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Vital But Vulnerable: The Population Structure of *Macaca maura* in Bantimurung Bulusaraung National Park, South Sulawesi

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ABSTRACT

Macaca maura is an endemic primate of South Sulawesi, currently listed as Endangered due to habitat fragmentation and increasing anthropogenic pressure. This study aims to analyze the population density, age structure, spatial distribution, and food types consumed by *M. maura* in the Karaenta Forest, TN Babul. This field study was conducted over four months (August–November 2024) using a grid-based home-range survey. The study area was divided into 1 × 1 km² grid plots; each encounter with *M. maura* was recorded with X–Y coordinates to visualize the movement patterns of each group. Data were collected through direct observation of eight groups (A–H) with a total of 193 individuals. Group sizes ranged from 13 individuals (Group F) to 39 individuals (Group A). Population density ranged from 52 to 134 individuals/km² with an average of 92 individuals/km². The age distribution, with an average IFR of 0.69, indicates that there is less than one infant per adult female in the *M. maura* population, suggesting a low reproductive rate. Most individuals were observed on the ground rather than in trees or on cliffs, indicating a preference for terrestrial habitats. Dietary records show considerable flexibility, with 27 plant species being utilized. These findings underscore the need for targeted habitat management strategies aligned with the species' ecological needs. This study provides baseline data to support future evidence-based conservation planning and environmental monitoring of *M. maura*.

1. Introduction

Indonesia is an archipelago with a highly diverse ecosystem, making it one of the world's centers of primate diversity. Of the approximately 200 primate species worldwide, 65 are found in Indonesia, of which 24 are endemic, underscoring the country's important role in primate conservation (Supriatna & Ario 2015). Biogeographically, this diversity is divided into three central regions: Sunda, Wallacea, and Sahul. Among the three, Wallacea is known as a transition zone with high endemism. Sulawesi, the largest island in Wallacea, emerges as a primate endemism hotspot, with 17 recorded endemic species, including macaques, tarsiers, and lorises, which together play an essential role in stabilizing tropical forest ecosystems (Cardeti *et al*. 2022).

One such endemic primate is *Macaca maura* Ogilby, 1841, whose distribution is limited to South Sulawesi. This species is listed as Endangered on the IUCN Red List because of a population decline of more than

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50% in the last three generations (Riley *et al.* 2023). The main factors driving this are habitat loss from deforestation, illegal hunting, and wildlife trade. This pressure is exacerbated by human population growth and infrastructure development, which trigger habitat fragmentation and degradation (Kelley 2018; Hansen *et al.* 2019; Ocampo-Peñuela *et al.* 2020; Hernández Tienda *et al.* 2022). This situation makes *M. maura* one of the key species that reflect the vulnerability of Sulawesi's endemic primates to landscape change and anthropogenic pressures.

Ecologically, the frugivorous *M. maura* plays a role in seed dispersal for forest regeneration and functions as a bioindicator of environmental conditions. Changes in group composition, declines in reproductive success, or shifts in activity toward human settlements may signal broader pressures such as habitat disturbance, food scarcity, or climate variability (Zak & Riley 2017; Sagnotti 2024). Thus, the population dynamics of *M. maura* are not merely a species issue but also an indicator of broader ecosystem health, and they require a strong data foundation for effective conservation interventions.

Bantimurung Bulusaraung National Park (TN Babul) has been designated as an essential sanctuary for *M. maura* and various other endangered species (Riley *et al.* 2023). This area encompasses a tropical rainforest ecosystem that is recognized as a key conservation area in South Sulawesi. However, the management of TN Babul faces serious challenges due to agricultural expansion, natural resource extraction, and tourism development, which intensify human-wildlife interactions and degrade forest integrity (Supriatna 2015; Beltrán *et al.* 2022). With these characteristics, TN Babul is a representative location for studying the demographic parameters and ecological aspects of *M. maura*, as it combines forest habitat diversity with significant anthropogenic pressure.

Although several studies describe the behavior and threats to *M. maura*, detailed demographic and ecological data remain limited (Zak & Riley 2016; Beltrán *et al.* 2022; Hernández Tienda *et al.* 2022; Riley *et al.* 2023). In the Karaenta Forest, which is part of TN Babul, no truly comprehensive study has yet measured population density, mapped age structure across groups, traced spatial distribution, or described the types of food consumed by *M. maura*. As a result, determining the habitat requirements of each group, establishing priority corridors, and deciding when and to what extent conservation interventions are necessary still rely on general assumptions rather than accurate local data.

In line with these needs, this study presents a detailed assessment of the population structure of *M. maura* in TN Babul. Specifically, this study measures population density, age distribution, spatial distribution, and food types to fill identified gaps in demographic and ecological data. By integrating demographic data and environmental observations into a single analytical framework, this study provides an empirical basis for conservation planning—including habitat management, corridor design, and restoration priorities—while offering a replicable approach for monitoring other threatened primates in Wallacea and Indonesia.

2. Materials and Methods

2.1. Study Area

A study of the population structure of *M. maura* was conducted in the Karaenta Forest, part of the TN Babul in South Sulawesi. This forest is classified as a tropical lower montane forest, characterized by limestone karst formations, seasonal water availability, and moderate canopy cover. Karaenta supports a mosaic of primary and secondary vegetation, providing diverse food sources, including fruit-bearing trees and broadleaf understory plants. However, parts of the forest are under anthropogenic pressure due to proximity to human settlements and tourism activity. These ecological conditions influence resource distribution, movement patterns, and group composition of *M. maura* within the study area. The geographic coordinates of Karaenta Forest are shown in Figure 1.

2.2. Procedures

2.2.1. Observational Data Collection

Direct observation of *M. maura* was conducted using an exploration-based patrol approach.Observation sheets were used to record group size, age distribution, spatial distribution, and food type. Each encounter was assigned WGS 84 geographic coordinates and indexed on a 1×1 km grid. Observations were conducted daily from 06:00 to 10:30, following predetermined patrol routes covering several habitat zones, for four months from August to November 2024. This time frame primarily captures the transition from the end of the dry season to the beginning of the rainy season in South Sulawesi, so that annual variations in reproduction, food availability,

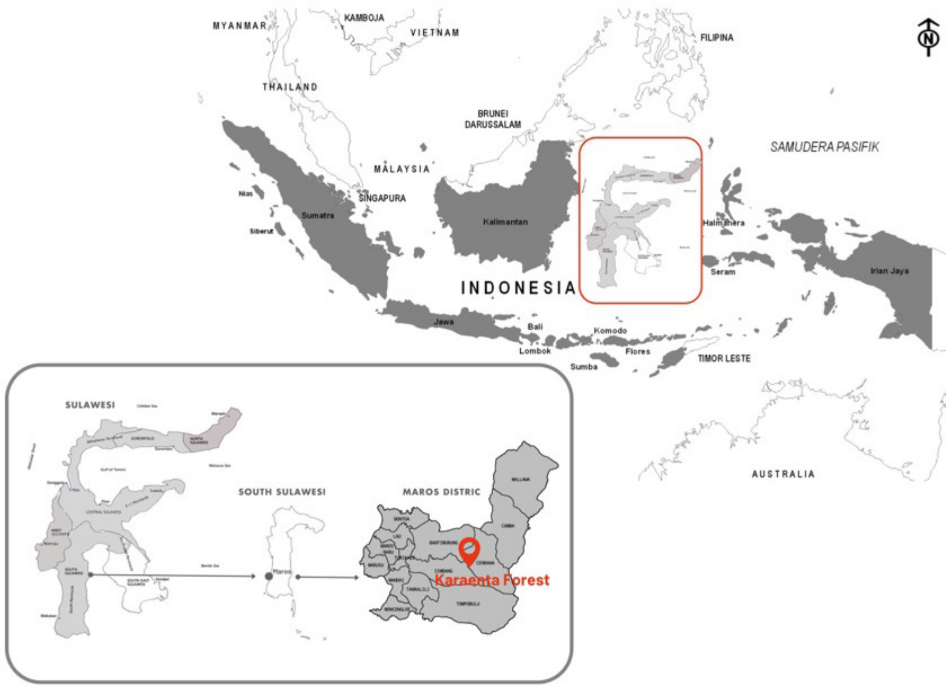

Figure 1. The research location is situated in the Karaenta Forest, which is part of the TN Babul. The Karaenta Forest is in Samangki Village, at the border between the Simbang sub-district and Cenrana sub-district, Maros District, South Sulawesi Province, Indonesia. Geographically, the Karaenta Forest is located at coordinates 4°37'08" S and 119°51'59" E

and spatial use patterns may not be fully captured. To minimize observer influence, observation distances were maintained at ten to fifteen meters, neutral-colored clothing was worn, direct eye contact was avoided, binoculars were used for distance estimation, observer positions were rotated to avoid staying too long at one point, and observations were stopped immediately when animals showed signs of stress or changes in movement.

To ensure that the same group is consistently recognized on repeat visits and to prevent double counting, the eight groups A to H are given unique codes and their identities are established at each encounter through easily recognizable individual characteristics, such as scars, differences in fur patterns, tail shape or length, finger anomalies, facial features, and the size of the alpha male. All characteristics were documented in a photo catalog and compared at each encounter to ensure consistent recognition without artificial tagging. Spatial fidelity was demonstrated by mapping daily travel corridors, core areas, and sleeping locations using a Garmin eTrex 10 handheld GPS, and all detections were then placed on the same grid. The stability of age distribution between visits also supports identity consistency. Two observers cross-check encounters that are close in space and time, and changes in group size of approximately 10% on adjacent dates trigger a verification procedure before a new group identity is established.

Information on food types was obtained from direct observations of feeding behavior, recording each plant species eaten by *M. maura* —fruit, leaves, flowers, or other parts of the plant. This data was supplemented by structured interviews with local communities and National Park officials, in which only food items confirmed through direct observation and supported by at least two independent informants were included in the primary analysis. Unconfirmed items were treated as supporting information and not used in the feeding richness calculation. Feeding richness was calculated based on the number of plant species eaten by the *M. maura* group during the observation period. Each species eaten was recorded only once, even if eaten more than once, to avoid duplication. Interviews used illustrated guides of plant species to minimize identification errors, and each report was matched to the time and location of the field observation. Data from observations and interviews were then used to calculate the total number of foraging species, which served as an indicator of feeding richness.

2.2.2. Population Structure Recording

Data on population density, age and sex distribution, spatial patterns, and feeding behavior were collected using the home range survey method (Barnett & Dutton 1995; Fleming *et al*. 2022), by following patrol tracks throughout the Karaenta Forest. Observation points were recorded with a handheld GPS device (Garmin eTrex 10) and georeferenced in real time using WGS 84 coordinates. The study area was overlaid with a 1×1 km² grid system, with the origin point (0,0) positioned at the southwest corner. Each detection of *M. maura* was assigned an X-Y coordinate corresponding to its grid position. These spatial records were then visualized in QGIS 3.28 to reconstruct movement patterns and estimate home ranges. This systematic approach enabled consistent spatial mapping and ensured accuracy across the entire survey area. The conceptual layout of the observation grid is illustrated in Figure 2.

Mapping of encounter points and consistency of group naming during analysis was conducted on a 1×1 km grid using the official TN Babul map application. Eight groups A–H were determined from the initial encounter locations and established through repeated observations. The spatial positions of encounter points are shown as blue dots in Figure 3.

To calculate the area range, all location points obtained from GPS recordings are first processed by removing duplicates and identifying outliers inconsistent with field records. Next, the coordinate data, originally in the geographic coordinate system (WGS 84), is reprojected to a metric projection system (UTM) so the area can be accurately calculated in square meters. In each group, all location points are combined, then the outermost points are connected to form the smallest convex polygon (Minimum Convex Polygon). This polygon is considered to represent the group's range of movement during the observation period. The polygon's area is calculated in GIS software (QGIS) using geometric calculations, then converted to square kilometers by dividing the area by 1,000,000. The area obtained is rounded to two decimal places, for example, 0.25 km² or 0.29 km².

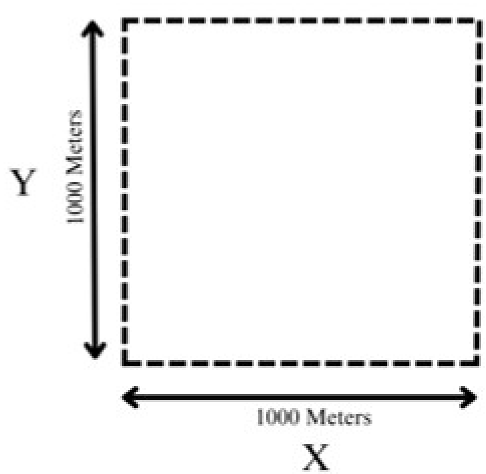

Figure 2. Movement observation grid

2.3. Data Analysis

This study employs descriptive statistical analysis as a fundamental approach to describe the population structure of *M. maura*. Population density is calculated using the Concentration Count method (Buckland *et al.* 2015), which is a technique commonly used in ecological surveys, particularly in animal population studies. This method estimates the number of individuals or groups within a specific area by assessing their concentration, or density, across multiple observation sites. The formula used to calculate population density is based on the equation from Buckland *et al.* (2015) as follows:

$$D = \frac{n}{A}$$

Where;
D : Population density (individuals/km²)
n : Number of individuals counted
A : Area surveyed (km²)

In addition to analyzing the proportions of age and sex classes, we calculated summary statistics, mean, standard deviation, and range for group size and population density across the eight *Macaca maura* groups. These metrics were visualized using boxplots generated with the ggplot2 package in R (version 4.3.1) to highlight distribution patterns and inter-group variation. To explore ecological associations, Spearman's rank correlation tests were conducted to evaluate the relationships between population parameters (group size and density) and feeding resource richness (number of plant species consumed per group), as well as between infant proportion and habitat zone type. The feeding data were organized into group-specific matrices by plant category. All analyses were performed in R using the ggplot2, dplyr, and stats packages, ensuring reproducibility and transparency in data processing.

The scope of analysis in this study remains at a basic level, limited to descriptive summaries and

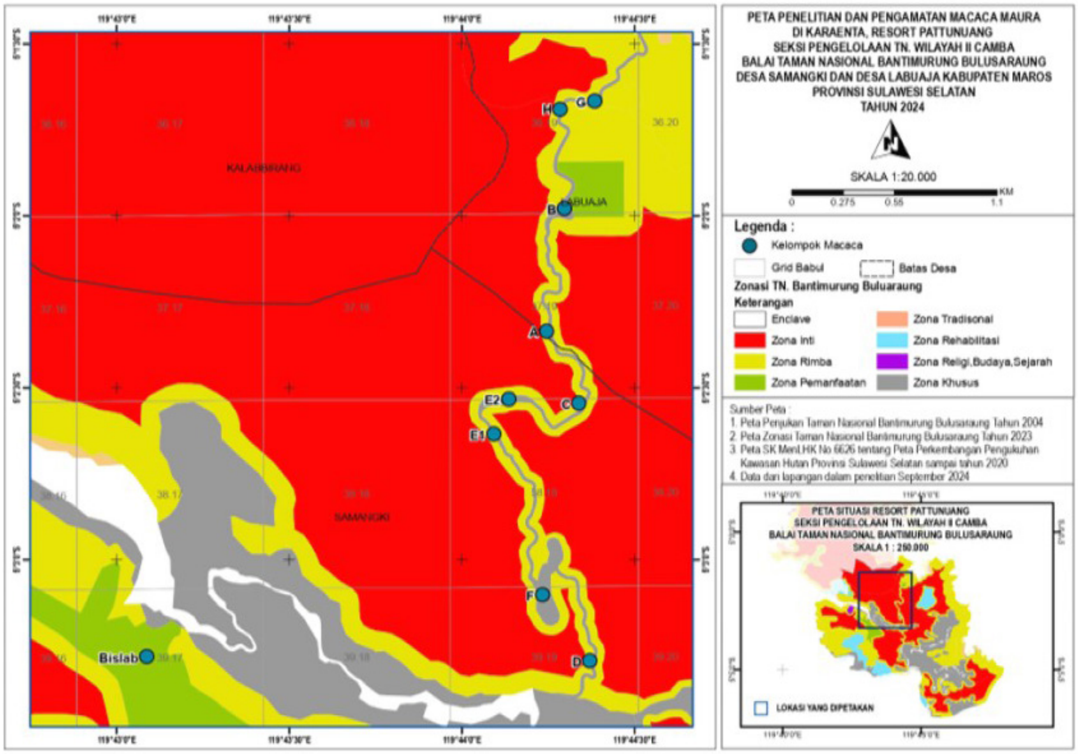

Figure 3. Map of encounter points of eight *M. maura* groups. Source: Map application TN Babul Eight *M. maura* groups (A–H) were identified based on initial encounter locations and are consistently labeled throughout the analysis

Spearman's correlation tests to assess relationships between measurements. This approach does not consider various habitat factors that could potentially influence the results, such as canopy density, distance to forest edges, habitat type, proximity to settlements, intensity of human activity, and availability of fruit trees. To strengthen the inferences, further research should collect habitat variables at the site level and apply more advanced modeling, such as general linear models or mixed general linear models with random effects by group.

3. Results

3.1. Population Density

Based on the survey conducted, the number of individuals and population density of *M. maura* in eight groups within the Karaenta Forest area of TN Babul, using the concentration method, are shown in Table 1.

In this study, each detected group of *M. maura* exhibited a well-defined range, resulting in minimal overlap between groups despite being within the same observation grid. This is because each group maintains its territory through consistent social interactions, characterized by behaviors that maintain distance between groups and by differences in individual physical characteristics that enable accurate group identification. During observation, unique characteristics such as permanent scars, tail shape and length, crest patterns or baldness, and variations in the size of dominant males allowed groups to be accurately separated. Thus, even though the groups were located close to each other within a single grid, overlap in their ranges was rarely observed. Therefore, the population density estimates obtained (52-134 individuals/km²) can be considered representative and not inflated by double-counting the same area.

A statistical correlation analysis was conducted to examine whether group-level population parameters, specifically group size and density, were associated with ecological factors, particularly feeding resource richness. The results of the Spearman's rank correlation test are presented in Table 2.

The Spearman correlation analysis revealed a statistically significant positive relationship between group size and feeding richness ($\rho = 0.714$, $p = 0.046$), indicating that larger groups tend to consume a wider variety of plant species. Meanwhile, the correlation between population density and feeding richness was

Table 1. Number of individuals, range area, and population density in eight groups of *M. maura* in Karaenta forest, TN Babul

Group name	Number of individuals	Range area (km^2)	Population density (Individual / km^2)
D	25	0.25	100
F	13	0.25	52
E	20	0.25	80
C	19	0.25	76
A	39	0.29	134
B	36	0.29	124
H	19	0.25	76
G	22	0.23	96
Average		0.25	92

Table 2. The results of the Spearman's rank correlation test

Parameter compared	ρ (rho)	p-value
Group size vs. feeding richness	0.714	0.046 *
Population density vs. feeding richness	0.660	0.072

positive but not statistically significant ($\rho = 0.660$, $p = 0.072$).

3.2. Age Distribution

Data on the age structure of *M. maura* populations are divided into several age categories: adult males, adult females, juveniles, infants, and newborns. This information is essential for understanding the population dynamics of the species, including population growth potential, reproductive stability, and social patterns within the group. The number of individuals in each age class can provide clues about reproductive success, survival rates, and social structure within the *M. maura* group. Using this data, further analysis of how group dynamics interact with habitat conditions affecting the species can be conducted. Data on the age composition of each *M. maura* group are presented in Table 3.

Group F shows an unusual composition, with a very low number of adult males (only one individual) and an unbalanced age distribution. One factor that may influence this is the location of group F, which is close to a road. Proximity to highways can increase human disturbance and mortality risk to individuals, whether due to hunting, vehicle collisions, or habitat destruction. The average IFR of 0.69 indicates that in the *M. maura* population in Karaenta, there is less than one infant per adult female, suggesting a low reproductive rate. To further illustrate the variation in age structure among the eight macaque groups, the age distribution data were visualized using boxplots. This representation provides a more straightforward overview of central tendencies and inter-group differences for each age class, including adult males, adult females, juveniles, infants, and newborns. It can be clearly observed in Figure 4.

3.3. Spatial Distribution

Spatial distribution data for *M. maura* were collected through repeated observations using an instantaneous group-scan. At the beginning of each encounter, each individual observed was classified into three substrate categories corresponding to karst habitats: (1) soil (terrestrial) located on the ground surface/litter; (2) trees on trunks, branches, or canopy; and (3) cliffs/rocks ≥2 m on limestone boulders, cliff surfaces, or karst walls with a minimum height of two meters from the ground surface. For each group, the number of individuals per category was summed across all encounters; these total numbers are presented in Table 4.

The distance between *M. maura* groups in the Karaenta Forest shows that even though these groups are relatively close to each other, they still have separate and clearly defined territories. Groups D and F are only 800 meters apart in the same grid. Even though groups F and E are in the same grid, they still have physical characteristics that clearly distinguish them. Each *M. maura* group has unique physical characteristics, such as scars, fur color patterns, body size, and facial features that distinguish groups F and E. The distances between C and A (500 m), A and B (600 m), and B and H (500 m) remain within the range of interaction. Groups H and G are the closest, separated by only 200 meters.

3.4. Type of feed consumed

Table 5 summarizes the 27 feed types consumed by *M. maura* in the Karaenta Forest area, TN Babul. The list was compiled from direct observations of confirmed feeding behavior and structured interviews validated by at least two independent informants, so that unconfirmed items were excluded from the analysis.

Table 3. Number of individuals and age distribution of eight *M. maura* groups in Karaenta forest. TN Babul

Group name	Age distribution					Infant to female ratio
	Adult male	Adult female	Juveniles	Infants	Newborns	
D	6	9	4	3	3	0.33
F	1	4	5	3	0	0.75
E	8	5	2	3	2	0.60
C	8	4	3	2	2	0.50
A	7	9	13	7	3	0.78
B	11	9	4	3	3	0.33
H	7	4	2	5	1	1.25
G	4	6	4	6	2	1.00
Average	6	6	4	4	2	0.69

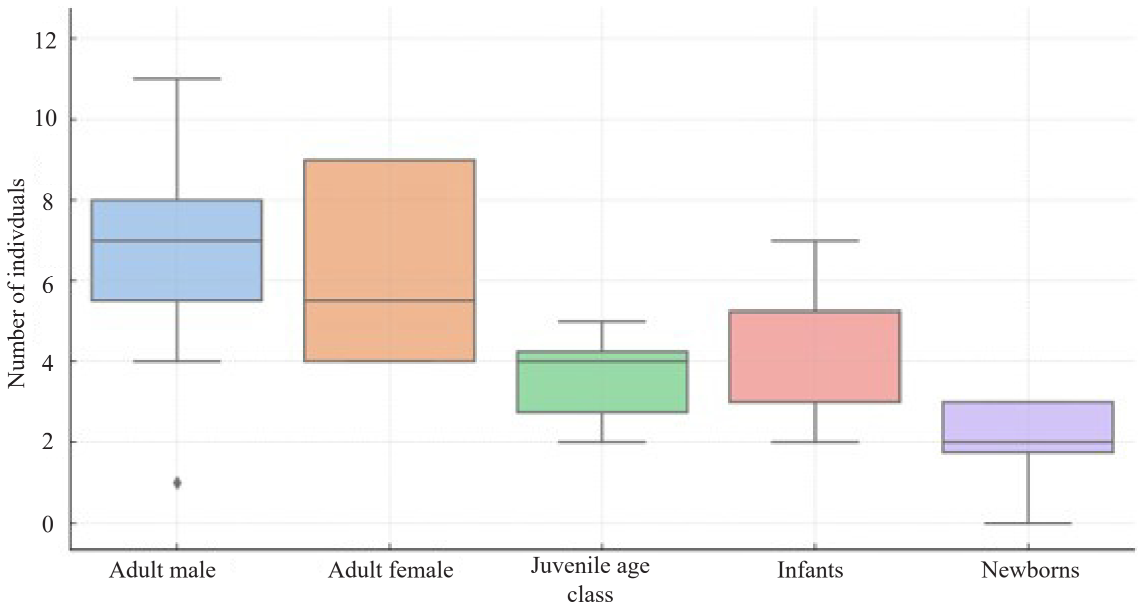

Figure 4. Boxplot of age class distribution across *M. maura* groups

Table 4. Spatial distribution percentage of *M. maura* on various substrates in Karaenta Forest, TN Babul

Group name	Spatial (%)		
	On the ground	Found in trees	On cliffs or rocks
D	72.0	16.0	12.0
F	76.9	23.1	0.0
E	75.0	10.0	15.0
C	73.7	10.5	15.8
A	71.8	12.8	15.4
B	83.3	8.3	8.3
H	63.2	10.5	26.3
G	81.8	13.6	4.5
Average	74.7	13.1	12.3

Table 5. Types of feed consumed for *M. maura* in Karaenta forest area, TN Babul

Feed type	Family	Part consumed
Pandanus sp	Pandanaceae	Fruit
Morinda citrifolia	Rubiaceae	Fruit
Dracontomelon dao	Anacardiaceae	Leaf, fruit
Litsea mappaceae	Lauraceae	Fruit
Poluscia nodosa	Araliaceae	Leaf
Phaleria capitate	Thymeleaeceae	Fruit
Aglaia tomentosa	Miliaceae	Fruit
Buchanania arborescens	Anacardiaceae	Fruit
Ziziphus angustifolius	Rhamnaceae	Fruit
Canthiumera robusta	Rubiaceae	Fruit
Melicope latifolia	Rutaceae	Fruit
Garuga floribunda	Burseraceae	Fruit
Canarium asperum	Burseraceae	Fruit
Litsea confuse	Lauraceae	Fruit
Garcinia bancana	Clusiaceae	Leaf
Pterocymbium tinctorium	Malvaceae	Fruit
Terminalia supitiana	Combretaceae	Fruit
Villebrunea rubbescens	Urticaceae	Flower, fruit
Albizia procera	Fabaceae	Fruit
Saccopetalum sp	Annonaceae	Fruit
Ficus ampelas	Moraceae	Fruit
Spondias pinnata	Anacardiaceae	Leaf, fruit
Neolamarckia cadamba	Rubiaceae	Fruit
Syzygium acuminatissima	Myrtaceae	Fruit
Mungtingia calabura	Mungtingiaceae	Fruit
Flacourtia jangomas	Salicaceae	Fruit
Macaranga conifera	Euphorbiaceae	Leaf, fruit

4. Discussion

4.1. Population Density

The population density of *M. maura* in the Karaenta forest area of TN Babul is recorded as very high, namely 52–134 individuals/km², with an average of 92 individuals/km². This figure far exceeds reports on similar species in relatively intact habitats, such as *M. nigra* in Tangkoko National Park, which only ranges from 30–50 individuals/km² (Supriatna 2015). Throughout the observation period, no indications of overlap between groups were found. Each group could be consistently identified through distinctive and relatively permanent physical characteristics, including scars or physical defects, variations in tail length and shape (e.g., bent or truncated tails), crest patterns or bald spots on the crown of the head, color patterns on the face and back, and differences in body size, especially in alpha males. This individual identification strengthened the validity of group separation and reduced the risk of double-counting.

The range for each group is relatively narrow, from 0.23 to 0.29 km². The limited range, combined with high individual density, indicates a concentration of the population in a narrow space (Albani *et al.* 2020). This pattern can be interpreted as a sign of habitat saturation, where the carrying capacity of the group's range is approaching its maximum limit, while also reflecting the limited opportunities for the group to expand into surrounding areas. This condition can have demographic and ecological consequences, including increased competitive interactions, pressure on food resources, and reduced reproductive success. Thus, these results highlight the urgency of assessing habitat carrying capacity more broadly and placing the area around Karaenta within the framework of integrated conservation planning.

4.2. Age Distribution

The age distribution, with an average IFR of 0.69, indicates that in the *M. maura* population in Karaenta, there is less than one infant per adult female, suggesting a low reproductive rate. (Riley *et al.* 2023) This pattern is often associated with low regeneration rates, either due to low birth rates or high juvenile mortality (Dharmawan *et al.* 2005). Group A is an exception, with a broader age range indicating relatively better reproductive success. However, this interpretation should be read with caution, as data collection was conducted only during a specific period. Several macaque species, including *M. maura*, exhibit seasonal or semi-seasonal reproductive patterns (Van Schaik *et al.* 1999). Thus, the low number of infants could also be a temporal bias, rather than a definite indicator of a decline in reproduction. Most groups showed a relatively balanced male-female ratio, except for Group F, which had only one adult male. This condition was likely influenced by its location near a highway, making it more vulnerable to disturbance and death from hunting or vehicle collisions. Although a balanced male ratio can increase male competition, this study did not include systematic behavioral observations. Therefore, the relationship between sex ratio and social conflict should be viewed as an indicative hypothesis, although it is consistent with the socioecological literature on macaques (Van Noordwijk 1985; Thierry 2007).

4.3. Distribusi Spasial

The spatial distribution of *M. maura* in Karaenta shows a high level of terrestriality, while the use of trees and cliffs/rocks ≥2 m is recorded repeatedly but in smaller proportions. This pattern is consistent with the ecological characteristics of karst, where the relatively open forest floor facilitates movement and foraging near the surface. At the same time, vertical elements are used contextually for height transitions, lookout points, and protection. These conclusions are consistent with the findings. Individual positions on "ground, trees, ≥2-m rocks" have been classified and show that elevation use depends on substrate availability and activity status, with the forest floor remaining the primary arena (Rahman *et al.* 2024). The study in the Nonggang karst area supports this description, showing that although the cliff surface and forest canopy are utilized, the primary function of the vertical substrate is more related to vertical mobility and surveillance than as a core activity space (Huang *et al.* 2015; Hussain & Huang 2022). The local ecology of Karaenta is characterized by a mosaic of landscapes, including karst plains and karst towers (Albani *et al*. 2020). This variation in landscape form influences the spatial behavior of *M. maura*. Groups whose range is dominated by rock tend to utilize cliffs or large rocks more frequently, while groups located in karst valleys exhibit more terrestrial behavior on the ground surface.

4.4. Type of Feed Consumed

The results of this study indicate that *M. maura* has an opportunistic frugivorous diet. Fruit is the primary source of energy, while vegetative parts, such as young leaves and flowers, are used when fruit availability is low or uneven in space and time. The wide variety of food sources is evident from the many tropical forest genera that contribute fruit, including Ficus, Canarium, Syzygium, Litsea, Pandanus, Buchanania, and Garuga. In addition, several plant groups in the Karaenta forest also provide easily digestible vegetative parts, such as Macaranga, Spondias, Garcinia, Dracontomelon, and Polyscias. Several genera play an essential role as key supporters in maintaining food continuity. Ficus fruits serve as a phenological buffer because they are relatively evenly available throughout the year, so they are often referred to as a keystone resource for fruit-eating primates. Canarium and Syzygium are essential sources of energy during the peak fruiting season, while Litsea usually experiences mass fruiting events that the group immediately exploits. When the diet is rich in sugar from fruit, young leaves, especially from Macaranga and Spondias, help balance protein and fiber intake. Other sources, such as Villebrunea flowers, complement micronutrient requirements. This combination forms a relatively stable dietary pattern, with fruit as the main source of energy and vegetative parts serving as fallback foods when fruit is limited. The nutritional patterns observed in Karaenta are consistent with previous reports on *M. maura* and other Macaca species in Sulawesi and Southeast Asia, which generally place fruit as a core component of the diet. The shift in consumption toward vegetative parts typically increases during periods of fruit scarcity, especially in highly dynamic karst ecosystems or seasonal forests. This high dietary flexibility can be viewed as an essential adaptive strategy for *M. maura* to maintain nutritional balance and survive in fragmented habitat landscapes (Zak & Riley 2017). However, this phenomenon can also be interpreted as a sign of ecological stress, as increased consumption of diverse plant species likely reflects reduced availability of preferred primary food sources.

This study has several limitations. First, the observation period, which lasted only four months and covered the end of the dry season to the beginning of the rainy season, did not fully capture seasonal variations in reproduction, food availability, and movement patterns. Second, although the coverage of eight groups provided a strong picture of the Karaenta area, these results cannot be considered representative of the entire TN Babul. Third, diet data were collected through validated, structured interviews, but reporting bias could not be entirely avoided. Therefore, further research should be conducted for at least 6 months, including genetic sampling to assess kinship and gene flow, and the use of camera traps or automatic sensors to improve observation accuracy. In terms of analysis, the application of more sophisticated statistical methods, such as Generalized Linear Models (GLMs), enables more robust testing of the relationships between population metrics (number of individuals per plot, presence/absence, and age-class proportions) and environmental covariates and anthropogenic pressures.

This study presents a comprehensive portrait of the *M. maura* population in the Karaenta Forest, TN Babul. From a demographic perspective, this study presents estimates of density, age structure, and sex ratio. From an ecological perspective, this study describes patterns of space utilization on various substrates and the diversity of food consumed. The integration of these two dimensions confirms the vulnerability of *M. maura* in a landscape under increasing pressure, while providing an essential basis for more adaptive conservation planning. This approach also has the potential to be replicated in other fragmented habitats in Indonesia, thereby strengthening efforts to protect endangered endemic primates.

In Conclusion, This study provides an overview of the *M. maura* population in the Karaenta Forest. The recorded population density is relatively high, suggesting a concentration of individuals within a narrow range. The age structure is dominated by adults, with a lower proportion of juveniles and infants, although variations between groups indicate differences in reproductive success. The spatial distribution shows strong terrestrial characteristics, while the use of trees and cliffs is more contextual for mobility and protection. In terms of feeding ecology, *M. maura* is an opportunistic frugivore, with fruit as its primary source of energy, while vegetative parts serve as fallback foods when fruit is scarce.

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References

Albani, A., Cutini, M., Germani, L., Riley, E.P., Ngakan, P.O., Carosi, M., 2020. Activity budget, home range, and habitat use of moor macaques (*Macaca maura*) in the karst forest of South Sulawesi, Indonesia. *Primates*. 61, 673-684. https://doi.org/10.1007/s10329-020-00811-8

Barnett, A., Dutton, J., 1995. Small Mammals (Excluding Bats), second ed. Expedition Advisory Centre. Royal Geographical Society, London.

Beltrán Francés, V., Spaan, D., Amici, F., Maulany, R.I., Putu Oka, N., Majolo, B., 2022. Effect of anthropogenic activities on the population of moor macaques (*Macaca maura*) in South Sulawesi, Indonesia. *International Journal of Primatology*. 43, 339-359. https://doi.org/10.1007/s10764-022-00279-x

Buckland, S.T., Rexstad, E.A., Marques, T.A., Oedekoven, C.S., 2015. Distance Sampling: Methods and Applications. Springer, University of St Andrew.

Cardeti, G., Cersini, A., Manna, G., De Santis, P., Scicluna, M.T., Albani, A., Simula, M., Sittinieri, S., De Santis, L., De Liberato, C., 2022. Detection of viruses from feces of wild endangered *Macaca maura*: a potential threat to moor macaque survival and for zoonotic infection. *BMC Veterinary Research*. 18, 418. https://doi.org/10.1186/s12917-022-03506-y

Dharmawan, A., Ibrohim, Tuarita, H., Suwono, H., & Susanto, P., 2005. Ekologi Hewan. UM Press.

Fleming, C.H., Deznabi, I., Alavi, S., Crofoot, M.C., Hirsch, B.T., Medici, E.P., Noonan, M.J., Kays, R., Fagan, W.F., Sheldon, D., Calabrese, J.M., 2022. Population-level inference for home-range areas. *Methods in Ecology and Evolution*. 13, 1027-1041. https://doi.org/10.1111/2041-210X.13815

Hansen, M.F., Nawangsari, V.A., van Beest, F.M., Schmidt, N.M., Fuentes, A., Traeholt, C., Stelvig, M., Dabelsteen, T., 2019. Estimating densities and spatial distribution of a commensal primate species, the long-tailed macaque (*Macaca fascicularis*). *Conservation Science and Practice*. 1, e88. https://doi.org/10.1111/csp2.88

Hernández Tienda, C., Majolo, B., Romero, T., Illa Maulany, R., Oka Ngakan, P., Beltrán Francés, V., Gregorio Hernández, E., Gómez-Melara, J., Llorente, M., & Amici, F., 2022. The habituation process in two groups of wild moor macaques (*Macaca maura*). *International Journal of Primatology*. 1-26. https://doi.org/10.1007/s10764-021-00275-7

Huang, Z., Huang, C., Wei, H., Tang, H., Krzton, A., Ma, G., Zhou, Q., 2015. Factors influencing positional behavior and habitat use of sympatric macaques in the limestone habitat of Nonggang, China. *International Journal of Primatology*. 36, 95-112. https://doi.org/10.1007/s10764-015-9813-9

Hussain, S., Huang, J., 2022. The impact of cultural values on green purchase intentions through ecological awareness and perceived consumer effectiveness: An empirical investigation. *Frontiers in Environmental Science*. 10. https://doi.org/10.3389/fenvs.2022.985200

Kelley, L.C., 2018. The politics of uneven smallholder cacao expansion: A critical physical geography of agricultural transformation in Southeast Sulawesi, Indonesia. *Geoforum*. 97, 22-34. https://doi.org/10.1016/j.geoforum.2018.10.006

Ocampo-Peñuela, N., Garcia-Ulloa, J., Kornecki, I., Philipson, C. D., Ghazoul, J., 2020. Impacts of four decades of forest loss on vertebrate functional habitat on Borneo. *Frontiers in Forests and Global Change*. 3, 1-13. https://doi.org/10.3389/ffgc.2020.00053

Rahman, F., Maulany, R.I., Ngakan, P.O., Rodriguez del Castillo, C., Majolo, B., Amici, F., 2024. Moor macaques (*Macaca maura*) remember earlier habituation despite changes in group composition. *International Journal of Primatology*. 45, 208-212. https://doi.org/10.1007/s10764-023-00413-3

Riley, E.P., Albani, A., Zak, A.A., Germani, L., Rothman, J.M., Carosi, M., Ngakan, P.O., 2023a. The potential conservation value of anthropogenically modified habitat for the endangered moor macaque *Macaca maura* in Sulawesi, Indonesia. *Oryx*. 57, 600-610. https://doi.org/10.1017/S003060532200151X

Riley, E.P., Albani, A., Zak, A.A., Germani, L., Rothman, J.M., Carosi, M., Ngakan, P.O., 2023b. The potential conservation value of anthropogenically modified habitat for the Endangered moor macaque *Macaca maura* in Sulawesi, Indonesia. *Oryx*. 57, 600-610. https://doi.org/10.1017/S003060532200151X

Sagnotti, C., 2024. Don't shock the monkey! A non-invasive multidisciplinary approach to the study of conservation issues for *Macaca maura* (HR Schinz 1825) in South Sulawesi, Indonesia.

Supriatna, J., 2015. Primates of Sulawesi: An update on habitat distribution, population and conservation. *Taprobanica*. 7. https://doi.org/10.47605/tapro.v7i3.189

Supriatna, J., Ario, A., 2015. Primates as flagships for conserving biodiversity and parks in Indonesia: Lessons learned from West Java and North Sumatra. *Primate Conservation*. 2015, 123-131.

Thierry, B., 2007. Unity in diversity: lessons from macaque societies. Evolutionary Anthropology: Issues, News, and Reviews. 16, 224-238.

Van Noordwijk, M.A., 1985. Sexual behaviour of Sumatran long-tailed macaques (*Macaca fascicularis*). *Zeitschrift Für Tierpsychologie*. 70, 277-296.

Van Schaik, C.P., Deaner, R.O., Merrill, M.Y., 1999. The conditions for tool use in primates: implications for the evolution of material culture. *Journal of Human Evolution*. 36, 719-741.

Zak, A.A., Riley, E.P., 2016. Comparing the use of camera traps and farmer reports to study crop feeding behavior of moor macaques (*Macaca maura*). *International Journal of Primatology*. 38, 224-242. https://api.semanticscholar.org/CorpusID:254541848

Zak, A.A., Riley, E.P., 2017. Comparing the use of camera traps and farmer reports to study crop feeding behavior of moor macaques (*Macaca maura*). *International Journal of Primatology*. 38, 224-242. https://api.semanticscholar.org/CorpusID:27258645