BIODIVERSITAS
Volume 26, Number 9, September 2025
Pages: 4673-4684

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d260938

Thermal drone monitoring of arboreal primates in a post-coal mining area in South Kalimantan, Indonesia

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Manuscript received: 16 July 2025. Revision accepted: 25 September 2025.

Abstract. *Iskandar S, Habibie H, Hafif AR, Choiron D, Novian R, Riadhah M, Triwibowo D, Kurniawan RR, Mardiah AA. 2025. Thermal drone monitoring of arboreal primates in a post-coal mining area in South Kalimantan, Indonesia. Biodiversitas 26: 4673-4684.* PT Adaro Indonesia in South Kalimantan, Indonesia, is committed to rehabilitating natural habitat and restoring biodiversity in post-mining areas. The proboscis monkey (*Nasalis larvatus*) and silvery lutung (*Trachypithecus cristatus*) are arboreal primates and protected species in accordance with regulations issued by Indonesian Minister of Environment and Forestry No. P.106/MENLHK/SETJEN/KUM.1/12/2018, the IUCN Redlist, and Appendix I of CITES. The monitoring program aims to monitor the population and habitat of these primates in Paringin, South Kalimantan, an area impacted by mining activities, using thermal drone technology as a non-invasive, efficient survey method. Thermal drones were deployed to identify primate sleeping sites with greater precision. Optimal flight parameters included a total flight distance of 41 km, 12 waypoints, a flight duration of 14 minutes and 23 seconds, a speed of 15 m/s, and an altitude of 120 meters—ensuring adequate canopy clearance and visibility. This method enabled reliable detection of primate groups, allowing accurate estimates of population density: 21.5 ind/km² in Post-Coal Mining Area and 6.61 ind/km² in BUPER for proboscis monkeys. Meanwhile, silvery lutungs have 25.3 ind/km² in Post-Coal Mining Area and 4.96 ind/km² in BUPER. However, age and sex composition could not be detected from thermal imagery. Vegetation analysis of the pit lake area recorded 21 tree species, with 664 trees, 1,431 poles, 2,096 stakes, and 3,100 seedlings, indicating regenerating habitat structure. The availability of food species and habitat suitability were identified as the primary drivers of primate distribution in the area. Thermal drone photography is capable of counting the total number of individuals in a detected group, but it may not be able to identify the composition of individuals based on age and sex categories.

Keywords: Proboscis monkey, silvery lutung, thermal drone

Abbreviations: BKSDA: *Balai Konservasi Sumber Daya Alam* (Natural Resources Conservation Regional Office), CITES: Convention on International Trade in Endangered Species of Wild Fauna and Flora, IUCN: International Union for Conservation of Nature

INTRODUCTION

PT Adaro Indonesia, as one of the leading mining companies in Indonesia, recognizes the importance of maintaining ecosystem balance after mining. Previously degraded areas require special attention, as mining expansion has affected primates ecosystem (Estrada et al. 2017). In response, PT Adaro Indonesia conducted initiatives to restore habitats and biodiversity in post-mining areas based on Indonesian Government Regulation No. 78 of 2010 concerning Post-mine Reclamation and Mine Closure. Monitoring the population and habitat of the proboscis monkey (*Nasalis larvatus* (van Wurmb, 1787)) (Figure 2) an endemic species of Kalimantan (Hanani et al. 2025) and the silvery lutung (*Trachypithecus cristatus* (Raffles, 1821)) (Figure 3) in Paringin (locally referred to as Paringin Tengah), particularly in areas affected by the mining activities of PT Adaro Indonesia, is crucial in the context of conservation and natural resource management. Proboscis monkeys and silvery lutungs are arboreal primates and protected species under the regulation of the Indonesian Minister of Environment and Forestry number P.106/MENLHK/SETJEN/KUM.1/12/2018, the IUCN Redlist, and Appendix I of CITES.

The proboscis monkey and silvery lutung belong to the Cercopithecidae family and Colobinae subfamily. The proboscis monkey is a primate endemic of Borneo, Indonesia, that inhabits mangrove forests, riverine forests, and peat swamps. The silvery lutung has a broader range of habitats, including peat forests, riverine mangrove forests, lowland forests, and highland forests. In addition to forest habitats, these two species could be found in natural vegetation and cultivation such as rubber plantations and gelam swamps (Iskandar et al. 2017; Soendjoto et al. 2023). Proboscis monkeys are distributed in several conservation areas in South Kalimantan, Indonesia, including the Nature Recreation Park Pulau Bakut, Wildlife Sanctuary Kuala Lupak, Nature Recreation Park Pulau Kembang, and the Nature Reserve Pulau Kaget. Proboscis monkeys are also found outside conservation areas in rubber plantations, karst ecosystems, mixed gardens, and riverine mangroves on Curiak Island with 21 individuals, and in gelam swamps covering 346 hectares with 258 individuals (Alikodra and Srimulyaningsih 2014). Additionally, 75 proboscis monkeys have been recorded in the riparian mangroves of Asam-Asam River, Batulicin. According to data from the Directorate of Biodiversity Conservation, Directorate General of Natural Resources and Ecosystem Conservation - Ministry of Environment and Forestry, the population of proboscis monkeys in South Kalimantan in various areas is 3,223 individuals (BKSDA South Kalimantan 2021). Notably, 72.3% of this population resides outside the conservation, while only 27.7% is found within protected zones.

The presence of the proboscis monkey and silvery lutung as a key species in PT Adaro Indonesia's mining area, enhances the conservation value of the site, due to habitat loss, degradation, and fragmentation affecting both species (Wardatutthoyyibah et al. 2019). Therefore, the management plan for the area should focus on designating it as a protected area or a special conservation zone. Survey activities to monitor the population of the proboscis monkey and silvery lutung are initial steps in developing the area's management plan. During the survey, drone thermal technology is used to detect these species' presence. Thermal drones can access remote and densely forested regions without disturbing the ecosystem (Ikhsan et al. 2024). Additionally, thermal drones are highly effective because they could detect temperature differences, helping to identify trees that serve as habitats for these species based on temperature variations. This study is also continued with validation and ground checking to confirm their presence.

Post-mining areas, both terrestrial and aquatic, have significant ecological function potential for biodiversity conservation (Prach and Tolvanen 2016). Although often considered a degraded area due to mining activities, this study shows that these areas could serve as a habitat for protected fauna. Although the potential of post-mining areas as biodiversity conservation habitats is increasingly recognized, empirical data on the population and spatial ecology of primates such as the proboscis monkey and silvery lutung remain limited. Moreover, the use of monitoring technologies, such as thermal drones, has rarely been applied in tropical forest environments. The aim of utilizing thermal drones for monitoring is to determine the number of individuals and structure of proboscis monkeys and silvery lutung in the post-mining area, analyze population density, identify and quantify food tree species, and assess spatial distribution patterns of both species using thermal imaging technology.

MATERIALS AND METHODS

Study area

The study was conducted in and around the reclamation area of PT. Adaro Indonesia, located in Paringin (locally referred to as Paringin Tengah), Balangan District, South Kalimantan, Indonesia. This area includes the Post-Mining Lake and the BUPER Area that functions as a hydrological buffer. Post-Mining Lakes are formed from reclaimed coal mining activities, and now function as artificial aquatic ecosystems that provide water sources for various fauna The BUPER Area is a rehabilitation zone with dense vegetation that provides shelter, a source of food, and a sleeping habitat for these primates. Proboscis monkeys are commonly found in riparian forests, peat swamps, mangroves, and rubber plantations, while silvery lutungs are more adaptable, living in lowland to highland forests and mangroves. Proboscis monkeys prefer tall trees as sleeping trees for safety, while silvery lutungs show greater flexibility in habitat application. The daily activities of these two primates include foraging in the morning, social interaction during the day, and resting in the afternoon and evening. The study area for thermal drone monitoring of the proboscis monkey and silvery lutung is shown in Figure 1.

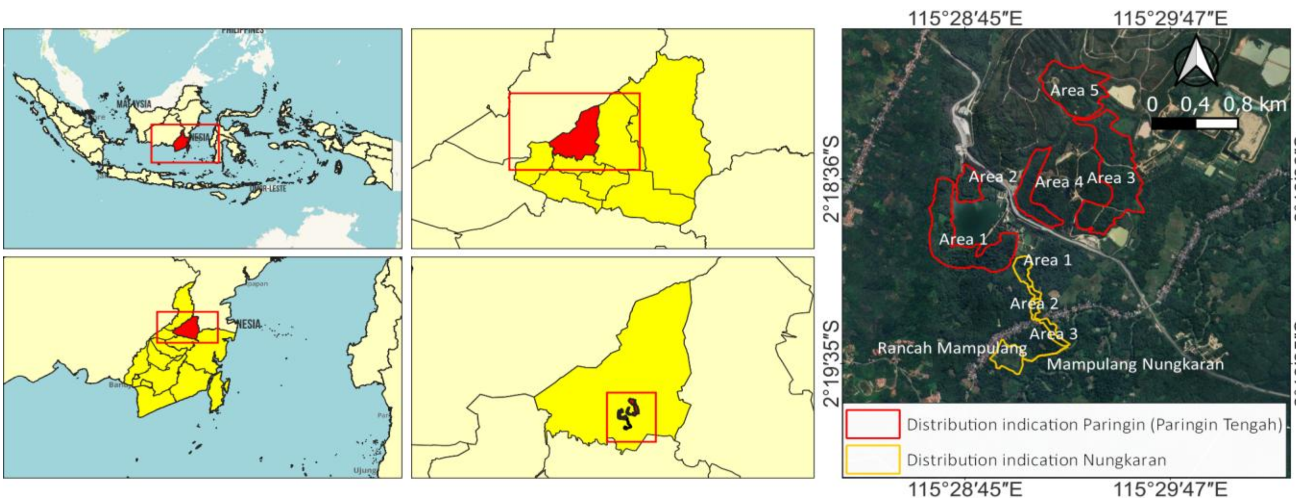

Figure 1. Study area of proboscis monkey and silvery lutung in Paringin, Balangan District, South Kalimantan, Indonesia

Procedures

The vegetation ground survey and data validation for proboscis monkey and silvery lutungs monitoring require various equipment, including research map, phi band, Global Positioning System (GPS) devices, compass, range finder, stationery, Personal Protective Equipments (PPE), telescope binocular, DLSR Camera Nikon D5600, and The Thermal Drone Systems. The thermal drone equipment used includes base Map (Topographic Map, land cover/forest map), drone models DJI Matrice 350 RTK, DJI Zenmuse H30T, and DJI Matrice 30 Thermal. The parameters of the drone flight path that are effective in monitoring proboscis monkeys and silvery lutungs were conducted during the drone process with a total distance of 41 km, 12 Waypoints, Flight Duration of 14 minutes and 23 seconds, Flight Speed of 15 m/s, and Flight Altitude of 120 meters to ensure the drone flies at this altitude to avoid trees and obtain a good vantage point for observation (Figures 4 and 5).

The monitoring process combines ground survey and thermal drone surveys to obtain accurate population estimates and habitat assessments. The ground survey employs a combination of the line transect method and the Concentration Count method, which involves direct observation of primate groups, habitat assessment, GPS and GIS data collection, and interviews with local communities to gather ecological insights. The initial aerial survey is conducted to identify areas where proboscis monkeys and silvery lutungs are likely to be found. Geographic Information System (GIS) software is used to measure these areas based on data collected during ground surveys. The survey is conducted at an altitude of 120 meters, with adjustments made according to the local topography to ensure optimal data collection. Application of thermal camera on drones to detect proboscis monkeys at night. The drone is equipped with a Red, Green, Blue (RGB) camera with zoom feature. Zooming allows for more accurate identification of species sighted.

Ground check monitoring involves conducting a population census of proboscis monkeys and silvery lutungs during two specific periods: in the morning, from 06:00 to 10:00 and the afternoon from 15:00 to 17:00, because proboscis monkeys and silvery lutung tend to look for the food in the morning and rest in the afternoon (Wardatutthoyyibah et al. 2023). Observers walk slowly along predetermined transect path, which are established based on prior drone survey results Specifically, the location of sleeping trees recorded during drone monitoring are used as indicators of primate presence. Individual and group counts are conducted twice daily, and population estimates are derived using a single data counting method, where the mean across replicates with variance from multiple observations is used as the final dataset.

Vegetation Identification is carried out to assess habitat structure and food availability. The recorded vegetation data are categorized according to plant stratification (La et al. 2024): trees (diameter > 10 cm), poles (diameter < 10 cm and height ≥ 1.5 m), and the sapling and seedling levels (height < 1.5 m including woody and herbaceous plants).

Data analysis

The data analysis process consists of several key steps. Ground survey analysis involves habitat assessment, where habitat quality is evaluated based on vegetation composition, water sources, and human disturbances. This analysis aims to determine the relationship between habitat conditions and primate populations. Regression analysis is used to assess the influence of habitat factors on the presence and overall health of the primate population. Additionally, a threat analysis is conducted to identify factors affecting these primates, including deforestation, hunting, human disturbances, and the impact of mining activities on both habitats and populations.

The thermal drone data analysis involves processing aerial imagery with DJI Thermal analysis tool to extract relevant information. Drone thermal captures images of primates based on their body temperature, which is higher than the surroundings, making it easier to detect individuals or groups of primates that are difficult to reach. Population analysis is carried out by identifying and counting individuals of proboscis monkey and silvery lutung based on thermal images. The population analysis identifies and counts proboscis monkeys and silvery lutung using thermal images. Additionally, space usage analysis maps primate distribution and identifies areas with high or low population density. Lastly, the ground-monitored data and vegetation data are analyzed using specific formulas.

Analysis of ground check monitored data

Population density is calculated based on the area of potential habitat, which is a modification of Laman and Aziz (2019):

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

Note: D: Density of population or group (ind/km^2) (group/km^2), N: Total of proboscis monkey or silvery lutungs observed (individual or group), A: Habitat area (km^2).

Analysis of vegetation data

The formula used to determine the vegetation parameters is as follows:

$$\text{Frequency} = \frac{\text{The number of points found from a certain type}}{\text{Total number of observation points}}$$

$$\text{Relative Frequency (RF)} = \frac{\text{Frequency of a type}}{\text{Frequency of all types}} \times 100$$

$$\text{Density} = \frac{\text{Density of a type}}{\text{Density of all types}}$$

$$\text{Relative Density (RD)} = \frac{\text{Frequency of a type}}{\text{Frequency of all types}} \times 100$$

$$\text{Importance Value Index} = \text{RF} + \text{RD}$$

RESULTS AND DISCUSSION

Results of monitoring the arboreal primates

Based on the results of the observations conducted on biodiversity, it is attached in Tables 1-6. Based on the data presented in Table 1, it has 21 individuals, occupying a 31-hectare habitat, with a population density of 67.74 ind/km^2. Meanwhile, in BUPER Area has 8 individuals of proboscis monkey were recorded within a 121-hectare habitat, resulting in a population density of 6.61 ind/km^2. For silvery lutung, the population density is 25.3 ind/km^2 with a total of 8 individuals occupying a 31-hectare habitat. Meanwhile, in the BUPER Area has 6 individuals were recored within a 121-hectare habitat, leading to a population density of 4.96 ind/km^2.

Based on the data presented in Tables 2 and 3, these results indicated that the number of seedlings is greater than the number of trees and stakes, but the number of stakes is less than the number of trees. Some plants could reduce runoff (Soendjoto et al. 2023). But, the research location has a gentle topography. The topography affects the structure of the vegetation; gentle topography during the rainy season would cause most of the forest to be flooded for a long time, which would inhibit the growth and development of seedlings. When this happens, it would affect the number of saplings in the forest.

Table 1. Number of individuals and age structure of the group of proboscis monkey and silvery lutung in the Post-Mining Lake Area and BUPER Area in Paringin, Balangan District, South Kalimantan, Indonesia

No	Groups	Time	Adult male	Adult female	Juvenile	Offspring	Infant	Unknown	Total
Proboscis monkey									
Post-Mining Lake Area									
1	Group 1	06.00-10.00	1	4	3	2	1	6	17
2	Group 2	06.00-10.00	--	--	4	--	--	--	4
Total									21
BUPER Area									
1	Group 1	15.00-17.00	1	2	3	2	--	--	8
Total									8
Silvery lutung									
Post-Mining Lake Area									
1	Group 1	06.00-10.00	1	3	2	2	--	--	8
Total									8
BUPER Area									
1	Group 1	15.00-17.00	1	3	1	1	--	--	6
Total									6

Figure 2. Proboscis monkey (*Nasalis larvatus*) in Paringin, Balangan District, South Kalimantan, Indonesia

Figure 3. Silvery lutungs (*Trachypithecus cristatus*) in Paringin, Balangan District, South Kalimantan, Indonesia

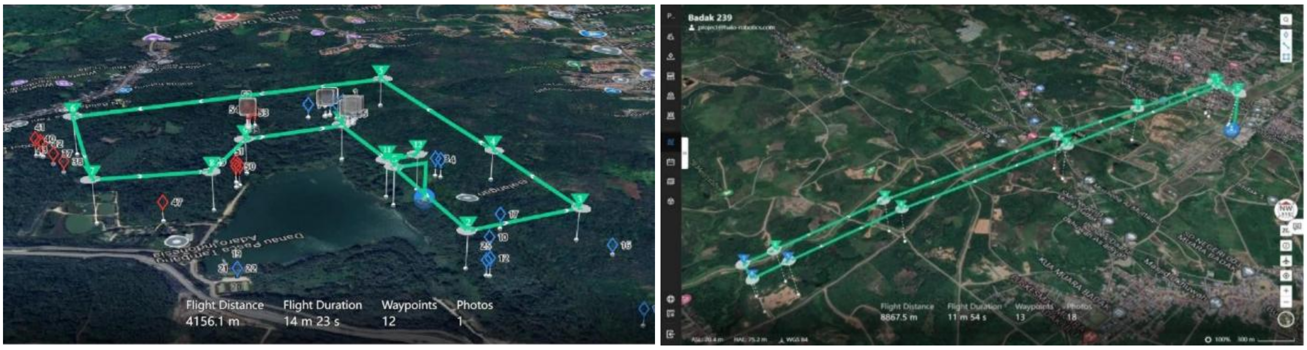

Figure 4. Thermal drone flight map in Paringin, Balangan District, South Kalimantan, Indonesia

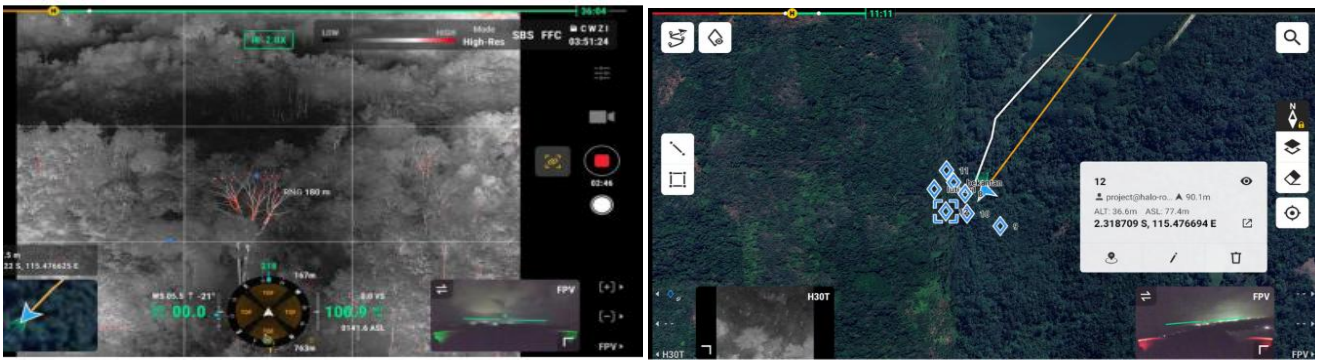

Figure 5. Thermal drone exploration in the Post-Mining Lake Area at night in Paringin, Balangan District, South Kalimantan, Indonesia

Table 2. The composition of vegetation type and the names of plant species at the tree, pole, sapling, and seedling levels recorded in the Post-Mining Lake Area, Paringin, Balangan District, South Kalimantan, Indonesia

Local names	English names	Latin names	Function	n	D	RD	F	RF	IVI
Tree level									
Alaban	Alaban	*Vitex pubescens* B.Heyne ex Wall., 1829	Sleeping tree (height 35 m)	9	300	45.18	0.2	9.09	54.27
Sengon	Batai	*Albizia chinensis* (Osbeck) Merr.	Sleeping tree (height 50 m)	3	100	15.06	0.4	18.18	33.24
Tarap	Tarap	*Artocarpus odoratissimus* Blanco	-	1	33	4.97	0.4	18.18	23.15
Medang	Medang	*Phoebe angustifolia* Meisn.	Sleeping tree (height 45 m)	2	66	9.94	0.2	9.09	19.03
Ambaratan	Ambaratan	*Macaranga gigantea* (Rchb.f. & Zoll.) Müll.Arg.	Sleeping tree (height 45 m)	1	33	4.97	0.2	9.09	14.06
Meranti	Meranti	*Shorea* sp.	Sleeping tree (height 45 m)	1	33	4.97	0.2	9.09	14.06
Kayu manis	Cinnamon	*Cinnamomum verum* J.Presl	-	1	33	4.97	0.2	9.09	14.06
Wresah	Wresah	*Amomum dealbatum* Roxb.	Food tree	1	33	4.97	0.2	9.09	14.06
Pohon salam	Salam tree	*Syzygium polyanthum* (Wight) Walp.	-	1	33	4.97	0.2	9.09	14.06
Total				20	664	100	2.2	100	200
Pole level									
Sungkai	Sungkai	*Peronema canescens* Jack	Food tree	12	400	27.95	0.4	20.00	47.95
Wresah	Wresah	*Amomum dealbatum* Roxb.	Food tree	8	266	18.59	0.2	10.00	28.59
Medang	Medang	*Phoebe angustifolia* Meisn.	Sleeping tree	7	233	16.28	0.2	10.00	26.28
Alaban	Alaban	*Vitex pubescens* B.Heyne ex Wall., 1829	Sleeping tree (height 35 m)	6	200	13.98	0.2	10.00	23.98
Kayu manis	Cinnamon	*Cinnamomum verum* J.Presl	-	6	200	13.98	0.2	10.00	23.98
Cempedak	Cempedak	*Artocarpus integer* (Thunb.) Merr.	Food tree	1	33	2.31	0.2	10.00	12.31
Pohon Salam	Salam tree	*Syzygium polyanthum* (Wight) Walp.	-	1	33	2.31	0.2	10.00	12.31
Kayu bawang	Kulim	*Scorodocarpus borneensis* (Baill.) Becc.	-	1	33	2.31	0.2	10.00	12.31
Kanidai	Kanidai	*Bridelia tomentosa* Blume	-	1	33	2.31	0.2	10.00	12.31
Total				43	1,431	100	2	100	200
Sapling level									
Rambai	Rambai	*Baccaurea motleyana* (Müll.Arg.) Müll.Arg.	Food tree	1	33	1.57	0.2	50	51.57
Karet	Rubber tree	*Hevea brasiliensis* (Willd. ex A.Juss.) Müll.Arg.	Food tree	15	500	23.85	0.2	10	33.85
Meranti	Meranti	*Shorea* sp.	Sleeping tree (height 45 m)	10	333	15.89	0.2	10	25.89
Alaban	Alaban	*Vitex pubescens* B.Heyne ex Wall., 1829	Sleeping tree (height 35 m)	10	333	15.89	0.2	10	25.89
Sungkai	Sungkai	*Peronema canescens* Jack	Food tree	8	266	12.69	0.2	10	22.69
Kanidai	Kanidai	*Bridelia tomentosa* Blume	-	7	233	11.12	0.2	10	21.12
Jambu-jambuan	Guavas	*Syzygium sp*	Food tree	5	166	7.92	0.2	10	17.92
Cempedak	Cempedak	*Artocarpus integer* (Thunb.) Merr.	Food tree	4	133	6.35	0.2	10	16.35
Palem hutan	Palm	*Livistona chinensis* (Jacq.) R.Br. ex Mart.	-	2	66	3.15	0.2	10	13.15
Total				63	2,096	100	2	140	240
Seedling level									
Kayu akar kuning	Kayu akar kuning	*Arcangelisia flava* (L.) Merr.	-	20	667	21.51	0.2	8.33	29.84
Pohon salam	Salam tree	*Syzygium polyanthum* (Wight) Walp.	Food tree	15	500	16.13	0.2	8.33	24.46
Tarap	Tarap	*Artocarpus odoratissimus* Blanco	-	15	500	16.13	0.2	8.33	24.46
Mahang	Mahang	*Macaranga* sp.	Food tree	4	133	4.30	0.4	16.67	20.97
Rotan	Rotten	*Calamus* sp.	-	10	333	10.75	0.2	8.33	19.09
Kanidai	Kanidai	*Bridelia tomentosa* Blume	-	8	267	8.60	0.2	8.33	16.94
Alaban	Alaban	*Vitex pubescens* B.Heyne ex Wall., 1829	Sleeping tree of (height 30 m)	7	233	7.53	0.2	8.33	15.86
Meranti	Meranti	*Shorea* sp.	Sleeping tree (height 45 m)	5	167	5.38	0.2	8.33	13.71
Medang	Medang	*Phoebe angustifolia* Meisn.	Sleeping tree (height 45 m)	5	167	5.38	0.2	8.33	13.71
Jambu-jambuan	Guavas	*Syzygium* sp.	Food tree	3	100	3.23	0.2	8.33	11.56
Petai	Petai	*Parkia speciosa* Hassk.	-	1	33	1.08	0.2	8.33	9.41
Total				93	3,100	100	2.4	100	200

Note: n: Total, R: Ratio, RD: Relative Density, F: Frequency, RF: Relative Frequency, IVI: Importance Value Index

Table 3. The composition of vegetation type and the names of plant species at the tree, pole, pile, and seedling levels recorded in area BUPER, Paringin, Balangan District, South Kalimantan, Indonesia

No	Local names	English names	Latin names	Function	n	D	RD	F	RF	IVI
Tree level										
	Alaban	Alaban	*Vitex pubescens* B.Heyne ex Wall., 1829	Sleeping tree of silvery lutung (30 m)	7	233	100	1	100	200
Total					7	233	100	1	100	200
Pole level										
1	*Alaban*	Alaban	*Vitex pubescens* B.Heyne ex Wall., 1829	Sleeping tree of silvery lutung (30 m)	4	33	100	1	100	200
Total					4	33	100	1	100	200
Sapling level										
	Melikope	Melikope	*Melicope* sp.	Food tree	2	266	66.67	0.2	50	116.67
	Kanidai	Kanidai	*Bridelia tomentosa* Blume	-	4	133	33.33	0.2	50	83.33
Total					6	399	100	0,4	100	200
Seedling level										
	Alaban	Alaban	*Vitex pubescens* B.Heyne ex Wall., 1829	Sleeping tree (Height 30 m)	8	267	53.33	1	33.33	86.67
	Kanidai	Kanidai	*Bridelia tomentosa* Blume	-	4	133	26.67	1	33.33	60.00
	Melikope	Melikope	*Melicope* sp.	Food tree	3	100	20.00	1	33.33	53.33
Total					15	500	100	3	100	200

Note: n: Total, R: Ratio, RD: Relative Density, F: Frequency, RF: Relative Frequency, IVI: Importance Value Index

Table 4. Frequency of daily activities of the proboscis monkeys group at the Post-Mining Lake Area, Paringin, Balangan District, South Kalimantan, Indonesia

Time of day	Activities		
	Feeding	Moving	Resting
Morning	52.2	26.08	21.7
Afternoon	28.6	14.3	57.1

Sources: Primary data (2024)

Based on the data presented in Table 4, revealed a variation in their daily activities. In the morning, feeding of 52.2% and moving of 26.08% were the most prominent activities, while resting accounted for only 21.7%. In contrast, during the afternoon, resting increased to 57.1%, whereas feeding of 28.6% and moving of 14.3% activities declined. These findings suggest that the proboscis monkeys are more active and allocate greater time for foraging in the morning, followed by increased resting during the afternoon.

Discussion

Thermal drone monitored

The use of drones thermal imaging in primate monitoring offers significant advantages when traditional methods are unusable (Longmore et al. 2017). Thermal drones are capable of detecting wildlife based on body heat signatures; however, their performance is highly dependent on environmental conditions such as humidity, ambient temperature, and canopy density (Camacho et al. 2023). Nonetheless, thermal imaging remains a promising tool, complementing traditional methods and supporting ongoing efforts to improve species distribution and abundance predictions (Vahidi et al. 2025). Based on the results of the drone photo count, drone photo analysis revealed two groups of proboscis monkeys in the lake habitat: one with 17 individuals and another with four, the latter suspected to be an all-male group, composed of young individuals. In addition, eight individuals of silvery lutungs were recorded in the same habitat. In the buffer zone, one group of proboscis monkeys with eight individuals and another group of silvery lutungs with six individuals were observed. This resulted in a total of 43 individual primates recorded across both sites (the Post-Mining Lake and the BUPER Area), exceeding the number reported by Burke et al. (2019), who documented only 41 individuals in a similar context.

This higher count may reflect an increase in primate presence due to habitat recovery or improved detection capabilities through thermal drone use. The different flight parameters also affect the detectability of primates in videos recorded by a drone thermal (Pinel-Ramos et al. 2024). Environmental variables, including vegetation density, proximity to water sources, and human disturbance levels, also influence primate distribution and visibility (Gazagne et al. 2024). At every point along the road, the drone must pause briefly to conduct observations. The observed behavior of the proboscis monkey includes social interactions, feeding patterns, and play activities. In contrast, the silvery lutung's behavior includes movement activities, interaction with the environment, and sleeping patterns. Proboscis monkeys and silvery lutung have the ability to camouflage with the canopy tree. The thermal drone could fly above the canopy and use the contrast between the warm body temperature of the primates and the cooler background vegetation (Mirka et al. 2022). It has its pros and cons, unrealistic assumptions and prerequisite conditions can canfound it because sometimes it is too far from the target (Baldwin et al. 2023).

Pros of thermal drone

The use of thermal drones in monitoring proboscis monkeys and silvery lutungs in the Paringin (locally referred to as Paringin Tengah) offers several advantages, which is the drone's ability to detect temperature differences in the environment, ranging from 25°C to 28°C. This allows them to identify trees that may serve as habitats for proboscis monkeys and silvery lutungs based on changes in surrounding temperatures. Drones could access remote or difficult-to-reach forested areas where dense vegetation, wetland terrain, or a lack of infrastructure limits accses (Ikhsan et al. 2024). Thermal drones are also effective under low-light conditions, particularly during the early morning or nighttime hours (Rahman and Setiawan 2022). They can detect animals in the upper canopy, overcoming restricted visibility due to thick foliage (Piel et al. 2022). Furthermore, drones provide rapid access to vast and challenging areas, enabling researchers to conduct broader and more systematic surveys in significantly less time than traditional ground-based methods (Trinh-Dinh et al. 2024). This efficiensy is especially useful in field studies where limited access and resources (Mathewson et al. 2008; Dahlen and Traeholt 2018).

In addition to spatial and logistical efficiency, thermal drones could detect individuals using standard visual imagery, especially in complex canopy environments, and were able to detect primates such as foraging, grooming, or playing (Gazagne et al. 2023). Based on thermal drone monitoring the nasal temperature of primates can be categorized the primates is in active or inactive (Ross et al. 2021). The potential benefits of using the thermal drone are evident (Mutalib et al. 2019). Drones can be used repeatedly to monitor habitat changes over time, providing valuable data for research and management and it has the potential to increase the coverage and continuity of long-term monitoring (Zhang et al. 2023).

Cons of thermal drone

Despite the many advantages of thermal drones, several limitations must be acknowledged when applying this technology. Adverse environmental factors such as rain, fog, and fluctuating ambient temperatures could significantly reduce the clarity and reliability of thermal data. These conditions interfere with the drone’s ability to detect meaningful temperature contrasts. However, that is not all environmental variables consistently act as limitations. For example, rainfall may enhance detection capabilities by accentuating temperature differences between animals and the surrounding vegetation (Gazagne 2024). Another technical limitation lies in the thermal drone’s inability to distinguish among species, particularly when species have similar body temperatures. Proboscis monkeys, silvery lutungs, and other sympatric primates often share overlapping thermal signatures (Burke et al. 2019). Misidentification may also occur when body sizes are similar (Zhang et al. 2020). Image resolution is also a critical factor; thermal cameras typically do not provide sufficient detail for definitive species identification, especially at higher altitudes. As a result, validation through ground-truthing or complementary visual methods is often necessary to confirm species identity and behavior.

Additionally, thermal drones are currently limited in their ability to determine individual characteristics such as species-specific morphology, sex, and age (Jumail et al. 2021). There are also logistical and financial challenges associated with drone operations. Thermal drones are costly, with expenses for equipment, maintenance, and training. Studies have shown that even low-impact drone activity could induce stress or behavioral changes in species, particularly when drones approach too closely or remain overhead for extended periods. Thermal drones data must cautiously within ecological and species-specific context.

Ground check monitoring

Proboscis monkey (*Nasalis larvatus*)

The habitat of proboscis monkey. A total of 29 proboscis monkeys were identified through thermal drone monitoring—21 individuals in the Post-Mining Lake Area and 8 individuals in the BUPER Area. This number is significantly lower compared to the findings of Hidayat et al. (2023) in Muara Kaman, East Kalimantan, where between 364 and 644 individuals were recorded. The relatively low population may be indicative of degraded habitat conditions. Habitat degradation often leads to a decline in the availability of essential resources such as food and shelter. Deforestation, land conversion, and mining activities likely contribute to the fragmentation and reduction of suitable habitat, resulting in population decline (Hidayat et al. 2023). The proboscis monkey groups observed in the Post-Mining Lake and BUPER Areas are suspected to be migrant groups that may have originated from habitats along the Balangan River, because they tend to sleep next to river, which provides access to food and escape routes from predators (Bennett 1988). Their presence in areas located further from the river may be caused by increasing threats such as hunting and land conversion. Environmental factors, such as rivers, swamps, or lakes, are known to influence the distribution and habitat selection of proboscis monkeys, the research was conducted in an area with high rainfall intensity (Triwibowo et al. 2021). In conclusion, the small number of individuals recorded does not necessarily reflect a naturally low population, but rather a consequence of habitat degradation and ecological displacement. Effective habitat restoration, including the protection of connecting riverine habitats to inland forest patches, could support the recovery of local proboscis monkey populations.

The behavior patterns of proboscis monkey. As large primates, proboscis monkeys (Koda et al. 2018) rely heavily on eating activities. In this study, eating behavior includes a sequence of actions such as taking food, carrying it to the mouth, consuming it, chewing, throwing away or dropping food that is held using various parts of the body. Based on the data presented in Table 4, it was recorded that approximately 52.2% of the proboscis monkey's daily activities were dedicated to feeding. The main time for feeding typically begins right after they wake up. Proboscis monkeys are folivorous primates, meaning that their diet is primarily composed of leaves. More than half of their diet consists of foliage, particularly young leaf buds. During observation, they were seen feeding on the leaves of *Albizia chinensis* (Osbeck) Merr. and *Hevea brasiliensis* (Willd. ex A.Juss.) Müll.Arg.. Due to the considerable distance between the observer and the proboscis monkeys, it was difficult to identify the specific parts of the plants being consumed. Previous studies have shown that the nasal temperature of primates tends to be lower during active behaviors compared to inactive states (Ross et al. 2021). Nasal temperature was found to be significantly influenced by both the type of food consumed and the composition of nearby individuals (Barrault et al. 2022), suggesting a link between physiological responses and social or environmental contexts. To optimize behavioral observations, it is recommended that the line of sight between the observer and the subject should not exceed 20 meters because the observed group in this study has not yet been habituated to human presence.

Sleeping tree and feeding tree. The trees selected by proboscis monkeys for sleeping are typically located within 0–50 meters from the riverbank. Interestingly, these sleeping trees are often the same species that also serve as their food sources. According to research findings, these monkeys commonly sleep in *A. chinensis* that reach heights between 30 and 50 meters and have trunk diameters ranging from approximately 35.88 to 50.08 cm. In addition, they also sleep on *Phoebe angustifolia* Meisn., *Macaranga gigantea* (Rchb.f. & Zoll.) Müll.Arg., and *Shorea* sp.. In the same habitat, a *Vitex pubescens* B.Heyne ex Wall., 1829 has smaller trunk diameters, ranging from 10.19 to 34.08 cm. This suggests that while proboscis monkeys prefer taller trees for sleeping, they do not necessarily seek the thickest trunks, possibly due to the structural flexibility or arrangement of the tree canopy. Proboscis monkeys are arboreal animals that tend to live and sleep in the forest canopy. This behavior allows them to navigate efficiently through the treetops and obtain the food. Their sleeping site selection—tall trees close to the river with access to food and canopy connectivity—demonstrates a complex ecological adaptation to their environment (Wardatutthoyyibah et al. 2023). This is a form of adaptation of the proboscis monkeys to their environment.

Silvery lutung (*Trachypithecus cristatus*)

The habitat of silvery lutung. Deforestation has had a significant impact on the lives of primates (Nurliani 2024). The silvery lutung is considered a relatively adaptable primate species, capable of surviving in environments with minimal or degraded habitat conditions. Outside the conservation areas, silvery lutung populations have been observed in a variety of habitat types and conditions, with varying population numbers. The number of silvery lutung in the Post-Mining Lake Area is 8 individuals and in the BUPER Area is 6 individuals, which can be considered small compared to Supriatna and Ramadhan (2016), who stated that the number of silvery lutung ranges from 10 to 24 individuals per group. The silvery lutung does not depend on the presence of water bodies for its survival. However, considering the habitat's carrying capacity, especially the high abundance of food types, the area is a potential habitat for the conservation of the silvery lutung in the future. The availability of abundant food sources and a vast habitat can ensure the growth of the silvery lutung population. The distribution of silvery lutung has a critical factor to influencing the sleeping site selection primates is access to food resources (Gazagne et al. 2025).

The habitat characteristics of silvery lutung. Silvery lutungs are known to be sensitive and timid in response to human presence (Supartono et al. 2016). This was observed in a study that found only 8 individuls in the Post-Mining Lake Area and 6 in the BUPER, which can be considered a small number. This cautious behavior suggests that human disturbance, such as habitat encroachment or tourism, can significantly affect their natural behavior and habitat use. Silvery lutungs are typically found in tropical rainforests, montane forests, and higher elevation forested areas. Although some populations have been observed in mangrove forests, their preferred habitats are those with tall trees and dense canopy cover. Silvery lutungs are primarily canopy dwellers and could often be seen moving through the upper layers of the forest, using the continuous canopy for locomotion, foraging, and safety from ground predators. As highlighted by Panagoda and Weerasinghe (2019), their dependency on undisturbed forest environments makes them particularly vulnerable to habitat degradation, fragmentation, and deforestation.

The identification of vegetation

Vegetation has a vital role (Triwibowo et al. 2023) for primates. Research has shown that proboscis monkeys sleep in sengon trees that have a height between 30 and 50 m and a diameter between 35.88 and 50.08 cm. Proboscis monkeys prefer trees with a relatively small diameter but tall and close to the water source. This is a form of adaptation of the proboscis monkeys to their environment, as the diameter of *V. pubescens* trees in this area ranges from 10.19 cm to 34.08 cm. The trees selected by the proboscis monkeys for sleeping are typically located within 0-50 meters of the riverbank, which also serves as their food source. Proboscis monkeys prefer to sleep on the riverbank (Wardatutthoyyibah et al. 2023).

The Proboscis monkey heads into the forest in the afternoon, where their activities generally include eating, sleeping, and playing. The proboscis monkey chooses the trees that are 5-9 meters tall to rest during the day. The proboscis monkey looks for shaded trees during the day to avoid exposure to sunlight. Shaded trees are those that are 4-10 meters tall, have a small diameter, and have many branches. The types of resting trees for the proboscis monkey are *Hevea brasiliensis* (Willd. ex A.Juss.) Müll.Arg., *V. pubescens,* and *A. chinensis.*

The proboscis monkeys in the ost-mining lake area and the BUPER Area consume all types of plants found in their habitat. The primates' distribution is influenced by vegetation type (Soendjoto et al. 2018). Based on the data presented in Table 2, from the results of the vegetation analysis, three types of plants favored by the proboscis monkey and the silvery lutung were recorded, namely *A. chinensis*, *V. pubescens,* and *Sizigium* sp., as well as cultivated *H. brasiliensis*. The Important Value Index (IVI) of the dominant species found at the tree is *V. pubescens* of 54.27% and pole level is *Peronema canescens* Jack of 47.56%, respectively at densities of 300 trees/ha and 400 trees/ha. Additionally, *A. chinensis* ranks second with an IVI of 33.24% at the tree level, and *Amomum dealbatum* Roxb. at the pole level with an IVI of 28.59%, and respectively at densities of 100 trees/ha and 266 trees/ha. Meanwhile in the sapling level, *H. brasiliensis* is dominant, having an IVI of 33.85% with 500 trees/ha density and at the seedling level, *Arcangelisia flava* (L.) Merr. has an IVI of 29.84% with a density of 667 trees/ha. This indicates that *A. flava* dominates the competition for nutrients, light, space, and distribution at the tree level. *Arcangelisia flava* is known to be a tree where proboscis monkeys and silvery lutung play, with the leaves serving as a food source for both. The type of vegetation at the seedling stage is higher compared to the tree and sapling stages. The research results show that there are 664 trees, 1,431 poles, 2,096 stakes, and 3,100 seedlings.

The daily activities of proboscis monkey and silvery lutung

The patterns of daily activity and behavior of the proboscis monkey vary depending on the condition and quality of their habitat. In the proboscis monkey group in the rubber plantation, the proportion of daily activity frequency consists of 41.30% for eating, 40.66% for resting, 15.64% for playing, and 2.4% for grooming. In the proboscis monkey group in Sungai Puting, Tatakan Village, the proportion of daily activities consists of 32.08% for eating, 13.97% for moving, 51.64% for resting, and 2.31% for social activities. (Iskandar et al. 2017). Meanwhile, in observation conducted at Post-Mining Lake Area, daily activities consisted of eating 52.2% in the morning and 28.6% in the afternoon, moving 23.08% in the morning and 14.3% in the afternoon, and resting 21.7% in the morning and 57.1% in the afternoon. The differences in the proportion of daily activities of the proboscis monkey are influenced, among other factors, by the vegetation characteristics (Bernard et al. 2021), the abundance of food sources, population density, and human presence.

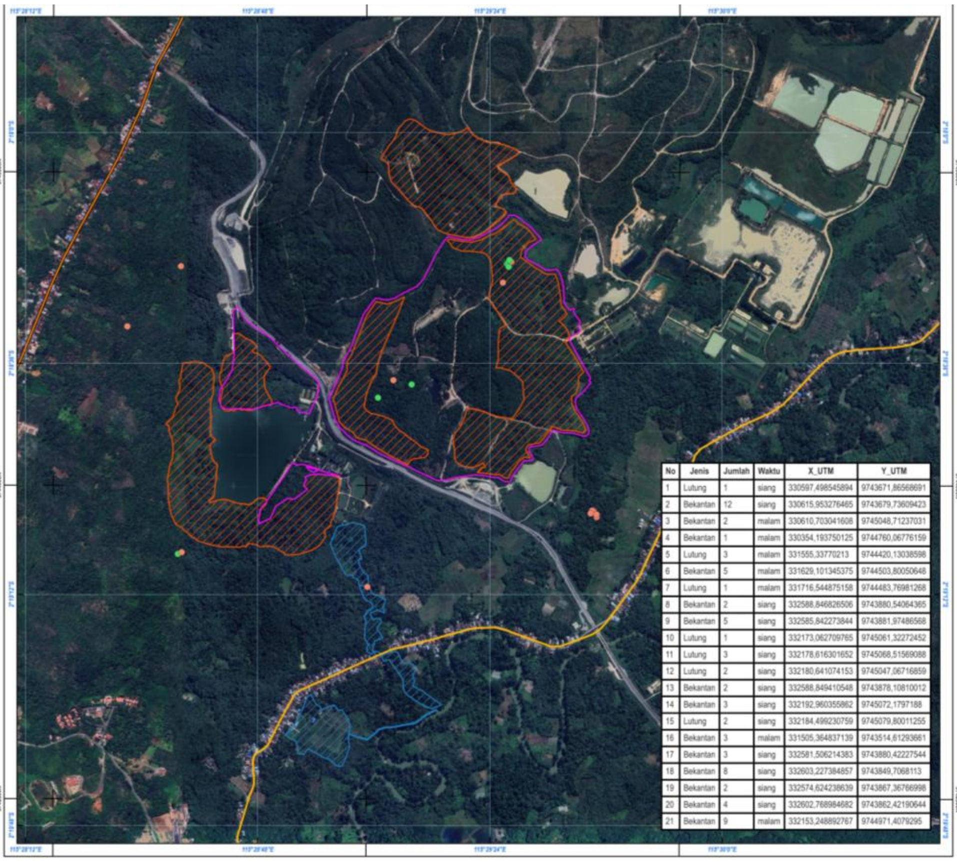

Figure 6. Sleeping tree map for proboscis monkey and the silvery lutung in the Paringin (locally referred to as Paringin Tengah), Balangan District, South Kalimantan, Indonesia

Conclusion, the observations in the Post-Coal Mining Area and BUPER Area showed that proboscis monkeys and silvery lutungs consist of various age groups, with a predominance of females and juveniles. The proboscis monkey population has the highest density in the Post-Coal Mining Area at 67.74 ind/km² and BUPER Area has 6.61 ind/km². Silvery lutung showed a more dispersed distribution pattern with lower population density, it has 25.3 ind/km² in Post-Coal Mining Area and 4.96 ind/km² in BUPER. The dominant vegetation used as sleeping trees and food sources includes *A. chinensis*, *V. pubescens*, *Syzygium* sp., and *H. brasiliensis*. The vegetation level stratification in the Post-Coal Mining Area was recorded as higher than in BUPER, at all levels from trees, poles, saplings, to seedlings. This study showed that thermal drones are a good way to spot primates based on their body heat, especially at night and in the morning. This tech is great for finding where they sleep, keeping track of their daily activities and distribution of primates in hard-to-reach areas. However, thermal drones have limitations in visually identifying gender, age, and species, so validation through ground checks is still required. The monitoring results indicate the potential for scaling up non-invasive monitoring methods (drone-ground) to inform conservation planning for protected species beyond formal conservation zones.

ACKNOWLEDGEMENTS

The journal article is written based on the research results (Thermal Drone Monitoring of Arboreal Primates in a Post-Coal Mining Area in South Kalimantan, Indonesia) funded by PT Adaro Indonesia in 2024. We would like to express our gratitude to all those involved, including Muhammad Azwar.

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