC. 2016. Impacts of large herbivores on spinescence and abundance of palms in the Pantanal, Brazil. Bot J Linn Soc 182: 465-479. DOI: 10.1111/ boj.12420.

Gunawan, Chikmawati T, Sobir, Sulistijorini. 2018. Distribution, morphological variation and new variety of *Baccaurea angulata* Merr. (Phyllanthaceae). Floribunda 6 (1): 1-11. DOI: 10.32556/floribunda.v6i1.2018.226.

Gunawan, Sulistijorini, Chikmawati T, Sobir. 2021. Predicting suitable areas for *Baccaurea angulata* in Kalimantan, Indonesia using Maxent modelling. Biodiversitas 22(5): 2646-2653. DOI: 10.13057/biodiv/d220523.

Gurjar GN, Swami S, Meena NK, Lyngdoh EAS. 2017. Effect of solar radiation on crop production. In: Arora S, Swami S, Bhan S (eds). Natural Resource Management for Climate Smart Sustainable Agriculture. Soil Conservation Society of India. New Delhi.

Hao S, Wang Y, Yan Y, Liu Y, Wang J, Chen S. 2021. A review on plant responses to salt stress and their mechanisms of salt resistance. Horticulturae 7 (6): 132. DOI: 10.3390/horticulturae7060132.

Harrison ME, Deere NJ, Imron MA et al. 2024. Impacts of fire and prospects for recovery in a tropical peat forest ecosystem. Proc Natl Acad Sci USA 121 (17): e2307216121. DOI: 10.1073/pnas.2307216121.

Hasanah N, Sulaeman R, Sribudiandi E. 2019. Study on stem traits of nibung (*Oncosperma tigillarium*) in Tameran Village, Bengkalis Regency. J For Sci 3 (1): 1-13.

Hasibuan HS, Wisnubroto MP, Edwin, Rezki D, Yulistriani. 2023. Identification and morphological characterization of sugar palm plants (*Arenga pinnata* Merr.) growing on different altitudes. J Agric 19 (2): 99-105. DOI: 10.30598/jbdp.2023.19.2.99.

Hultera, Prasetyo LB, Setiawan Y. 2020. Spatial model of the potential deforestation in 2020 & 2024 and the prevention approach, in Kutai Barat District. J Nat Resour Environ Manag 10 (2): 294-306. DOI: 10.29244/jpsl.10.2.294-306.

Jalil M, Purwantoro A, Daryono BS, Purnomo. 2020. Distribution, variation, and relationship of *Curcuma soloensis* Valeton in Java, Indonesia based on morphological characters. Biodiversitas 21 (8): 3867-3877. DOI: 10.13057/biodiv/d210856.

John A, Olden JD. Oldfather MF, Kling MM, Ackerly DD. 2024. Topography influences diurnal and seasonal microclimate fluctuations in hilly terrain environments of coastal California. Plos One 19 (3): e0300378. DOI: 10.1371/journal.pone.0300378.

Khwarahm NR. 2020. Mapping current and potential future distributions of the oak tree (*Quercus aegilops*) in the Kurdistan Region. Ecol Process 9: 56. DOI: 10.1186/s13717-020-00259-0.

Liu J, Wang L, Sun C, Xi B, Li D, Chen Z, He Q, Weng X, Jia L. 2021. Global distribution of soapberries (*Sapindus* L.) habitats under current and future climate scenarios. Sci Rep 11 (1): 1974. DOI: 10.1038/s41598-021-98389-8.

Ma B, Sun J. 2018. Predicting the distribution of *Stipa purpurea* across the Tibetan Plateau via the MaxEnt model. BMC Ecol 18: 10. DOI: 10.1186/s12898-018-0165-0.

Macedo-Santana F, Flores-Tolentino M, Hernández Guzmán G. 2021. Diversity patterns of palms in Mexico using species distribution models. Écoscience 28: 137-147. DOI: 10.1080/11956860.2021.1888522.

Mukrimin M, Ghiffary MI, Anshari MF, Gusmiaty G, Restu M. 2021. Dynamics of soil properties under an exotic pine (*Pinus* sp.) species growing in Bantaeng Regency. IOP Conf Ser: Earth Environ Sci 807 (2): 022043. DOI: 10.1088/1755-1315/807/2/022043.

Negari SIT, Ningtyas SRA, Hanun Z, Sulton MN, Kusumaningrum L, Indrawan M, Sugiyarto, Sutomo, Setyawan AD. 2023. Agroforestry suitability evaluation using remote sensing in Jatiyoso Sub-district, Karanganyar District, Central Java, Indonesia. Biodiversitas 24 (12): 6761-6769. DOI: 10.13057/biodiv/d241239.

Partomihardjo T, Hermawan E, Pradana EW, Widiastuti Y. 2020. Riparian Flora and Peat Swamp Forest for the Restoration of Degraded High Conservation Value (HCV) Areas. Zoological Society of London (ZSL) Indonesia Programme, Indonesia.Patharkar OR, Walker JC. 2019. Connections between abscission, dehiscence, pathogen defense, drought tolerance, and senescence. Plant Sci 284: 25-29. DOI: 10.1016/j.plantsci.2019.03.016.

Penn CJ, Camberato JJ. 2019. A critical review of soil chemical processes that control how soil pH affects phosphorus availability to plants. Agriculture 9 (6): 120. DOI: 10.3390/agriculture9060120.

Phillips SJ, Anderson RP, Dudík M, Schapire RE, Blair ME. 2017. Opening the black box: An open-source release of Maxent. Ecography 40: 887-893. DOI: 10.1111/ecog.03049.

Pradhan PS, Setyawan AD. 2021. Filtering multi-collinear predictor variables from multi-resolution rasters of WorldClim 2.1 for Ecological Niche Modeling in Indonesian context. Asian J For 5(3): 111-122. DOI*:* doi.org/10.13057/asianjfor/r050207.

Rahayu Y, Fitmawati, Herman. 2013. Analysis of sago (*Metroxylon sago* Rottb.) diversity in three types of habitat in Padang Island of Meranti Archipelago. Biosaintifika 5 (1): 16-24. [Indonesian]

Rezazadeh A, Harkess RL, Telmadarrehei T. 2018. The effect of light intensity and temperature on flowering and morphology of potted red firespike. Horticulture 4: 36. DOI: 10.3390/horticulturae4040036.

Romadlon MA, Zahra FA, Nugroho GD, Piyoto A. 2021. Population, habitat characteristics, and modelling of Endangered Orchid, *Paphiopedilum javanicum* in Mount Lawu, Java, Indonesia. Biodiversitas 22 (4): 1996-2004. DOI: 10.13057/biodiv/d220448.

Rugayah, Widjaya EA, Praptiwi. 2004. Guidelines for Collecting Flora Diversity Data. Indonesian Institute of Sciences, Bogor, Indonesia.

Setiawan A. 2022. Indonesian biodiversity: Problems and conservation efforts. Indones J Conserv 11 (1): 13-21. DOI: 10.15294/ijc.v11i1.34532.

Slik JWF, Arroyo-Rodríguez V, Aiba S-I et al. 2015. An estimate of the number of tropical tree species. Proc Natl Acad Sci USA 112 (24): 7472-7477. DOI: 10.1073/pnas.1423147112.

Tawade S, Choudhary RR, Chavan VS. 2022. Effects of forest fire on forest ecosystem, biodiversity and loss of plant and animal species. Intl J Adv Res 10 (6): 597-600. DOI: 10.21474/IJAR01/14926.

Wang G, Wang C, Guo Z, Dai L, Wu Y, Liu H, Wu Y, Liu H, Li Y, Chen H, Zhang Y, Zhao Y, Cheng H, Ma T, Xue F. 2020. Integrating the Maxent model and landscape ecology theory for studying spatiotemporal dynamics of habitat: Suggestions for conservation of the endangered red-crowned crane. Ecol Indic 116: 106472. DOI: 10.1016/j.ecolind.2020.106472.

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

Wei J, Li X, Lu Y, Zhao L, Zhang H, Zhao Q. 2019. Modeling the potential global distribution of *Phenacoccus madeirensis* green under various climate change scenarios. Forests 10: 773. DOI: 10.3390/f10090773.

Worthington TA, Zhang T, Logue DR, Mittelstet AR, Brewer SK. 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: 10.1016/j.ecolmodel.2016.09.016.

Wulantika T. 2020. Morphological characterisation of enau plants in Sungai Naniang village. J-PEN Borneo: Agric Sci J 3 (2): 7-15. DOI: 10.35334/jpen.v3i2.1481.

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: 10.1016/j.ecoleng.2018.01.009.

Zhao R, Wang S, Chen S. 2024. Predicting the potential habitat suitability of *Saussurea* species in China under future climate scenarios using the optimized Maximum Entropy (MaxEnt) model. J Clean Prod 473: 143552. DOI: 10.1016/j.jclepro.2024.143552.

Zhou J, Li P, Wan J. 2022. Effects of light intensity and temperature on the photosynthesis characteristics and yield of lettuce. Horticulturae 8: 178. DOI: 10.3390/horticulturae8020178.