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Research Paper

Distribution and Habitat Characteristics of the Müller's Gibbon (*Hylobates muelleri*) in a Degraded Sub-watershed Landscape of South Kalimantan, Indonesia

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ABSTRACT

The Klampiaw gibbon (*Hylobates muelleri*), an endemic primate of Borneo, faces increasing threats from habitat fragmentation and deforestation. This study investigates the spatial distribution and habitat characteristics of *H. muelleri* in the Kusan Hulu sub-watershed, South Kalimantan, Indonesia. Field surveys conducted between July and September 2024 employed line transects, vegetation sampling, and habitat assessments across land cover types including secondary forests, agroforestry areas, and degraded lands. Results indicate that *H. muelleri* is mainly found in secondary forests with dense canopy cover, tall tree structures (>20 m), and the presence of key food sources such as Ficus and Artocarpus species. Gibbon groups tend to avoid open and plantation areas with low tree diversity and limited vertical complexity. Sixteen individuals were recorded across four observation zones, with the highest encounter rate (1.5 individuals/km) in well-connected forest corridors. Importance Value Index (IVI) analysis revealed dominant tree species that support gibbon foraging and movement. Conservation actions should focus on protecting natural habitats, restoring degraded areas with food tree species, reducing anthropogenic disturbances, and involving local communities in habitat management. These findings support evidence-based conservation planning for *H. muelleri* in tropical watershed landscapes and provide insights into the ecological requirements of Bornean gibbons.

Keywords: *Hylobates muelleri*, habitat preference, secondary forest, IVI, tropical watershed, conservation strategy

INTRODUCTION

Primates play a crucial ecological role in maintaining the dynamics and sustainability of tropical forest ecosystems, particularly through seed dispersal and their contribution to the maintenance of forest vegetation structure [1][2]. Among the endemic primates of Borneo, Hylobates muelleri—commonly known as the Müller's gibbon—is a key arboreal species belonging to the lesser apes group, currently classified as Vulnerable by the IUCN. Its conservation status is increasingly threatened by ecological pressures arising from habitat degradation and fragmentation [3] [4]. Due to its sensitivity to land cover changes and anthropogenic disturbances, this species serves as a reliable bioindicator for assessing the health of tropical forest ecosystems.

The natural habitat of H. muelleri is primarily found in lowland to hilly tropical forests, characterized by dense canopy cover and the presence of tall trees, which facilitate horizontal locomotion and provide essential refuge and social interaction sites [5] [6] . However, the rapid conversion of forests into agricultural land, plantations, and other land-use types in South Kalimantan has resulted in a significant reduction in both the extent and quality of its natural habitat [7] [8].

The Kusan Hulu sub-watershed (Sub-DAS) is one of the landscapes experiencing intense ecological pressure due to widespread deforestation and land-use change. Despite these challenges, the area holds considerable potential as a remaining habitat for Bornean endemic primates, particularly H. muelleri. Unfortunately, scientific studies on the spatial distribution and ecological characteristics of this species' habitat in the region remain scarce. Therefore, this study aims to identify and analyze the spatial distribution and structural characteristics of H. muelleri habitats in the Kusan Hulu sub-watershed. The findings are expected to provide valuable scientific input for the development of landscape-based conservation strategies to ensure the long-term survival of this species in its natural environment.

MATERIALS & METHODS

Research Location

This study was conducted in the Kusan Hulu sub-watershed (Sub-DAS), located within the administrative boundaries of Kotabaru and Tanah Bumbu Regencies, South Kalimantan, Indonesia. The study area encompasses a range of land cover types, including primary forest, secondary forest, and converted land. Field surveys were carried out from July to September 2024, covering both the dry and rainy seasons to facilitate access and enhance visual detection of gibbons. The specific location of *Hylobates muelleri* survey sites is illustrated in Figure 1

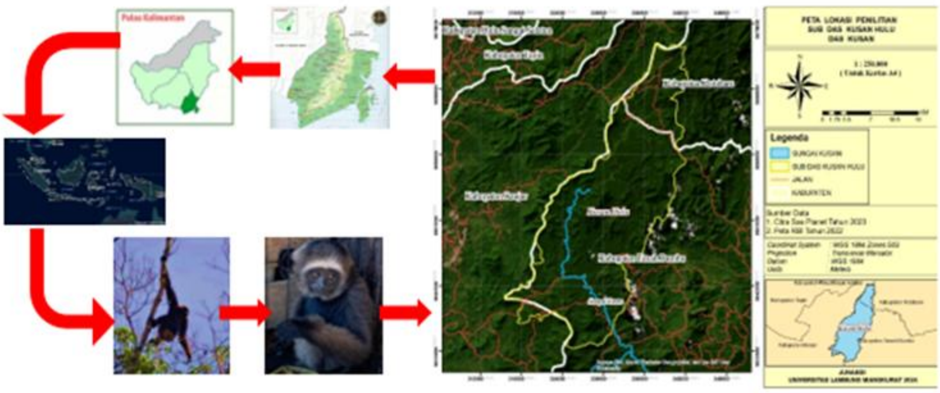

Figure 1. Research location of Gibbon klampiaw (*Hylobates muelleri*)

The equipment used in this study includes digital cameras, binoculars, compasses, measuring tapes, thermohygrometers, machetes, GPS (Global Positioning System), timestamps, tally sheets, roll meters, stationery, raffia ropes, scientific calculators, type identification books, and maps of research locations. Primary data were obtained through direct observation in the field, while secondary data was obtained through literature studies, map images, and previous research results. Spatial analysis was performed using ArcGIS software version 10.8 for mapping the distribution of langurs and woody vegetation.

a. Gibbon Presence Survey

The field survey was carried out by the line transect method in the morning, starting at

06.00 to 17.00 WITA. Observations are made when langurs begin to be active until mid-day. Each individual or group of langurs found was recorded at its coordinate points using GPS, as well as microclimatic parameters such as temperature and humidity were recorded using a thermohygrometer.

b. Vegetation Data Collection

Habitat characteristics were analyzed based on vegetation structure variables, including: tree density, tree diameter (DBH), tree height, and canopy cover. Measurements were made on plots measuring 20 m × 20 m placed around the location of the owa find. Other ecological variables noted were the height of the place, distance to the water source, and the level of human disturbance. In each plot, all types of woody plants found were inventoried and recorded using a tally sheet. Each type of plant was analyzed using the Important Value Index (INP) formula to determine its relative dominance in the vegetation community.

c. Data Analysis

Spatial data on gibbon distribution and habitat characteristics were analyzed using ArcGIS 10.8 software to generate distribution maps. Coordinate data from field observations were used as spatial inputs, then tabulated and analyzed descriptively. Vegetation analysis was carried out by calculating the Important Value Index (INP) and the Shannon-Wiener Diversity Index (H') to determine the community structure of vegetation. The INP calculation is carried out using the following formula [9]:

INP = Relative Density + Relative Frequency + Relative Dominance

The results of this analysis are used to identify plant species that play an important role as a component of langur habitat, both as a source of feed and as a shelter..

RESULT

1. Spatial Distribution by Type of Land Cover

The distribution of the results of the klampiaw gibbon research in the Kusan Hulu Sub-Watershed can be seen in Table 1 and Figure 2. The results of field surveys conducted at 19 observation points in the Kusan Hulu Watershed, South Kalimantan, indicate that the distribution pattern of the klampiaw Gibbon (*Hylobates muelleri*) is quite evenly distributed in various types of land cover. Based on observation data, the number of gibbon individuals detected ranges from one to three per point. The observation points with the highest number of individuals, namely three tails, were found in the habitats of primary forests (T1), secondary forests (T3), bushes (T7), and community gardens (T17). This pattern shows that *H. muelleri* has the ability to occupy various types of habitats, including habitats that have undergone structural changes due to anthropogenic activity.

Table 1. Distribution of Klampiaw Gibbons in various types of land cover in the Kusan Hulu Sub Watershed

Points	Coordinate points	Number of Gibbons	Types of Land Cover
T1	-3.029177, 115.530453	3	Primary Forest
T2	-3.014153, 115.496180	2	Primary Forest
T3	-3.028698, 115.55535	3	Secondary Forest
T4	-3.043988, 115.525730	2	Secondary Forest
T5	-3.240046, 115.442591	2	Garden
T6	-3.270784, 115.389679	2	Garden
T7	-2.999564, 115.521843	3	Bushland
T8	-3.055967, 115.529967	3	Bushland
T9	-3.056790, 115.544497	2	Settlement
T10	-3.041478, 115.508829	2	Secondary Forest
T11	-3.047289, 115.503222	2	Primary Forest
T12	-3.063236, 115.483957	2	Garden
T13	-3.082459, 115.488155	2	Secondary Forest

T14	-3.100961, 115.481117	1	Bushland
T15	-3.110167, 115.504503	2	Settlement
T16	-3.198859, 115.505060	2	Primary Forest
T17	-3.203365, 115.481136	3	Garden
T18	-3.217541, 115.466108	2	Bushland
T19	-3.242431, 115.444947	2	Secondary Forest

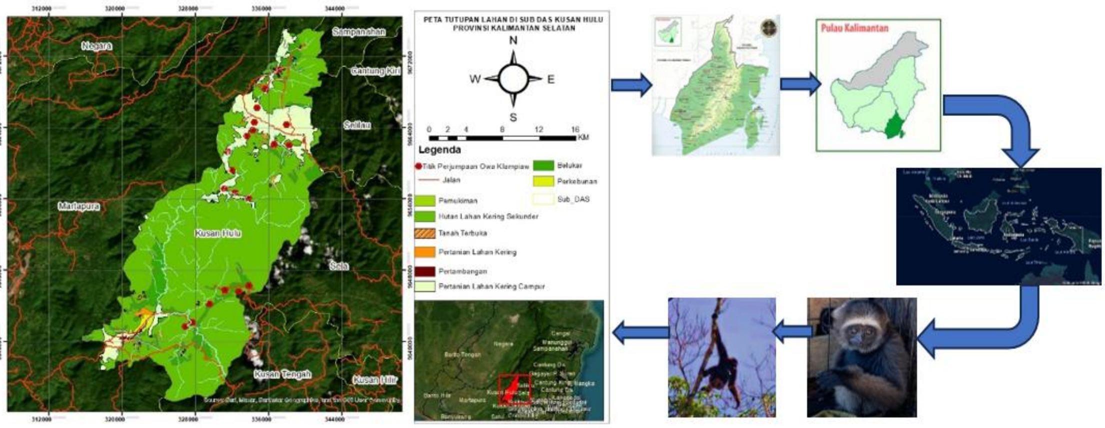

Figure 2. Distribution map of klampiaw gibbon in the Kusan Hulu sub watershed

2. Vegetation Preferences: Dominant and Functional Species

Vegetation analysis conducted at 19 observation points within the Kusan Hulu sub-watershed revealed specific preferences of the Müller's gibbon (*Hylobates muelleri*) for certain tree species, particularly in relation to their ecological functions and habitat structure. The data indicate that species belonging to the family *Moraceae*, especially *Ficus fistulosa* and *Artocarpus* spp., dominated six observation points where gibbon presence was also notably high. The occurrence of these species holds significant implications for the survival of the gibbons, particularly as they serve as primary food sources. Table 2 and Figure 3 describes the dominant vegetation preferences and key habitat components for *H. muelleri*.

Species within the genus *Ficus* are widely recognized as critical food plants for various arboreal primates in tropical regions due to their unique reproductive strategy, which involves asynchronous year-round fruiting [10]. This phenological trait makes *Ficus* a stable and dependable food resource across seasons, particularly during periods of fruit scarcity. Consequently, the presence of *Ficus* is often considered a keystone element in tropical forest ecosystems, supporting both the diversity and abundance of frugivorous fauna [11]. In the context of *H. muelleri*, the dominance of *Ficus* species may be interpreted as an indicator of adequate energy availability to support daily activities, including locomotion, infant care, and social behaviors.

Figure 3. Vegetation preferences of the habitat of the klampiaw gibbon

Table 2. Contribution of Plant Communities to the Carrying Capacity of Gibbon Habitats

Points	Meeting Location	Number of Gibbons found	Vegetasi Dominate	Family	H'	R	E
T1	-3.029177, 115.530453	3	*Shorea montegina*	Deptoracarpaceae	2,71	17,63	0,94
T2	-3.014153, 115.496180	2	*Ficus fistolosa*	Moraceae	2,56	15,61	0,93
T3	-3.028698, 115.55535	3	*Artocarpus odoratissimus*	Moraceae	2,31	15,61	0,85
T4	-3.043988, 115.525730	2	*Shorea johorensis Foxy*	Deptoracarpaceae	2,56	15,61	0,93
T5	-3.240046, 115.442591	2	*Vitex pubescens*	Lamiaceae	2,71	15,63	0,98
T6	-3.270784, 115.389679	2	*Ficus fistolosa*	Moraceae	2,4	10,58	0,89
T7	-2.999564, 115.521843	3	*Artocarpus lanceifolius*	Moraceae	2,46	15,67	0,89
T8	-3.055967, 115.529967	3	*Pretospermum javanicum*	Malvaceae	1,97	9,57	0,86
T9	-3.056790, 115.544497	2	*Shorea montegina*	Deptoracarpaceae	2,58	17,69	0,89
T10	-3.041478, 115.508829	2	*Shorea montegina*	Deptoracarpaceae	2,27	9,58	0,99
T11	-3.047289, 115.503222	2	*Dracontomelon dao*	Anacardiaceae	2,64	17,62	0,91
T12	-3.063236, 115.483957	2	*Syzgyium lineatum*	Myrtaceae	2,71	17,63	0,94
T13	-3.082459, 115.488155	2	*Vitex pubescens*	Lamiaceae	2,71	15,63	0,98
T14	-3.100961, 115.481117	1	*Lagerstromeia*	Lythraceae	2,42	20,61	0,97
T15	-3.110167, 115.504503	2	*Neolamarckia cadamba*	Rubaceae	2,46	15,67	0,89
T16	-3.198859, 115.505060	2	*Shorea montegina*	Deptoracarpaceae	2,58	17,69	0,89
T17	-3.203365, 115.481136	3	*Ficus fistolosa*	Moraceae	2,58	17,69	0,89
T18	**-3.217541, 115.466108**	**2**	***Ficus fistolosa***	**Moraceae**	**2,71**	**14,63**	**1**
T19	-3.242431, 115.444947	2	*Macaranga gegantia*	Euphorbiaceae	20,6	0,78	0,78

3. Preference Towards Vegetation Structure and Crown Stratification in Habitat Selection

The habitat preferences of arboreal primates, particularly those from the subfamily *Colobinae* such as *Presbytis fredericae* and members of the family *Hylobatidae* such as *Hylobates muelleri* (Müller's gibbon), are not solely determined by vegetation species composition, but are significantly influenced by the complexity of vertical structure and forest canopy stratification. Vegetation serves multiple ecological functions for primates, acting as sites for resting, playing, foraging, and shelter [12] [13] [14] [15] [16]. Vegetation surveys conducted at 19 observation points within the Kusan Hulu sub-watershed revealed that *H. muelleri* individuals were more frequently detected in locations with multilayered canopy stratification, particularly in areas dominated by stratum A (upper canopy, >30 m) and stratum B (middle canopy, 20–30 m). These findings align with the ecological characteristics of gibbons as highly arboreal species that depend on the upper canopy layer for key daily activities such as foraging, resting, and social interaction.

4. Contribution of Plant Communities to Habitat Carrying Capacity

The diversity of woody vegetation is a key determinant of habitat quality and carrying capacity for arboreal species such as the Müller's gibbon (*Hylobates muelleri*). Results from plant community analysis at observation points within the Kusan Hulu sub-watershed indicate that the Shannon-Wiener diversity index (H') ranged from 1.97 to 2.71. The highest values were recorded at points T14 (H' = 2.71) and T1 (H' = 2.67), reflecting a diverse and relatively stable plant community structure. Furthermore, the highest species richness index (R = 20.61) was also found at T14, underscoring the ecological importance of this location in providing sufficient habitat resources for gibbon populations.

The species evenness index (E), ranging from 0.85 to 1.00, suggests that species distribution across most observation points is relatively uniform, with no excessive dominance by a single or few species. Such balanced vegetation composition is crucial for gibbons, as it supports the availability of diverse food sources, optimal perching sites, and protection from predators and environmental stressors. Although gibbons are known to have a flexible yet selective diet, they rely primarily on fruits, young leaves, and flowers from a wide range of tree species in both primary and secondary forests [17] [18].

5. Topographic and Microclimatic Factors

The ecological adaptation of Müller's gibbon (*Hylobates muelleri*) to variations in physical environmental conditions reflects the species' habitat flexibility in coping with landscape heterogeneity in the Kusan Hulu sub-watershed. Survey data collected from 19 observation points revealed that most gibbon occurrences were recorded in areas with moderate slopes, ranging from 8% to 15%. However, the presence of two individuals was also recorded at point T11, which is characterized by steep slopes exceeding 20%. This suggests that steep topography is not a primary limiting factor for gibbons, provided that essential habitat components such as upper canopy vegetation and continuous canopy pathways remain intact and functional.

DISCUSSION

1. Habitat Preference of Müller's Gibbon (*Hylobates muelleri*) in Relation to Land Cover Types

The analysis of *Hylobates muelleri* habitat preference across different land cover types in the Kusan Hulu sub-watershed revealed a varying distribution of individuals. Among the five observed land cover categories, the highest number of individuals was recorded in secondary forest (n=11), followed by primary forest (n=9), gardens (n=9), and bushland (n=9). The lowest count was observed in settlement areas (n=4).

The relatively high occupancy in secondary forests suggests that this species exhibits a certain degree of adaptability to moderately disturbed habitats. This observation is consistent with findings by [19], who reported that some arboreal primate species, including gibbons, are capable of utilizing secondary forests as alternative habitats, provided that vertical canopy structure and vegetation connectivity support arboreal locomotion and foraging behavior. Secondary forests often display a more heterogeneous floristic composition, offering a wider array of short-term food resources [20].

Conversely, despite being ecologically more stable and typically offering optimal habitat conditions, primary forests supported a comparable number of individuals to more modified environments such as gardens and bushland. This pattern may indicate that while primary forests remain essential as core habitats, spatial pressures and fragmentation could have diminished their effective carrying capacity. According to [21], gibbon population distribution is influenced not only by habitat quality but also by the availability of sufficient ranging space and low levels of anthropogenic disturbance.

The equal representation of individuals in garden and bushland areas (n=9 each) further supports the hypothesis that *H. muelleri* exhibits ecological plasticity in habitat use. Gardens, which typically consist of mixed cultivation or homestead areas with scattered fruiting trees, may provide opportunistic food resources such as bananas, papayas, or rambutans. Although suboptimal, such environments may serve as temporary resource patches within fragmented landscapes. Similarly, bushlands—comprising shrub-dominated vegetation interspersed with pioneer trees—may function as movement corridors or temporary refuges. This aligns with [22] observations that gibbons are capable of utilizing suboptimal habitats when the vegetation structure still accommodates arboreal activity.

2. Dominant Vegetation Composition in the Habitat of Müller's Gibbon (Hylobates muelleri)

The structure and composition of vegetation play a pivotal role in shaping the ecological carrying capacity of habitats for arboreal primates such as Müller's gibbon (*Hylobates muelleri*). Vegetation surveys conducted across the study area revealed that the most dominant species were *Shorea montegina* (n=4) and *Ficus fistulosa* (n=4). Other species appeared with lower frequencies, including single occurrences of *Shorea johorensis Foxy*, *Artocarpus odoratissimus*, *Dracontomelon dao*, and *Neolamarckia cadamba*.

a. Ecological Role of Dominant Species

The presence of *Ficus fistulosa* as a dominant species underscores its critical ecological role in supporting frugivorous primates. As a recognized keystone species in tropical forest ecosystems, *Ficus fistulosa* produces fruit throughout the year, thus providing a continuous energy source during periods of fruit scarcity [10]. Its dominance in the landscape indicates a habitat with high feeding potential for gibbons, contributing to dietary stability.

In contrast, while *Shorea montegina* does not directly contribute to the gibbon's diet, it fulfills a vital structural function by forming tall, dense canopy layers. These canopy structures enable gibbons to navigate the forest without descending to the ground, a behavior crucial for avoiding predators and minimizing human disturbance. As noted by [23], species within the *Shorea* genus serve as key vertical scaffolds in dipterocarp forests, essential for maintaining arboreal connectivity.

b. Supporting Vegetation and Species Diversity

The presence of additional species such as *Vitex pubescens* (n=2), *Artocarpus lanceifolius*, and *Macaranga gigantea* suggests a relatively diverse vegetation structure. Both *Vitex pubescens* and species of *Artocarpus* are seasonal fruit producers that may serve as supplementary food sources for gibbons [24]. This diversity reduces dependency on a narrow range of food plants and buffers the gibbon population against seasonal food shortages.

Species recorded with single individuals—such as *Syzygium lineatum*, *Pterospermum javanicum*, and *Lagerstroemia* spp.—enhance habitat complexity. Such structural diversity is essential for supporting natural behaviors in gibbons, including vocalization, social play, and canopy resting. Furthermore, complex canopy structures improve habitat connectivity, facilitating more efficient inter-patch movement [25].

c. Conservation Implications

The dominance of *Ficus fistulosa* and the presence of various native fruit trees indicate that the study area holds substantial potential for supporting long-term gibbon populations—provided that major disturbances such as selective logging are prevented. The occurrence of pioneer species like *Macaranga gigantea* and *Neolamarckia cadamba* also suggests that the area has undergone prior disturbance and is currently undergoing secondary succession.

To ensure the sustainability of gibbon populations, conservation strategies should prioritize the protection and enrichment of fruit-bearing species, especially those belonging to the Moraceae (*Ficus*) and Artocarpaceae (*Artocarpus*) families. Ecological restoration efforts could focus on replanting these species as key food sources. Simultaneously, maintaining the integrity of *Shorea* species is critical for preserving the vertical canopy structure that supports arboreal locomotion and spatial continuity.

In summary, the dominant vegetation composition in the habitat of *Hylobates muelleri* reflects the presence of key species that fulfill two fundamental ecological needs of arboreal primates: food availability and structural support for arboreal life. The co-dominance of *Ficus fistulosa* and *Shorea montegina* illustrates a balance between nutritional resources and habitat architecture. Moreover, the observed heterogeneity in vegetation composition suggests a relatively intact ecosystem, making it a strong candidate for landscape-level conservation centered on indicator species such as Müller's gibbon.

3. Vegetation Family Composition as a Determinant of Habitat Structure and Function for Müller's Gibbon (*Hylobates muelleri*)

The structure of plant communities at the family level offers vital insights into ecosystem dominance and the habitat's carrying capacity for arboreal fauna such as *Hylobates muelleri*. The vegetation survey revealed that the families *Moraceae* and *Dipterocarpaceae* dominate the study area, with 6 and 5 individual trees respectively, followed by *Lamiaceae* (2 individuals), and several families represented by a single individual each (*Anacardiaceae*, *Euphorbiaceae*, *Myrtaceae*, *Malvaceae*, *Lythraceae*, and *Rubiaceae*).

a. Ecological Role of Moraceae and Its Significance for Primates

Moraceae, particularly the genus *Ficus*, constitutes a critical component of tropical rainforest ecosystems. Species within this family exhibit asynchronous fruiting cycles, providing a continuous food resource for frugivorous species, including *Hylobates muelleri* [10]. The dominance of *Moraceae* thus suggests a high availability of fruit resources year-round, even during periods of scarcity from other plant families.

In addition, *Ficus* species are characterized by broad ecological tolerance, wide distribution, and high colonization capacity, thriving in varied light conditions and moderately disturbed environments [26]. Their presence not only supports primate populations through food availability but also reflects an advanced stage of forest regeneration and ecological succession.

b. Structural and Functional Contributions of Dipterocarpaceae

The second most dominant family, *Dipterocarpaceae*, represented by five individuals, typically comprises emergent tree species with large diameters and high canopies. These structural characteristics are essential for providing vertical movement corridors for arboreal primates and offer shelter from predators and anthropogenic disturbances [23].

Dipterocarpaceae also play a crucial role in regulating local microclimates, water cycles, and carbon storage. Although they do not produce fruit as continuously as *Ficus* spp., their presence often indicates a mature or minimally disturbed forest ecosystem, reinforcing their importance in habitat quality assessment for conservation efforts.

c. Supporting Ecological Functions of Minor Families

The presence of less dominant families, such as *Lamiaceae* (2 individuals), and other single-representative families (*Anacardiaceae*, *Euphorbiaceae*, *Myrtaceae*, etc.), points to a moderate level of taxonomic diversity, which contributes to ecosystem complexity. Species like *Vitex pubescens* (Lamiaceae) are known to provide edible fruits and young leaves consumed by primates [24]. Meanwhile, members of *Euphorbiaceae* and *Myrtaceae* enhance vegetation stratification and contribute to nutrient cycling and habitat heterogeneity.

Other families such as *Rubiaceae* and *Lythraceae*, commonly associated with early successional stages or open areas, indicate microhabitat variability that supports diverse plant and animal communities. These families also enrich the ecosystem's food web, offering both direct (e.g., fruit, flowers) and indirect (e.g., structural habitat) benefits.

d. Vegetation Family Composition and Gibbon Habitat Preference

The composition of plant families reflects the ecosystem functions aligned with *Hylobates muelleri*'s ecological requirements. [27] noted that gibbons selectively inhabit areas with complex vertical structure and a prevalence of fruiting trees, particularly from the genera *Ficus*, *Artocarpus*, and *Syzygium*. Thus, the dominance of *Moraceae* in this study supports the suitability of the habitat in terms of both nutritional provision and canopy connectivity.

The presence of *Dipterocarpaceae* is also essential in meeting spatial and protective requirements. Gibbons, being strict arboreal species, rely heavily on continuous canopy pathways and avoid ground movement due to elevated predation and disturbance risks [22]. The emergent structure provided by species such as *Shorea* is crucial in maintaining uninterrupted canopy cover, minimizing fragmentation, and enhancing safe arboreal locomotion.

e. Conservation and Management Implications

These findings provide a foundational basis for habitat-based conservation planning. Management strategies aimed at conserving *Hylobates muelleri* habitats should prioritize the preservation and enrichment of *Moraceae* and *Dipterocarpaceae* families through targeted enrichment planting and protection of existing mature individuals. These families not only support primate feeding ecology but also facilitate the development of structurally complex, resilient forest ecosystems necessary for the long-term survival of arboreal species.

4. The Relationship Between Vegetation Structure and the Presence of *Hylobates muelleri* in the Sub-Kusan Hulu Watershed Forest Landscape

Vegetation structure plays a crucial role in shaping the habitat quality and presence of arboreal primates such as the Müller's gibbon (*Hylobates muelleri*). Observations from 19 sampling sites revealed variation in key ecological indices—namely Shannon-Wiener diversity index (H′), species richness (R), and evenness (E)—which serve as indicators of habitat suitability and complexity.

a. Vegetation Diversity and Its Influence on Gibbon Occurrence

Shannon-Wiener diversity index values across sampling sites ranged from 1.97 to 2.71, indicating moderate to high diversity levels [28]. The highest H′ values (2.71) were observed at sites T1, T8, T10, T12, and T17, each of which recorded the presence of 2–3 gibbon individuals. These findings suggest that higher vegetation diversity enhances habitat quality by offering a wider array of food sources, shelter options, and complex canopy structures suitable for gibbon daily activities such as feeding, resting, and locomotion [27]

In contrast, the lowest diversity value (H′ = 1.97 at T15) was associated with only two individual gibbons, implying limited structural and ecological support within that habitat. This condition is likely due to the dominance of a few plant species or anthropogenic disturbances such as land conversion and forest fragmentation.

b. Species Richness and Habitat Complexity

The highest species richness values were recorded at T16 (R = 20.61) and T9 (R = 20.60), reflecting a high number of distinct vegetation types. However, only two gibbon individuals were observed at each of these sites. This indicates that species richness alone does not necessarily correlate with habitat carrying capacity. In certain cases, elevated richness may stem from the proliferation of pioneer or shrub species that offer limited ecological value to gibbons [29].

Conversely, site T7 recorded the highest gibbon count (three individuals) despite a lower richness value (R = 9.58). This suggests that the presence of ecologically significant species such as *Ficus* spp. or trees with complex crown structures may be more critical for habitat functionality than overall species count. This finding aligns with the theory of "functional diversity," which emphasizes the ecological roles of particular species in sustaining ecosystem services [30].

c. Evenness Index and Ecosystem Stability

Evenness values (E) ranged from 0.78 to 1.00 across all sampling points, indicating varied distribution of individuals among species. Site T17 exhibited a perfect evenness score (E = 1.00) and also supported three gibbons. High evenness generally reflects a more balanced and stable ecological community, which is favorable for sensitive arboreal primates like *Hylobates muelleri* [31].

Interestingly, T7 (E = 0.99) and T8 (E = 0.98) also supported high gibbon numbers, despite having relatively low species richness. This suggests that the uniform distribution of a few key species may be more supportive of gibbon presence than a dominance by non-functional species.

In contrast, T9, with a high species richness (R = 20.6) but lower evenness (E = 0.78), presents an ecological anomaly. The strong dominance of one or two species may restrict resource variety and reduce the site's overall suitability as gibbon habitat.

d. Linking Gibbon Abundance to Ecological Parameters

A consistent positive correlation was observed between Shannon-Wiener diversity (H′) and gibbon abundance. Sites with $H' \geq 2.6$ generally hosted three individuals, whereas those with $H' \leq 2.4$ typically supported only 1–2 individuals. This trend underscores vegetation diversity as a reliable predictor of habitat suitability for *Hylobates muelleri*.

Similarly, evenness index values showed a positive trend, where E > 0.9 correlated with higher gibbon presence. This supports the hypothesis that a balanced distribution of tree species contributes to ecosystem stability, which in turn facilitates the persistence of arboreal species.

However, species richness (R) exhibited no clear pattern in relation to gibbon abundance. For instance, T16 with the highest R (20.61) still only recorded two individuals. This reinforces the notion that not all species contribute equally to habitat functionality, and that conservation efforts should prioritize key species that provide essential ecological functions for gibbons.

5. Environmental Factors Influencing the Distribution of Hylobates muelleri in the Sub-Catchment Area of Kusan Hulu

The spatial distribution of arboreal species such as the Klampiau gibbon (*Hylobates muelleri*) is profoundly influenced by abiotic environmental factors, particularly slope, air temperature, and relative humidity. Observations at 19 locations within the Sub-Catchment Area of Kusan Hulu reveal significant correlations between these environmental variables and the number of gibbons observed.

a. Slope and Availability of Arboreal Habitat

Slope is a crucial topographic factor influencing habitat preferences for primates. Among the 19 observed locations, the majority (17 points) are situated on slopes ranging from 8–15%, while only two points, T1 (0–8%) and T11 (20–45%), deviated from this range. Interestingly, T1, despite its gentle slope (0–8%), recorded the highest number of gibbons (3 individuals). This suggests that lower slopes may offer better accessibility to resources or more intact primary vegetation. In contrast, T11, with the steepest slope (20–45%), hosted only two individuals, indicating that excessively steep slopes may limit gibbon movement and hinder the formation of connected canopies, which are essential for arboreal locomotion [27].

Overall, slopes in the 8–15% range support gibbon presence, as seen at T3, T7, T8, and T17, each recording three individuals. This pattern supports the hypothesis that gibbons prefer habitats with moderate slopes that are ecologically stable while still providing natural topographic challenges.

b. Temperature as a Thermal Comfort Determinant

Ambient temperature influences primate daily activity and thermal metabolism. Recorded temperatures ranged from 24°C to 29°C, with locations that hosted more gibbons (3 individuals), such as T1, T3, T7, T8, and T17, generally falling within the 24–28°C range. Conversely, sites with higher temperatures (29°C), such as T2 and T4, observed only two individuals. This supports previous findings that the optimal temperature for gibbon daily activities lies between 24–27°C, facilitating foraging and locomotion [32]. Higher temperatures tend to limit activity due to the increased risk of overheating, ultimately impacting their daily activity patterns.

This correlation is further substantiated by conditions at T6 and T8 (both at 26°C), which recorded two and three individuals, respectively. Physiologically, moderate temperatures support metabolic efficiency without imposing significant thermal stress [33].

c. Relative Humidity and Food Availability

Relative humidity ranged from 75% to 80% across most sites, with the exception of T19, which showed an anomalous value of 480% (likely due to measurement error). Therefore, data from T19 were excluded from ecological interpretation. Locations with humidity levels between 78% and 80%, such as T1, T3, T10, T12, and T17, supported higher gibbon presence. High humidity is associated with better vegetation productivity, including the availability of fruits and young leaves, which are essential food sources for gibbons [34]. Moreover, the humid microclimate facilitates the growth of epiphytes and lianas, which gibbons use as vertical movement corridors.

Lower humidity (e.g., 75% at T9 and T14) correlates with fewer gibbons (2 and 1 individuals), supporting the notion that gibbons prefer areas with higher humidity, which supports water balance and more consistent food availability.

d. Interaction of Environmental Variables

A multivariate approach to the data suggests that no single variable fully explains gibbon distribution. Instead, a combination of moderate temperature, high humidity, and moderate slopes appears to have the greatest influence. For example, T17, which hosted three gibbons, had an ideal combination of 27°C temperature, 80% humidity, and 8–15% slope. Conversely, T14, with a slope of 8–15%, recorded only one individual, likely due to the low temperature (24°C) combined with lower humidity (75%). This demonstrates that temperature and humidity interact synergistically to influence habitat preferences.

This study concludes that the presence of *Hylobates muelleri* in the Sub-Catchment Area of Kusan Hulu is heavily influenced by physical environmental variables, particularly slope, air temperature, and relative humidity. The optimal habitat for gibbons lies on moderate slopes (8–15%), at moderate temperatures (24–27°C), and with high humidity (78–80%). These findings are crucial for conservation efforts, particularly for planning conservation zones, habitat restoration, and monitoring the impacts of climate change on this endemic species.

6. The Influence of Physical Environmental Factors on the Distribution of Klampiau Gibbons (Hylobates muelleri) in the Kusan Hulu Sub-Watershed

The spatial distribution of arboreal species, such as the Klampiau Gibbon (*Hylobates muelleri*), is heavily influenced by various habitat environmental parameters. This study identifies several physical factors—elevation, distance from water sources, distance from settlements, and distance from main roads—that are presumed to play key roles in the habitat preferences of this species. Observations across 19 monitoring points reveal a complex relationship between habitat parameters and the number of individuals encountered at each site.

a. Elevation Above Sea Level (MDPL)

Elevation ranges from 30 m (T19) to 506 m (T7). The highest numbers of gibbons (3 individuals) were found at elevations between 432–506 m, at sites such as T1 (432 m), T3 (478 m), T7 (506 m), T8 (439 m), and T17 (467 m). These findings indicate that gibbons prefer habitats within mid-elevation zones. This preference is likely linked to the availability of connected forest canopies and abundant food sources in these zones [35]. Conversely, locations at very low (T19, 30 m) or very high elevations (T4, 501 m) recorded only two individuals, suggesting that extreme elevations may limit habitat suitability. Ecologically, mid-elevations provide stable humidity levels and optimal temperatures for arboreal and social activities of gibbons, as noted by [36], who suggested that many primate species tend to occupy mid-elevations for ecosystem stability and food source variability.

b. Distance to Water Sources

Water is a vital resource for all living organisms, including gibbons, which, despite being arboreal, require regular access to water. Analysis shows that sites with water sources within 20–100 meters supported higher gibbon numbers. For instance, T1 and T7 each recorded three individuals at 50 meters from water, while T3 recorded three individuals at 100 meters. However, T19, with the farthest distance from water (400 meters), recorded only two individuals. This suggests a clear preference for habitats close to water sources such as streams or tributaries. This finding aligns with [37] research in Central Kalimantan, which found that gibbons are more commonly found near riparian areas due to higher plant productivity and access to drinking water. The microhabitats around rivers typically offer higher humidity, dense canopies, and greater floristic diversity, which support gibbon feeding and locomotion activities.

c. Distance from Settlements

Anthropogenic disturbances are a critical factor in primate distribution. Sites located more than 500 meters from settlements, such as T10 and T17, generally recorded higher gibbon numbers (T17 = 3 individuals), while sites located less than 100 meters from settlements, such as T2 and T5, recorded fewer individuals (2 individuals). This indicates that gibbons are highly sensitive to human activity. [38] highlighted that Klampiau gibbons avoid areas with high human activity due to noise pollution, hunting, and habitat fragmentation. Interestingly, T1 recorded three individuals despite being only 100 meters from a settlement, suggesting that factors like tree canopy cover or actual disturbance levels might be more important than linear distance alone. In this context, it is crucial to consider whether such sites are protected from visual or acoustic disturbances through vegetation cover.

d. Distance from Roads

Roads are another indicator of human activity. Sites such as T7 and T1, located only 50 meters from roads, recorded three gibbons. This seems contradictory to the hypothesis that gibbons avoid disturbed areas. However, it is important to note that the type of road (dirt road, village path, or highway) significantly affects its ecological impact. If the road is infrequently used or is a narrow footpath, its impact on fauna may be minimal. In contrast, sites like T14, located 200 meters from a road, recorded only one individual, suggesting that the presence of roads does not always directly correlate with gibbon numbers. Therefore, in conservation contexts, the quality of disturbance caused by roads should be analyzed rather than just the physical proximity to roads. [39] suggest that factors such as noise, artificial lighting, and high human presence around roads contribute significantly to habitat disruption, more so than the mere presence of infrastructure.

The distribution of Klampiau gibbons in the Kusan Hulu Sub-Watershed is influenced by a combination of physical environmental factors:

- Optimal elevation ranges from 430 to 500 meters above sea level.
- Ideal distance to water is less than 100 meters, facilitating daily biological activities.
- Distances from settlements greater than 300 meters are generally preferred, indicating sensitivity to anthropogenic disturbances.
- Distance from roads is not the sole indicator of disturbance pressure but should be analyzed in conjunction with road usage intensity.

These findings are important for the management of conservation areas and the planning of ecological corridors in the Kusan Hulu Sub-Watershed. They provide valuable insights into preserving the natural habitat of gibbons and minimizing fragmentation caused by human activities.

CONCLUSION

Strategies for the development of coffee-based agroforestry in Sultan Adam Forest Park are by optimizing the favorable climate and geography by utilizing assistance programs and government policies to expand coffee cultivation, optimizing the favorable climate and geography by utilizing assistance programs and government policies to expand coffee cultivation, developing coffee agro-tourism by demonstrating environmentally friendly and pest-resistant cultivation practices, increasing tourist attractiveness and strengthening branding, submitting proposals and obtaining funds from the government for infrastructure development and improvement, increasing coffee production by using new technology and more efficient cultivation methods to meet increasing market demand, increase farmers' involvement in agro-tourism programs to improve farmers' economic welfare, improve coffee quality and strengthen branding to create added value so that products remain competitive despite fluctuating prices, use pest- and disease-resistant coffee varieties to ensure stable production and quality, face competition from outside coffee, improve coordination and management of farmer groups for production efficiency and reduce costs, so as to be able to compete with market prices and improve cultivation techniques through intensive training and adoption of the latest technology to improve production quality and quantity.

Declaration by Junaedi, Abdi Fithria, Badaruddin

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