

Current status of long-tailed macaque (*Macaca fascicularis*) on small islands in the Southern Sumatra, Indonesia

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Manuscript received: 13 January 2025. Revision accepted: 22 February 2025.

Abstract. Hasibuan MM, Tohir RK, Munawaroh K, Maryanto I, Maharadatunkamsi, Lubis AM, Rahmandani F, Irhamuddin, Sujadi, Gunarto E, Rafsanjani YH. 2025. Current status of long-tailed macaque (*Macaca fascicularis*) on small islands in the Southern Sumatra, Indonesia. *Biodiversitas* 26: 971-980. The global population status of the Long-Tailed Macaque (LTM/*Macaca fascicularis*) was recently reassessed, resulting in its reclassification from Vulnerable to Endangered due to an estimated population decline of approximately 40% over the past three generations. To better understand and validate its updated IUCN status, we conducted a population study on Tabuan, Legundi, and Umang-umang Islands in Lampung Province, located in the southern region of Sumatra, Indonesia. On the other hand, management challenges arise due to its current International Union for Conservation of Nature (IUCN) status, even though it is locally regarded as a pest by the local population. To establish effective and sustainable management strategies, updated population data is crucial, particularly in regions with limited information. This research aimed to address the need for population status data in Sumatra. As part of a broader study focusing on the distribution of *M. fascicularis* in Sumatra, this study specifically targets the understudied small islands located in the southern region of Sumatra Island. The research was conducted from April 25 to May 4, 2024, on three islands within Lampung Province: Tabuan, Legundi, and Umang-umang Islands. Data were collected using the transect method, covering a total distance of 43.42 km. The findings revealed an estimated total population of approximately 9,948 *M. fascicularis* individuals, distributed as follows: 6,523 on Tabuan Island, 3,415 on Legundi Island, and a single group of around 10 individuals on Umang-umang Island. These findings provide insights into previously underrecognized and underpublicized populations of LTM in Southern Sumatra, elucidate the potential for colonization of new territories by LTM on the surveyed islands, and underscore conflicts with local communities in specific areas. Therefore, it is imperative to intensify management efforts to improve habitat conditions, mitigate conflicts, and enhance the overall success of LTM conservation and management strategies.

Keywords: Conservation strategies, food sources, human, population, transect method

INTRODUCTION

One of Indonesia's primate species, the Long-Tailed Macaque/LTM (*Macaca fascicularis*) has recently garnered attention due to its upgraded conservation status to "Endangered" (Hansen 2022). Before 2020, the species was categorized as "Least Concern" (LC), reclassified as "Vulnerable" in 2020, and finally elevated to "Endangered" in 2022 (Hansen 2022). The reclassification of *M. fascicularis* reflects a substantial population decline of approximately 40% over the past three generations (Hansen 2022). The transition of the LTM from "Vulnerable" to "Endangered" has critical implications for the management and conservation of the species. According to Gamalo et al. (2023), the LTM is experiencing a declining population and faces significant threats. However, Hilborn and Smith (2023) argue that the claims made by Hansen (2022) and Gamalo et al. (2023) lack robust data to substantiate the reported population decline and misinterpret existing scientific literature.

There are two prevailing arguments regarding the population and conservation status of LTM. The first suggests that the population of LTM is in a critical state due to significant declines and over-utilization (Hansen 2022; Gamalo et al. 2023). The second contends that LTM remain abundant in Indonesia and, in some cases, even pose a pest problem (Sulistiyadi et al. 2021). In 2000, the International Union for the Conservation of Nature (IUCN) classified the LTM as an invasive species, noting its introduction to several areas where its population had grown rapidly (Lowe et al. 2000). The combination of high population density and the remarkable adaptability of LTM contributes to frequent human-macaque interactions and potential conflicts (Tsuji and Ilham 2021; Zhao et al. 2023). The recent elevation of the long-tailed macaque's conservation status from "Vulnerable" to "Endangered" carries significant implications for the species' management strategies. High population densities in certain areas threaten local biodiversity and disrupt agricultural activities, making management practices such as eradication, translocation, and

contraception challenging under the current "Endangered" classification (Moore et al. 2023).

Assessing the current state of LTM in Indonesia is further complicated by the lack of data on the population and distribution of this species in the country. Currently, many studies focus on the main island due to its high biodiversity and massive urban land expansion, leading to a bias in conservation research and investment of conservation funds (Chisholm et al. 2016; Johnson et al. 2019; Russell and Kueffer 2019; Simkin et al. 2022; Gabi and Abdullah 2024). Whereas small islands that are sometimes neglected usually hold unique biodiversity compared to continents and other large islands, so their existence is very important (UN-OHRLLS 2017). Research on small islands therefore needs to be carried out, particularly for LTM, which are currently in the global spotlight (Badihi et al. 2024; Garber et al. 2024).

The southern region of Sumatra Island, including Lampung Province, encompasses several small islands where the presence of LTM has been recorded. However, data on the population status of LTM in these islands remain scarce, with only five publications documenting their presence on Umang-Umang Island, Tabuan Island, and Condong Darat Island (Amir et al. 1991; Perwitasari-Farajallah et al. 2001; Paryadi et al. 2006; Muslim 2012; Risdiyansyah et al. 2014). Beyond these scientific publications, additional information regarding the presence of LTM has been identified for Legundi Island. The lack of up-to-date and credible data highlights the need for contributions from the government, researchers, and other stakeholders to enhance the effectiveness of conservation policies for LTM in Indonesia. This study aimed to investigate the distribution, population size, and potential human-wildlife conflicts involving LTM, which have not been previously documented (with the exception of Tabuan

Island in 1991) on several small islands in southern Sumatra. The findings are expected to provide a more comprehensive understanding of the LTM population in southern Sumatra and inform conservation strategies at both regional and national levels.

MATERIALS AND METHODS

Study area

The study was conducted on three small islands located in the Southern Sumatra, all of which fall under the administrative jurisdiction of Lampung Province, Indonesia: Tabuan, Legundi, and Umang-Umang Islands (Figure 1). Prior to determining the study sites, a preliminary survey was conducted to obtain information regarding the presence of LTM populations on several small islands in Lampung. This survey encompassed a literature review, including scientific journals, theses, unpublished reports, seminar proceedings, books, and other types of publications (posters, multimedia, and magazines). Additionally, interviews were conducted with government officials (represented by the Natural Resources Conservation Centre and the Forestry Service of Lampung Province) and non-governmental organizations. Tabuan Island, covering an area of 3,328 ha, is inhabited and supports a naturally distributed population of LTM. Genetic studies suggest that the macaques on Tabuan Island exhibit a slightly different genetic structure compared to their counterparts on the Sumatran mainland (Amir et al. 1991; Perwitasari-Farajallah et al. 2001). Legundi Island, which is also inhabited, has an area of 1,908 ha, while Umang-Umang Island, covering only 9.6 ha, remains uninhabited. The LTM on these two islands was introduced from mainland Sumatra (SK Dirjen 22/Kpts/DJ-VI/1993).

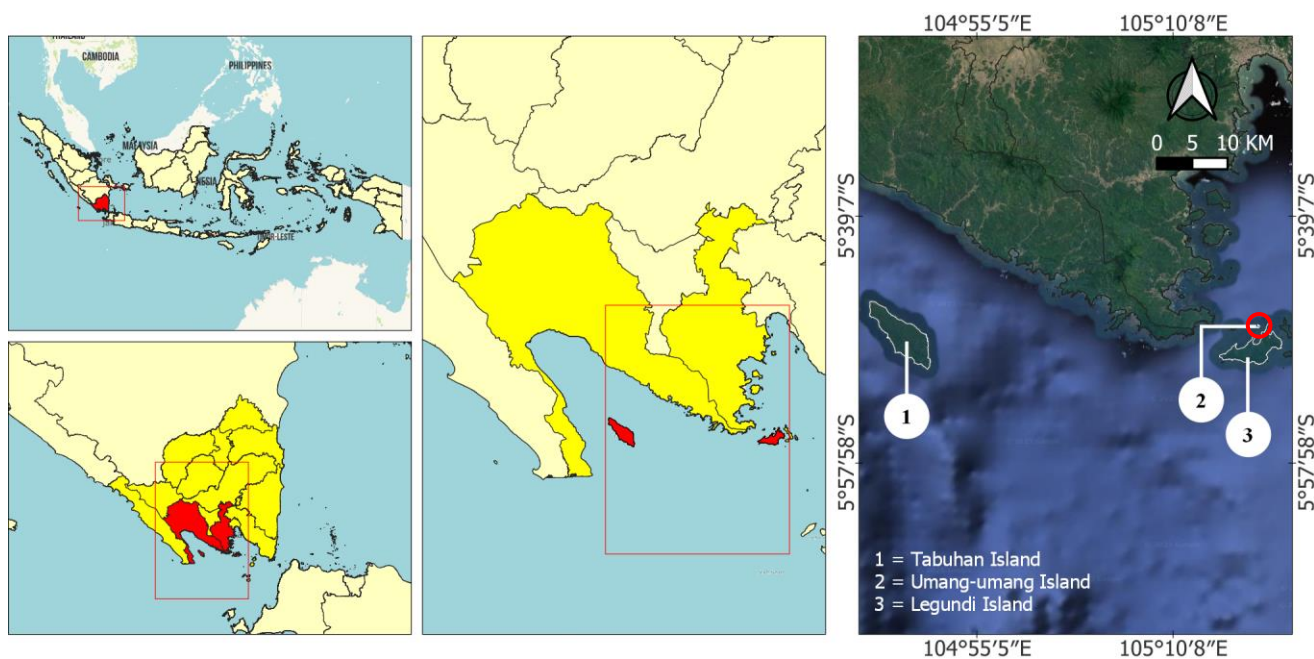


Figure 1. Location of (1) Tabuan, (2) Umang-Umang (red circle), and (3) Legundi Island in Tanggamus and Pesawaran, Lampung Province, Indonesia

The ecosystems of Tabuan, Legundi, and Umang-Umang Islands comprise coastal forest formations and lowland tropical forests, with vegetation ranging from sparse to dense. We conducted a land cover analysis utilizing Sentinel-2 satellite imagery, selected for its high spatial resolution (10-60 m) and comprehensive spectral coverage across 13 bands. Employing a supervised classification approach, we applied the Maximum Likelihood Classification (MLC) method, which is extensively used in remote sensing for its effectiveness in handling multispectral data and probabilistic decision-making framework (Furkuor et al. 2017). To validate our classification results, we collected and documented field coordinate points corresponding to various land cover types, serving as verification data. The analysis revealed that Tabuan Island features a topography varying from lowlands to elevations of up to 671 m above sea level dominated by secondary forest vegetation covering 2,078 ha (62% of the total island area). The remaining land use includes agroforestry (945 ha), open areas (213 ha), and residential zones (92 ha). Legundi Island has a maximum elevation of 300 m above sea level and is predominantly covered by secondary forest (1,243 ha, 65%). Other land uses include agroforestry (305 ha), open land (131 ha), and settlements (229 ha). In contrast, Umang-Umang Island has a sloping topography, with land cover entirely consisting of secondary forest across its 9.6-ha area.

Data collection

We ensured that no LTM were captured, handled, or harmed during our research on Tabuan Island, Legundi Island, and Umang-umang Island. Data collection took place from 25 April to 4 May 2024 and involved multiple research groups working across the three islands under study. Each research group standardized their methodologies for one month prior to the study. The standardization process encompassed methodological discussions, simulations of population structure differentiation, and simulations of LTM observation in the forest surrounding Bandar Lampung during the preceding week. The research employed three distinct data collection methods: i) Investigation of the introduction and management history of long-tailed macaque breeding on Umang-Umang Island, as well as their migration processes to Legundi Island; ii) Estimation of long-tailed macaque density and population on the three islands; iii) Mapping the distribution and population structure of LTM on each island.

Population origin

A comprehensive literature review was conducted to examine the population history of LTM on each island. This review incorporated a wide range of sources, including peer-reviewed scientific papers, gray literature and national regulation, which are recognized as valuable resources for conservation research (Haddaway and Bayliss 2015). The process of literature collection was conducted utilizing the Publish or Perish (PoP) application (Harzing 2011) in conjunction with manual internet searches. The primary research databases employed in this study were Google Scholar and Scopus. The search procedure was executed

within the "title words" section, incorporating the keywords "monyet ekor panjang", "long-tailed macaque", "*Macaca fascicularis*", "Tabuhan", "Tabuan", "Legundi" and "Umang-Umang." The retrieved search results were subsequently stored in .csv file format and later converted into .xls format for further analysis. To further validate the population history of LTM at these sites, interviews were conducted with local communities.

Population and density estimation

Observations were conducted using the line transect/perpendicular distance method (Figure 2) and the concentration count method. The line transect method, incorporating perpendicular distance measurements, is one of the most widely used techniques for estimating the density and population size of primate species (Buckland et al. 2015). The width of the transect path was determined based on the perpendicular distance between the target primates and the transect line (Fitriana et al. 2024). LTM were counted and recorded during each visually confirmed encounter along the transect line. To minimize the likelihood of double counting, observation periods were carried out simultaneously by 3-4 teams on separate observation trails. Each team, consisting of 2-4 individuals, traversed the trails at an average speed of 1.6 km/h (Glennie et al. 2021).

To enhance the precision of data collection and mitigate the risk of duplicate counts, individuals of LTM were systematically recorded only when observed within the forward line of sight of the observer. Individuals located behind the observer or within previously surveyed areas were deliberately excluded from the dataset. This methodological approach was carefully designed to minimize redundancy and ensure that each individual was counted only once, thereby improving the reliability of population estimates and reducing observational bias in areas with overlapping survey zones. Additionally, the direction of macaque movement was recorded to prevent double counting caused by individuals crossing the observer's path (Buckland et al. 2015; Fitriana et al. 2024). Data collected included the number of individuals, transect length, angle and distance of encounters, age class, sex, and observed activity of the macaques. Observations were conducted twice daily: in the morning within 06.00 to 10.00 and the afternoon (within 14.00-18.00), aligning with the solar activity patterns in the southern region of Sumatra. Each morning and afternoon session constituted one daily observation unit. Observations on each transect were repeated over two consecutive days to ensure data consistency and to confirm the number of groups and individuals within each group.

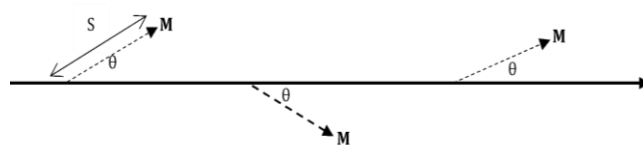


Figure 2. Illustration of the observation path. M: encountered point of LTM; S: observer to animal distance, θ : animal encounter angle

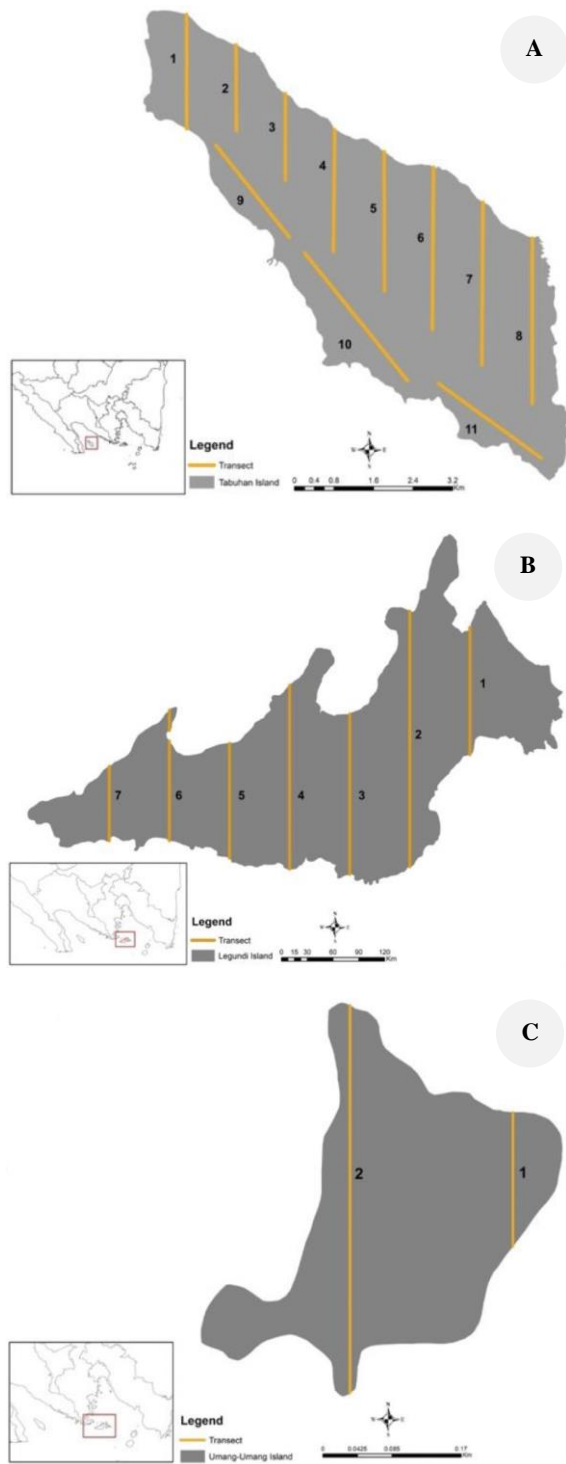


Figure 3. Survey transects. A. Tabuan; B. Legundi; C. Umang-umang islands, Lampung Province, Indonesia

Transects were systematically designed based on the established home range of LTM on the main islands, which spans approximately 1 km in radius (Fitriana et al. 2024). This informed the spatial arrangement of the survey, ensuring a uniform 1 km distance between transects to optimize coverage while minimizing redundancy. Initially, 11 transects were delineated on Tabuan Island, extending along a north-to-south gradient to capture a wide spatial

distribution of the habitat (Figure 3.A). However, steep topography in the southern region rendered the endpoints of transects 2 through 8 inaccessible, resulting in gaps in observational data for this area. To address this limitation, three additional transects were established to overcome these logistical challenges and provide a more comprehensive survey of the island's macaque population.

On Legundi Island, seven transects were established, following a strategic layout similar to that on Tabuan Island to maximize habitat coverage (Figure 3.B). In contrast, the smaller size of Umang-Umang Island required the establishment of only two transects, proportionate to its geographic scale and logistical feasibility (Figure 3.C). Across all three islands, the cumulative transect length totaled 43.42 km, distributed as follows: 26.16 km on Tabuan Island, 16.66 km on Legundi Island, and 0.6 km on Umang-Umang Island. This transect facilitated systematic monitoring while addressing the distinct topographical and spatial constraints of each island, ensuring robust and representative data collection.

The observational data collected during the survey were systematically analyzed to estimate population density and total population size. To enhance data reliability and mitigate overestimation, a comprehensive data-cleaning protocol was implemented to address potential double counting, particularly from repeated coverage of transect routes (Buckland et al. 2015). This process involved a rigorous evaluation of recorded group encounters to identify duplicates that could result from observing the same groups at different locations or times. Duplicate records were identified by overlaying spatial data of encounter points, focusing on their proximity (Fitriana et al. 2024).

Encounters occurring within a predefined radius of 300 m were classified as likely representing the same group. To refine the dataset further, the record with the highest number of observed group members was selected from overlapping points to ensure the most complete observation was retained. This approach minimized redundancy while maintaining the accuracy of the group data. The delineation process also incorporated ecological assumptions regarding group stability and territorial behavior, with the 300 m threshold informed by knowledge of group movement patterns and home range overlap for the species. This methodology provided a systematic framework for reducing duplication while preserving the integrity of the dataset, enabling robust statistical analysis. As a result, the final dataset supported more precise population parameter estimates, offering a reliable basis for understanding population dynamics within the surveyed areas.

Distribution and population structure

We systematically recorded the geographic coordinates and land cover types at each sighting of LTM across the island to facilitate an assessment of their spatial distribution. These sighting points were subsequently overlaid onto a pre-existing land cover map developed as part of the study. This spatial analysis enabled a comparison of macaque sightings across various land cover types, offering valuable insights into their habitat preferences. Specifically, the analysis allowed for the identification of land cover types,

such as forested areas, agricultural zones, or urban environments that were more frequently associated with macaque presence (Fitriana et al. 2024).

To complement this spatial analysis, concentrated observation methods were employed at strategically selected locations with a high likelihood of frequent macaque encounters. These locations were chosen based on the assumption that certain areas have a higher concentration of macaques (Putri et al. 2024). During these sessions, all visually observable macaques within the designated observation area were systematically enumerated and recorded. This approach allowed for precise estimates of population parameters, including group sizes, social interactions, and, where possible, age and sex distributions within observed groups. The integration of concentrated observation data with geographic and habitat information provided a comprehensive understanding of the behavioral ecology and population structure of LTM. This combined methodology offered robust insights into their habitat preferences, group dynamics, and distribution patterns across the island's diverse land cover types.

Data analysis

Population origin

A critical review of authoritative literature forms the foundational framework for understanding the origins and establishment of LTM populations in the investigated regions. These scholarly resources, including peer-reviewed journals, thesis research, national policies, and regulatory frameworks, span diverse domains such as ecology, behavior, and conservation. Collectively, they provide essential insights into the historical and ecological factors that have shaped the distribution and behavior of LTM. By conducting a descriptive analysis of these sources, we derived a comprehensive understanding of how environmental conditions, such as habitat availability and resource distribution, have influenced macaque populations in the study area.

The findings from this literature review were integrated with empirical data on species richness and the spatial distribution of macaques across various regions. This comparative approach facilitated the identification of correlations between observed patterns of macaque sightings and key ecological variables, including land cover types, habitat fragmentation, and anthropogenic impacts. This integrative analysis enabled a more nuanced interpretation of how macaques have adapted to different environments over time and the factors contributing to their persistence in diverse landscapes (Fitriana et al. 2024). The convergence of insights from both literature and empirical data provides a robust framework for understanding the dynamics of LTM populations. This framework elucidates their ecological requirements, adaptive strategies, and the broader environmental factors governing their distribution and long-term survival.

Population and density estimation

Following the data cleaning process, a comprehensive analysis of population density was conducted for each island. Population density estimates were then interpolated

across the total area of each island to derive precise estimates of the LTM population. The methodology for calculating population density per unit area is outlined in the formula below, offering a rigorous framework for understanding the estimation process (Buckland et al. 2015).

Observation plot width:

$$Lt = \frac{j_1 + j_2 + j_3 + j_4 + \dots + j_n}{n}$$

$$j = S \times \sin \theta$$

Where,

- Lt : transect width
- j : distance
- n : number n...
- S : observer to wildlife distance
- θ : animal angle

Density:

$$K = \frac{N}{L}$$

Where,

- K : density
- N : individual number
- L : plot area
- Lt : transect width
- j : distance

Distribution and population structure

Population structure analysis was conducted by categorizing individuals into age classes and sexes, including: adult females (distinguished by larger body size, with some observed parenting young), young (offspring being parented by adult females), and juveniles (smaller in size compared to adults but independent) (Li et al. 2022). Sex differentiation was determined based on observable characteristics, including physical appearance and the presence of scrotum for males and nipples for females (Fitriana et al. 2024). The analysis of population structure involved comparing the proportions of individuals within each age class and sex category. The results, including the total number of individuals, their distribution across age classes, and sex ratios, are presented in a descriptive quantitative format to provide a clear understanding of the population dynamics.

RESULTS AND DISCUSSION

Population origins

The LTM population on Tabuan Island is an isolated native group, genetically distinct from its closest neighbors on Sumatra Island. According to Perwitasari-Farajallah et al. (2001), the LTM population on Tabuan Island exhibits genetic differences compared to the nearest populations on Sumatra. In contrast, the populations on Umang-Umang and Legundi Islands were introduced from Sumatra (SK Dirjen PHKA Nomor 08/IV/Set-3/2005). In 1996,

approximately 200 LTM were introduced to Umang-Umang Island to establish an island breeding colony (SK Dirjen 22/Kpts/DJ-VI/1993; PHKA, 2005). This breeding program was officially recognized by the Indonesian Government under Law No. 5 of 1990 on the Conservation of Living Natural Resources and Ecosystems and Government Regulation No. 8 of 1999 on the Utilization of Plant and Animal Species. By 2005-2006, LTM populations had been observed in several groups on Legundi Island. Their presence is believed to have resulted from individuals crossing the 730-m strait separating Legundi from Umang-Umang Island. This movement is plausible, as LTM and other members of the *Macaca* genus are known for their ability to swim. However, this distance is notably greater than previously recorded swimming ranges, which have been documented at approximately 200 m (Yao et al. 2020; Han 2021).

The migration of the LTM population from Umang-Umang Island to Legundi Island, separated by approximately 730 m, is hypothesized to result from a combination of ecological and physiological factors. Previous studies emphasize the importance of active foraging strategies in macaques to meet the energetic demands essential for group cohesion and reproduction (Touitou et al. 2021; Zhang et al. 2022). On Umang-Umang Island, the availability of food resources is severely constrained by the dominance of mantangan (*Merremia peltata*) vegetation and secondary forests primarily composed of saplings, which provide limited foraging opportunities and low caloric yields. The island's small spatial extent further restricts the macaques' ranging behavior, limiting access to diverse and sufficient food resources. These challenges are compounded by a scarcity of freshwater sources, a critical factor influencing habitat utilization by LTM (Hansen et al. 2020). Collectively, these ecological limitations likely disrupted normal reproductive cycles and posed significant threats to population viability. Such pressures may have driven the migration of macaques in search of more favorable habitats on Legundi Island, which could better support their ecological and physiological needs.

From an ecological perspective, LTM are characterized by dietary plasticity and behavioral flexibility, traits that enable them to adapt to a wide range of environmental conditions (Luncz et al. 2017; Tee et al. 2019; Osman et al. 2022). The migration to Legundi Island, where ecological conditions are more favorable, can therefore be interpreted as an adaptive response to environmental stressors on Umang-Umang Island. Legundi Island offers a more consistent supply of food and freshwater, as well as a larger area for foraging and social interactions factors critical for maintaining group cohesion and promoting reproductive success (Girard-Buttoz et al. 2015; Ruslin et al. 2019). This observed migration aligns with ecological theories of habitat selection, which suggest that individuals will relocate to optimize access to essential resources when environmental pressures surpass critical thresholds (Otani et al. 2020; Effendy et al. 2024).

Behavioral studies on LTM reveal that their high adaptability to novel habitats and food sources has been a key factor in their evolutionary success. Luncz et al. (2017)

observed that LTM can incorporate new food items, including anthropogenic and plantation-derived resources, into their diets within a relatively short timescale, often under 15 years. This behavioral plasticity not only facilitates rapid acclimatization to new ecological conditions but also enhances their ability to exploit diverse habitats, from natural forests to heavily modified human landscapes. Additionally, their foraging strategies are underpinned by advanced cognitive abilities, such as social learning and problem-solving. These skills enable LTM to efficiently identify and utilize novel resources, further supporting their adaptability and survival in changing environments.

The resilience of LTM populations is further reinforced by their ability to utilize "elastic" food resources, as described by Sari et al. (2023). Elastic resources, which exhibit seasonal or spatial variability, act as a critical buffer against ecological unpredictability. This dietary flexibility, characterized by the capacity to shift between primary and supplementary food sources, ensures stability in energy intake even under fluctuating environmental conditions. This adaptability has positioned LTM as one of the most ecologically successful primate species, thriving in a wide range of habitats, from isolated islands to urban peripheries. The migration to Legundi Island can therefore be viewed not only as a survival strategy but also as a demonstration of the intrinsic flexibility and resilience that underpin their ecological success.

Population and density estimation

A total of 68 encounters with LTM were documented across all observed transects. After eliminating potential duplicate counts, 44 distinct sightings were confirmed during the observation period. The number of individuals recorded at each encounter ranged from 1 to 34, with an average group size of 8.5 individuals. LTM were consistently observed along every transect, indicating that they are distributed across the entirety of Tabuan Island. Their dominant distribution was observed at the ecotone between secondary forests and community plantations. On Legundi Island, 16 sightings of LTM groups were documented. The group sizes ranged from 9 to 36 individuals, with an average group size of 19.8 individuals. LTM on this island showed a preference for vegetation in the vicinity of community plantations, particularly in the northeastern part of the island, which is a concentration of agricultural activity. This behavior aligns with previous studies noting the high adaptability of LTM and their tendency to prefer areas near human activities (Hambali et al. 2014; Schurer et al. 2019; Entezami et al. 2024). However, this preference has led to frequent human-wildlife conflicts, with LTM often being shot due to their perceived interference with agricultural activities. On Umang-Umang Island, only one encounter was documented, consisting of a single adult or a small group of 10-20 individuals. This observation aligns with information from local fishermen who frequently visit the area, reporting that LTM are rarely seen on this island. The LTM observed on Umang-Umang Island likely represent the remaining members of a group that migrated to Legundi Island.

Group sizes of LTM observed on the islands ranged from 1 to 36 individuals, with a mean group size of 12. These group sizes are relatively small compared to findings from mainland populations. For example, studies in western Sumatra reported group sizes ranging from 10-68 individuals, with a mean of 57.3 (Ilham et al. 2017). In Jambi Province, group sizes ranged from 20-30 individuals, with a mean of 25.5 (Putri et al. 2024). In West Java, groups consisted of 26 and 38 individuals (Hartati et al. 2023), while Baluran National Park in East Java recorded an average group size of 89 individuals (Hansen et al. 2019). Other studies have documented even larger group sizes, with up to 100 individuals per group (Luncz et al. 2017; Tee et al. 2019). Notably, Boonkusol et al. (2018) reported group sizes reaching as many as 700 individuals in Lopburi Province, Thailand. In contrast, findings from smaller islands generally report smaller group sizes. For instance, Deli Island recorded group sizes of 3-46 individuals, with a mean of 10.29 (Fitriana et al. 2024). Similarly, Kalao Island and Bonerate Island in South Sulawesi reported group sizes ranging from 1-46 individuals, commonly consisting of 5-23 individuals per group (Fitriana et al. 2024). On Flores Island, group sizes in Kelimutu National Park ranged from 5-50 individuals, with a mean of 22.66 (Fauzi et al. 2020). However, some exceptions have been noted; for example, Perwitasari-Farajallah et al. (2023) documented a large mean group size of 40.6 individuals on Tinjil Island, with a total of 627.38 ± 23.53 individuals across 16 groups.

The distribution of LTM on Tabuan Island appears more evenly spread compared to Legundi Island, where populations are clustered around agricultural areas. Tabuan Island's more natural habitat aligns with the species' behavior, which tends to be more sensitive to human presence. Observations were constrained by the LTM heightened sensitivity and the dense vegetation, which limited the detection of individuals in each group. LTM are particularly responsive to perceived threats from humans, often exhibiting avoidance behaviors (Avenzora et al. 2023; Fitriana et al. 2024). The population structure of LTM on Tabuan Island was not comprehensively identified due to these constraints. Of the total 6,367 individuals observed, only 45% were categorized by age class, consisting of 28% adults, 7% juveniles, and 5% infants. Additionally, only 15% of the observed population was identified by sex, with males comprising 11% and females 4%, leaving the remaining 85% unidentified. Similar challenges were encountered on Deli Island, where the dense habitat and LTM sensitivity also hindered thorough population structure analysis (Fitriana et al. 2024). In contrast, the population structure of LTM on Legundi Island was relatively easier to observe, likely due to their frequent interactions with the local community. Observations revealed that the groups on Legundi Island consisted of 52% adults, 32% juveniles, and 16% infants. These differences highlight the influence of habitat characteristics and human interaction.

Distribution and population structure

Tabuan Island, the largest of the three islands, spans 3,328 ha and hosts a natural population of LTM. In contrast, Legundi Island (1,908 ha) and Umang-Umang Island (9.6 ha) are inhabited by introduced LTM populations. The estimated population densities of LTM on Tabuan and Legundi Islands are relatively similar, at 1.96 individuals per ha and 1.79 individuals per ha, respectively. In comparison, the population density on Umang-Umang Island is significantly lower, at 0.11 individuals per ha. Based on these densities, the total LTM population is estimated at 6,523 individuals (number of variances: 1189.7) on Tabuan Island, 3,415 (var: 512.8) individuals on Legundi Island, and fewer than 10 individuals on Umang-Umang Island. Population estimation studies on other islands have yielded similar findings. For instance, Tinjil Island is estimated to host 627.38 ± 23.53 individuals, while Deli Island, Kalao Island, and Bonerate Island are estimated to host 4,860, 1,064, and 618 individuals, respectively (Nasri et al. 2023; Perwitasari-Farajallah et al. 2023; Fitriana et al. 2024). The high population on Tabuan Island is likely supported by the availability of natural food resources, which sustain the island's native LTM population. Legundi Island, like Deli Island, has an introduced LTM population. Over the past 20 years, the LTM population on Legundi Island has steadily grown, originating from the introduction of 200 individuals from Umang-Umang Island. The number of individuals per group varied across islands, with group sizes ranging from 1-34 individuals per sighting.

According to distribution mapping (Figure 4), LTM with larger populations are typically found near areas of high human activity, such as villages, agricultural plots, or fishermen's huts. LTM were predominantly observed in forested habitats, with group sizes ranging from 1-20 individuals (represented by red and yellow points). In contrast, larger groups exceeding 20 individuals (represented by blue and orange points) were primarily located along the island's periphery, within 0-750 m of the coast, where human settlements and agricultural activities are concentrated. These findings suggest that LTM exhibit a preference for areas associated with high anthropogenic activity, such as plantations, on both natural (Tabuan) and introduced (Legundi) Islands. On Tabuan Island, this distribution reflects the species' attraction to areas with abundant food resources and human-related activities. Similarly, on Legundi Island, the observed distribution indicates a strong interaction between LTM and agricultural areas. On Umang-Umang Island, which lacks permanent community settlements or plantations due to its management by a private entity (Pers. Comm.; SK Dirjen 22/Kpts/DJ-VI/1993; PHKA, 2005), a different pattern was observed. Although no permanent human activity occurs, the island is frequently used as a fishing ground by the local community, particularly along the beach with the most extensive sandy area. Notably, this beach coincides with the location of the sole LTM group identified on the island.

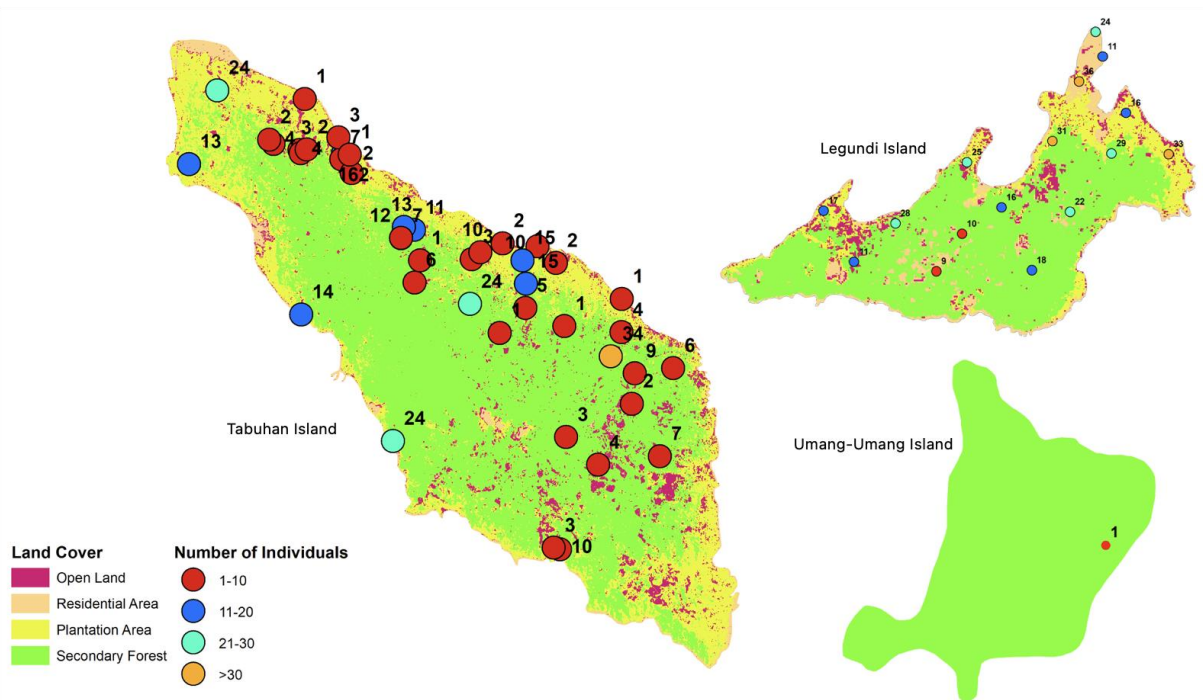


Figure 4. Distribution of LTM in Tabuan, Legundi, and Umang-Umang Island, Lampung Province, Indonesia

Several studies have consistently demonstrated that LTM tend to gravitate towards areas characterized by high levels of human activity (Brotcorne et al. 2015; Boonkusol et al. 2018). The population size and distribution of LTM are significantly influenced by anthropogenic factors, including habitat modification, urbanization, and direct interactions with humans. In regions undergoing urban expansion, such as tourist destinations in Malaysia and Thailand, LTM have been increasingly compelled to adapt their behavior for survival in human-dominated environments (Boonkusol et al. 2018; Entezemi et al. 2024). In these settings, LTM frequently exploit anthropogenic food sources, leading to significant alterations in their natural dietary patterns and social behaviors. This dependence on human-provided sustenance has been associated with changes in group dynamics, including a reduction in affiliative interactions and increased inactivity during periods of intense human presence (Ilham et al. 2017; Luncz et al. 2017; Entezami et al. 2024). For example, research by Cenni et al. (2023) demonstrated that LTM in Bali exhibited decreased foraging activity due to the consistent availability of anthropogenic food sources, highlighting the profound behavioral shifts induced by human interaction.

The presence of LTM in areas near human activities can be attributed to habitat loss or their preference for locations with high human activity, which often offer increased food availability (Moore et al. 2023; Fitriana et al. 2024). However, this proximity significantly heightens the potential for human-wildlife conflicts. If not addressed promptly, these conflicts could have detrimental effects on both human communities and macaque populations. To address this issue, comprehensive management strategies are urgently needed. Such strategies should aim to balance the

conservation of macaque populations with the mitigation of human-wildlife conflicts in shared landscapes, fostering a harmonious coexistence between humans and wildlife.

In conclusion, the estimated population of LTM across the three islands is approximately 9,948 individuals (var: 957.12), with more than 6,523 individuals residing on Tabuan Island. Our findings contribute to the existing body of knowledge, providing an update on the limited data that can inform LTM population management policies on small islands, particularly in the southeastern part of the island of Sumatra. While the LTM population on Tabuan Island generally tends to avoid human contact, some groups inhabit areas in or around community plantations, where they are often perceived as pests. Their presence near plantations and settlements leads to conflicts, as they consume fruits and agricultural products. In response, local residents attempt to deter them, sometimes resorting to the use of air rifles.

These conflicts are likely driven by the increasing population of LTM and the concurrent decline in habitat area and quality. These findings underscore the urgent need for strategies to systematically collect data on the distribution and spatial patterns of LTM, as well as the nature and extent of conflicts with local communities. We recommend investigating the origins of the LTM populations on Legundi and Umang-Umang Islands to evaluate the outcomes of the island breeding colony program and to inform future conservation initiatives for this species. In particular, periodic assessments of food availability on each island are essential to determine the environmental carrying capacity and monitor population trends over time. These efforts will be critical for ensuring sustainable management and conservation of LTM populations.

ACKNOWLEDGEMENTS

We extend our sincere gratitude to all parties who contributed to the success of this research. We are particularly grateful to the Biosystematics and Evolution Research Centre (National Research and Innovation Agency/BRIN), BKSDA Lampung-Bengkulu, ITERA, and the communities of Tabuan and Legundi Islands for their invaluable support and collaboration. Special thanks also go to CV Universal Fauna and the Indonesian Biology Society for their assistance in organizing survey funding. Finally, we acknowledge the contributions of many other individuals and organizations whose support, discussions, and coordination were essential to the completion of this research.

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