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Distribution Probability Analysis of the Javan Slow Loris Using Maximum Entropy Modeling in Mount Masigit Kareumbi Protected Area, West Java, Indonesia

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Abstract. The Javan slow loris (*Nycticebus javanicus*) is an endemic primate of Java that plays a vital role in maintaining ecosystem balance. However, illegal wildlife trade and habitat loss have caused severe population declines. The Mount Masigit Kareumbi Protected Area (MMKPA) was designated as a reintroduction site for this species in 2018–2019, yet post-release monitoring of its distribution has not been conducted. This study aimed to identify environmental variables influencing distribution and to predict potential habitat in MMKPA using Maximum Entropy (MaxEnt) modeling with a stepwise variable selection approach. Eight predictor variables were tested, covering ecological, topographic, climatic, and anthropogenic aspects. A total of 61 occurrence records were obtained from direct sightings and indirect signs such as feeding traces. Direct observations recorded 17 individuals utilizing key food plants, including *Calliandra calothyrsus*, *Schima wallichii*, *Hibiscus macrophyllus*, and *Caryota mitis*. The best-performing model incorporated four predictors—precipitation, slope, land surface temperature, and distance to settlements—achieving an accuracy of 0.92. Highly suitable habitat (146 ha; 1.2%) was concentrated near Cimulu, while moderately suitable areas (522 ha; 4.8%) occurred along forest edges. This distribution pattern indicates limited dispersal and a high risk of human–wildlife conflict, emphasizing the need for targeted conservation strategies in MMKPA.

1. Introduction

The Javan slow loris (*Nycticebus javanicus*) is an endemic primate species found exclusively on the island of Java, with a distribution covering Banten, West Java, Central Java, and East Java. In comparison to the Sumatran slow loris (*Nycticebus coucang*) and the Bornean slow loris (*Nycticebus bengalensis*), the Javan slow loris is characterized by a relatively larger body size and distinct whitish-grey fur. One of its most recognizable features is a diamond-shaped facial pattern, formed by dark stripes that extend across the forehead and branch toward the eyes and ears. Ecologically, this species plays an essential role as an ecosystem regulator. As an omnivore, it contributes to seed dispersal, flower pollination, and insect population control, including those insects that may become agricultural pests [1].

The current status of the Javan slow loris is alarming. Over the past 24 years, its population has declined by an estimated 80% [2]. Several drivers underlie this decline, including illegal wildlife trade, habitat loss due to land-use change, disturbances from human activities, and intrinsic biological constraints such as a slow reproductive rate [3]. The International Union for Conservation of Nature (IUCN) lists the species as Critically Endangered (CR), indicating an extremely high risk of extinction in the near future. Furthermore, the Javan slow loris is included in Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), which prohibits international commercial trade. Within Indonesia, the species is fully protected under Law No. 5 of 1990 on the Conservation of Living Natural Resources and their Ecosystems, as well as Government Regulation No. 7 of 1999 on the Preservation of Plant and Animal Species.

One of the conservation strategies that has been implemented is the reintroduction of confiscated individuals into natural habitats. Between 2010 and 2013, a release program was carried out in Gunung Halimun-Salak National Park. Out of 18 released individuals, only three were confirmed to survive and remain active, representing a success rate of approximately 16.67% [4]. Eight individuals died, two were returned to captivity, and five lost contact, demonstrating the complexity and challenges of reintroduction efforts. These results emphasize the importance of habitat assessment, long-term monitoring, and adaptive management to improve reintroduction outcomes for this species.

The Mount Masigit Kareumbi Protected Area (MMKPA) in West Java represents one of the key conservation landscapes for the Javan slow loris. Covering administrative regions within Bandung, Sumedang, and Garut districts, the area is recognized as a natural habitat for this species. Since 2018, MMKPA has been designated as a reintroduction site for confiscated Javan slow lorises, managed by the West Java Natural Resources Conservation Agency (BBKSDA) in collaboration with International Animal Rescue (IAR Indonesia). Despite its importance, systematic monitoring of the Javan slow loris population and distribution within MMKPA has not yet been conducted. This knowledge gap poses challenges for conservation planning, as spatial information on species distribution is essential for guiding effective interventions.

At the same time, MMKPA is under pressure from anthropogenic disturbances that threaten habitat quality. A study reported the occurrence of forest fires and land encroachment within the area, both of which have the potential to degrade habitats and disrupt species survival [5]. Without a clear understanding of distribution patterns, it is difficult to anticipate how such threats may affect the long-term persistence of the Javan slow loris.

Against this background, the objective of the present study is to predict the probability distribution of the Javan slow loris in MMKPA using environmental predictor variables. These include topographic, ecological, climatological, and anthropogenic factors that are expected to influence species occurrence. Unlike previous reintroduction efforts that primarily relied on short-term survival observations, this study applies species distribution modeling as a spatially explicit tool to evaluate post-release outcomes at the landscape scale. By integrating occurrence data from reintroduced individuals with environmental predictors, the Maximum Entropy (MaxEnt) model enables an assessment of whether released Javan slow lorises occupy environmentally suitable areas and how their distribution relates to anthropogenic pressures. In this context, distribution probability is used as an indirect indicator of reintroduction success, reflecting habitat selection, dispersal limitation, and potential risks such as human–wildlife conflict.

The model generated provides not only predictions of distribution probability but also identifies key environmental drivers shaping post-reintroduction spatial patterns. This approach offers a novel contribution by linking species distribution modeling with reintroduction evaluation, thereby supporting evidence-based monitoring, habitat management, and adaptive conservation strategies. Ultimately, this study contributes to improving the long-term effectiveness of reintroduction programs for the Critically Endangered Javan slow loris in MMKPA.

2. Methodology

2.1. Research location

The study was conducted in the Mount Masigit Kareumbi Hunting Reserve (MMKPA), West Java, Indonesia, which covers an area of 12,420.7 hectares. The site is managed by the Natural Resources Conservation Agency of West Java (BBKSDA Jawa Barat) and is officially designated as a conservation hunting reserve. Administratively, MMKPA extends across three regencies: Sumedang, Garut, and Bandung, with geographic coordinates between 6°52'58.6"–7°0'12.80" S and 107°50'58.6"–108°1'39" E. The research was carried out from January 2023 to January 2024.

MMKPA is characterized by hilly and mountainous topography, with its highest elevation at Mount Kerenceng (1,736 m above sea level). The slope gradient generally ranges from 20° to 30°. Based on the Schmidt–Ferguson climate classification, the area falls under type C, with an annual rainfall averaging 1,900 mm, relative humidity between 60% and 90%, and a mean annual temperature of approximately 23 °C.

As illustrated in Figure 1, land cover in MMKPA is dominated by plantation forests and primary dryland forests. The reserve directly borders villages and community-owned lands, and it also contains two enclaves: Cimulu and Cigumentong. These settlements maintain close socio-ecological relationships with MMKPA, as residents cultivate agricultural fields near the borders and some harvest pine resin within designated use zones.

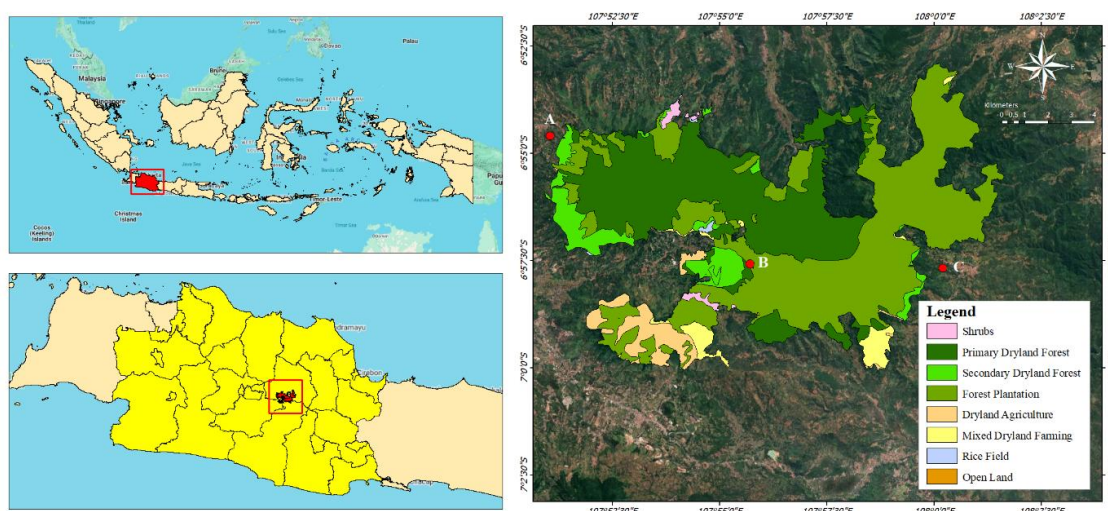


Figure 1. Map of study area and land cover of Mount Masigit Kareumbi Protected Area, West Java, Indonesia: b. Cigendel Village; b. Cimulu Hamlet; c. Cibugel Village

2.2. *Data collection*

The presence data of Javan slow loris were obtained through direct field observations using an exploratory survey method. This approach was applied in three primary locations: Cigendel Village, Cimulu Hamlet, and Cibugel Village. The selection of these sites was based on previous release records as well as information provided by reserve managers and local communities regarding areas with potential loris presence. Observations were conducted at night between 19:00 and 01:00 local time, following the nocturnal behavior of the species. In total, surveys were carried out along nine transect lines. A transect width of 40 m (20 m on each side) was assumed, representing the effective visual detection distance for identifying Javan slow lorises under the vegetation density conditions of MMKPA. Based on this assumption, the total surveyed area covered approximately 100 hectares, equivalent to about 0.8% of the total MMKPA landscape.

To complement the primary field observations, secondary data sources were also utilized. Additional coordinates of loris encounters were obtained from IAR Indonesia. Spatial datasets included DEMNAS satellite imagery and the Indonesian Topographic Map, accessed through the Tanahair online platform. Furthermore, Landsat 8 imagery (bands 3 and 5) was downloaded from the United States Geological Survey (USGS) database to generate vegetation indices. Climate variables were derived from WorldClim bioclimatic datasets, while land cover information for MMKPA was provided by the BBKSDA Jawa Barat.

2.3. *Data analysis*

The analysis in this study was based on four categories of predictor variables: topographic, ecological, climatological, and anthropogenic. Topographic predictors included elevation and slope, both derived from DEMNAS satellite imagery and processed using the surface tool in ArcGIS. Ecological predictors comprised land cover type, which differentiated primary forest, secondary forest, and plantation forest, obtained from the BBKSDA Jawa Barat. Additionally, the Normalized Difference Water Index (NDWI) was calculated from Landsat 8 imagery (bands 3 and 5) using the raster calculator tool.

Climatological predictors were derived from WorldClim bioclimatic datasets, specifically BIO12 (annual precipitation) and BIO1 (mean annual temperature). These datasets were clipped to the MMKPA region to ensure spatial relevance and subsequently prepared as input for modeling. Anthropogenic predictors included distance from roads and distance from settlements, both of which were obtained from the Indonesian Topographic Map and processed using the distance tool. To ensure compatibility across all variables, each predictor was standardized into ASCII format with the same resolution and extent, enabling integration into the species distribution model.

The probability distribution of the Javan slow loris was modeled using the Maximum Entropy (MaxEnt) algorithm. MaxEnt was selected due to its ability to utilize presence-only data and its robustness against spatial error. Species occurrence data were formatted into CSV files containing species name, latitude, and longitude, while the environmental predictors in ASCII format were incorporated as explanatory layers. Model performance was evaluated by randomly partitioning 30% of occurrence records as testing data and 70% as training data.

To identify the relative importance of each predictor, a jackknife test was applied. The results were then used to guide stepwise modeling, which aimed to select the optimal combination of predictors contributing to the distribution of the Javan slow loris. The output of the optimal model

ranged from 0 to 1. Using a threshold value of 0.333, the distribution probability was classified into three categories: low (0–0.333), moderate (0.333–0.667), and high (0.667–1). Response curves were further analyzed to interpret the ecological ranges of predictor variables that were most influential in determining the species' distribution. Model accuracy was assessed using the Area Under Curve (AUC) of the Receiver Operating Characteristic (ROC). The classification of AUC values followed the criteria: failed (0.5–0.6), poor (0.6–0.7), fair (0.7–0.8), good (0.8–0.9), and excellent (0.9–1.0) [6].

3. Results & Discussion

3.1. Javan Slow Loris Encounter Results

Based on field observations, a total of 61 coordinate points of Javan slow loris presence were successfully collected. Among these, 29 points were contributed by IAR Indonesia, which represented encounters with native individuals in MMKPA during post-release monitoring. The encounter records consisted of both direct and indirect observations (Figure 2). Direct encounters were facilitated by the distinctive eyeshine of the species, which appears as a bright yellow-green reflection when illuminated by a flashlight. This strong and unique reflection makes the Javan slow loris relatively easy to identify at night, as it is caused by the presence of the tapetum lucidum behind the retina, a highly light-sensitive layer [7]. This anatomical feature is unique to lorises and is not present in other nocturnal primates.



Figure 2. Encounters of Javan slow loris in the Mount Masigit Kareumbi Protected Area, West Java, Indonesia: a. direct encounter; b. indirect encounter

Indirect encounters were identified through feeding traces such as bite marks. The Javan slow loris feeds on fruits, nectar, and plant exudates or sap. A recent study demonstrated that exudate-producing species were more abundant in MMKPA compared to other food sources [8]. To access exudates, the loris gnaws at tree bark or branches using its specialized lower front teeth, then licks and consumes the sap that flows out. In this study, bite marks were found on *Etlingera coccinea* (tepus) stems and *Acacia decurrens*. When tepus stems are wounded, they release a mucus-like, sweet-tasting liquid preferred by lorises. Meanwhile, *Acacia decurrens* has been reported as an important year-round food source in highland agricultural areas, with several studies confirming its regular consumption by Javan slow lorises [9–11]. Exudates are particularly

important because they provide essential nutrients such as calcium, which are vital for the species' survival.

In Cimulu Hamlet, three Javan slow lorises were directly observed. They were found on branches of *Calliandra calothyrsus* (red calliandra) located at the interface between forest and community farmland. Research conducted in Cipaganti, Garut, reported that red calliandra nectar accounted for 32% of loris feeding preferences, ranking as the second most consumed food item [12]. The loris consumes nectar by delicately licking it from between the stamens without damaging the flowers. The ecological importance of red calliandra lies in its nocturnal blooming pattern and its capacity to flower throughout the year, thus ensuring a stable food supply [13].

In Cigendel Village, no direct encounters with lorises were recorded. However, dried bite marks were found on *Etlingera coccinea* stems, suggesting past foraging activity. This indicates that lorises may have previously occupied the area but subsequently moved, as they are known to shift their foraging ranges in response to food availability.

In Cibugel Village, a total of 14 individuals were observed. Several were associated with feeding plants such as *Albizia procera* (kihiang), *Swietenia mahagoni* (mahogany), *Schima wallichii* (puspa), *Hibiscus macrophyllus* (tisuk), and *Caryota mitis* (sarai). Lorises were also recorded using bamboo clumps. The presence of bamboo is a critical component of loris habitat, serving both as a food resource and as shelter. A recent study emphasized that nearly half of insect-foraging activities occurred within bamboo patches, highlighting its importance for loris ecology [14]. Bamboo stands also provide safe resting sites and protection from predators, further underlining their significance in loris habitat selection.

Overall, these encounter records illustrate both the spatial distribution and feeding ecology of the Javan slow loris in MMKPA. The combination of direct and indirect observations not only confirms their presence but also provides valuable insights into their reliance on specific plant species and habitat structures. Conservation strategies should therefore prioritize the protection of both native vegetation and secondary or introduced species that play important ecological roles, such as *Acacia decurrens* and *Calliandra calothyrsus*, to ensure the sustainability of loris populations in this critical landscape.

3.2. Combination of Predictor Variables

The coordinates of Javan slow loris occurrences and eight predictor variables were used as inputs for the MaxEnt model to generate a distribution map. The accuracy of the resulting model was evaluated using the Receiver Operating Characteristic (ROC) curve. ROC is a curve that illustrates the performance of a binary classifier system to enable prediction [15]. The Area Under Curve (AUC), which represents the area beneath the ROC curve, serves as an indicator of the model's accuracy.

Stepwise modeling was carried out to compare the accuracy of each combination of predictor variables (Table 1). When one variable was eliminated, the model's accuracy decreased. The best combination was selected based on fewer variables while maintaining an accuracy level close to that of the full model with eight variables. The optimal combination consisted of four predictors. When rounded, this combination achieved the same accuracy value of 0.92 as the model with eight predictors. Therefore, the probability distribution mapping was based on precipitation, slope, land surface temperature, and distance to settlements.

Table 1. Accuracy of each predictor variable combination of Javan slow loris distribution probability in the Mount Masigit Kareumbi Protected Area, West Java, Indonesia

Predictor Variables	Area Under Curve
elevation, slope, land cover type, NDWI, precipitation, temperature, distance from roads and distance from settlements	0.924
elevation, slope, land cover type, precipitation, temperature, distance from roads and distance from settlements	0.923
elevation, slope, precipitation, temperature, distance from roads and distance from settlements	0.919
slope, precipitation, temperature, distance from roads and distance from settlements	0.919
slope, precipitation, temperature and distance from settlements	0.917
slope, temperature and distance from settlements	0.913
slope and distance from settlements	0.902
distance from settlements	0.875

The ROC curve for the model with four predictors is presented in Figure 3. a. The training data used to build the model (70%) yielded an accuracy of 0.917, while the testing data (30%) used for validation resulted in a higher accuracy of 0.954. Both values fall into the “very accurate” category. The higher AUC value for the testing data compared to the training data indicates that the model has good generalization capacity and can be reliably applied to predict Javan slow loris habitat distribution beyond the dataset used for model construction.

The results of the Jackknife test are shown in Figure 3. b. This analysis was conducted to assess the relative contribution of each environmental variable to the prediction model. Excluding precipitation resulted in a significant decline in accuracy (green), whereas distance to settlements contributed strongly to accuracy when used as the sole predictor (blue). These findings indicate that precipitation and distance to settlements are the two most influential variables in predicting the distribution of the Javan slow loris in MMKPA.

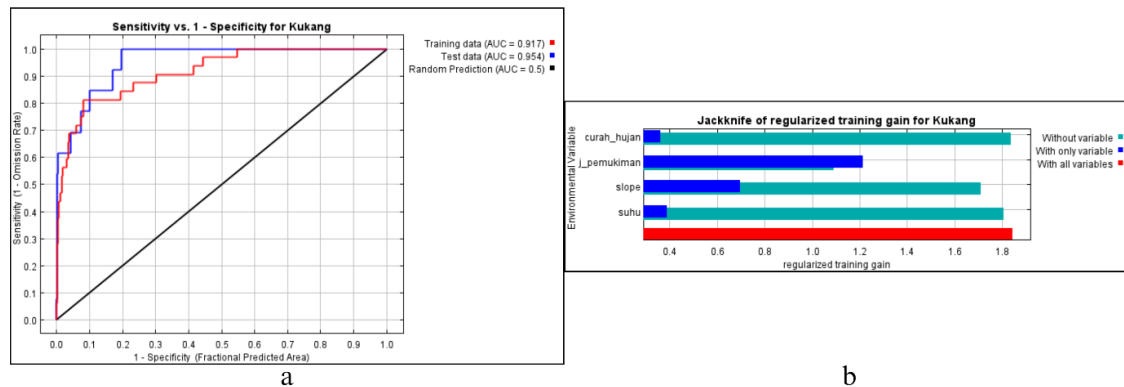


Figure 3. MaxEnt modeling results of Javan slow loris distribution probability in the Mount Masigit Kareumbi Protected Area, West Java, Indonesia: a. ROC curve; b. Jackknife test

3.3. Relationship Between Distribution and Predictor Variables

One of the outputs of MaxEnt modeling is the response curve for each predictor variable. This feature allows for the exploration of non-linear relationships between the predictors and the target species. In the context of this study, it enabled us to identify the specific values of each variable that influence the distribution of the Javan slow loris within MMKPA. The response curves thus provide valuable insights into the ecological preferences of the species and the environmental thresholds that define its habitat.

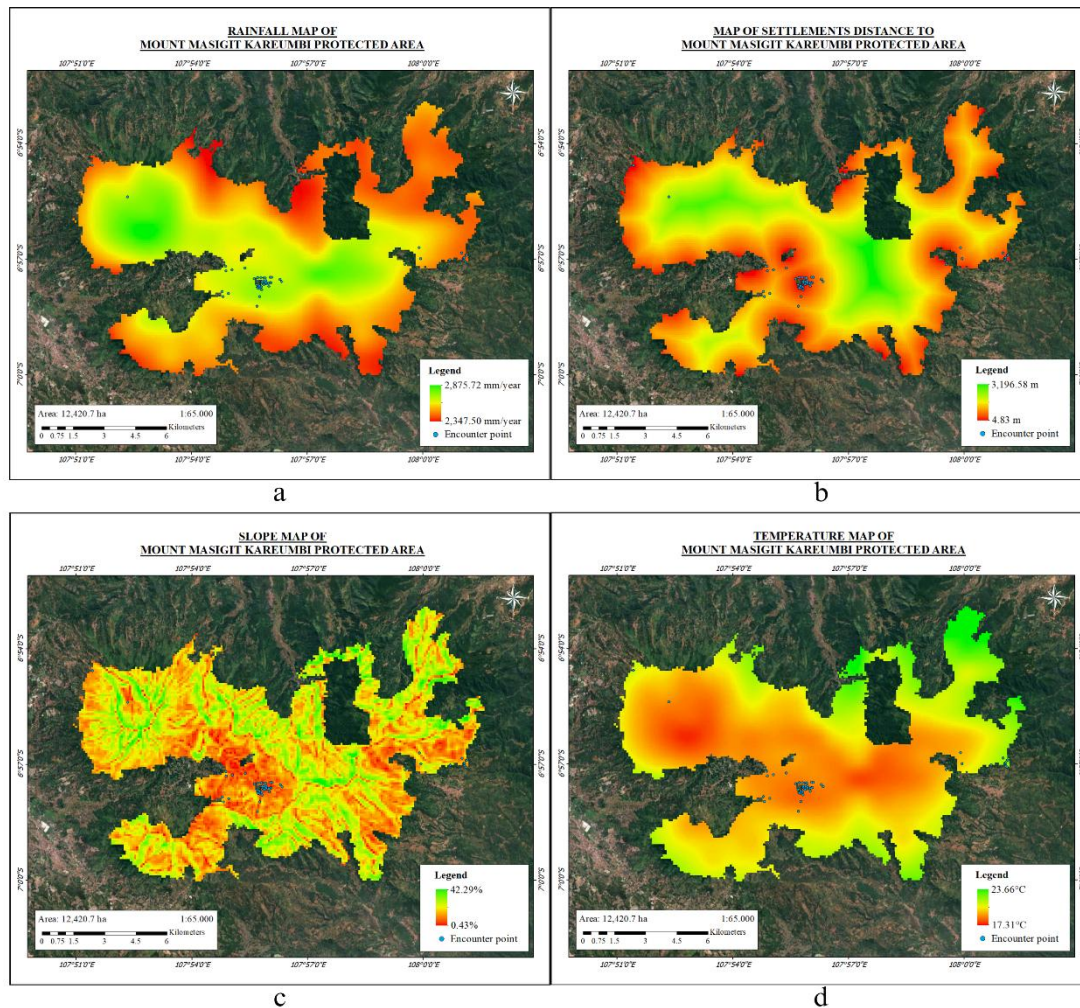


Figure 4. Predictor variable maps of Javan slow loris distribution probability in the Mount Masigit Kareumbi Protected Area, West Java, Indonesia: a. rainfall; b. distance from settlements; c. slope; d. land surface temperature

Figure 4. a illustrates the spatial distribution of rainfall across MMKPA and the corresponding occurrence points of the Javan slow loris. There is a clear tendency for encounter frequency to increase with higher annual precipitation. The species was observed primarily in areas with rainfall above 2,400 mm. High rainfall contributes to greater vegetation growth, thereby increasing the availability of food plants [16]. As a species with limited ranging behavior, the Javan slow loris generally remains close to food resources, which explains its stronger association with high-rainfall areas. The western and central regions of MMKPA, characterized by higher precipitation, thus represent potential hotspots for the species.

MMKPA is surrounded by settlements, with the maximum distance from human habitation reaching 3,198 m. Distance to settlements is considered an anthropogenic variable that could potentially disrupt slow loris habitat. Interestingly, however, the data show a tendency for higher encounter rates near settlements (Figure 4. b). Being a generalist species, the Javan slow loris can adapt to resource availability in modified landscapes. The presence of enclaves, such as

settlements and community plantations, creates biotic edge effects. While fruit-bearing vegetation may decline in these areas, the availability of leaves and insects tends to increase [17]. Furthermore, several key food plants of the slow loris, including *Hibiscus macrophyllus*, *Swietenia mahagoni*, and *Albizia procera*, are more abundant at forest edges. The frequent occurrence of slow lorises near community plantations suggests a form of ecological interaction, where the species also contributes to pest control.

In terms of topography, the Javan slow loris was found across a gradient ranging from flat areas (0–8% slope) to steep slopes (25–45%). However, there is a marked tendency for distribution to be concentrated in flatter areas (Figure 4. c). Slope influences both accessibility and resource use by wildlife [18]. While some wild species select steeper slopes to avoid disturbances or predators, this does not appear to be the case for the Javan slow loris. In MMKPA, potential predators such as the Javan leopard (*Panthera pardus melas*) and Javan hawk-eagle (*Nisaetus bartelsi*) are more commonly associated with steeper terrain. Consequently, slow lorises may perceive flatter areas as safer habitats.

Vegetation density also tends to increase with slope [19]. This may enhance fruit availability during certain seasons. However, as omnivores, slow lorises require year-round food resources such as nectar and insects. High vegetation density in steep areas may reduce the abundance of insect prey and shade-intolerant nectar plants like *Calliandra calothyrsus*. Importantly, no slow lorises were recorded in very steep slopes (>45%), consistent with the fact that MMKPA has a maximum slope of only 42.29%.

The species was most frequently encountered in areas with land surface temperatures ranging from 18°C to 22°C (Figure 4. d). This indicates a preference for moderately warm environments, which are often associated with secondary forests and forest edges where food resources such as fruiting trees and insect prey are more abundant. Previous studies have suggested that slow loris activity decreases under cooler night temperatures and bright moonlight, conditions that may increase predation risk and heat loss [20]. Therefore, the association with moderate surface temperatures highlights the species' reliance on habitats that balance food availability with physiological and ecological safety.

Taken together, the response curves highlight the critical influence of rainfall, proximity to settlements, slope, and land surface temperature in shaping the distribution of the Javan slow loris in MMKPA. These findings underscore the complex interplay of ecological and anthropogenic factors and emphasize the need for integrated habitat management strategies that account for both natural and human-modified landscapes.

3.4. Probability Distribution of the Javan Slow Loris

The probability distribution generated by the best-fit model was classified into three categories: low, medium, and high probability of occurrence (Figure 5). High probability areas were concentrated around the enclaves of Cimulu and Cigumentong, covering approximately 146 hectares, which represents only 1.2% of the total MMKPA landscape. Medium probability areas extended across 522 hectares, or 4.8% of MMKPA, primarily distributed along the forest edges in both the western and eastern regions. These results highlight that only a small fraction of the landscape provides suitable habitat conditions for the Javan slow loris.

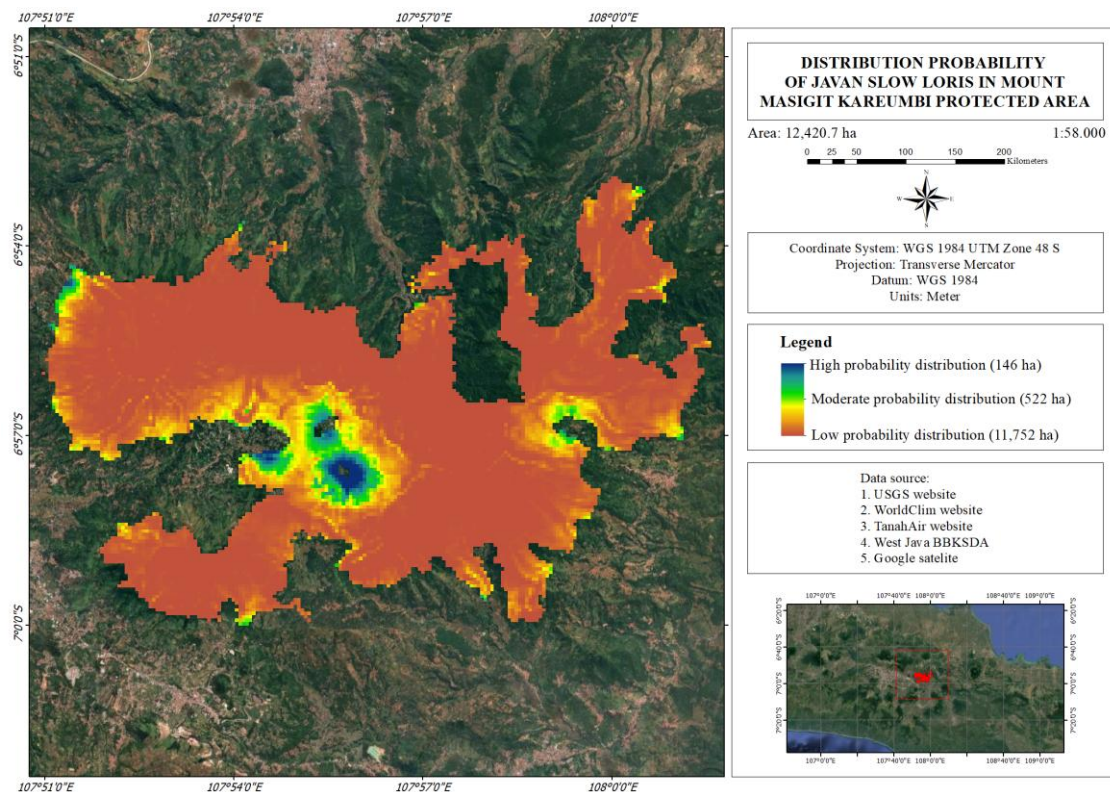


Figure 5. Probability distribution map of the Javan slow loris in the Mount Masigit Kareumbi Protected Area, West Java, Indonesia

From a conservation planning perspective, this distribution map provides spatial guidance for prioritizing management actions. High-probability areas can be designated as priority monitoring and protection zones, where post-reintroduction surveillance, population assessments, and habitat protection should be intensified. Medium-probability areas along forest edges may function as potential dispersal corridors and thus represent suitable targets for habitat enhancement, such as enrichment planting of key food resources or restoration of vegetation structure to facilitate movement.

The restricted distribution of the species within MMKPA can be explained by its biological and ecological characteristics. Slow lorises are known for their low metabolic rates, which result in slower movements compared to other primates. Their home range size varies between 3 and 8.16 ha, with daily travel distances ranging from only 12 to 558.33 m [21]. The core area actively used by the Javan slow loris is even smaller, approximately 1 to 1.77 ha. Therefore, the limited distribution observed in MMKPA reflects the relatively small spatial requirements of the species.

Despite this, several potential threats must be considered in light of the mapped distribution. The clustering of high-probability habitats around Cimulu enclave raises the possibility of human-wildlife conflict when individuals enter settlements. Local communities often lack awareness about the ecological role of the Javan slow loris, and encounters may be dangerous because the species possesses venom secreted from the brachial gland, which can cause seizures or unconsciousness in humans [22]. Such conflicts also pose risks to the slow loris itself, including the possibility of vehicle collisions when individuals cross roads near human habitation.

Species distribution is generally correlated with dispersal rates [23]. The Javan slow loris is solitary, and young individuals remain with their mothers for up to three years, during which they learn survival skills such as venom use [24]. The clustered distribution pattern identified in MMKPA suggests low dispersal ability. This could reflect two underlying conditions. First, population growth rates may be low, with few juveniles dispersing to new areas. This is consistent with the species' slow reproductive rate, as females give birth to only one offspring approximately every 1.5 years [25]. This hypothesis warrants further research on population dynamics of the Javan slow loris in MMKPA.

The second possible explanation for limited dispersal is that specific ecological characteristics act as barriers to expansion beyond the enclaves. These constraints may relate to the availability of key food plants or vegetation types that support the species' activity but were not incorporated into the current modeling framework. Detailed habitat assessments are therefore needed to identify the vegetation attributes that define the limits of Javan slow loris distribution.

Overall, the distribution model serves as a decision-support tool for conservation planning in MMKPA. By identifying priority areas for monitoring, restoration, and conflict mitigation, the map enables a more targeted and efficient allocation of conservation resources. Importantly, this spatially explicit approach also provides a framework for evaluating post-reintroduction outcomes, offering a practical basis for adaptive management aimed at ensuring the long-term persistence of the Javan slow loris in MMKPA.

4. Conclusion

This study shows that the post-reintroduction distribution of the Javan slow loris in MMKPA is highly restricted, with only a small proportion of the landscape exhibiting high and moderate distribution probabilities. Using MaxEnt modeling, precipitation, slope, land surface temperature, and distance to settlements were identified as the most influential predictors shaping species distribution. The response curves indicate that higher rainfall, moderate surface temperatures, gentle slopes, and proximity to settlements are associated with increased loris occurrence. Importantly, this study demonstrates the application of species distribution modeling as a spatial tool for evaluating reintroduction outcomes, extending beyond traditional survival-based assessments. The clustered distribution pattern around enclave areas suggests limited dispersal following reintroduction, likely influenced by the species' slow reproductive rate and habitat-specific constraints. The resulting distribution probability map provides practical guidance for post-release monitoring, identification of dispersal limitations, and mitigation of human-wildlife conflict. This spatially explicit approach supports adaptive management and contributes to improving the long-term effectiveness of reintroduction programs for the Critically Endangered Javan slow loris in MMKPA.

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