BIODIVERSITAS
Volume 25, Number 11, November 2024
Pages: 4233-4243

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d251123

Sunda pangolin (*Manis javanica*) responses to human impact in Sabah, Malaysia

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Manuscript received: 23 September 2024. Revision accepted: 15 November 2024.

Abstract. *Kodoh J, Adros C, Shairi NA, Besar NA, Abdullah MT, Sompud J. 2024.* Sunda pangolin *responses to human impact in Sabah, Malaysia. Biodiversitas 25: 4233-4243.* The Sunda pangolin (*Manis javanica* Desmarest, 1822), categorized as Critically Endangered, faces significant challenges due to human-driven threats, including poaching, habitat destruction, and illegal trade. The comprehensive impact of these factors remains underexplored, especially in specific locales such as the Universiti Malaysia Sabah (UMS) campus, Malaysia. This study, conducted from June to December 2023 within the Sustainable Forest Education Research Area (SFERA@UMS), evaluated the species' response to human disturbance through camera trap surveys. The investigation focused on how proximity to human settlements and noise pollution influence the distribution and behavior of *M. javanica*. Results from 1,647 camera-trap nights revealed that *M. javanica* demonstrated a preference for areas with reduced anthropogenic interference, shown by a weak yet significant positive correlation between greater distance from human settlements and pangolin presence ($rs = 0.071^{**}$, $p<0.001$). Additionally, mean noise levels negatively impacted visitation frequency ($rs = -0.075^{**}$, $p<0.001$), suggesting that noise pollution disrupts natural behaviors critical for survival, such as foraging. These results align with findings that wildlife, particularly species with secretive and nocturnal habits, tend to avoid regions with substantial human activity. The uneven spatial distribution of pangolins underscores the need for conservation initiatives that mitigate the adverse effects of human encroachment and noise pollution. Recommended actions include establishing buffer zones around critical habitats, enhancing public awareness, and employing technology for continuous monitoring. Integrating conservation strategies that address habitat quality, community involvement, and technological advancements is crucial for protecting *M. javanica* and supporting broader biodiversity efforts. These findings contribute to understanding the localized impacts of human activities on endangered species and highlight the importance of comprehensive, multi-faceted approaches for their conservation and habitat management.

Keywords: Artificial intelligence, biodiversity, Borneo, camera trapping, early warning system

Abbreviations: SFERA@UMS: Sustainable Forest Education and Research Area; UMS: Universiti Malaysia Sabah

INTRODUCTION

The Sunda pangolin (*Manis javanica* Desmarest, 1822), a Critically Endangered species, faces a bleak future driven by relentless anthropogenic pressures. While poaching, illegal trade, and habitat destruction are well-documented threats, the comprehensive effects, including both direct and indirect human impacts on this elusive creature, remain largely unknown. Their nocturnal, solitary, secretive nature and dwindling numbers have challenged scientific research, leaving this enigmatic mammal vulnerable to a silent, localized extinction. The *M. javanica* is a widely distributed species across Southeast Asia from Myanmar to Indonesia (Pantel and Anak 2010), except in the Philippines (Chong et al. 2020). It is the only pangolin species in Sabah (Pantel and Anak 2010). The species is truly unique, with a streamlined body covered with stiff, keratinous, and overlapping, rounded scales, except on its muzzle, throat, underbelly, and inner surface of limbs (Phillipps and Phillipps 2016; Chong et al. 2020). These physical characteristics invoke a sense of wonder and admiration. The species is categorized as Critically Endangered in the IUCN Red List of Threatened Species (Challender et al. 2019).

The Universiti Malaysia Sabah (UMS) main campus was established on 4.04 km^2 of land at Sepanggar Bay in the district of Kota Kinabalu City, Malaysia. Within the campus grounds, a patch of forest known as UMS Forest covers about 1.2 km^2 (Majuakim et al. 2018). In 2022, the university management gazetted 0.25 km^2 of the UMS forest as a forest reserve known as the Sustainable Forest Education Research Area (SFERA@UMS) managed by the Faculty of Tropical Forestry. The *M. javanica* was surprisingly discovered in SFERA@UMS recently (Sompud et al. 2023). Sompud et al. (2023) recorded the distribution of *M. javanica* in Sabah for the last ten years through past research. They found that their locality was mainly within the eastern part of Sabah. They also recorded new sightings of the species in UMS, Kota Kinabalu, through citizen scientists and camera traps. Panjang et al.

(2024) projected the distribution of Sunda pangolins in Sabah using MaxEnt niche modelling and consolidated species location data. Their findings highlight the critical habitat features required by the species, indicating regions with dense forest cover and minimal human disturbance as key areas for sustaining pangolin populations. This helps identify potentially suitable habitats that are essential for focused conservation efforts within the region.

The *M. javanica* population in the wild is dwindling solely due to anthropogenic pressures, mainly from poaching, illegal trade, and habitat destruction (Zhang et al. 2015; Challender et al. 2019). Despite being a Critically Endangered species, they are one of the mammals that receive little scientific attention. Various anthropogenic pressures affect *M. javanica*, and while some of these pressures have been documented, the extent to which they influence pangolin populations remains insufficiently understood. Further research is crucial to comprehensively assess these impacts and develop strategies that enhance the species' sustainability. This is most likely because of their predominantly nocturnal, solitary, elusive, and secretive nature, which is becoming increasingly rare (IUCN SSC Pangolin Specialist Group et al. 2018).

Research on the population dynamics, ecology, and life history of *M. javanica* has been limited. They still need to be researched than other mammalian species (IUCN SSC Pangolin Specialist Group et al. 2018; Nash et al. 2020). Notably, mammals such as the Malayan tapir (*Tapirus indicus* Desmarest, 1819) and the Bornean orangutan (*Pongo pygmaeus* Linnaeus, 1760) have been studied extensively, with well-documented behavioral patterns and habitat requirements (Ancrenaz et al. 2021; Pinondang et al. 2024). In contrast, *M. javanica*, despite its Critically Endangered status, remains underrepresented in ecological research.

Most current knowledge on *M. javanica* is anecdotal. There is limited knowledge regarding the unique and distinct ecology of *M. javanica* (Chong et al. 2020). According to Phillipps and Phillipps (2016), *M. javanica* sleeps during the day in the hollows of dead or alive trees or amongst undergrowth vegetation, and they are active during the night. Pangolins can occur where large numbers of food (ants and termites) can be found (Chong et al. 2020). The species is intolerant to colder temperatures (IUCN SSC Pangolin Specialist Group et al. 2018) and often die outside their natural range due to exposure.

Most current literature on pangolin ecology concerns other pangolin species that inhabit different latitudes and habitats and have different ecological niches than the *M. javanica* (Chong et al. 2020). For instance, the Chinese pangolin (*Manis pentadactyla* Linnaeus, 1758) and the Indian pangolin (*Manis crassicaudata* É.Geoffroy Saint-Hilaire, 1803) have been subjects of research focusing on their habitat preferences and poaching pressures. However, these studies are geographically specific to regions like Nepal and northern India (Katuwal et al. 2017; Qasim et al. 2024), differing from the tropical rainforests and mixed landscapes inhabited by *M. javanica*. In addition, *M. javanica* inhabits Southeast Asia's tropical and subtropical forests, exhibiting unique adaptations such as specialized arboreal foraging behaviors (Chong et al. 2020). This contrasts with *M. pentadactyla*, which favors temperate forest regions and has been shown to adapt to colder climates with seasonal behavior shifts (Challender et al. 2019). These ecological and behavioral differences underscore the potential impact of region-specific studies on informing tailored conservation strategies for *M. javanica*, highlighting their importance.

Despite limited research on *M. javanica* within the UMS campus, there is significant potential for developing targeted conservation strategies to protect the local *M. javanica* population. It is crucial that we build on initial observations and studies to pave the way for tailored conservation efforts that address the unique challenges this species faces in the region. With dedicated research and strategic planning, effective measures can be implemented to support the sustainability of *M. javanica* at UMS.

Our research investigates the impact of anthropogenic pressures on Sunda pangolins within the UMS campus. We focused on two key pressures: proximity to human settlements and anthropogenic noise levels. To assess the pangolins' responses, we analyzed their spatial distribution and visitation frequency using camera trapping surveys. Our hypothesis postulates that *M. javanica* exhibits a negative response to these pressures, avoiding areas with proximity to human settlements and those with higher levels of anthropogenic noise. This underscores the need for immediate action to mitigate these pressures.

MATERIALS AND METHODS

Study area

This study was conducted at SFERA@UMS, Sabah, Malaysia (Figure 1). It was gazetted on 22 June 2022 as a forest reserve for UMS that covers 25.1 ha of forested land (Sompud et al. 2023). SFERA@UMS is a forest with a diversified environment, ranging from an open canopy mostly covered with bushes and grasses to a fragmented secondary forest. The vegetation is similar to a typical lowland forest. Stands of *Acacia* spp. dominate some areas. The terrain varies from flat to hilly, with occasionally steep slopes (Majuakim et al. 2018). The topography ranges from 37 to 190 masl. The area receives abundant amounts of rain with high humidity. The mean annual temperature and rainfall are 28°C and 2,700 mm, respectively.

Three main areas on the eastern side of SFERA@UMS are constantly occupied by residential colleges, almost entirely by UMS students. These three residential colleges are Tun Fuad Residential College (KKTF), E Residential College (KKE), and Tun Mustapha Residential College (KKTM). Five thousand seven hundred students actively reside on the UMS campus. The KKE accommodates 2,700 students, KKTM accommodates 1,600 students, and KKTF about 1,400 students (Universiti Malaysia Sabah 2015). These three human settlements were chosen to investigate the anthropogenic pressure on the *M. javanica* population at SFERA@UMS.

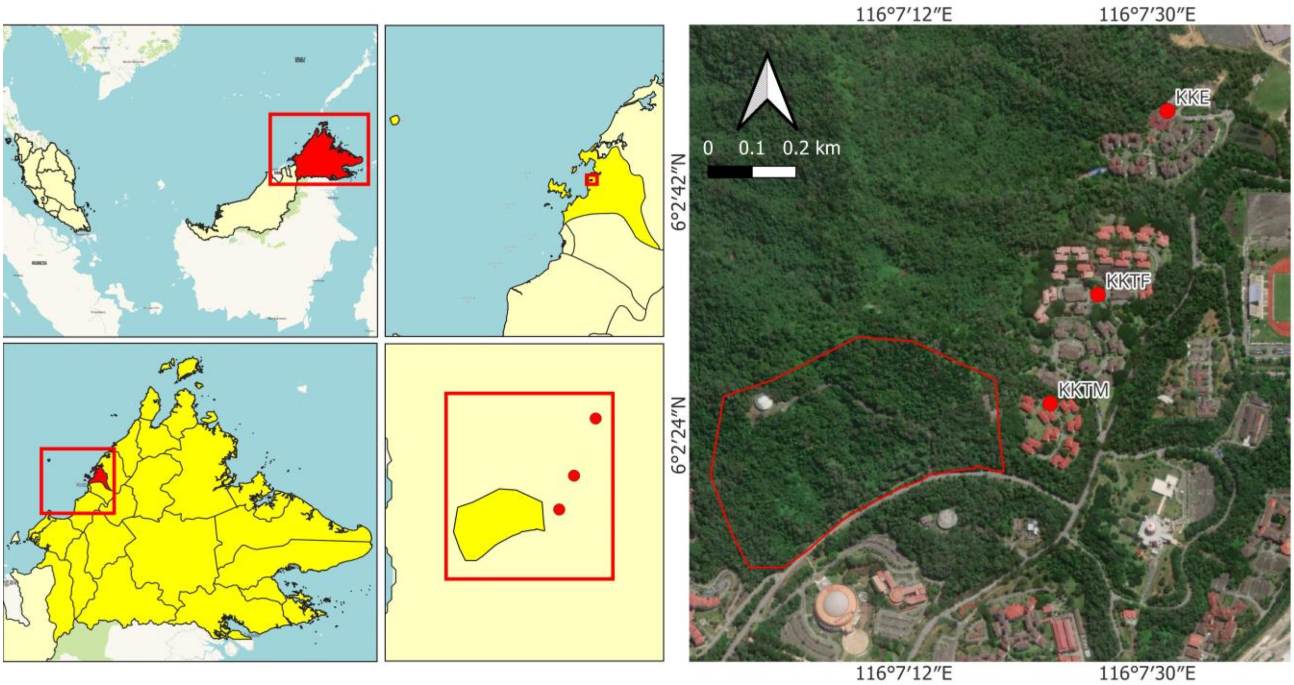

Figure 1. Location of SFERA@UMS within the main campus, Sabah, Malaysia. KKTF (Tun Fuad Residential College), KKE (E Residential College), and KKTM (Tun Mustapha Residential College) represent the residential areas near the study site, which were used to assess anthropogenic pressures on *M. javanica*

Methods

Camera trapping survey

At the onset of this study, meticulous preparations were undertaken to select the most suitable experimental design for our objectives, which focused on utilizing camera trap surveys (Meek et al. 2014). Recognizing the importance of effectively capturing wildlife data, we carefully assessed various factors, including the target species, habitat characteristics, and potential biases in data collection (Iannarilli et al. 2021), evaluating species-specific responses to camera-trap survey designs. We conducted preliminary trials involving camera placements in various microhabitats characterized by different vegetation densities, proximity to water sources, and termite mounds to determine optimal capture conditions. These tests focused on *M. javanica* and co-occurring nocturnal species to evaluate detection rates and camera sensitivity. The results of these assessments, which informed the deployment strategy, are available in supplementary materials. This approach ensured that our design would yield reliable and comprehensive insights into wildlife behavior. This thorough approach aligned with our research goals and aimed to enhance the overall efficacy of the camera trap surveys we employed.

Nine camera trappers were deployed in this research (Figure 2). In this study, SFERA@UMS was divided into three zones: Zone A, Zone B, and Zone C. Zone A was closest to the main road, followed by Zone B, further inland, and Zone C, furthest from the road. The Google Random Number Generator randomly selected three sampling plots in every zone. The circular points in the experimental design represent the center coordinates of the randomly selected plots, which were used as a reference to mark their location. A stratified random design was used to select the camera trap stations to reduce bias and to obtain a representation of the whole study area (Kays et al. 2020). The study area was divided into 100m × 117m grids. The grids measured 100 m × 117 m, selected to balance comprehensive coverage of the study area with feasible spacing for effective monitoring. Grids are usually constructed based on the home range of the studied species (Trolliet et al. 2014; IUCN SSC Pangolin Specialist Group 2018). The average stable home range size of *M. javanica* is 1.58 km^2, ranging from 0.29 km^2 to 2.63 km^2 (Sompud et al. 2023). However, a smaller grid size was chosen due to the study area's size and the research's duration.

The camera trapping survey was conducted for six months, from mid-June to mid-December 2023. Purposive sampling (Campbell et al. 2020) was conducted for this study. Camera traps were installed in locations where pangolin activity is anticipated, such as termite mounds, burrows, and branches of fallen trees, to increase the detection of *M. javanica* (Bruce et al. 2018; Simo et al. 2020; Ichu 2022). The camera trap models used were the Suntek model of Trail camera HC-800M and Reconyx Hyperfire HG600. Each camera trap was mounted on a tree at a one-meter height (Tawa et al. 2022). The Suntek Model was set to take three-burst shots of images and one 90-second video with a one-minute time interval after each trigger. On the other hand, the Reconyx was set to take ten-burst shots of images because it cannot take videos. Importantly, the camera traps were meticulously monitored monthly to ensure their condition and retrieve data, providing a reliable and robust dataset.

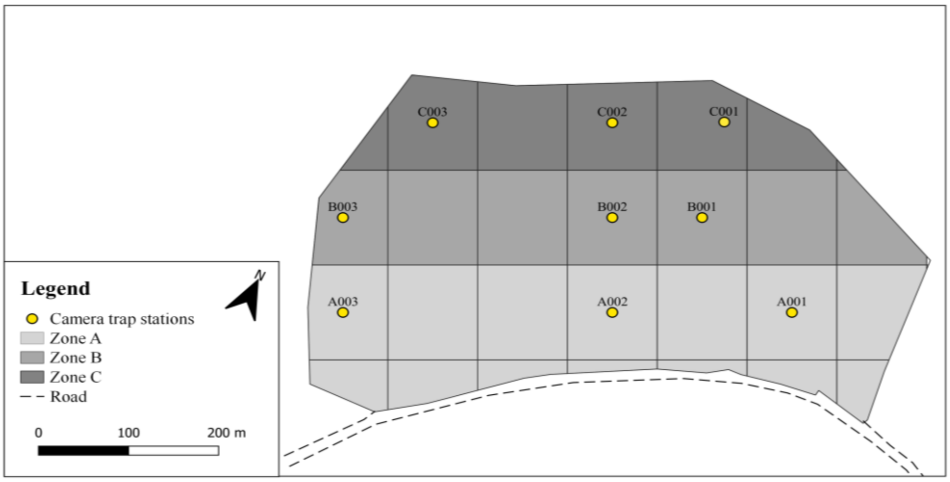

Figure 2. The camera trap station locations with the experimental design

Anthropogenic pressures survey

At each camera trap station, the distance to the nearest human settlement was measured using Google Earth Pro, applying a straight-line Euclidean distance method for accuracy (Tamang et al. 2022). Anthropogenic noise levels were recorded using a RadioShack digital sound level meter, capturing data in decibels (dBA) (Luther and Magnotti 2014). This detailed approach ensured precise measurements of both proximity to human settlements and noise levels for evaluating their impact on *M. javanica* presence. As previously stated, this study categorized KKTM, KKTF, and KKE as human settlements. Three monthly readings of the anthropogenic noise were taken and recorded. The mean, maximum, and minimum decibels were computed.

Data analysis

Photographs captured within a 30-minute window, showing the same animal or multiple animals during a single visit to the termite nests, were considered a single event (Lazarus et al. 2021; Tawa et al. 2022). The camera trap data was utilized to calculate the total number of *M. javanica* events and total trapping nights in every station. The data obtained was arranged in Microsoft Excel. The visitation frequency was calculated by dividing the number of independent events by the total number of trapping nights (Tawa et al. 2022; Matthews et al. 2023), as shown in the formula shown below.

The statistical analysis in this study employed Spearman's rank correlation, a non-parametric method suitable for assessing the strength and direction of monotonic relationships between variables (Sedgwick 2014). This test is non-parametric, meaning it does not require the data to follow a normal distribution, making it appropriate for ecological data that often deviate from such assumptions. A one-tailed test was used to evaluate statistical significance, focusing on whether the observed relationship was unidirectional, aligning with the hypothesis that *M. Javanica's* presence would decrease with increased proximity to human settlements and higher anthropogenic noise levels. This approach is justified when the research hypothesis is directional, as it increases statistical power by testing for an effect in only one specified direction. Data from the camera trap stations were organized based on distances from human settlements. They measured anthropogenic noise levels, facilitating the analysis of their relationship with the presence of *M. javanica*. Although this study primarily examined the independent impacts of proximity to roads and anthropogenic noise on *M. javanica*, future work should consider assessing the correlation between these variables to isolate their individual effects better.

RESULTS AND DISCUSSION

A total of 1,647 trapping nights yielded 5,044 photographs and videos. They varied across stations due to short battery life, camera theft, malfunction, and corrupted memory cards. Two Suntek camera traps were stolen during the study.

Spatial distribution

Sunda pangolins were observed in all three zones of the study area (Figure 3), but their spatial distribution was uneven, with a higher concentration in the western portion of SFERA@UMS. This finding highlights the importance of targeted conservation efforts in these specific areas (Belmont et al. 2022) to ensure the survival of the *M. javanica* within the SFERA@UMS ecosystem. Anthropogenic pressures may influence the observed spatial distribution pattern. Sompud et al. (2023) reported detecting *M. javanica* at the C001 station, but our study did not detect it.

Anasari et al. (2021) reported that in Bukit Barisan Selatan National Park, Indonesia, the spatial distribution of *M. javanica* was influenced by several specific environmental factors, including habitat type, vegetation density, and human disturbances. These factors impacted the species' use of space and movement patterns, contributing to an uneven distribution. The study indicated that areas with dense vegetation and minimal human presence supported higher pangolin activity, while regions with fragmented habitat or significant human activity showed reduced presence. These findings align with the current study's results, which also revealed that *M. javanica* preferred areas with lower anthropogenic pressure, such as greater distance from human settlements and lower levels of noise pollution. The parallels between these studies emphasize the importance of minimizing human disturbances and preserving continuous, undisturbed habitats to support *M. javanica* populations.

Sulaksono et al. (2022) documented that medium-sized mammals exhibit noticeable shifts in their distribution and behavior in response to human activities. Their findings demonstrated that disturbances such as noise and human presence could lead to avoidance behaviors, habitat shifts, or changes in activity patterns. These responses were observed as species moved away from areas of high human influence to regions offering more cover and reduced disturbance. This aligns with the current study's observations on *M. javanica*, where camera trap data revealed a clear pattern: the Sunda pangolin's presence was greater in areas situated further from human settlements and where anthropogenic noise levels were lower. The findings reinforce the concept that human activities can disrupt natural behaviors and force wildlife to adapt by seeking quieter, less disturbed environments. This response not only highlights the vulnerability of medium-sized mammals like *M. javanica* but also emphasizes the need for strategies that reduce human impacts to maintain their habitat preferences and ecological stability.

Visitation frequency

While the total number of trapping nights for this study was 1,647, encompassing all camera trap stations over the six-month research period, the number of nights varied significantly between individual stations. Only three stations, i.e., A003, B003, and C003, recorded the presence of *M. javanica*. These stations accounted for a combined total of 315 trapping nights, specifically 175 for A003, 20 for B003, and 120 for C003. Station B003 recorded only 20 trapping nights due to equipment issues, resulting in fewer data points compared to other stations. This discrepancy may have led to an overestimation of the visitation frequency at B003, potentially influencing the overall analysis. It is crucial to acknowledge this bias, which underscores the need for uniform data collection to ensure reliability.

The remaining 1,332 trapping nights included stations where no pangolins were detected, reflecting the uneven spatial distribution of *M. javanica* across the study area. A003 registered two independent detection events, while B003 and C003 each recorded one. The visitation frequencies of A003, B003, and C003 were 0.0114, 0.0500, and 0.0083. The relative sizes of the individuals captured from the camera traps were compared (Figure 4). We report that at least one individual, *M. javanica*, was using the forested area of SFERA@UMS.

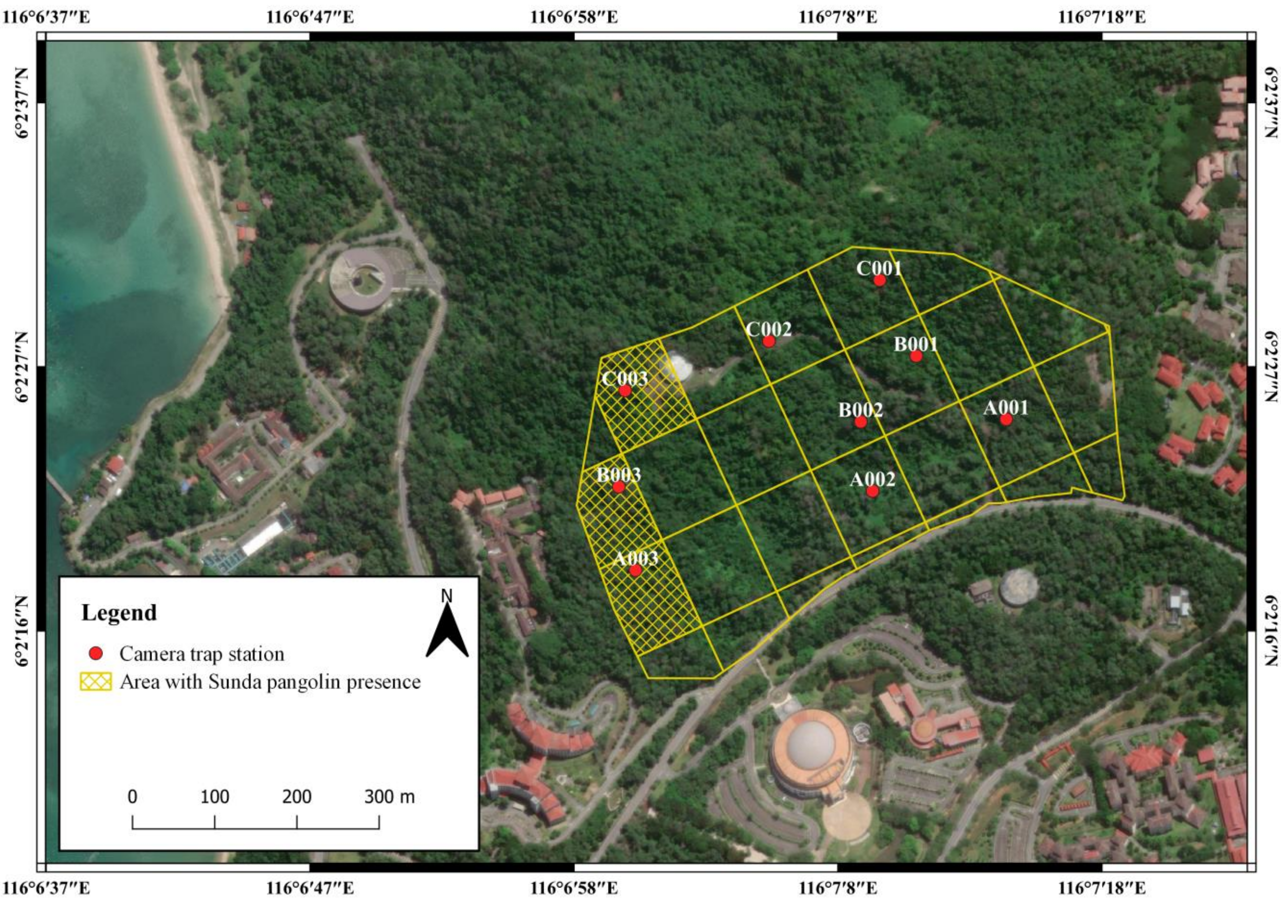

Figure 3. The spatial distribution of the *Manis javanica* in SFERA@UMS, Sabah, Malaysia

Figure 4. *Manis javanica* at a termite mound at: A. Camera station A003; B. Camera station B003; and C. Camera station C003

Based on this study's results, the *M. javanica* active period is 19:00-02:00 h. Sompud et al. (2023) recorded the presence of the *M. javanica* in their camera trapping survey at 22:45 h and 01:45 h. While Sompud et al. (2019) reported the activity pattern at Gaya Island, Sabah was from 20:21 to 02:22 h. Gray et al. (2022) discovered through their camera trapping survey that the Sunda pangolins' activity occurred around 03:00 to 04:00 h collectively across the Vietnam study sites. The result indicates that the *M. javanica* foraging time is at night, but the time varies according to the study locations. Some nocturnal animals emerge at night to avoid predators, providing a greater sense of safety (Sulaksono et al. 2023).

Anthropogenic pressures

Human settlement proximity

The analysis showed that the relationship between the distance to human settlements and the presence of *M. javanica* was positive, as indicated by Spearman's rank correlation coefficient (rs = 0.071**, $p<0.001$, n = 15,132). Although this correlation was statistically significant, it was weak, suggesting that while *M. javanica* was more likely to be detected at greater distances from human settlements, this trend alone did not strongly explain their occurrence. The preference for areas further from human activity implies that pangolins may be avoiding regions with higher levels of anthropogenic disturbance. Such areas, characterized by reduced human presence, likely offer more favorable conditions for the natural behavior and habitat needs of the species. However, the weak nature of the correlation indicates that additional, unmeasured factors also influence the distribution and detection of *M. javanica*. This finding aligns with Maurice et al. (2019), who noted that pangolins can adapt to some modified environments like livestock farms if protected but generally avoid heavily disturbed or densely populated areas.

At increasing distances from the human settlements, the absence of direct human activities creates favorable conditions for the survival of pangolin populations, reproduction, and feeding behaviors. On the other hand, habitat fragmentation, increased poaching risks, and other human disturbances can negatively affect the existence and well-being of the Pangolin population when they are closer to human settlements (Shrestha et al. 2021). The movement and behavior of *M. javanica* within SFERA@UMS can be further monitored in the future by incorporating other methods, such as radio telemetry. Using radio telemetry, migratory routes, critical stopover sites, and anthropogenic barriers to migration from remote areas can be identified (Gutema 2015). In Singapore, where poaching is minimal, the relationship between *M. javanica* and human settlement proximity is less obvious and more complicated as it resides in highly developed areas (Nash et al. 2020). The species have been observed using urban structures such as pipes to pass beneath buildings to access forested areas.

Mammals lacking sensitivity to human pressures are susceptible to poaching (Riggio et al. 2018). In human settlements where domestic dogs are reared adjacent to forested land, they are a potential issue for both nocturnal and diurnal species. Gray et al. (2024) reported capturing video from their camera trap surveys of domestic dogs threatening wildlife in forested areas in Vietnam.

Compared to our study, only a few feral dogs were found on campus, but we did not find any evidence that they use the forested area in SFERA@UMS. No still images or videos of dogs were captured during the study. This may also positively contribute to the survivability of the population of *M. javanica* here.

Anthropogenic noise

The anthropogenic noise detected in this study ranged from 51.3 dBA to 59.3 dBA (Figure 5). The graph illustrates the frequency of pangolin visits at different monitoring stations alongside each site's recorded mean, maximum, and minimum noise levels. Notably, stations characterized by elevated noise levels, such as A001 and B002, showed no pangolin activity, indicating that higher noise intensities correlate with reduced visitation. In contrast, stations like B003, which maintained moderate noise levels, recorded a higher frequency of visits. *M. javanica* was observed at stations where mean noise levels fell between 51.3 and 54.2 dBA. We found a significant negative correlation between pangolin visitation frequency and mean noise levels (Spearman's rank correlation, rs = -0.075**, p<0.001, n = 15,132). These findings suggest a negative correlation between noise intensity and pangolin presence, supporting the hypothesis that elevated noise disrupts pangolin behavior and deters site visitation. The pronounced reduction in visitation frequency with increasing noise levels underscores the species' sensitivity to anthropogenic noise, thereby highlighting the need for conservation efforts to mitigate the ecological impact of noise pollution on wildlife. This ecological relationship underscores the importance of understanding and addressing the species' sensitivity to noise disturbance, which likely disrupts their natural behaviors, such as foraging and movement, leading them to avoid noisier environments.

The Kruskal-Wallis H-test analysis indicated significant differences in the mean decibel levels among the various camera trap stations ($H \approx 15{,}130.87$, $p<0.001$). This finding demonstrates substantial variability in noise exposure across different sites within the study area. Consequently, this variability validates the observed relationship between anthropogenic noise and the visitation frequency of *M. javanica*. These results support the interpretation that anthropogenic noise may influence habitat use and behavioral patterns of *M. javanica*, reinforcing the need for targeted conservation strategies to mitigate noise pollution in critical habitats.

Areas further away from human settlements have less noise and lower human disturbance, especially at night when fewer people and cars pass by. For instance, some stations adjacent to roads and trails recorded no pangolins even though there were termite nests. These stations were located alongside the roads UMS residents or visitors often use, as they are part of the hiking trail leading up to UMS Peak, such as C002 (Figure 3). Meanwhile, UMS students were often seen in the camera traps of A001 and A002 because the area is frequently used for practical work purposes. Their presence contributed to the proximity and anthropogenic noise while conducting their practical work.

Anthropogenic noise, generated by urban development, transportation, and industry, has become a recognized stressor impacting wildlife, although its full effects remain inadequately understood (Shannon et al. 2015; Kok et al. 2023). Research indicates that noise can alter communication, disrupt mating, and reduce foraging efficiency, with species responses varying by sensitivity, exposure duration, and ecological context (Kunc and Schmidt 2019). When combined with stressors such as habitat loss, climate change, and disease, noise pollution can have compounded effects (Berkhout et al. 2023). Birds, for instance, may experience disrupted vocalizations essential for mating. Gilbert et al. (2017) reported that the avifauna community responds variably to anthropogenic noise, with some bird species exhibiting reduced vocal communication, which can affect mating success and territory defense. This disruption ultimately impacts their abundance and species richness in areas with elevated noise levels. Similar findings were noted in our study with *M. javanica*, where higher noise levels correlated with decreased visitation frequency, highlighting the broader implications of noise pollution on different taxa. Marine mammals can suffer stress and disorientation, leading to strandings (Erbe et al. 2019; Sørensen et al. 2023). These impacts highlight the need for continued research and targeted conservation strategies to address noise pollution's multifaceted effects on wildlife. The weak negative correlation between visitation frequency and mean decibel levels (Spearman's $rs = -0.075$, $p<0.001$, $n = 15{,}132$) suggests that *M. javanica* tends to avoid areas with higher noise levels, aligning with existing findings on wildlife sensitivity to noise (Shannon et al. 2016). This behavior underscores the potential for noise pollution to disrupt foraging and habitat use in this critically endangered species, emphasizing the need for conservation measures that minimize noise exposure in their habitats.

Despite the increasing awareness of these impacts, there needs to be more research on how certain species, such as *M. javanica*, respond to anthropogenic noise. As a nocturnal and highly secretive mammal, the Sunda pangolin's behavioral and physiological reactions to noise pollution remain largely unexplored. Given their critically endangered status due to poaching and habitat loss, understanding how noise pollution affects them could be crucial for their conservation. However, more data is needed to assess the full extent of the threat, highlighting a significant gap in the study of noise pollution's effects on lesser-known species. According to Chong et al. (2020), pangolins are very sensitive to noise and human presence. The *M. javanica* immediately flees or freezes when it senses a human presence. DiPaola et al. (2020) stated that *M. javanica* is thought to use acoustic information to avoid or detect predators. Compared to many other effects of human activity on wildlife, the effects of added noise sources have received less research attention. The effects include harm to the auditory system, masking sounds necessary for survival and procreation, imposing chronic stress and the associated physiological reactions, shock, interfering with mating behavior, and population decreases (Shannon et al. 2016).

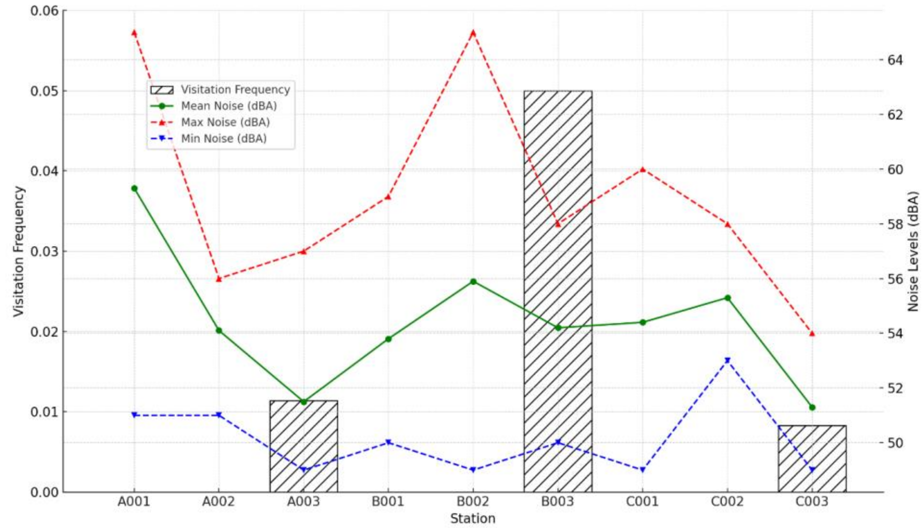

Figure 5. The anthropogenic noise (Decibel) detected at each camera trap station with the *Manis javanica* detection

Future research directions on anthropogenic impacts and conservation strategies

According to Kasper et al. (2024), *M. javanica* can be found in a large oil palm plantation in East Kalimantan, Indonesia. However, they reported the detection of *M. javanica* within the mixed-use landscape with several protected forest patches. Sulaksono et al. (2022) reported that human activity, particularly sand mining, negatively impacts *M. javanica* in Indonesia. The *M. javanica* was the foremost species that occupied areas devoid of humans, apart from the Asian Plam Civet (*Paradoxurus hermaphroditus* Pallas, 1777), long-tailed macaque (*Macaca fascicularis* Raffles, 1821) and barking deer (*Muntiacus muntjac* Rafinesque, 1815) in Indonesian forest (Sulaksono et al. 2023). Katuwal et al. (2017) reported anthropogenic impacts on Chinese pangolins (*Manis pentadactyla* Linnaeus, 1758). Their study shows that the species avoids areas with forest fires and livestock grazing in Nepal but does not avoid forest paths used by residents, which led to *M. pentadactyla* poaching. Darren et al. (2014) revealed that the Temminck's ground pangolin (*Smutsia temminckii* Smuts, 1832) greatest anthropogenic threat was electrocutions, with the mortality rates as high as one individual per 11 km of electrified fence per year.

Gilbert et al. (2017) reported that the response of the avifauna community may vary among species from the same family. Gilbert et al. (2018) have highlighted the detrimental effects of anthropogenic noise on bird populations in Gaya Island, Sabah, noting significant reductions in abundance and species richness in areas with 60 dB and above noise level. Their findings demonstrated that increased noise levels disrupt avian habitats, decreasing opportunities for foraging and breeding. Similarly, our study on *M. javanica* at UMS revealed a negative response to anthropogenic noise, as these mammals tended to avoid noisy areas altogether. Both studies underscore the critical impact of human-induced disturbances on wildlife, illustrating how noise pollution can lead to habitat displacement and reduced biodiversity. While Gilbert et al. (2018) focused on birds, our findings on *M. javanica* further emphasize the broader ecological consequences of noise, reinforcing the need for conservation strategies that mitigate such disturbances in diverse ecosystems.

The findings of this study underscore the importance of small habitats, such as SFERA@UMS, in supporting species with smaller home ranges like the *M. javanica*. These habitats serve as vital refuges, providing foraging and breeding sites essential for survival. Moreover, small habitats can function as ecological stepping stones within more extensive corridors (Herrera et al. 2017), facilitating connectivity not only for smaller species but also for larger mammals, such as tigers and elephants, thus contributing to a broader conservation network.

Future research should investigate the specific impacts of anthropogenic noise on *M. javanica* by conducting controlled experiments to quantify the effects of different noise levels on their activity and behavior patterns. Also, assessing habitat quality or constructing a habitat suitability index (Paudel et al. 2015) within different zones, considering factors like vegetation density, food availability, and den sites, will provide a more comprehensive understanding of the interplay between habitat quality and anthropogenic pressures (Ten et al. 2021). Evaluating the effectiveness of specific conservation actions, such as hedgerows as noise barriers and habitat restoration, is crucial for ensuring their success. These can be incorporated into time-predicting models (Zainuddin et al. 2019) for better holistic conservation strategies. Moreover, exploring the role of human-wildlife conflict through interviews with residents will shed light on perceptions and potential conflicts, informing the development of conservation strategies that address ecological and social needs (Jomes et al. 2023). Expanding the study area to other regions within Sabah or across the Sunda pangolin's range will provide a broader understanding of the factors affecting populations and inform more effective conservation efforts at a larger scale.

In the case of other endangered species in Malaysia, various authors have highlighted habitat protection as the key driver for long-term population sustainability. For instance, Ten et al. (2020) emphasize that effective habitat preservation is essential for the survival of the Malayan Tiger (*Panthera tigris jacksoni*, Linnaeus, 1758), while Zakaria et al. (2024) suggest that the Asian Elephant (*Elephas maximus* Linnaeus, 1758) also relies heavily on protected and connected habitats. In addition to habitat conservation, these studies advocate for adopting advanced monitoring technologies, such as biosensors, infrared drones, Artificial Intelligence (AI), and the Internet of Things (IoT), to create early warning systems for law enforcement agencies. Such systems can provide real-time data to combat poaching and illegal trade more effectively, particularly in biodiversity hotspots like Sabah.

This technological approach could greatly benefit the conservation of the Sunda pangolin, which, like the *P. tigris jacksoni* and *E. maximus*, suffers from habitat loss, poaching, and human-wildlife conflict. Integrating these advanced tools would allow conservationists and authorities to monitor pangolin populations, track poaching activities, and respond swiftly to threats. Implementing high-tech solutions aligns with Malaysia's National Biological Policy (2022-2030) and the Sustainable Development Goals (SDG 2030), which advocate for collaborative efforts among institutions, local communities, and international organizations to protect and co-manage endangered species. Institutional collaboration is essential to the success of these conservation efforts. Government agencies, research institutions, Non-Governmental Organizations (NGOs), and local communities must work together to develop holistic strategies encompassing habitat preservation, law enforcement, and community involvement. Collaborative frameworks, such as community-led conservation programs and partnerships with technology companies to deploy AI-driven solutions, could enhance the effectiveness of pangolin protection initiatives.

The involvement of local communities, particularly those living near pangolin habitats, is critical. These communities should be engaged in conservation programs through education, incentives, and alternative livelihood projects that reduce reliance on illegal wildlife trade (Jomes et al. 2023). Strengthening local stewardship, combined with scientific research and advanced technology, will play a crucial role in ensuring the long-term survival of the Sunda pangolin and other endangered species in Sabah and Malaysia.

Study limitations

In this study, the low occurrence rate of *M. javanica*, with only four independent detection events recorded over 1,647 camera-trap nights, presents an explicit limitation that may impact the robustness and generalizability of the findings. The limited number of detections restricts the statistical power of the analyses, particularly the relationships observed between pangolin presence, proximity to human settlements, and anthropogenic noise levels. Consequently, while significant correlations were identified, caution must be exercised when interpreting these results due to the potential for variability and sampling bias inherent in such a sparse dataset.

A notable limitation of this study is the potential correlation between the independent variables of proximity to human settlements and levels of anthropogenic noise. While Spearman's rank correlation was used to evaluate the relationships between these variables and the presence of *M. javanica*, it is acknowledged that these independent variables may not act independently. Proximity to human settlements can often be associated with increased noise levels, potentially confounding the observed effects. Therefore, it isn't easy to attribute the observed relationship solely to one factor without considering the influence of the other. This overlap should be recognized as a constraint in interpreting the results, as the study's design did not control for multicollinearity between independent variables.

Future research should address these limitations by extending the monitoring duration and deploying camera traps in a broader range of habitats, including more profound and remote forest areas. Such an approach would likely increase the detection rate and yield a more representative sample, enhancing the reliability of statistical analyses. Additionally, incorporating advanced methods such as stratified random sampling or remote acoustic sensors could improve data collection by capturing a broader spectrum of pangolin activity and responses to environmental factors. Rigorous statistical techniques, such as mixed-effects models or multivariate analysis, should also be considered to account for potential confounding variables and improve the analytical depth of future studies.

Though constrained by limited data, the findings presented herein provide a preliminary understanding of how *M. javanica* might respond to human-induced pressures within semi-urban forested landscapes. These initial insights contribute valuable information to the sparse research on the species' ecological behavior under anthropogenic influence. Acknowledging these limitations is essential to contextualize the results and inform subsequent, more comprehensive studies, which should aim to strengthen data collection methodologies and expand the scope of analysis for more robust conclusions.

In conclusion, the anthropogenic pressures investigated in this study, specifically the proximity of human settlements and anthropogenic noise, significantly affect *M. javanica*. These pressures are not unique to pangolins but are emblematic of the human-induced threats that have driven many of Earth's most precious biodiversity to extinction. If left unaddressed, such pressures will have severe repercussions for critically endangered species like *M. javanica* and the sustainability of ecosystems that humans depend on. In light of this, immediate and concerted efforts are required to mitigate the negative impacts of human activities on pangolin populations. The proximity of human settlements to critical habitats and the intrusion of noise pollution have disrupted pangolin behavior, particularly in terms of foraging and habitat use. It is crucial to implement strategies that minimize these disturbances to ensure the preservation of *M. javanica*. This includes establishing no-go zones or protected areas where human activities are restricted, particularly around sensitive habitats within urbanized and semi-urbanized regions like university campuses. The importance of raising public awareness cannot be overstated. Conservation efforts must extend beyond regulatory frameworks to foster an understanding among local communities about the ecological importance of species like *M. javanica*. Public education campaigns, mainly targeting communities near pangolin habitats, can play a pivotal role in reducing human-wildlife conflict and illegal poaching activities. Moreover, advanced monitoring technologies such as biosensors, infrared drones, AI, and IoT should be deployed to create early warning systems to enhance conservation efforts. These tools could provide real-time data to law enforcement agencies, enabling rapid responses to illegal activities and helping ensure better protection for pangolins. Such technological interventions align with Malaysia's National Biological Policy (2022-2030) and the global Sustainable Development Goals (SDG 2030), emphasizing the need for collaborative, multi-stakeholder approaches to biodiversity conservation. Therefore, a proactive, multi-faceted approach that includes habitat protection, technological monitoring, and public education is necessary to ensure the long-term survival of *M. javanica*. This approach safeguards the pangolin's future and maintains biodiversity and ecological integrity, fostering a harmonious coexistence between humans and wildlife. In doing so, we help secure a sustainable future for both Malaysia's rich biodiversity and the global ecosystem for generations to come.

ACKNOWLEDGEMENTS

The research permit obtained from Sabah Biodiversity Centre, Malaysia was JKM/MBS.1000-2/13 JLD.2 65. The UMS research grant GUG0611-1/2023 provided financial support for conducting fieldwork for this research. The camera traps were available through the Universiti Malaysia Sabah, Malaysia grant SBK 0424-2018 and Pangolin Consortium. We thank all the reviewers for their constructive and invaluable comments that further improved and enhanced this article.

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