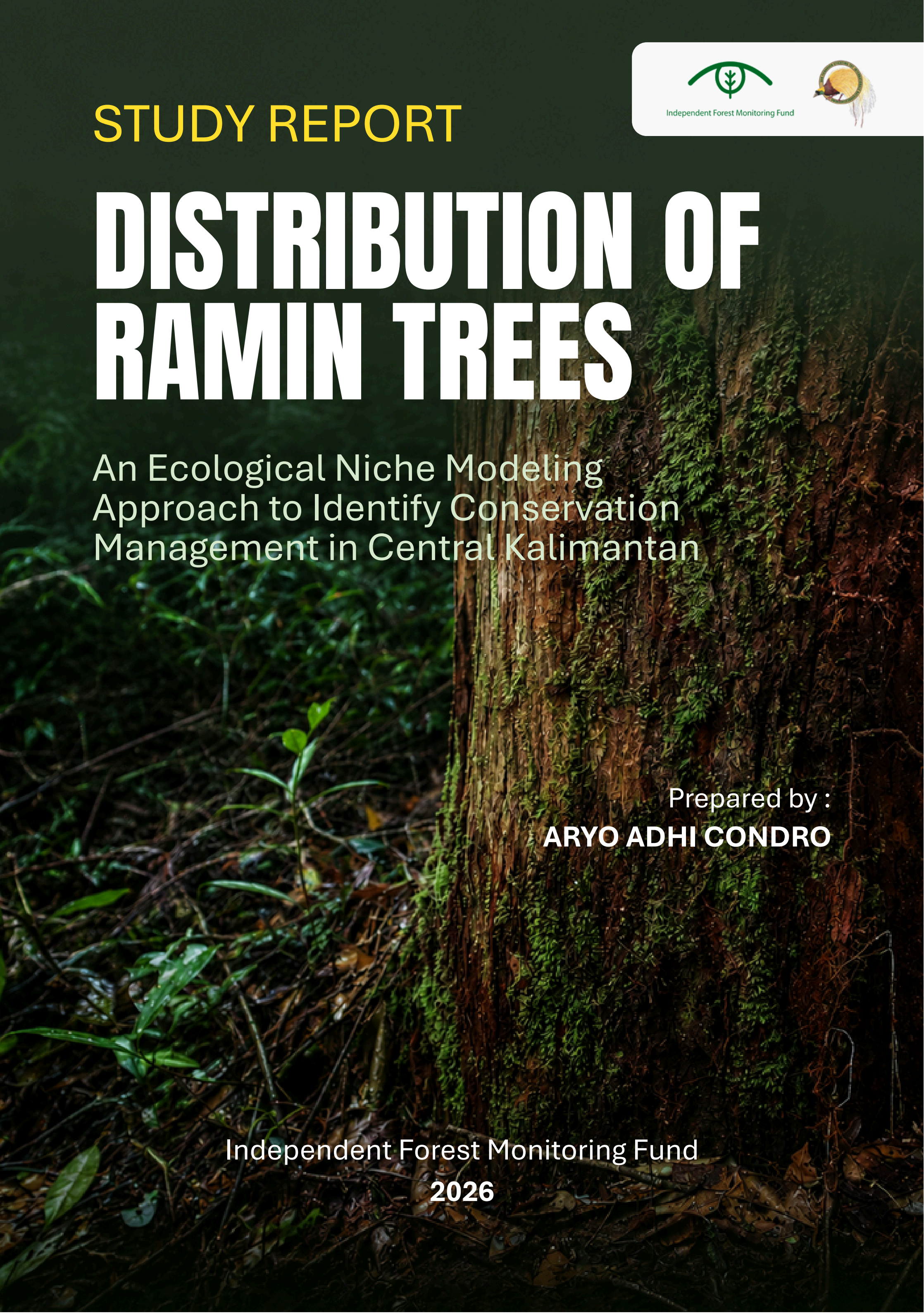

STUDY REPORT

DISTRIBUTION OF RAMIN TREES

An Ecological Niche Modeling Approach to Identify Conservation Management in Central Kalimantan

Prepared by :
ARYO ADHI CONDRO

Independent Forest Monitoring Fund
2026

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Introduction

The conservation of Gonystylus spp., commonly known as Ramin, represents a critical challenge within the biodiverse landscapes of Borneo. Gonystylus spp. is an indigenous tree species native to Indonesia and Malaysia, with a substantial presence across Borneo. This species is a large tree, capable of reaching impressive heights of 40-45 meters with a diameter at breast height (DBH) of 60-120 cm, and is distinctly recognized by its large, protruding roots. Its preferred habitat encompasses lowland, swamp, or peat-swamp environments, including peripheral mixed swamp forests, where it can occasionally form pure stands. Ramin demonstrates a particular affinity for areas characterized by deep peat, typically ranging from 350 to 600 cm, and conditions of high soil moisture content. These specific hydrological and edaphic factors are essential for its establishment, as they naturally restrict the growth of faster-growing competitor species.

The ecological significance of Ramin extends beyond its individual presence. It serves as a vital habitat for various animal species and contributes significantly to the distinct floral composition and structural integrity of peat swamp forest ecosystems. These tropical peat swamp forests are globally recognized for their immense ecological importance, functioning as substantial carbon stores. Estimates suggest that Indonesia's peatlands alone hold approximately 55 gigatons of carbon, representing 56% of the world's tropical peatland area and 77% of global peat carbon.

Beyond carbon sequestration, these forests provide crucial ecosystem services, including water regulation and disaster risk reduction, which are vital for regional environmental stability. These unique forests support a significant proportion of the region's fauna, including critically endangered species such as orangutans and Sumatran tigers, whose survival is directly imperiled by the degradation of Ramin's habitat. The specialized and challenging conditions of peat swamps have also fostered the evolution of numerous endemic species, particularly specialized freshwater fish, underscoring the irreplaceable biodiversity value of these ecosystems.

The International Union for Conservation of Nature (IUCN) Red List has assessed Gonystylus bancanus as Critically Endangered (CR), reflecting an extremely high risk of extinction in the wild. This severe conservation status is primarily a direct consequence of historical and ongoing overexploitation for its highly valued timber and extensive habitat loss. onystylus genus, which comprises over 30 species with 15 classified as 'Vulnerable' or worse, is listed on CITES Appendix II, an international agreement designed to regulate trade and prevent further overexploitation.

Figure 1. Portrait of Gonystylus bancanus (Ramin)

Ecological Niche Modelling (ENM), often interchangeably referred to as Species Distribution Modelling (SDM), is a sophisticated statistical approach employed to predict the geographic distribution of species and assess the suitability of their habitats. The fundamental principle underlying ENM is the concept of the ecological niche, which posits that a species' presence and abundance are determined by a specific set of environmental conditions, such as temperature, precipitation, and soil characteristics. The Hutchinsonian niche concept, defining this niche as a hypervolume in a multidimensional environmental space, forms the theoretical bedrock of ENM. The modeling process typically involves several key steps: rigorous data collection (including both species occurrence and environmental variables), meticulous data preprocessing, strategic model selection (with popular algorithms including Maximum Entropy (MaxEnt) and Random Forest), and thorough model evaluation and validation. MaxEnt, a machine learning algorithm, is particularly well-suited and widely used for presence-only data, a common scenario for rare or elusive species.

ENM has emerged as an indispensable tool in plant conservation, offering a robust framework to identify suitable habitats for rare and endangered plant species, pinpoint areas of high conservation value, forecast the impacts of climate change on species distribution, and provide data-driven insights for conservation and management decisions.

ENM has emerged as an indispensable tool in plant conservation, offering a robust framework to identify suitable habitats for rare and endangered plant species, pinpoint areas of high conservation value, forecast the impacts of climate change on species distribution, and provide data-driven insights for conservation and management decisions.

This research is designed to strategically leverage Ecological Niche Modelling to significantly enhance the conservation efforts for Gonystylus bancanus specifically within Central Kalimantan Province, Borneo Island.

Figure 2. Ramin Stands in Central Kalimantan

DATA & *METHODS*

Study Area

The study will maintain a focused geographical scope specifically on Central Kalimantan Province, Borneo Island. Our study areas with the total area of about 15,325,282 hectares were meticulously integrating environmental variables particularly pertinent to its unique peat swamp forest ecosystems and Ramin's distinct biological characteristics (Figure 1). We will focus on the ramin within peatland ecosystems (i.e., indicating a critically endangered ramin tree species) to be identified – *Gonystylus bancanus*.

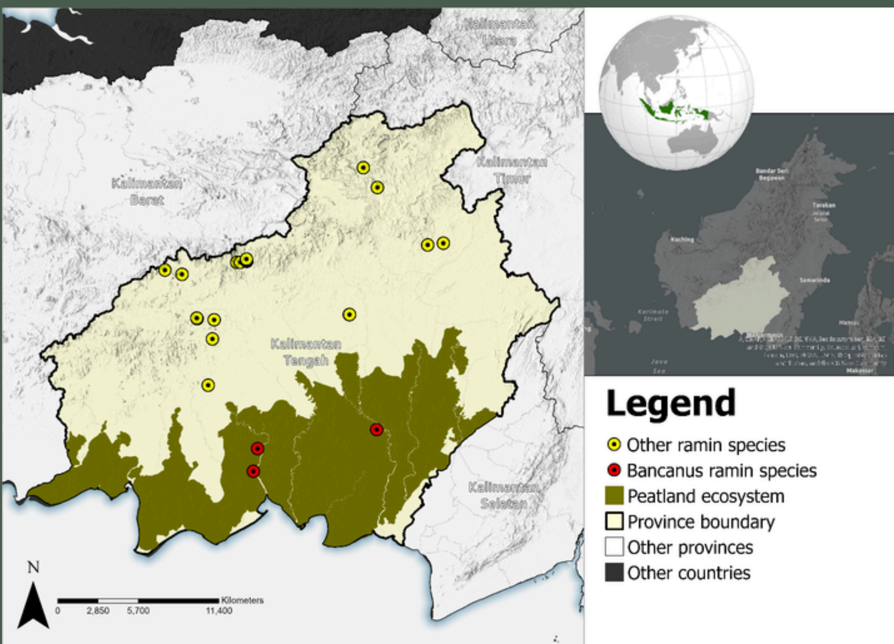

Figure 3. Map of study area for ramin tree identification in Central Kalimantan, Indonesia. Red dotted indicates Gonystylus bancanus occurrence, one of the most critical ramin species in the world.

Occurrence *Data*

We collected species occurrence records of Gonystylus spp. from vegetation surveys as well as other data sources such as Global Biodiversity Information Facility (GBIF, 2025). This study compiled 644 records of ramin species for entire Borneo Island, 624 points from GBIF and 20 points from the surveys. We focused our study on Gonystylus bancanus, one of the most critical ramin species. It's classified as Critically Endangered (CR) under the IUCN Red List,[1] primarily due to its poor natural regeneration and intrinsically slow growth rate. The species is also threatened by habitat degradation resulting from the clearance of its native peat and freshwater swamp forests for agriculture and infrastructure. Additionally, G. bancanus is the dominant species among the other ramin species.

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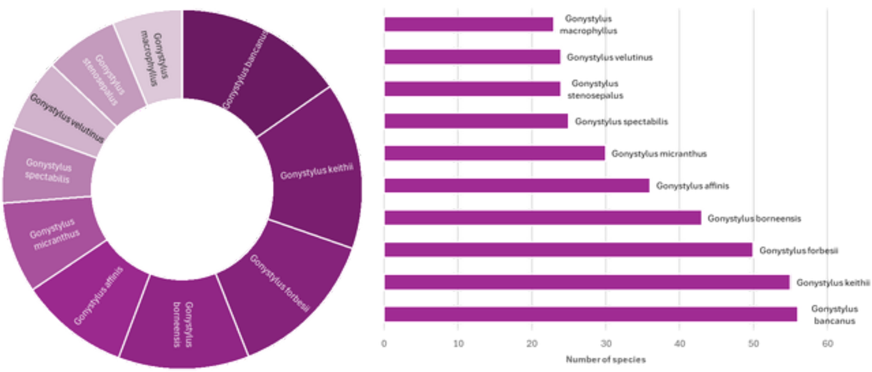
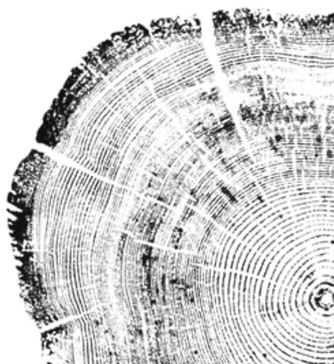


Figure 4. Composition of the ramin species across the study area.

1. https://www.iucnredlist.org/species/32941/68084993

This study conducted a thinning process (Velazco et al., 2019) toward occurrences data to reduce spatial autocorrelation and sampling bias effects. Afterwards, we used 240 records of species. We generated pseudo-absence data (n = 10,000) in equal prevalence with a random selection of geographically and environmentally stratified as the absence data were not available (Barbet-Massin et al., 2012).

Figure 5. Field Verification of Ramin Stands



Environmental *Layers*

Figure 6. *Field Verification of Ramin Stands*

This study used 19 environmental predictors to capture the potential distribution of Gonystylus spp. based on topography, biophysics, climate, carbon, anthropogenic, soil properties, and satellite-derived parameters (Table 1). The previous study showed the importance of using soil properties versus climatic variables in the case of endemic species (Tomlinson et al., 2020).

Climatic factors are fundamental drivers of species distribution, directly influencing physiological processes like photosynthesis, respiration, and reproduction. Climatic variables, including temperature and solar radiation from CHELSA-Climate, along with precipitation, are fundamental given their direct influence on the ramin tree's physiological processes like photosynthesis and metabolism. These factors establish the broad climatic envelopes within which the species can thrive, defining its thermal and hydrological requirements.

Given ramin's association with specific habitats, peat properties are crucial, notably the distance to peatland derived from the Ministry of Forestry data as well as peat thickness. These variables act as a spatial proxy for the characteristic of peat swamp forests, to which ramin is adapted. In addition, the carbon variable group, comprising Above-ground biomass, Below-ground biomass, and Soil organic carbon, is crucial for understanding the ramin tree's ecological niche and its role within the broader ecosystem.

Figure 7. Field Verification of Ramin Stands

These variables quantify the various carbon pools within a given area, offering insights into the productivity, health, and carbon sequestration potential of the ramin's habitat.

Topography significantly influences microclimate, hydrology, and soil development. Slope (SRTM-NASA) mediates water runoff, soil erosion, and solar exposure (Chen & Zhang, 2022; Pouteau et al., 2012). Aspect (SRTM-NASA), referring to the direction a slope faces, influences incident solar radiation and prevailing wind patterns, thereby creating microclimatic variations that can facilitate or constrain ramin's establishment by affecting local temperature and moisture regimes (Yang et al., 2020).

To capture biophysical parameters, we used forest-related variables such as distance to forests, canopy height, and canopy cover. Distance to forest (EU-JRC) highlights the importance of existing forest cover for connectivity and habitat availability. Canopy cover, directly impacts light availability and understory microclimate, which are critical for ramin's growth stages. Canopy height (m), sourced from Lang et al. (2023), provides a crucial structural attribute of the forest, reflecting stand maturity, successional stage, and vertical habitat complexity, all of which are relevant to the ramin tree's niche.

Soil characteristics are fundamental to plant growth, providing physical support, water, and nutrients. pH and cation exchange capacity (CEC) (SoilGrids 2.0) govern nutrient availability and overall soil fertility. Nitrogen content (SoilGrids 2.0), a key macronutrient, is essential for protein synthesis and plant growth. Its availability in the unique, often nutrient-poor, peat soils can be a limiting factor for ramin, making it a vital predictor of its distribution.

Human activities significantly modify natural landscapes and can profoundly impact species distributions. Human modification data by Theobald et al. (2020) provides a quantitative measure of cumulative human impacts across terrestrial ecosystems. This variable accounts for various pressures such as human settlement, agriculture, infrastructure, and resource extraction, which can lead to habitat loss, fragmentation, and altered environmental conditions. For the ramin tree, which often inhabits valuable timber forests and peatlands, understanding the extent of human modification is critical for identifying areas where its distribution may be constrained by anthropogenic disturbance, thus informing conservation efforts and sustainable management strategies.

Figure 8. Ramin Pneumatophores Emerging on Wet Peatlands

We also used several spectral signature indices based on optical satellite imageries to capture the responses of ramin tree to the spectral band with regards of vegetation characteristics and soil moisture. Kernel normalized difference vegetation index (kNDVI), a unified vegetation indicator that produces robust proxies for canopy structure, leaf pigment content, and photosynthetic potential (Camps-Valls et al., 2021) based on a recent composite of Sentinel-2 optical satellite imageries. A higher kNDVI value generally indicates denser and healthier vegetation, providing valuable information about the photosynthetic capacity and overall vigor of the plant community in a given area.

For the ramin tree, which thrives in specific forest ecosystems, kNDVI can effectively delineate areas with suitable vegetation structure and biomass. The Normalized Difference Moisture Index (NDMI), also known as the Normalized Difference Water Index (NDWI), is highly effective in assessing vegetation water content and, by extension, soil moisture.

Water availability is a primary limiting factor for plant growth and distribution, especially for species in tropical and subtropical environments like the ramin tree. A higher NDMI value typically indicates higher moisture content. This index can therefore provide crucial information about the hydrological conditions of the ramin tree's habitat, helping to identify areas with sufficient water availability to support its growth and survival.

We resampled all 19 environmental covariates to a spatial resolution of 100 meters. We conducted variable selection based on Pearson correlation following Dormann et al. (2013) to overcome collinearity issues that can affect the model output (Feng et al., 2019). After variable selection process, we only used 17 environmental predictors, eliminating above-ground biomass, kNDVI, and distance to road (See Appendix 1).

Table 1.

Model predictors in predicting ramin tree species in Central Kalimantan

Group	Variables	Unit	Source	Note
Climate	Temperature	˚C	CHELSA-Climate (Karger et al., 2020)	
	Precipitation	mm	CHELSA-Climate (Karger et al., 2020)	
	Solar radiation	W/m2	CHELSA-Climate (Karger et al., 2020)	
Carbon	Above-ground biomass	Mg/ha	Living biomass data (Harris et al., 2021)	
	Below-ground biomass	Mg/ha	WCMC (Spawn et al., 2020)	
	Soil organic carbon	Mg/ha	SoilGrids 2.0 (Poggio et al., 2021)	
Peat properties	Distance to peatland	km	Ministry of Forestry	
	Peat thickness	cm	PEATGRIDS (Widyastuti et al., 2025)	
Biophysical	Distance to forest	km	EU-JRC (Bourgoin et al., 2024)	
	Canopy height	meters	ETH (Lang et al., 2023)	

Group	Variables	Unit	Source	Note
	Canopy cover	%	Analisis penulis	
Satellite-derived spectral information	kNDVI	Unitless	Oleh (Camps-Valls et al., 2021)	Sentinel-2
	NDMI	Unitless	Oleh (Theobald et al., 2020)	Sentinel-2
Antropogenik	Human modification	%	(Theobald et al., 2020)	
Topographic	Slope	%	SRTM-NASA (Jarvis et al., 2006)	
	Aspect	Degree	SRTM-NASA (Jarvis et al., 2006)	
Soil properties	pH	Unitless	SoilGrids 2.0 (Poggio et al., 2021)	
	N-content	g/kg	SoilGrids 2.0 (Poggio et al., 2021)	
	Cation exchange capacity	cmol/kg	SoilGrids 2.0 (Poggio et al., 2021)	

Model *Calibration*

We modelled Gonystylus spp. based on an ensemble model from various single machine learning algorithms – i.e., maximum entropy (MXD), boosted regression trees (BRT), random forest (RDF), and support vector machine (SVM) (Breiman, 2001; Cortes & Vapnik, 1995; Elith et al., 2008; Phillips et al., 2006) by using ENMTML package in R (Andrade et al., 2020). The ensemble model was calculated based on the transformation of the first component of the principal component analysis from four single models, considered by Sørensen metric (Thuiller, 2004). We ran the k-fold partition which randomly split the dataset into 10 number of folds (Fielding & Bell, 1997) to create an ideal model evaluation that requires a dataset in which occurrences are independent of the ones used to fit the model.

We provided several determination metrics: area under the curve (AUC), Kappa, true skill statistic (TSS), Jaccard, and Sørensen (Allouche et al., 2006; Leroy et al., 2018) to evaluate the model performance. To convert the continuous map of the species distribution into a binary map, we used the threshold that maximizes Sørensen value (Allouche et al., 2006). Moreover, we performed spatially restricted species distribution models based on a posteriori method (i.e., buffered minimum convex polygon of the occurrence data) as well as peatland areas restriction zone to deal with overprediction (Kremen et al., 2008; Mendes et al., 2020) and emphasized our study for Gonystylus bancanus species.

Threats and Conservation Management of *Ramin trees*

We investigated historical deforestation in Central Kalimantan, as critical habitat for ramin trees using Tropical Moist Forests (TMF) data, developed by Vancutsem et al. (2021) during 1987 – 2024 to capture the main drivers of ramin species loss. In Indonesia, intensive industrial forestry, logging activities, and agricultural development has been occurred since 1970s (Margono et al., 2012). Then, we classified defore-station data into three classes: (i) no deforestation; (ii) deforestation before old-FSC cut-off date (< 1995); (iii) deforestation after old-FSC cut-off date (1995 – 2020); (iv) deforestation after EUDR cut-off date (2021 – 2024). Furthermore, we also over-layed our deforestation data with the potential ramin distribution. In addition, we overlay predicted ramin distribution with forest concession in Central Kalimantan to better understand ramin occu-rrences under private-sector territory.

Figure 9. Ramin Stands at the Boundary of Land Clearing Areas

To understand the distribution of ramin trees (Gonystylus bancanus) within protected areas in Central Kalimantan, we're conducting a spatial analysis by overlaying two crucial datasets. First, we'll use a predicted ramin distribution map. This map will then be integrated with protected areas data sourced from World Database Protected Areas (WDPA) by WCMC – UNEP. Additionally, we also investigated potential ramin distribution within various protected areas designation.

This approach allows us to both visually and quantitatively pinpoint areas where potential ramin habitats intersect with established protected area and forest concession boundaries. By doing so, we can assess the extent to which predicted ramin populations fall under legal protection, which is absolutely critical given ramin's endangered conser-vation status.

RESULTS & *DISCUSSION*

Model Evaluation and Potential *Ramin Tree Distributions*

Our study demonstrated that Random Forest algorithm model for Gonystylus spp. outperformed other algorithms, including Ensemble model. Random Forest model achieved a good Sørensen index average with the value of about 0.751 ± 0.002 (Table 2)

Tabel 2.

Model evaluation for Gonystylus spp. for various algorithms based on discrimination metrics. BRT: Boosted Regression Trees, MXD: Maximum Entropy; RDF: Random Forest; SVM: Support Vector Machine; and ENS: Ensemble.

Algoritm	Discrimination metrics				
	AUC	Kappa	TSS	Jaccard	Sorensen
BRT	0.701 ± 0.003	0.292 ± 0.007	0.292 ± 0.007	0.574 ± 0.002	0.729 ± 0.002
MXD	0.654 ± 0.003	0.213 ± 0.005	0.213 ± 0.005	0.551 ± 0.002	0.710 ± 0.001
RDF	0.720 ± 0.002	0.384 ± 0.007	0.384 ± 0.007	0.602 ± 0.003	0.751 ± 0.002
SVM	0.719 ± 0.002	0.338 ± 0.004	0.338 ± 0.004	0.590 ± 0.002	0.742 ± 0.001
ENS	0.723 ± 0.003	0.317 ± 0.006	0.317 ± 0.006	0.577 ± 0.002	0.731 ± 0.002

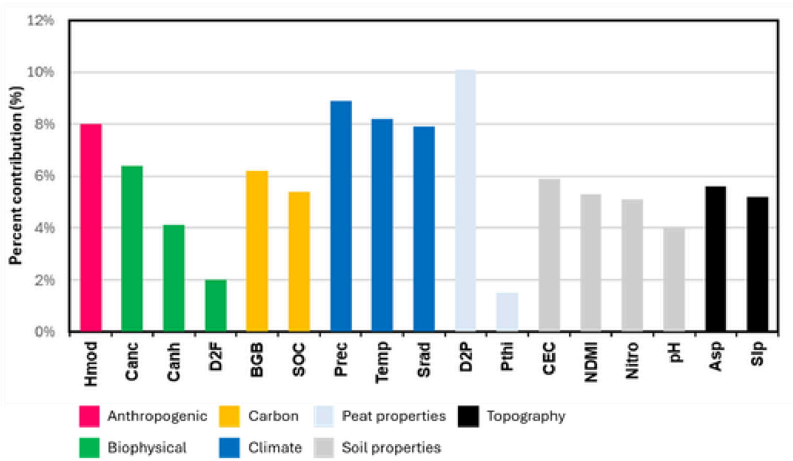
Figure 10. Portrait of Felled Ramin Trees

Our analysis revealed that climate, soil-properties, and biophysical aspects were the most influential predictors of Gonystylus spp. potential distribution (Figure 3A), contributing approximately 25.0%, 20.3%, and 12.5%, respectively.

In addition, distance to peatland had the highest variable importance score, contributing to 10.1% of the model, followed by precipitation (8.9%) and temperature (8.2%).

Based on the provided figure below (Figure 3B), a clear narrative emerges regarding the environmental factors influencing the potential distribution of ramin. The strongest correlation, and thus the most significant driver, is a high positive relationship with Distance to Peatland (r=0.716), sugges-ting that the species' potential distribution is highly concentrated in or near peatland areas. This is supported by a strong negative correlation with Soil Organic Carbon (r=−0.574), which indicates that ramin tends to prefer soils with lower organic matter content, potentially favoring mineral-rich swamp areas rather than deep, highly organic peat. Furthermore, a moderately strong positive correlation with Solar Radiation (r=0.569) suggests that ramin's distribution may be favored in more open canopy conditions or forest edges, perhaps related to its regeneration requirements. Other variables, while less influential, still offer insights; for instances, a positive correlation with Precipitation (r=0.329) aligns with the species' preference for wet, swampy habitats. Conversely, a moderate negative correlation with Cation Exchange Capacity (r=−0.353) and weak correlations with factors like Canopy Height, Temperature, and pH suggest that these are not the primary limiting factors for ramin's distribution. In summary, the potential distribution of ramin appears to be primarily governed by a combination of hydrological and soil properties, specifically its close association with peatlands and preference for lower soil organic carbon, with sunlight availability playing a secondary but notable role (See probability of ramin distribution in Figure 4).

A



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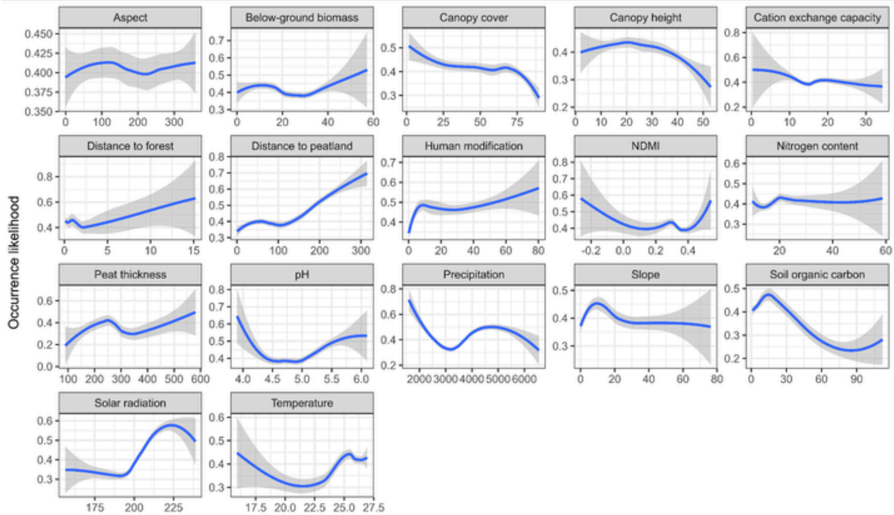


Figure 11. Variable importance of potential distribution of ramin species in Central Kalimantan (A) and response curve for all selected predictors for ramin potential distribution model (B). Hmod: human modification, Canc: canopy cover, Canh: canopy height, D2F: distance to forest, BGB: below-ground biomass, SOC: soil organic carbon, Prec: precipitation, Temp: temperature, Srad: solar radiation, D2P: distance to peatland, Pthi: peat thick, CEC: cation exchange capacity, NDMI: normalized difference moisture index, Nitro: nitrogen content, Asp: aspect, and Slp: slope.

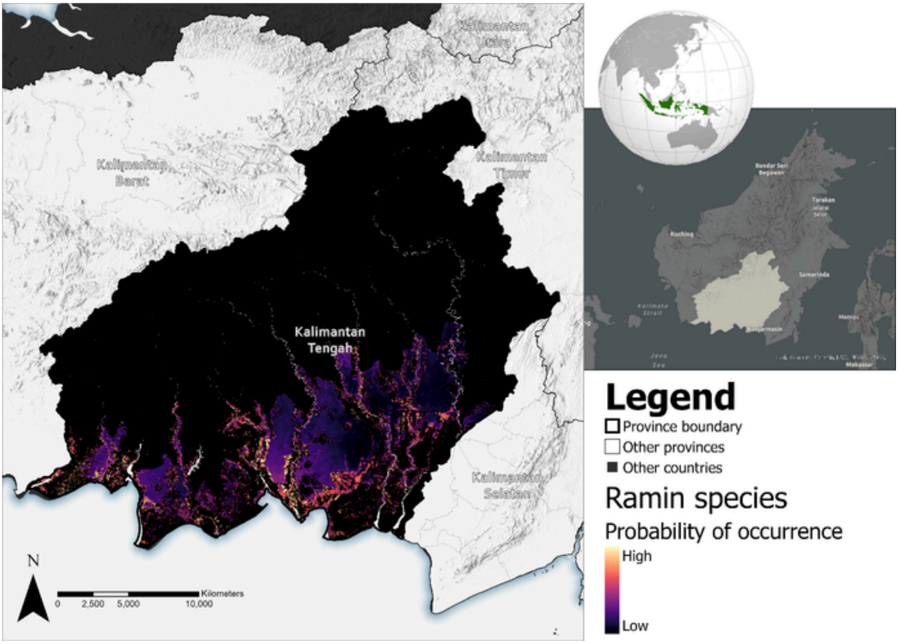


Figure 12. Probability of ramin distribution in Central Kalimantan based on the best model (i.e., Random Forest).

Based on the best model result, the potential ramin distribution in Central Kalimantan reveals a critical conservation challenge. The result shows a total potential area of approximately 75,947.40 hectares, of which the vast majority, 65,533.15 hectares (86.3%), is found outside of formally protected areas.

This is a highly significant finding, as it indicates that the bulk of the species' potential habitat remains vulnerable to land conversion and other human activities.

Our analysis further highlights that the distribution is not uniform across the province; the potential habitat is heavily concentrated in a few key districts (Figure 5). **Katingan** stands out as the most critical district, containing the largest total potential area at **18,945.59 hectares**, with a substantial portion of this located within its non-protected zones. Similarly, **Kotawaringin Timur** and **Kotawaringin Barat** are also major strongholds, with approximately **15,242.17 hectares** and **13,412.39 hectares** respectively. The data from Kotawaringin Timur is particularly alarming from a conservation perspective, as entire of its potential ramin habitat is currently unprotected. In conclusion, this analysis underscores that an effective conservation strategy for ramin in Central Kalimantan must adopt a landscape-level approach that extends well beyond the boundaries of existing protected areas, prioritizing urgent conservation and management efforts in the districts of **Katingan** and **Kotawaringin Timur**, where the largest and most vulnerable populations of the species are likely to be found.

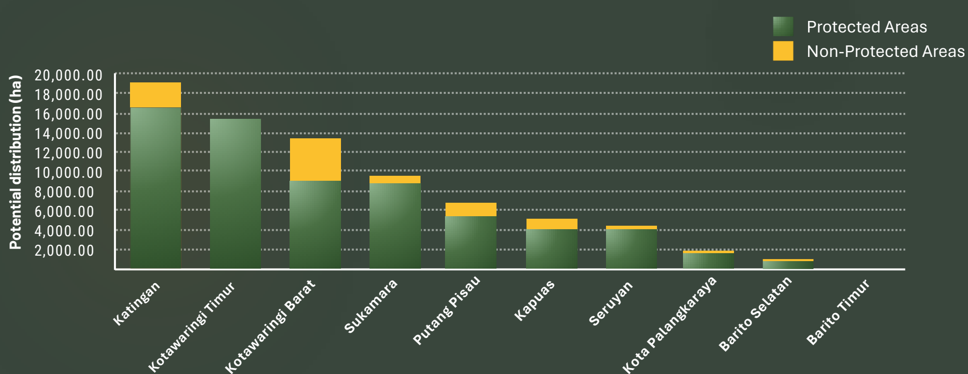


Figure 13. Potential distribution of ramin species in Central Kalimantan, divided by district level within and outside protected areas.

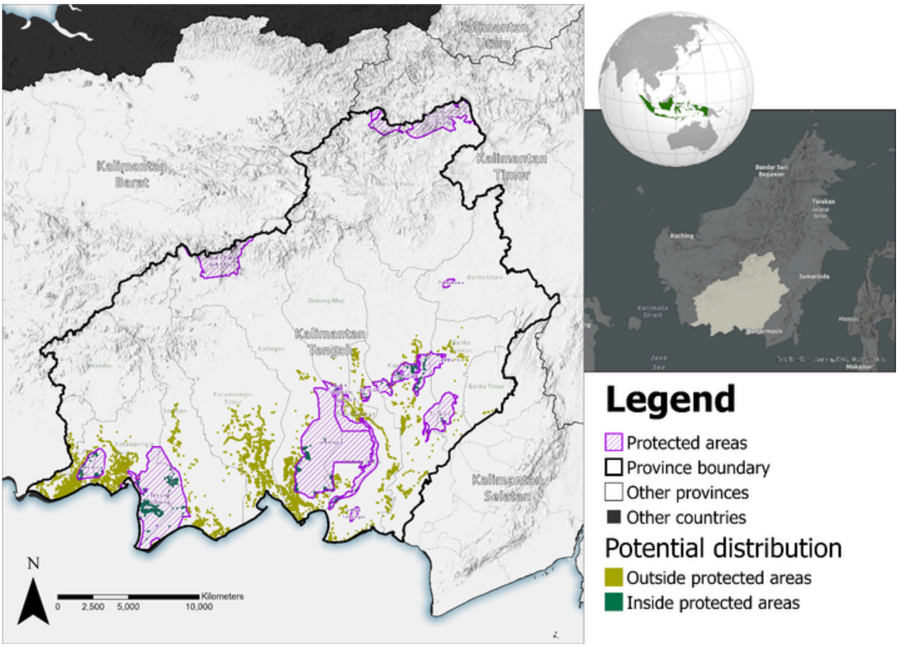


Figure 14. Potential distribution of ramin species in Central Kalimantan.

THREATS AND CONSERVATION MANAGEMENT OF *RAMIN TREES*

Figure 15. Ramin Stands Along the Boundary of Land Clearing Areas

Deforestation Over the Years in *Kalimantan Tengah*

Between 1988 and 1996, while the overall deforestation in Central Kalimantan was at a relatively low and stable rate (e.g., 80,419 ha in 1996), the deforestation within the potential ramin distribution area was also at a moderate level, with a loss of 103.94 hectares in 1996. This period likely represents the impact of conventional logging practices and low-intensity land clearing, which posed a significant, but not catastrophic, threat to the species. A major inflection point occurred from **1997** to **1998**. The result for overall deforestation shows a massive spike to **535,564 ha** in 1997 and **402,768 ha** in 1998. This is directly reflected in the findings, which records a corresponding sharp increase in habitat loss to **562.19 ha** and **337.95 ha** respectively. This synchronous and dramatic increase in deforestation across both datasets strongly suggests that large-scale, province-wide events, such as the 1997-1998 El Niño-driven fires and the associated government-led land conversion projects, were the primary drivers of ramin habitat destruction (Parameswaran et al., 2004).

These events not only cleared forests but also altered the peatland hydrology, making it more vulnerable to future fires and less suitable for ramin, a species dependent on a waterlogged environment. These conditions, combined with widespread land clearing for agricultural expansion, and the use of fire as a land management tool, created a positive feedback loop that led to catastrophic, uncontrolled wildfires and extensive forest loss (Varma, 2003).

Following this catastrophic period, deforestation within the ramin distribution area remained volatile. While overall deforestation rates were lower, they still caused significant habitat loss. A second, smaller spike is visible around 2006, with ramin habitat loss reaching **374.31 ha**, which is proportionally higher compared to the total deforestation. This indicates that despite a general decline in forest loss, pressures on the specific peat swamp ecosystems where ramin resides continued.

Gambar 16. Monitoring the Potential of Ramin Stands

Loss of Ramin *Habitat*

2015
1.431,51 ha

2016
1.563,98 ha

The extreme peaks in ramin habitat loss in 2**015 (1,431.51 ha)** and **2016 (1,563.98 ha)**, while total deforestation was below 100,000 ha, point to highly localized but devastating events. These likely represent major peatland fires or intensive clearing within core ramin habitats, disproportionately affecting the species (Condro et al., 2018).

The most recent period, from **2017 to 2024**, presents a crucial shift. The data shows a dramatic and sustained decline in deforestation within ramin's distribution, with annual losses consistently below 100 hectares, reaching a low of **36.61 ha** in 2021. This trend, which aligns with the overall decrease in deforestation, indicates a positive response to recent conservation policies, such as the peatland restoration initiatives and moratoriums on new land concessions in primary forests. The sharp drop in habitat loss for this critically endangered species is a direct consequence of improved land-use governance and fire prevention, offering a much-needed opportunity for the recovery and restoration of its remaining populations.

Sub-regional Deforestation Variations within *Central Kalimantan*

The spatial analysis of deforestation in Central Kalimantan reveals significant sub-regional variations in both overall forest loss and the specific impact on ramin habitat, as shown in the provided district-level data.

Highest Deforestation Rate

Kotawaringin Timur
761.386,58 ha

Seruyan
530.668,65ha

Kotawaringin Barat
416.958,97 ha

Kotawaringin Timur emerges as the district with the highest overall deforestation, recording a staggering **761,386.58 hectares** of forest loss. This is closely followed by **Seruyan** and **Kotawaringin Barat**, with **530,668.65 ha** and **416,958.97 ha** respectively. This concentration of deforestation is likely linked to the rapid expansion of industrial-scale plantations, which have been historically concentrated in these areas.

More critically, the data demonstrates that these same districts are also centers of ramin habitat loss. **Kotawaringin Barat** and **Kotawaringin Timur** show the highest ramin defore-station, at **1,947.55 ha** and **1,631.45 ha** respectively. This high degree of overlap between overall deforestation hot-spots and ramin habitat destruction suggests a strong spatial correlation, indicating that the drivers of defore-station are directly impacting the fragile peat swamp forests where ramin resides. The disproportionate loss of ramin habitat in these districts, compared to their overall land area, underscores their critical importance for ramin conservation.

In contrast, districts like **Murung Raya, Barito Utara**, and **Kota Palangkaraya** show significantly lower overall deforestation rates. This could be attributed to factors such as geographical remote-ness, less suitable land for large-scale agricultural con-version, or the presence of protected areas. Conse-quently, these districts also show either no or very low ramin deforestation, making them potential strongholds for the species' long-term survival. The data for **Murung Raya** (21,418.51 ha overall deforestation, with no recorded ramin deforestation) and **Barito Utara** (95,324.06 ha overall, with no recorded ramin deforestation) provides a crucial spatial perspective on where conservation efforts might be most effective.

IMPACT OF INTERNATIONAL ENVIRONMENTAL REGULATIONS ON DEFORESTATION IN CENTRAL KALIMANTAN AND ITS EFFECT ON THE CONSERVATION OF RAMIN

Before FSC Old-Cut Off Date

(Pra-1994)

The initial period, from 1988 to 1993, represents a time before stringent international forest management stan-dards like those from the Forest Stewardship Council (FSC) became influential. During this time, overall deforestation in Central Kalimantan was relatively low, with an average annual loss of **54,345 hectares.** Defore-station within the potential ramin distribution area was correspondingly minimal, with an average annual loss of **81.01 hectares.**

This low-level deforestation was primarily driven by local land use changes and unsustainable selective logging practices, which, while harmful, did not yet represent the industrial-scale habitat destruction that would come later.

After FSC Old-Cut Off Date

(1994-2020)

This phase is marked by a dramatic and sustained increase in deforestation. While the FSC's old cut-off date of 1994 was intended to prevent forest conversion for certification,

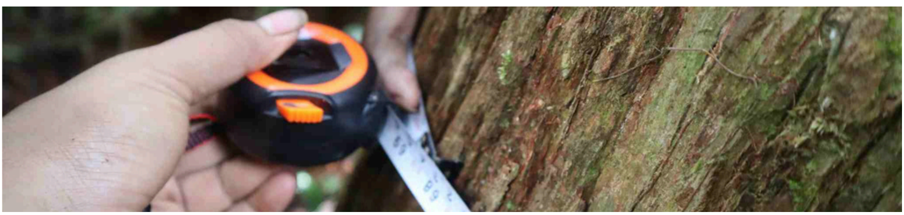


Figure 17. Verification of Ramin Stands

the data shows that this period was actually the most destructive for the region. Overall deforestation surged, peaking at **535,564 hectares** in 1997. This trend is mirrored and amplified within the ramin distribution area, which experienced its highest ever recorded annual loss of **1,563.98 hectares** in 2016. This period of high defore-station coincides with significant socioeconomic pressures, including the 1997 Asian Financial Crisis and the expansion of industrialscale plantations for palm oil and pulpwood. The high defore-station rates within the ramin distribution area, particularly during the 2015-2016 El Niño event, show that these fragile peat swamp forests were disproportionately targeted, pushing the critically endangered ramin species to the brink.

During EUDR Cut-Off Date

(Pasca-2020)

The most recent period, from 2021 to 2024, is defined by the cut-off date of the European Union Defore-station Regulation (EUDR), which aims to ban products linked to deforestation after December 31, 2020. This period is a turning point. Both overall deforestation and ramin habitat loss have plummeted. Overall defore-station averaged just 24,142 hectares per year, while ramin deforestation dropped to an average of only 42.94 hectares.

This significant decline demonstrates a strong link between new, far-reaching international regulations and a reduction in deforestation on the ground. The threat of market exclusion from a major economic bloc like the EU, coupled with Indonesia's own strengthened national policies on peatland and forest protection, has created a powerful incentive for a decoupling of economic activities from deforestation, offering a crucial reprieve for the ramin species and its unique ecosystem.

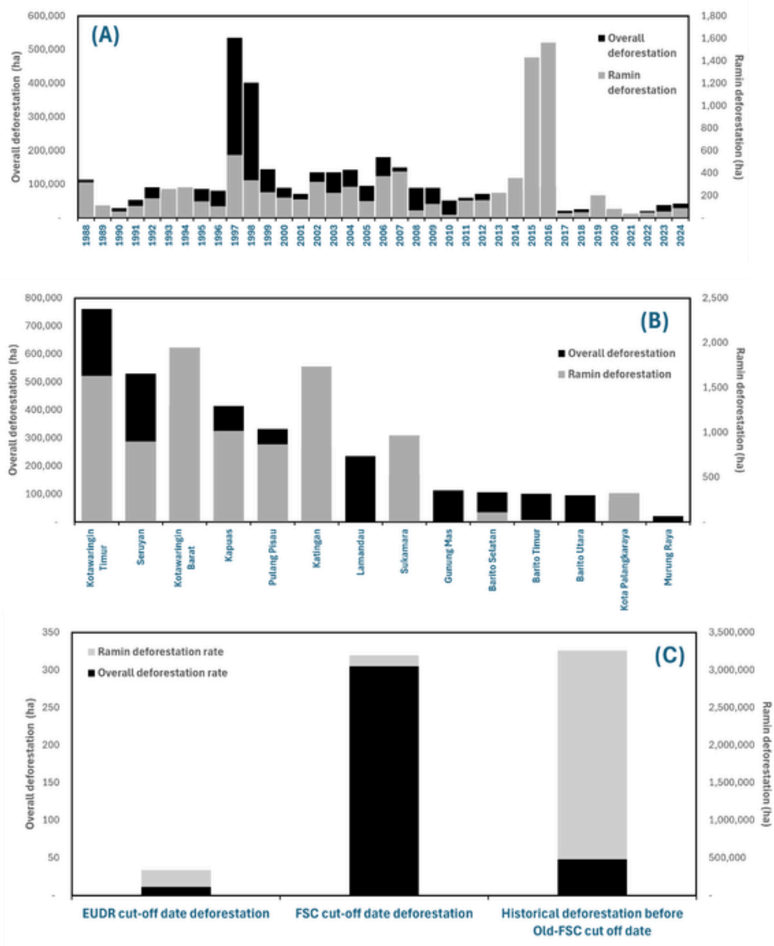


Figure 18. Overall and ramin deforestation in Central Kalimantan over 1988-2024 (A), by district (B), and by international regulation cut-off date (C).

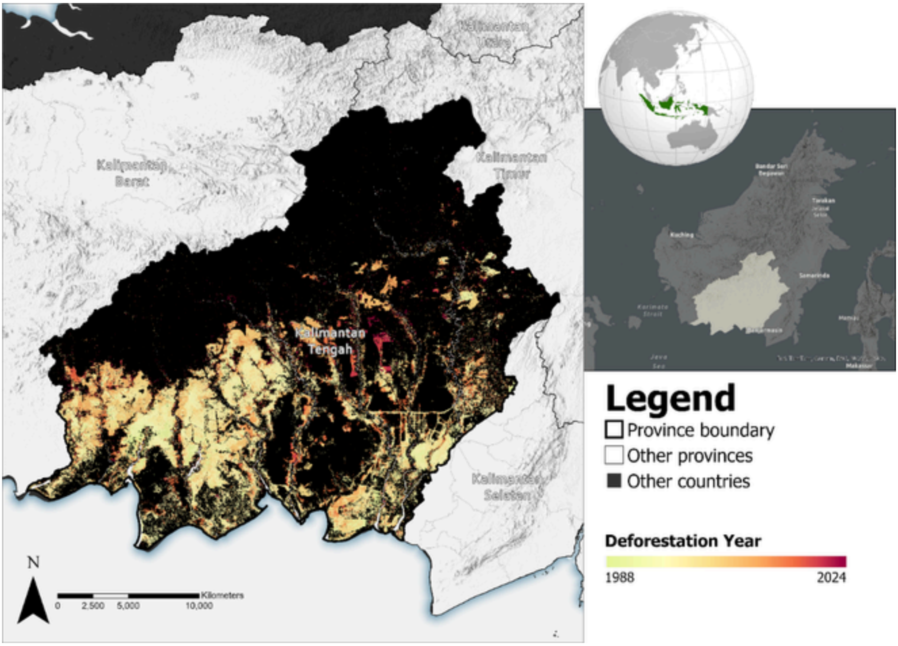


Figure 19. Historical deforestation during 1988 – 2024 in Central Kalimantan.

Ramin Distribution under Forest Concessions *in Central Kalimantan*

Our findings revealed that a significant portion of the potential ramin habitat is situated within production and ecosystem restoration concessions (i.e., PBPH), creating the management of these areas crucial for the species' conservation.

Katingan contain the largest areas of potential ramin distribution within forest concessions. Specifically, this district has a substantial area of potential ramin distribution within ecosystem restoration concessions, and its total ramin distribution within forest concessions (3,256.06 ha) is the highest among all districts. In addition, **Kotawaringin Timur** and **Seruyan** also had a large potential ramin distribution within ecosystem restoration with the total area of about 1657.26 hectares and 946.7 hectares, respectively. The presence of ramin within these conservation-focused concessions is a positive sign, as these areas are designated for the rehabilitation of degraded forests, offering a potential pathway for ramin population recovery. This spatial allocation highlights the potential for these concessions to serve as crucial refuges and restoration sites for the species.

Figure 20. Indications of Illegal Logging of Ramin Trees

In contrast, other districts show a different pattern. **Seruyan** and **Pulang Pisau**, for example, have a high percentage of their ramin distribution within Industrial Timber Plantation (HTI) concessions. This indicates that while the district has the most ramin habitat under concession management, it is also the most threatened, as timber plantations are a major driver of clear-cutting and forest conversion.

The data also reveals that some districts, like Murung Raya and Barito Utara, have a low or zero potential ramin distribution within forest concessions. This, combined with their previously noted low overall deforestation rates, suggests that these areas are naturally less impacted by industrial forestry and may function as critical ramin strongholds outside of formal concession boundaries.

The distribution of ramin within different concession types provides a nuanced understanding of conservation challenges and opportunities. The high concentration of ramin within timber and logging concessions in some districts represents a significant conservation challenge, necessitating stringent monitoring and the enforcement of sustainable forestry practices. Conversely, the presence of ramin in Ecosystem Restoration concessions in other districts offers a clear opportunity for targeted, in-situ conservation efforts. Therefore, effective conservation strategies must be spatially explicit, addressing the distinct land-use pressures in each district while leveraging the potential of conservation-focused concessions for habitat restoration.

Table 3.

Potential ramin distribution within forest concessions by districts in Central Kalimantan.

District	Total in hectares (Potential ramin distribution within Forest concessions)				
	Ecosystem Restoration	Logging concession	Timber plantation	Others	Grand Total
Katingan	3.256,06				3.256,06
Sukamara				2.357,54	2.357,54
Kotawaringin Timur	1.657,26		43, 43	27,57	2.357,54
Seruyan	946,7		63, 75		1.010,45
Pulang Pisau			11, 75		11,75
Barito Timur	9,66				9,66
Kapuas		6,21			6,21
Barito Selatan				6,2	6,2
Grand Total	**586.968**	**621**	**11.893**	**239.131**	**838.613**

In addition, we found that PT Rimba Makmur Utama (Ecosystem Restoration designation) was the largest potential ramin distribution within forest concessions in Central Kalimantan (4.913.33 hectares), followed by PT Prima Nusantara Abadi Kobar and PT Rimba Raya Conservation with the total area of about 2357.54 hectares and 946.70 hectares, respectively.

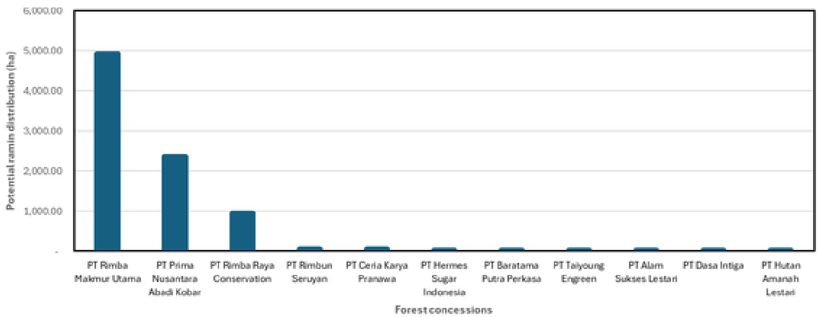


Figure 21. Potential ramin distribution within forest concessions in Central Kalimantan.

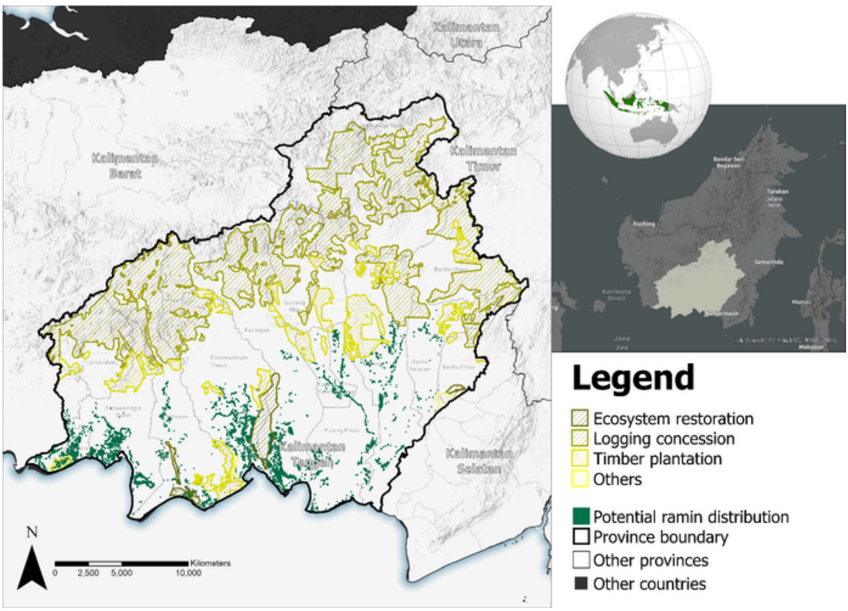


Figure 22. Map of potential ramin distribution under forest concessions in Central Kalimantan.

Conservation of Ramin *in Central Kalimantan*

Building on the understanding that the majority of potential ramin habitat is located in non-protected areas, a more detailed examination of the distribution within existing protected zones provides crucial insights into the species' current conservation strongholds. The analysis of protected areas reveals that the total potential ramin distribution of **10,414.25 hectares** is not evenly distributed across the protected area network. **Tanjung Putting National Park** emerges as the most significant sanctuary, provid-ing a critical refuge for the species with approximately **4,016.98 hectares** of potential habitat.

Following closely, **Sebangau National Park** also serves as a vital stronghold, contribut-ing another **3,720.27 hectares.** Together, these two national parks account for a substantial portion of the species' protected distribu-tion in the region. Other protected areas, such as the **Lamandau Wildlife Reserve** and various **Ex PLG Nature Reserves**, also contribute to the conservation effort, albeit with smaller areas (Table 4).

This detailed breakdown reinforces the notion that while a significant portion of the total potential habitat is vulnerable, these specific protected areas are in-valuable for the long-term persistence of Ramin, acting as core conservation zones and potentially serving as source populations for surrounding landscapes.

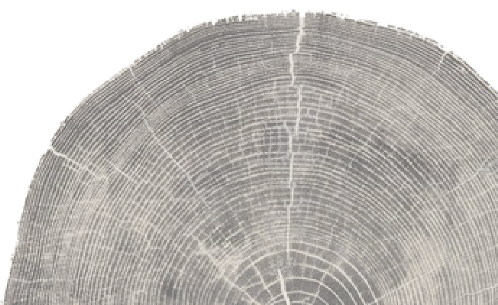


Table 4.

Statistics of potential ramin distribution within protected areas in Central Kalimantan.

Protected Areas	Total in Hectare
National Park	7.737,25
Sebangau	3.720,27
Tanjung Puting	4.016, 98
Nature Recreation Park	9,80
Tanjung Keluang-Teluk Keluang	9,80
Undesigned	1.217,67
Bukit Rawi (Eks PLG II)	54,96
Marang (Eks PLG I)	0,01
Sungai Barito	705, 34
Sungai Kapuas	114,64
Tanjung Malatayur	342,72
Wildlife Reserve	1.449,53
Lamandau	1.449,53
Grand Total	3.720,27

If we deep dive into protected areas designation, we found that potential ramin distribution likely occurred in undesigned protected areas, with the total of about **3565.55 hectares (34.24%)**, followed by wilderness (e.g., zona rimba) and rehabilitation zones with the total areas of about 2376.95 hectares (22.82%) and 2206.86 hectares (21.19%), respectively. Only small proportion of ramin distribution that occurred within core zone **(292.97 hectares)**, indicating the susceptability of ramin with regards of protection management (Table 5).

The presence of ramin in undesignated and wilderness areas suggests a need for targeted conservation efforts and further assessment to determine the appropriate management strategies for these habitats. While the presence of ramin in rehabilitation zones is positive for restoration efforts, the low numbers in core and special zones may indicate either a lack of ramin presence in those specific areas or the effectiveness of past conservation measures in those zones. Future conservation strategies should prioritize these high-concentration areas, particularly the undesignated and wilderness zones, to ensure the long-term survival of this species.

Table 5.

Potential ramin distribution by protected areas designation in Central Kalimantan.

Protected areas designation	Total in hectares
Core Zone	292,97
Special Zone	39,38
Utilization Zone	503,21
Rehabilitation Zone	2.206,86
Wilderness Zone	2.376,95
Traditional	1.429,33
Undesigned	3.565,55
Grand Total	10.414,25

This habitat vulnerability is further exacerbated by the complex regulatory landscape surrounding the species. While one of ramin species is classified as Critically Endangered (CR) by the IUCN and is regulated internationally under Appendix II of CITES, there is a noticeable gap in robust, on-the-ground national enforcement that would provide the necessary protection for the remaining populations.

Despite the critically endangered status of Gonystylus bancanus, the current **export quota** for ramin species remains substantial, totaling **750,000 kg**.[2] **Central Kalimantan** serves as the **primary sourcing region** for these exports. This sustained high volume of trade, concentrated in a single geographical area, underscores the **critical necessity of implementing robust conservation strategies** for G. *bancanus* within Central Kalimantan.

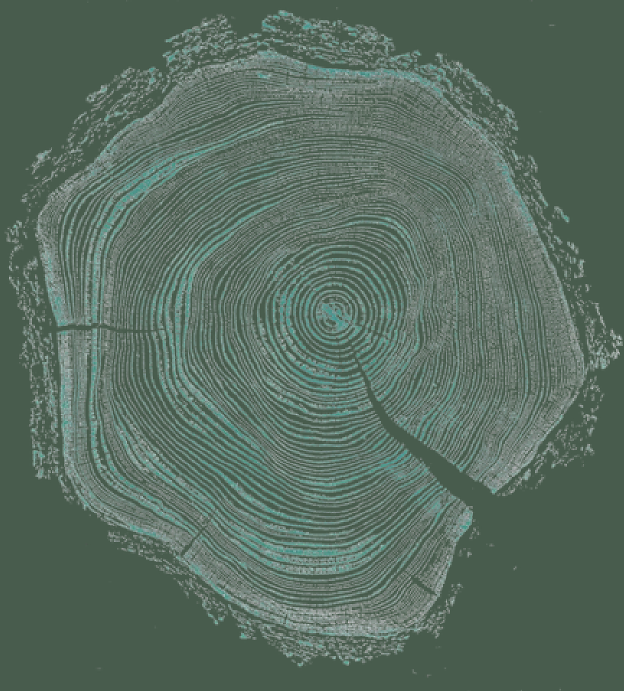
2. https://balaikliringkehati.kemenlh.go.id/wp-content/uploads/2024/07/Kuota-penangkapan-pengambilan-TSL-2024.pdf

Table 6.

Export quota in 2024 at national level for ramin species.

Species Name	Quota (Kg)			Sourcing Area
	Total	Domestic	International	
Gonystylus spp.	750.000	75.000	675.000	*Grand Total*
	500.000	50.000	450.000	*Central Kalimantan*
	250.000	25.000	225.000	*West Kalimantan*

The presence of a significant potential habitat within a few key protected areas is a positive sign, highlighting their importance as core refuges. Besides, indigenous people and local communities within the study areas also recognize the importance of ramin conservation for preserving vital ecosystem services, such as soil and water regulation, in the surrounding environment. However, for a species whose populations are still subject to **illegal logging** and **habitat degradation**, these protected zones alone are insufficient. The findings from this analysis collectively underscore the urgent need for a comprehensive, landscape-level conservation strategy that not only strengthens the management of existing protected areas but also addresses the lack of protection for the vast majority of its potential habitat, which exists in vulnerable non-protected lands. This is crucial for ensuring the long-term viability of the species in Central Kalimantan.



CONCLUDING *Remarks*

Caveat of the *Study*

A significant caveat is that the existing protected area network is **insufficient** for the long-term protection of Ramin, as the majority of its potential habitat is unprotected. The ENM faces two opposing limitations regarding model accuracy: the potential for **false positive** predictions in areas historically cleared for industrial plantations, where the species has vanished, and the potential for **false negative** predictions. The repeated field discovery of Ramin in areas outside the previously predicted potential points, such as in the Rimba Zone of Sebangau National Park and in the KSA/KPA Sungai Barito area, which has largely been converted to oil palm, suggests that Ramin can survive in highly disturbed or sub-optimal environmental conditions. This ability to persist causes the model to potentially **underpredict** the actual distribution in these off-niche areas. Furthermore, local information confirms that Ramin scarcity, even in conservation zones like TN Sebangau, is a result of historical timber concession (HPH) activities, meaning that areas predicted as highly suitable by the ENM may already be ecologically empty, requiring intensive ground verification.

Conclusion

The Ecological Niche Modeling (ENM) study successfully mapped the potential habitat of the critically endangered Gonystylus spp. in Central Kalimantan, identifying approximately 75,947.40 hectares. The model, which utilized the high-performing Random Forest algorithm, confirmed that the species' distribution is primarily governed by hydrological and soil properties, specifically a close association with peatlands and a preference for lower soil organic carbon. A key finding is that the vast majority (86.3%, or 65,533.15 hectares) of this potential habitat is situated outside of formally protected areas, leaving it highly vulnerable to land conversion and human activities. Field monitoring confirms this ongoing threat, with Ramin points repeatedly found **outside** previously determined potential locations, including one finding located within active land clearing for an oil palm plantation in Katingan Regency, where the tree is at risk of being lost in the near future.

Recommendation

The primary recommendation is to implement a **comprehen-sive, landscape-level conservation strategy** that extends well beyond the boundaries of existing protected areas to secure the species' long-term viability. Urgent, spatially explicit conservation and management efforts must be prioritized in the districts identified as key strongholds, notably Katingan and Kotawaringin Timur. For future Ramin identification and conservation, monitoring efforts must be systematically expanded to include areas often missed by ENM predictions, such as roadsides, riverbanks, degraded land, oil palm, and rubber plantations. Searches should leverage key ecological co-indicators found during field monitoring: Ramin roots emerging to the surface, the co-occurrence of **Jelutung** species, and the consistent presence of **Orangutan nests** in the surrounding forest. Furthermore, existing conservation initiatives, such as the village forest in Petak Puti under a carbon trading scheme, should be strengthened to protect Ramin populations.

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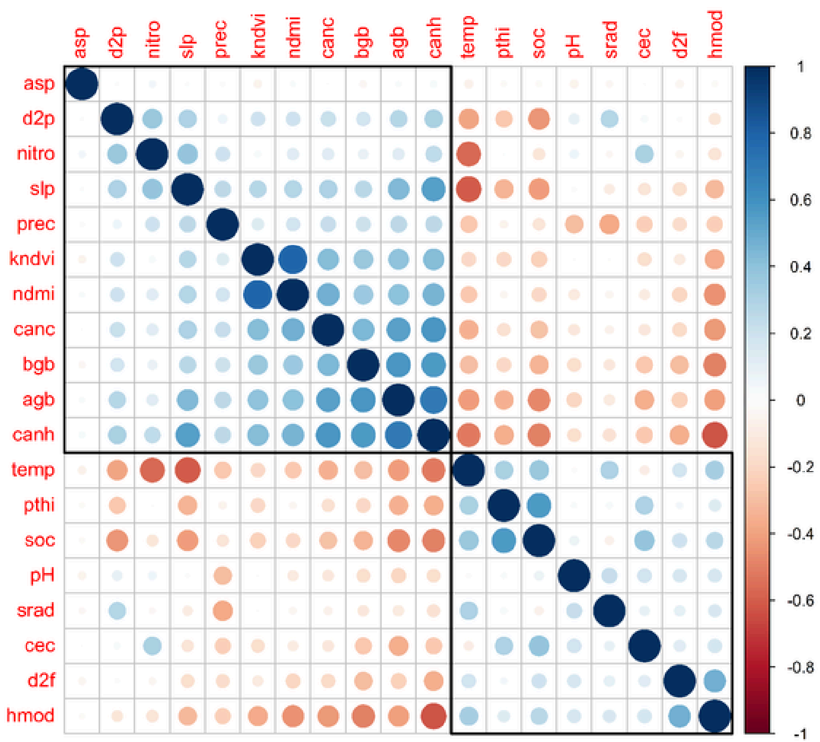
Appendices

Appendix 1.

Multicollinearity analysis for Gonystylus spp. potential distribution. cec: cation exchange capacity; canc: canopy cover; bgb: below-ground biomass; hmod: human modification; prec: annual precipitation; pthi: peat thickness; asp: Aspect; agb: Above-ground-biomass; temp: temperature; nitro: nitrogen content; slp: slope; canh:



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