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Distribution and estimation of economic losses due to long-tailed macaque in the sago agroindustry in Lingga District, Riau Islands, Indonesia

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Abstract. *Prameswari AS, Masy'ud B, Zuhud EAM, Al Manar P. 2025. Distribution and estimation of economic losses due to long-tailed macaque in the sago agroindustry in Lingga District, Riau Islands, Indonesia. Biodiversitas 26: 5385-5394.* The long-tailed macaque (*Macaca fascicularis*) is an opportunistic primate that frequently interacts with community-based agricultural systems, including the sago agroindustry in Lingga District, Riau Islands, Indonesia. Such interactions can cause material losses and threaten the sustainability of local livelihoods. This study aimed to analyze the population distribution, age structure, and economic impact of sago log damage caused by macaques. Field surveys were conducted using line transects, spatial analysis using ArcGIS 10.8, and structured interviews with sago farmers. The results recorded 18 groups comprising 116 individuals, with an average population density of 10.74 individuals/km². Sub-adults represented the dominant age class, displaying the highest levels of foraging and social activity, which increased their contact with stored sago logs. The average log damage reached 11,860.63±1,519.95 cm³ (9.56±1.22%), corresponding to a starch loss of 1.61±0.26 kg per log and annual economic losses of approximately IDR 22.7±3.6 million. Although local communities employ traditional deterrents, such as covering sago logs with sea sand and sago fronds, their effectiveness remains limited owing to inconsistent application and high labor requirements. This study provides one of the first empirical estimates of wildlife-induced post-harvest losses in the sago sector and highlights the need for integrated mitigation strategies that combine traditional ecological knowledge with scientific approaches, including physical barriers, habitat management, and buffer crop planting. Such integrative, community-based management is essential to minimize economic losses, mitigate human-wildlife conflict, and enhance the long-term sustainability of the sago-based agroindustry.

Keywords: Conflict mitigation, *Macaca fascicularis*, *Metroxylon sagu,* sustainability, wildlife

INTRODUCTION

Sago (*Metroxylon sagu*) is a carbohydrate-rich palm of the Arecaceae family that grows widely in Southeast Asia, particularly in Indonesia, Malaysia, the Philippines, and Papua New Guinea (Naim et al. 2016; Al Manar et al. 2023). Adapted to wetlands, peatlands, and marginal soils unsuitable for other crops, sago is recognized as a resilient food resource under conditions of land limitation and climate variability (Asano et al. 2021; Azhar et al. 2022; Sasaki et al. 2025). In Indonesia, it is cultivated in many provinces, with Papua serving as the main production center (Bintoro et al. 2018). Beyond its role as a staple food, sago also provides raw materials for the food, feed, bioethanol, and bioplastic industries, supporting food diversification and sustainable development (Karim et al. 2021).

Lingga District, Riau Islands Province, Indonesia, has a long tradition of sago utilization and is one of the regions with a significant local distribution (Al Manar et al. 2023). As both a staple food and an economically valuable commodity, sago supports food security and coastal livelihoods. However, its agroindustry remains underdeveloped owing to sub-intensive cultivation, rudimentary post-harvest technology, and limited product diversification. Measuring starch yield and agronomic parameters is essential for evaluating productivity and potential losses in the production chain (Chua et al. 2021). Among the various limiting factors, wildlife disturbance, especially by long-tailed macaques (*Macaca fascicularis*), is often overlooked despite its potential to reduce starch quality, quantity, and processing efficiency (Sha and Hanya 2013; Rifaie et al. 2024). In Lingga, a major threat comes from long-tailed macaques, opportunistic foragers widely reported in Southeast Asia that exploit crops and post-harvest resources when natural food is scarce. This behavior indicates that sago-based agroecosystems are particularly vulnerable to macaque interference not only during cultivation but also at the post-harvest stage, posing both ecological and economic risks to sustainable production.

Regionally, studies on *M. fascicularis* show two major dimensions of impact: ecological and economic. Ecologically, frequent incursions into croplands near forest edges demonstrate spatial overlap between macaque habitats and agricultural zones, contributing to habitat fragmentation and conflict (Kuswanda et al. 2023; Rifaie et al. 2024). Economically, crop-raiding behavior leads to measurable losses such as reduced yields and damaged produce, similar to observations in Sri Lanka (Jayarathne et al. 2025) and Nepal (Koirala et al. 2021), where primate activity caused income reductions of up to 4.2% of household crop earnings. These examples underline that even seemingly minor wildlife interference can have significant economic consequences, particularly for high-value or small-scale commodities.

The main challenge facing the development of the sago agroindustry in the Lingga District is pest infestation by *M. fascicularis*, which feeds on sago stalks after harvest. This condition not only causes the loss of sago starch, which can be processed into valuable products, but also reduces the quality of the raw materials entering the production chain. The impact of these losses ultimately leads to reduced income for sago processing communities and hampers the development of a locally resource-based agroindustry. Despite extensive reports of crop raiding by *M. fascicularis* in other regions, there remains a lack of empirical data on the spatial distribution of macaque populations and the magnitude of their economic impact on sago processing systems in the Lingga District. Addressing this knowledge gap is essential for developing effective pest mitigation strategies and designing sustainable management policies tailored to the local socio-ecological context. Therefore, this study aimed to analyze the population distribution, age structure, and economic impact of *M. fascicularis* in the sago agroindustrial area of the Lingga District. It has been hypothesized that areas near forest edges and waterways have higher macaque encounter frequencies and greater post-harvest losses, reflecting a strong ecological-economic linkage between macaque activity and sago production.

MATERIALS AND METHODS

Study area

This study was conducted from July to August 2024 in Lingga District, Riau Islands Province, Indonesia (Figure 1). Lingga District, officially established in 2003 through Law No. 31/2003, is geographically located between 0°20'N-0°40'S and 104°-105°E. The region is bordered by Batam City and the North Natuna Sea to the north, the Bangka Sea and Berhala Strait to the south, Indragiri Hilir to the west, and the North Natuna Sea to the east. Lingga has a humid tropical climate with an average annual rainfall of 244.1 mm in 2024, and its topography is dominated by steep slopes, with more than 76.9% of the area having gradients above 15% (Lingga District Central Statistics Agency 2024).

Data collection

Research data were collected through in-depth interviews, participant observation, and direct field observations. In-depth interviews were conducted to gather information on community experiences, perceptions, and adaptation strategies to *M. fascicularis* disturbances, while participant observation provided a contexlog understanding of farmers' interactions with their environment. Direct observations using the line transect method were conducted to record the presence, activity, and intensity of macaque disturbances in sago plantations, and to map the distribution patterns of these animals. In each of the six study villages, a 2 km transect line was established and surveyed three times to ensure replication and minimize spatial bias.

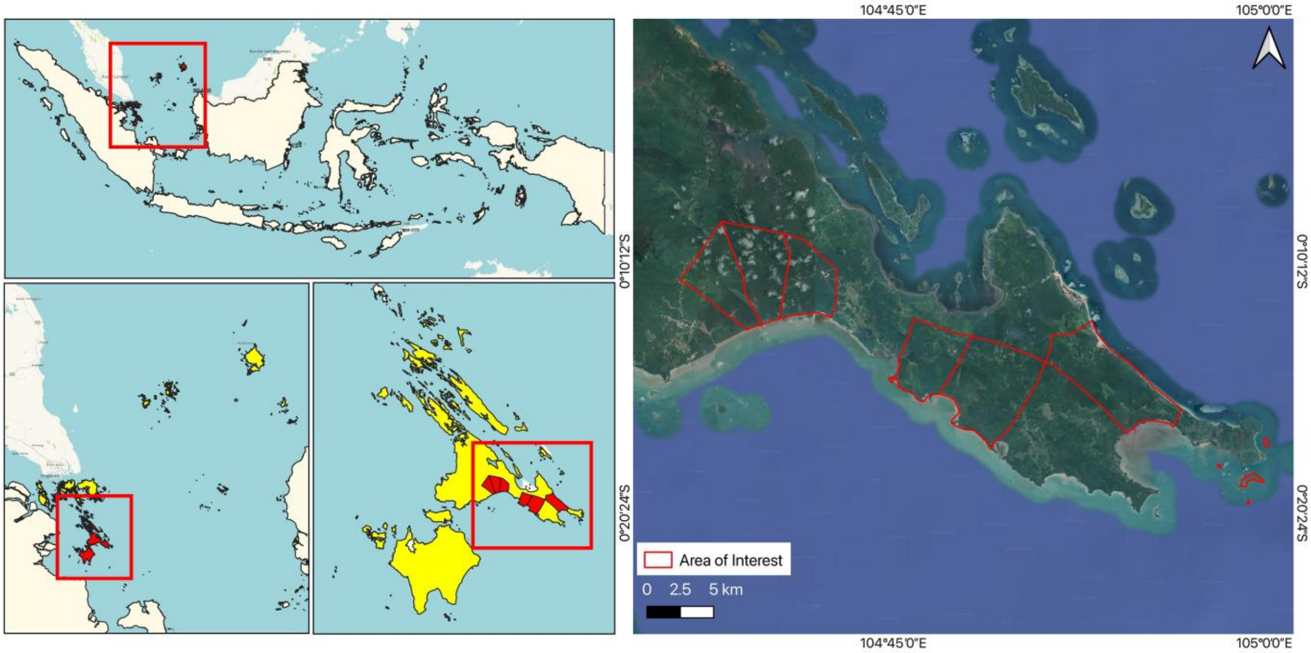

Figure 1. Study site location in Lingga District, Riau Islands Province, Indonesia

Along each transect, all sightings of *M. fascicularis* were recorded, including group size, activity, and GPS coordinates, which were later processed in ArcGIS 10.8 to produce a spatial distribution map of the species. The line transect method is widely used in wildlife ecology because it can provide accurate estimates of population distribution and density within an area (Thomas et al. 2010; Buckland et al. 2015). The transect locations were purposively selected in sago-producing villages with known macaque activity and surveyed only during the dry season owing to logistical constraints. As such, the results represent an exploratory baseline of *M. fascicularis* distribution and activity rather than a definitive population estimate.

The estimation of losses to the sago agroindustry caused by *M. fascicularis* was conducted through in-depth interviews with agroindustry owners across six sago-producing villages in the Lingga District. A total of 89 respondents, all of whom were directly involved in the sago agroindustry as owners or workers of small-scale sago processing units, were interviewed using a purposive sampling approach to ensure that they possessed firsthand experiences of macaque disturbance and economic loss. The respondents provided information on the extent of sago damage, macaque attack frequency, and the corresponding economic value lost due to starch reduction or log damage. These data were analyzed to estimate potential annual economic losses, forming the basis for developing pest mitigation strategies and sustainable management practices. To strengthen the validity of the interview results, direct field measurements of damaged sago logs were also performed. The damage volume was calculated by measuring the dimensions of the cavities or missing sections on each log and comparing them with the total log volume. This dual approach ensured that loss estimates reflected not only respondents' perceptions but also direct physical evidence of loss. The integration of social and ecological methods is considered effective in human-wildlife conflict research, as it combines quantitative data on species distribution with qualitative insights into the socioeconomic impacts experienced by local communities (Redpath et al. 2013).

Data analysis

Data related to the distribution of *M. fascicularis* obtained from the coordinate points of encounters in the field were then processed using ArcGIS 10.8 software. The results are presented in the form of a distribution map that visualizes the spatial distribution of *M. fascicularis* in the sago agroindustrial area of the Lingga District. This spatial analysis was combined with a qualitative descriptive approach to provide an understanding of the distribution patterns and potential interactions between animals and sago plantation areas. Next, the population density of *M. fascicularis* was calculated and analyzed descriptively and qualitatively using the basic population density formula:

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

Where: D: population density (individuals/ha), N: number of individuals observed, A: area of observation (ha).

Population density was estimated using a simple encounter-based formula (D = N/A) as an initial approximation, acknowledging that the detection probability was not corrected through distance sampling due to logistical constraints. Thus, the density values should be considered indicative rather than absolute. Future research employing distance sampling or camera-based detection is recommended to obtain more robust estimates. This method is widely used in wildlife ecology studies because it is relatively simple and provides an initial overview of the distribution and density of the target species (Thomas et al. 2010; Buckland et al. 2015). The integration of spatial analysis with a population density approach is expected to produce comprehensive information regarding the level of *M. fascicularis* disturbance to the sago agroindustry, while also providing the basis for mitigation strategies. Furthermore, to statistically test whether population densities differed significantly among the six observation sites, a nonparametric Kruskal-Wallis test was performed using SPSS software (version 24). This test was selected because the dataset consisted of a single density value per location (n: 6), which did not meet the assumptions of normality and homogeneity required for parametric tests such as ANOVA. The Kruskal-Wallis test evaluates whether the median population densities across different locations differ significantly ($p<0.05$, indicating a significant difference).

Furthermore, identification of the age structure of *M. fascicularis* was also carried out to understand the composition of the population in the field. The determination of age classes was adapted from Napier and Napier (1967), with adjustments based on field-appropriate morphological traits that can be consistently observed under natural conditions. Infants (0-1.25 years) were recognized by their very small body size, pinkish facial skin, fine hair, unsteady locomotion, and strong dependence on their mothers. Juveniles (1.25-5 years) exhibited intermediate body size, darker facial coloration, denser fur, and more independent movement, often engaging in active play with peers. Sub-adults (5-10 years) were distinguished by their larger body size, elongated limbs, darker pelage, and facial morphology approaching adult form, although not yet fully developed. Adults (10-21 years) were characterized by the largest and most robust body size, fully developed fur and facial morphology, and clear sexual dimorphism, with males displaying broader shoulders and more prominent canine teeth. Information on age structure is important for providing an overview of population dynamics, growth potential, and its implications on the level of disturbance in sago plantations.

The estimated economic losses due to *M. fascicularis* damage to the sago agroindustry were calculated using several analytical steps. The first step was to determine the aclog percentage of sago damage, which was formulated as follows:

$$\text{Percentage of Damage (\%)} = \frac{\text{Damage log volume}}{\text{Intact log volume}} \times 100\%$$

The aclog damage level criteria for sago logs were divided into four categories: light damage (0-25%), moderate damage (25-50%), heavy damage (50-75%), and very heavy damage (75-100%). This percentage-based damage classification is a common approach in agro-ecological research, crop damage mapping, and post-disaster loss assessments, because it provides easily interpretable and comparable measurements across studies. Similar schemes have been validated and used in leaf damage/pest attack studies, yield loss measurements, and forest change severity maps (Toepfer et al. 2021; Wegmueller and Townsend 2021; Hu et al. 2022; Bhandari et al. 2023). Based on the damage percentage, potential starch loss was calculated using the following formula:

Potential Starch Loss (kg) = Starch Content per log × Percentage of Damage

The estimation of starch weight was based on the study by Al Manar et al. (2023), who previously assessed the starch content of sago palms in each of the study villages. Economic loss was calculated as the estimated starch loss per log multiplied by the total number of logs affected and the prevailing market price of sago starch. The attribution of damage to *M. fascicularis* was confirmed through direct field observations, including bite marks, feeding traces, and information from agroindustry workers. However, the absence of camera-trap validation and laboratory calibration between starch volume and weight introduces uncertainty into these estimates. Therefore, the calculated losses should be regarded as preliminary approximations that provide the first quantitative insight into the economic impact of macaque disturbance on the sago agroindustrial landscape. Next, the potential loss of starch was converted into an economic value by calculating the potential daily economic loss as follows:

Potential Economic Loss (IDR) = (Potential Starch Loss × Starch Product Price) × Number of Logs per Day × Production Intensity

Finally, to obtain a comprehensive picture, an estimate of annual economic losses was made considering total production, which is formulated as follows:

Estimated Annual Loss (IDR) = Potential Economic Loss × Production Amount per Year

This approach allows for more measurable loss calculations, both in terms of raw material loss in the form of sago starch and the economic value lost due to *M. fascicularis* attacks. The estimated economic losses provide a quantitative picture of the real impact of wildlife disturbances on sago agroindustry productivity, thereby providing a basis for determining the management priorities. This information also provides a crucial basis for formulating pest mitigation strategies, wildlife management, and sustainable sago agroindustry development policies in the Lingga District.

RESULTS AND DISCUSSION

Distribution and population of long-tailed macaques

Macaca fascicularis in Lingga District is distributed in various locations, including sago forests, post-harvest sago storage areas, rivers, and sago mill areas (Figure 2). Sago forests, dominated by *M. sagu*, *Alstonia scholaris*, and *Syzygium claviflorum*, serve as food sources and shelter for *M. fascicularis*. Rivers in the area are used not only as water sources and sago transportation routes, but also as shelters at night.

The distribution pattern of *M. fascicularis* across diverse habitat types indicates a high degree of ecological adaptability to human-modified environments. Previous studies have reported similar behavior, where *M. fascicularis* selects sleeping sites near rivers as a strategy to avoid predators (Brotcorne et al. 2014). Furthermore, the species' ability to exploit disturbed habitats and utilize available vegetation for food and shelter has been well documented (Osman et al. 2022), supporting observations from the Lingga region.

Recent research has shown that *M. fascicularis* prefers large trees with wide canopies to sleep, particularly in habitats that have been disturbed or modified by humans. Studies on northern pigtailed macaques (*Macaca leonina*) in degraded forests also revealed that sleeping site selection is strongly influenced by canopy height, stem density, and proximity to food sources. In habitats with limited availability of tall emergent trees, macaques often sleep in familiar areas with higher canopy cover and near feeding sites, suggesting that food accessibility and predator avoidance remain key determinants of sleeping site choice in human-modified environments (Gazagne et al. 2020).

Figure 2. Long-tailed macaque encounters: A. Sago forest, B. Post-harvest sago log storage location, C. Sago mill area

Furthermore, research on Sulawesi, Indonesia, crested macaques (*Macaca nigra*) also indicates that they prefer sleeping trees with larger trunk diameters and wider canopies than surrounding trees. These trees also serve as a food source, with 79% of the sleeping trees providing food. This optimal selection of sleeping trees is related to the need for protection from predators and extreme weather as well as for monitoring the surrounding environment (Qomariah et al. 2023).

A similar phenomenon can be observed in *M. fascicularis* in the sago agroindustry in Lingga District, where it is more active and sleeps in the sago forest. *Macaca fascicularis* is also found in the mangrove forest near the sago mill, with plant species such as *Rhizophora mucronata, Rhizophora stylosa*, and *Sonneratia alba* (Figure 3). This condition is likely associated with the declining availability of large-canopy trees that provide optimal sleeping sites for *M. fascicularis*. The reduction of these trees, primarily because of their use by local communities as building materials and the expansion of oil palm and other agricultural lands, has increased pressure on the species' natural habitat and subsequently influenced its behavior and distribution patterns.

Previous studies have shown that *M. fascicularis* exhibits high ecological flexibility in its choice of habitat and food sources. This aligns with the research by Hansen et al. (2020), which emphasized the ecological adaptability of *M. fascicularis* across a wide range of habitat types, from primary and secondary forests to mangroves and watersheds. This adaptability allows this species to thrive in diverse ecosystems, including areas experiencing anthropogenic pressure. This flexibility was further strengthened by the findings of Osman et al. (2022) through a metabarcoding analysis of *M. fascicularis* feces in disturbed habitats in Malaysia. This study identified over 800 plant species utilized as food, demonstrating the species' ability to explore available plant resources in fragmented habitat conditions. Similar findings were also reported by Wulandari et al. (2022) in South Sumatra, where *M. fascicularis* was able to carry out normal activities in plantation forests by utilizing vegetation such as *Acacia crassicarpa* and *Melaleuca cajuputi* as food sources and shelter.

Furthermore, recent research in Jambi by Putri et al. (2024) showed that *M. fascicularis* population density tends to be higher in habitats adjacent to rivers. These locations provide access to water, diverse vegetation, and opportunities to exploit additional food sources from human activities in riparian areas. This pattern confirms that rivers and their riparian habitats play a crucial role in supporting the sustainability of *M. fascicularis* populations, even amid increasingly intense environmental changes. The combined results of these studies demonstrate the high ecological adaptive capacity of *M. fascicularis*, which on the one hand supports the species' survival but increases the potential for negative interactions with human activities, including the sago agroindustry.

Based on these observations, *M. fascicularis* is frequently observed feeding on sago palms (Figure 4). Sago palms are a potential energy source because of their high starch content and chemical composition dominated by carbohydrates, which play key roles in energy metabolism. This makes the sago palms an attractive target for these animals, especially after harvest, when access to the pith of the trunk is more open.

Ecologically, *M. fascicularis* is considered primarily frugivorous, with fruits comprising the dominant component of its diet in natural habitats, although the species also exploits other available food items when fruit availability declines (Hasan et al. 2023). Although primarily frugivorous, this species is also an opportunistic omnivore that can utilize a variety of alternative food sources, such as young leaves, flowers, insects, and even small animals, especially during periods of fruit scarcity (Sha and Hanya 2013; Ruslin et al. 2019). This dietary flexibility demonstrates a high adaptive capacity, allowing it to survive in both disturbed ecosystems and cultivated areas. Consumption of the sago log can be understood as an adaptation to local resource availability, with the starch-rich pith of the sago palm serving as an energy reserve for *M. fascicularis*.

Figure 3. *Macaca fascicularis* in the mangrove forest around the sago mill

Figure 4. *Macaca fascicularis* is eating stored sago logs on the roadside in Lingga District, Riau Islands Province, Indonesia

Recent studies have also highlighted that the interaction of *Macaca* species with anthropogenic resources, such as agricultural crops and agroindustrial products, often increases when their natural habitat experiences fragmentation (Osman et al. 2022; Bindhani et al. 2025). Thus, the existence of post-harvest sago palms serves not only as an alternative food source but also as a potential trigger for conflict between humans and wildlife in sago production areas. Kim et al. (2024) showed that *Macaca* species have a preference for a plant-based diet, including fruits, but can also consume a variety of other food types depending on availability. Furthermore, Gombash et al. (2025) used metabarcoding to assess the diet of *M. fascicularis* in Southeast Asia and found that they consumed a wide variety of plants and small animals. Reinegger et al. (2023) also revealed that *M. fascicularis* has a flexible foraging strategy, adapting its diet to the availability of food sources in its environment. Distribution map of *M. fascicularis* in the sago area of the Lingga District (Figure 5).

The results showed 18 groups of *M. fascicularis* consisting of 116 individuals, with an average population density of 10.74 individuals/km² (Table 1). Population density varied among the six study sites, ranging from 4.44 individuals/km² in Keton Village to 16.11 individuals/km² in Musai Village. However, the Kruskal-Wallis test indicated that these differences were not statistically significant (H: 5.00, df: 5, p: 0.416).

Table 1. Population density of *Macaca fascicularis* in Lingga District, Riau Islands Province, Indonesia

Location	Total (individuals)				Total (individuals)	Population density (individuals/km^2)
	Infant	Juvenile	Sub-adult	Adult		
Panggak Laut	1	6	18	3	28	15.56
Nerekeh	1	8	12	5	26	14.44
Musai	1	7	14	7	29	16.11
Pekaka	0	0	8	7	15	8.33
Keton	0	0	6	2	8	4.44
Teluk	0	0	8	2	10	5.56
Total	3	21	66	26	116	
Mean±SD					19.33±8.14	10.74±4.83

Note: Values represent the total number of individuals observed per location. Mean±SD indicates the average population size and density across the six sites. The Kruskal-Wallis test showed no significant difference in population density among the sites (H: 5.00, df: 5, p: 0.416)

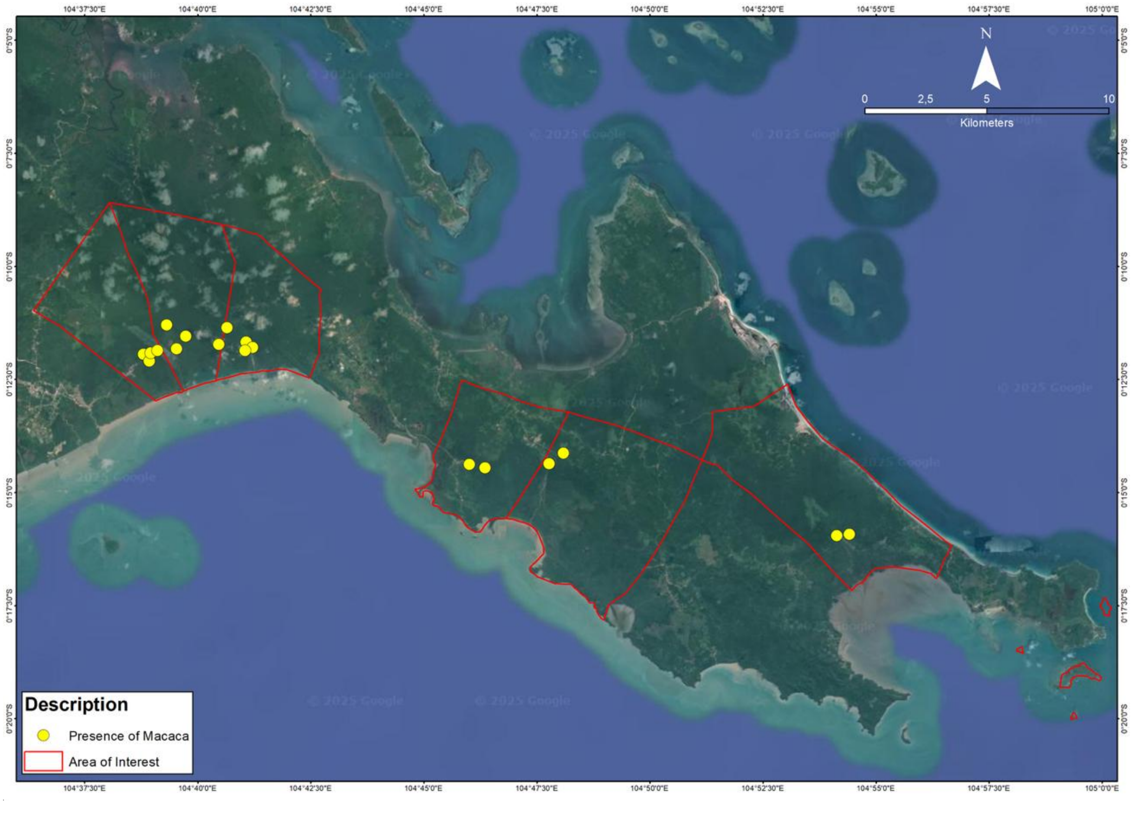

Figure 5. Distribution map of *Macaca fascicularis* in Lingga District, Riau Islands Province, Indonesia

Although the variation in population density among villages was statistically insignificant, the spatial differences likely reflected ecological contrasts, particularly in habitat quality, food availability, and proximity to human settlements. Similar patterns have been reported in other regions, where *M. fascicularis* density correlates with vegetation structure and the presence of anthropogenic food sources (Hansen et al. 2019; Perwitasari-Farajallah et al. 2022; Putri et al. 2024). In the Lingga region, this trend highlights the species' ecological flexibility and increasing dependence on human-modified habitats, especially post-harvest sago areas that provide abundant and accessible starch resources. Field data further revealed that sub-adults constituted the largest proportion of the population, exceeding other age classes. This demographic structure aligns with previous findings that sub-adults exhibit higher social activity and foraging behavior (Hanifa et al. 2023; Rianti et al. 2024). Their exploratory nature and mobility make them the most active foragers, and thus the main contributors to log damage. Behavioral observations in both captive and wild populations (Arianti and Salsabila 2024; Fitriani and Wijayanti 2024) have similarly demonstrated that sub-adults spend a greater share of their daily activity on feeding and movement, increasing the likelihood of contact with human resources.

Understanding this age-based interaction pattern has direct implications for management. Sub-adult dominance indicates a young and expanding population, which, if unmanaged, could intensify future damage rates. Targeted deterrent strategies, such as selective monitoring near high-risk zones, physical barriers, and habitat modification, should therefore prioritize areas with high sub-adult activity. This approach is more cost-efficient than general deterrence and aligns with ecological management principles that focus on the most active demographic groups (Velankar et al. 2024). Furthermore, a high proportion of sub-adults may signify robust reproductive potential, suggesting population growth if food and habitat conditions remain favorable. Consequently, mitigation measures must integrate ecological monitoring with community-based efforts to ensure a long-term balance between macaque populations and local livelihoods. In the context of the sago agroindustry, linking population ecology with socioeconomic management provides a realistic foundation for sustainable conflict mitigation in the Lingga District.

Estimated losses to the sago agroindustry due to long-tailed macaques

Measurements of sago palm damage in six villages within the sago agroindustry area showed an average damage volume of 11,860.63±1,519.95 cm^3 (9.56±1.22%), classified as light (Table 2). Despite this, the damage signifies a negative interaction between *M. fascicularis* and community agroindustrial activities. Each damaged log results in an average starch loss of 1.61 kg, determined by comparing the starch weight of intact and damaged logs using a wet-weight method with 0.01 g precision. Annually, the estimated economic loss in Lingga District reaches IDR 22.7±3.6 million. Although categorized as light, the cumulative impact is significant for smallholders processing 20-30 logs per month, equating to a 32-48 kg starch loss or a 5-10% income reduction, directly affecting household food security and cash flow.

While this figure may seem small in the context of a large industry, it is significant for household-scale agroindustries and farming groups that rely heavily on sago as their primary source of income. This loss can also increase farmers' workloads because of the need for additional effort in processing and securing raw materials. This finding aligns with previous studies showing that *M. fascicularis* often causes significant economic losses through crop raiding. As an opportunistic species, *M. fascicularis* utilizes cultivated plants as an alternative food source when natural food sources are limited or habitats are fragmented (Schurer et al. 2019). Hill (2018) confirmed that primates, including macaques, are among the top causes of agricultural yield losses in various tropical regions. A cross-site study by Deneke et al. (2024) showed that losses caused by primates can reach significant levels in terms of household income, depending on the intensity of the attack and the type of crop damaged. Beyond direct economic losses, the presence of *M. fascicularis* can trigger broader socio-ecological problems. Predation on sago logs often occurs in villages directly adjacent to forests or secondary lands, where the primate's natural habitat is diminishing. Forest fragmentation and land conversion for plantations and settlements encourage *M. fascicularis* to seek alternative food sources from human activities (Sha et al. 2009). This places local communities in a vulnerable position, having to bear the burden of economic loss while facing conflicts with protected wildlife. This phenomenon also has an important ecological dimension, as the shift in *M. fascicularis* feeding behavior from natural sources to cultivated crops reflects an imbalance in the ecosystem, potentially disrupting the sustainability of natural resources.

Table 2. Estimated economic losses of the sago agroindustry in Lingga District, Riau Islands Province, Indonesia (n: 30)

Location	Volume of damage (cm^3)	Percentage of damage (%)	Estimated starch loss (kg)	Potential economic loss (IDR/month)	Estimated economic loss (IDR/year)
Panggak Laut	11,498.15	9.27	1.66	3,211,843.88	25,694,750.00
Nerekeh	13,602.38	10.96	1.66	2,936,079.52	23,488,636.12
Musai	11,414.59	9.20	1.29	2,753,707.04	22,029,656.31
Pekaka	12,651.39	10.20	2.01	3,212,713.73	25,701,709.83
Keton	12,741.60	10.27	1.69	2,912,059.53	23,296,476.22
Teluk	9,255.67	7.46	1.34	1,997,840.58	15,982,724.62
Mean±SD	11,860.63±1,519.95	9.56±1.22	1.61±0.26	2,837,374.04±449,053.41	22,698,992.35±3,592,427.98

In the long term, this interaction not only harms humans but can also affect the sustainability of *M. fascicularis* populations. This aligns with Riley's (2007) findings in Sulawesi, which showed that primate dependence on anthropogenic food sources can alter ecological behavior and increase the potential for conflict with humans. Based on field observations, damaged sago logs exhibit distinct physical changes compared to intact logs. These changes included a darker to blackish color, the appearance of holes on the surface with blackish spots, a softer texture, and an unpleasant odor due to the decay process. This damage can be caused by various factors, one of which is wildlife activity, particularly *M. fascicularis*, which feeds on the starch-rich middle layer of logs. Sago logs eaten by *M. fascicularis* generally exhibit holes in the center, resulting from their feeding behavior, which tends to scavenge the core of the sago trunk (Figure 6). This section was selected because it is the most abundant and nutritious source of starch. The holes left behind are usually circular or indented in the center of the trunk, as *M. fascicularis* removes the outer fibers and directly extracts the starchy tissue. This consumption pattern is similar to damage to other palms, where primates select the most accessible and energy-rich parts of the plant (Holzner et al. 2021). Consequently, damaged logs not only lose their economically valuable starch reserves but also become more susceptible to attack by secondary pests and decay microorganisms. This ultimately reduces the quality and quantity of starch that can be harvested by the community.

The Lingga community possesses unique and effective local wisdom to prevent *M. fascicularis* from attacking sago logs. The traditional method involves sprinkling sea sand over the surface of a sago log and then covering it with sago fronds. This combination acts as both a physical and sensory barrier: the sea sand roughens the log's surface and creates instability, whereas the additional sago fronds provide a protective layer and reduce the direct visibility of the log. This discourages *M. fascicularis* from approaching or scavenging the center of the log, as the surface feels unfamiliar and uncomfortable to walk on or dig through. Furthermore, sago fronds can limit odors from the sago log, which might attract animals and slow the entry of moisture or microorganisms that accelerate decay after the initial damage. This locally developed technique illustrates how traditional ecological knowledge has evolved as an adaptive response to wildlife pressure, emphasizing community resilience and practical innovation using readily available materials. Beyond its cultural significance, this method also aligns with the ecological principles of non-lethal mitigation, minimizing environmental disturbance while maintaining productivity.

Therefore, a combination of local approaches and scientific innovations such as the use of physical barriers, habitat management, and buffer crop planting strategies should be considered to reduce the intensity of attacks (Hsiao et al. 2013; Hockings 2016; Koirala et al. 2021; Burudi et al. 2025). Such integration of indigenous practices and science-based management represents a socially acceptable and ecologically sound strategy for mitigating human-wildlife conflict. Ultimately, this integrative approach is expected to reduce economic losses while supporting biodiversity conservation and sustaining the productivity of sago-based agroindustrial systems in the Lingga District.

While these findings provide valuable insights for developing community-based mitigation strategies, it is equally important to recognize the methodological constraints that may influence the precision and generalizability of the results. This study has several potential sources of bias and limitations. First, the estimation of starch loss was based on visual identification of damage and a limited sample size per site, which may underestimate losses in areas with higher macaque density. Second, the conversion of starch weight to economic value assumes a uniform market price, whereas actual prices fluctuate seasonally. Third, nocturnal foraging behavior and indirect signs of feeding could lead to under-detection of macaque activity. In addition, the observational approach used in this study may have limited the ability to distinguish macaque-induced damage from damage caused by other wildlife species. Therefore, future research should incorporate continuous monitoring using camera traps, larger and seasonally distributed samples, and participatory field validation with local communities to enhance data reliability and strengthen management recommendations.

In conclusion, the long-tailed macaque (*M. fascicularis*) exhibits a relatively high population density in the sago agroindustrial landscape of the Lingga District, particularly along forest edges, rivers, and log storage areas. The dominance of sub-adult individuals contributes to moderate but significant damage to sago logs (9.56±1.22%), causing an average starch loss of 1.61 kg per log and annual economic losses exceeding IDR 22 million. The species' continued adaptation to sago forests as an alternative habitat and food source reflects its ecological flexibility, but also raises concerns about potential population increases, safety risks, and future human-wildlife conflicts. Therefore, sustainable management integrating habitat restoration, population monitoring, and community-based deterrent practices is essential to maintain coexistence and ensure the long-term resilience of the sago-based agroindustry in the Lingga District.

Figure 6. Sago logs eaten by long-tailed macaques

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