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Historic record, current distribution and habitat selection of Chinese pangolin in Yangmingshan National Park, Taiwan

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ABSTRACT

The Chinese pangolin (*Manis pentadactyla*), a critically endangered species experiencing global population decline, requires a clear understanding of its habitat preferences and distribution for effective conservation. This study examined the current population status, habitat use and selection of Chinese pangolins in Yangmingshan National Park, Taiwan. By comparing the distribution of pangolin burrows with historical records, we evaluated changes in their range within the park. We analyzed relationship between environmental factors and presence of pangolin's burrow to identify the habitat preference. From June 2018 to November 2019, we recorded 707 pangolin burrows across more than 90 % of the 94 surveyed grid cells. The consistent presence of pangolins in historically active areas suggests that their distribution within the park has remained largely stable. Habitat selection modeling indicated a preference of pangolin for Formosa acacia forests, areas with higher solar radiation, and lower elevations. While proximity to roads and human settlements did not significantly influence habitat selection, pangolins tended to avoid areas near hot springs which was associated with human disturbance such as recreational activity. Although we found that termite abundance was not significant different between sites with and without pangolin burrows, the sample size was limited. This research provides updated information of distribution of Chinese pangolins in the national park that can serve as baseline data for future population monitoring. The results offer critical insights into the ecological requirements to support broader conservation efforts aimed at ensuring the species' long-term survival in Taiwan.

1. Introduction

Pangolins are specialized mammals with a highly selective diet, feeding almost exclusively on ants and termites, which play vital roles in ecosystems as predators and scavengers. By consuming these insects, pangolins help regulate their populations, influencing lower-level food chains and maintaining ecological balance (Bignell and Eggleton, 2000; Hölldobler and Wilson, 1990). Additionally, pangolins may act as ecosystem engineers by digging burrows that promote soil turnover and nutrient cycling, contributing to forest dynamics and regeneration (Chao et al., 2020; Davidson et al., 2012). These burrows also provide habitats for various small vertebrates and invertebrates (DeGregorio et al., 2022; Desbiez and Kluyber, 2013). However, despite their ecological importance, pangolins are among the most endangered species globally and remain the most widely trafficked mammals in the world (Challender et al., 2019b),

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with trafficking rates continuing to increase after the pandemic (Aditya et al., 2021). The demand for their meat and scales, particularly for food and traditional medicine, has led to population declines across their range (Challender et al., 2019b). Nevertheless, despite their status as a global conservation priority, ecological and biological data on wild pangolins remain limited (Heighton and Gaubert, 2021; Pietersen and Challender, 2019).

The Chinese pangolin (*Manis pentadactyla*), found in southern China, Taiwan, northern Southeast Asia, and parts of India and Nepal, is experiencing a rapid population decline due to habitat degradation and extensive illegal trade for its meat, skin, and scales (Challender et al., 2014; Challender et al., 2019b). As a result, it is now listed as "Critically Endangered" on the IUCN Red List (Challender et al., 2019a) and on Appendix I by the Convention on International Trade in Endangered Species of Wild Fauna and Flora. In Taiwan, Chinese pangolin is primarily found at altitudes below 1000 m, most commonly in the areas between 300 and 500 m, with rare records above 2000 m (Chao, 1989), and mainly inhabits forested areas such as broadleaf forests, mixed broadleaf-coniferous forests, secondary forests, and bamboo forests. Historically, Chinese pangolins faced extreme hunting pressure, with nearly 60,000 skins exported annually from the 1950s to the 1970s (Chao, 1989). However, with the enactment of Taiwan's Wildlife Conservation Act in 1989, which banned pangolin hunting and trade, populations have gradually recovered (Kao et al., 2019; Sun et al., 2019). Nevertheless, threats such as habitat loss, accidental trapping, and injuries from domestic dogs (*Canis lupus familiaris*) persist (Sun et al., 2019). The Chinese pangolin is currently classified as "Rare and Valuable" under Taiwan's Wildlife Conservation Act and listed as "Vulnerable" on Taiwan's Red List of Terrestrial Mammals.

Studying pangolin habitat use and selection is essential for understanding their resources needs and its environmental requirements, offering crucial information for habitat restoration and aiding in the planning of conservation and management strategies (Guisan and Thuiller, 2005; Pietersen and Challender, 2019). Habitat selection involves wildlife choosing an appropriate environment as a habitat based on various cues directly or indirectly related to resources necessary for survival and reproduction (Morris, 2003). By analyzing environmental factors, such as elevation, and resources, like food abundance, at locations where pangolin is present, researchers can identify the environmental characteristics pangolins use. Pangolins are difficult to observe due to their burrowing, solitary, and nocturnal nature, as well as their specialized diet, which makes trapping them for research challenging. Moreover, they also bury their feces and leave shallow footprints, making it hard to study their habitat use through scat and tracks. However, the burrows that pangolins dig for foraging or nesting are the most observable signs of their presence. The number and location of these burrows can help identify pangolin activity and are often used as indicators for population distribution and habitat use. This makes survey of burrow a key method for understanding pangolin behavioral ecology and is currently the primary approach for studying their habitat use and selection (Ingram et al., 2019; Willcox et al., 2019).

While studies on pangolin habitat use have been conducted in Taitung in southeastern Taiwan, only a few survey records exist for northern Taiwan, such as the transect survey of burrow traces in the Muzha area of New Taipei City (Tsai et al., 2004) and the study on

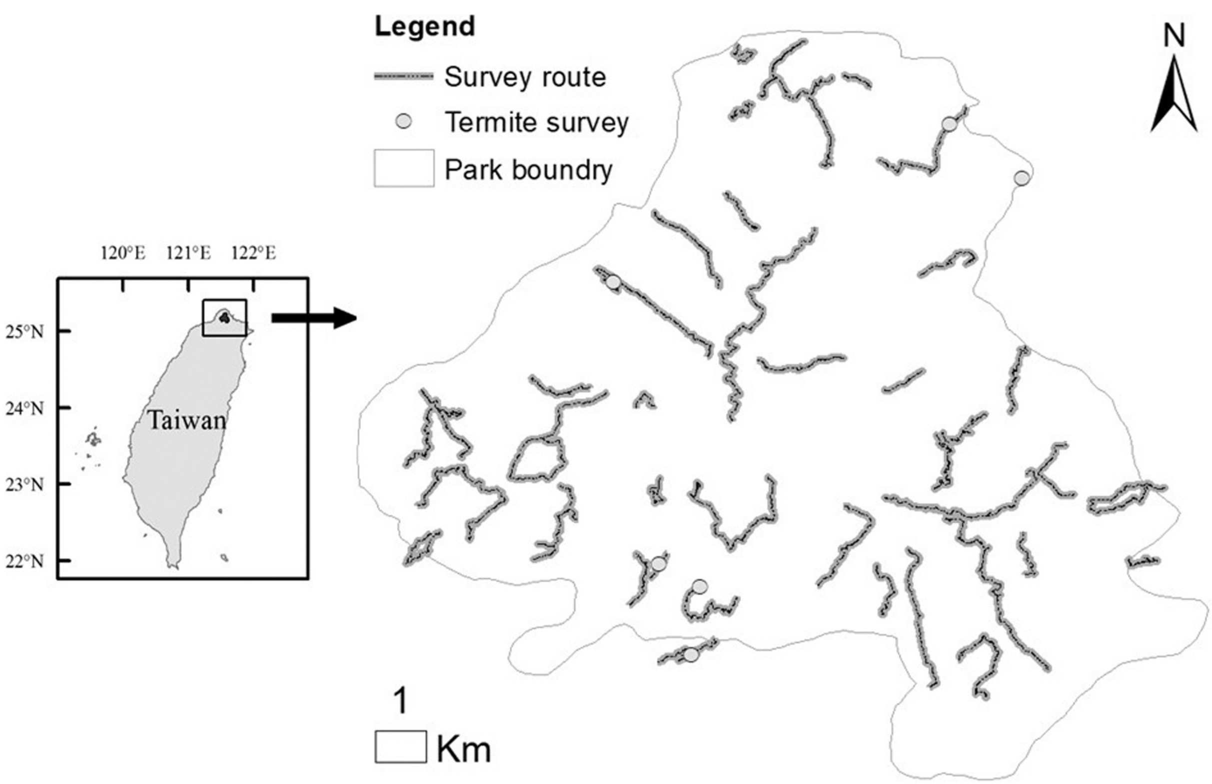

Fig. 1. Layout of the survey routes and termite survey sites in Yangmingshan National Park, Taiwan.

burrow habitats in the Feitsui Reservoir area (Fan, 2005), which is now over 20 years old. Given the rapid environmental changes in the region, updated research is needed to assess the current distribution and habitat use of pangolins in northern Taiwan. Yangmingshan National Park (YMSNP) is the largest and most protected mid-to-low elevation mountainous area in northern Taiwan, serving as an important site for ecological education and research. Although occasional pangolin burrows have been reported in the park, comprehensive data on their distribution remain scarce, with only a few sightings documented between 2012 and 2017 (Ju and Pei, 2014; Yen et al., 2017). Thus, there is a critical need to update our understanding of the species' population and habitat status in the park.

Additionally, food availability plays a crucial role in pangolin habitat use. Termites are major food source for pangolins (Difouo et al., 2024; Karawita et al., 2020; Wu et al., 2005). Previous studies have primarily relied on the presence of termite mounds or ant nests to examine food resources influencing habitat selection (Sharma et al., 2020; Suwal et al., 2020). However, termites in Taiwan do not form conspicuous mounds, making it difficult to survey food resources and assess their effect on pangolin habitat use. The ratio of termites to ants in pangolin feces is approximately 1:1 (Sun, 2020), with termite species composition and abundance in feces resembling that of the field (Liang, 2017). Therefore, measuring termite abundance in soil can serve as a useful proxy for food availability in pangolin habitats.

In this study, we aim to investigate the current population status, habitat use, and selection of Chinese pangolins in YMSNP. By comparing burrow distribution with historical records, we assessed changes in distribution of pangolins in the park. We compared environmental factors at burrows with random sites to determine if Chinese pangolin shows preferences for specific environmental factors. In addition, we explored effects of food availability on habitat use of Chinese pangolin by comparing abundance of termite in areas with and without pangolin burrows.

2. Material and methods

2.1. Study area

The Yangmingshan National Park is in the center of Taipei–Keelung metropolitan area of northern Taiwan (Fig. 1). Established in 1985, the park spans an area of 113 km^2, ranging in elevation from 56 to 1120 m. The park is part of the Tatun Volcano Group with hot springs and fumaroles scattered throughout the area. The average annual temperature in Yangmingshan National Park is 17.1–18.8°C, and the average rainfall is 4206–4812 mm (https://www.ymsnp.gov.tw/, accessed 1 Jul 2023). The park's vegetation is predominantly composed of lowland evergreen broad-leaved forests, characterized by Machilus sp. and Acacia sp., covering 76 % of its total area. Other types of land cover include agriculture (7 %), herbaceous plants (6 %), broad-leaved thickets (4 %), forest plantation (4 %), and others (3 %) (Hsu, 2008). The park is home to at least 26 mammal species, with seven of them being endemic to Taiwan, representing 27 % endemism (Chen, 2011). Approximately 9000 residents inhabit the park (Executive Yuan of Taiwan, 2022), and it attracts around 4.5 million tourists annually as of 2018–2019 (https://www.ymsnp.gov.tw/, accessed 1 Jul 2023).

2.2. Historic record of pangolin

We collected location records of Chinese pangolins within the YMSNP from 1995 to 2017. The sources of these records include research articles on Web of Science, Google Scholar, thesis on National Digital Library of Theses and Dissertations in Taiwan, research reports on the website of YMSNP (https://www.ymsnp.gov.tw/), and Forestry and Nature Conservation Agency (https://conservation.forest.gov.tw/), Yangmingshan National Park Headquarters, National Parks of Taiwan Biodiversity Database, and Taiwan Roadkill Observation Network (https://roadkill.tw/). For online resources, we used "pangolin" and "Yangmingshan" as keywords. We extracted literature or record containing "pangolin" and "Yangmingshan" or "Taipei" or "New Taipei" in titles, abstracts or keywords. We browsed titles and abstracts in the search results and extracted information of survey of pangolin in the YMSNP.

2.3. Survey of distribution of pangolin

To survey the distribution of pangolins systematically through the national park, we overlaid the park with a regular grid with cells of 1 km^2 generated by ArcMap 10.1 (ESRI Redlands, CA, USA). After preliminary investigation in the park, we excluded 46 grid cells because of limited accessibility due to terrain topography and human residence, resulting in a total of 94 grid cells (67 % of 140 grid cells) were surveyed. We established 20 survey routes with total length of 67.3 km in 2018 and conducted six surveys on the 20 routes from June 2018 to September 2019. We established additional 24 routes in 2019 and surveyed for one to three times from April to September in 2019. The total length of 44 survey routes was 125 km (Fig. 1). During the survey, we searched for active and old burrows of pangolin within 5 m on either side of the routes. Any burrows encountered while on the way to the survey routes were also recorded. For each burrow, we marked and recorded the location to avoid repeated count. We measured the diameter of the entrance and the maximum depth we can reached with flexible steel tape of burrow. The volume of the excavated soil is calculated using the cave's diameter and depth ($\pi \times \text{radius}^2 \times \text{depth}$). We excluded burrows with diameter less than 9 cm, which were likely created by other species such as The Chinese ferret-badger (*Melogale moschata*) and The Formosan wild boar (*Sus scrofa taivanus*). The locations of the burrows identified indicate the distribution range of pangolins in the park, which is then compared to the historical records of pangolins in the park from 1995 to 2017.

2.4. Habitat selection function and habitat map

To understand habitat selection of Chinese pangolin, we compared environment of burrow with random locations in the surveyed area. In previous studies of pangolin habitat use in Taiwan, a one-hectare grid was used as the spatial resolution (Lai, 2014). Therefore, we first divided the 1-square-kilometer grid cells into 1-hectare grid cells and selected the grids containing survey routes to represent surveyed area. Since some burrows were not recorded during route surveys, we selected burrows located within these grid cells to represent the environment used by pangolins. An equal number of random points were then generated within the grids to represent the environmental factors available to pangolins within the survey area. A total of 506 burrows were recorded within the survey grids from 2018 to 2019, so 506 random points were generated within the grid cells.

Environmental conditions such as elevation, slope, aspect, solar radiation, and distance to water resource, as well as anthropogenic factors including distance to roads and human settlement could affect occurrence of the Chinese pangolin (Lai, 2014; Panta et al., 2023; Sharma et al., 2020; Shrestha et al., 2021). Therefore, for each burrow and random location, we recorded election, slope, aspect, solar radiation, NDVI (Normalized Difference Vegetation Index), land cover, and distance to water body and human disturbance. Elevation, slope, and solar radiation were derived from Digital Elevation Model provided by the Ministry of the Interior, Taiwan (https://data.gov.tw, accessed 1 Feb 2018). The NDVI was calculated using images from the USGS Landsat 8 satellite taken on September 8, 2019. The resolution of elevation, slope, solar radiation and NDVI was uniformly set to $20 \times 20\ m^2$ due to the precision of the data provided by governmental agencies. Aspect was categorized as follows: northeast (0–90 degrees), southeast (91–180 degrees), southwest (181–270 degrees), and northwest (271–360 degrees). We extracted types of land cover at burrow from layers of vegetation cover provided by the national park (Chen, 2011; Hsu, 2008) and layer of forest cover provided by The Forestry and Nature Conservation Agency in Taiwan (https://data.gov.tw, accessed 11 Nov 2019). We classified land cover into four types: red nanmu forest, Formosa acacia forest, other types of forest (*Fargesia* thickets, bamboos, *Cryptomeria japonica*, etc.), and non-forest land (grass land, farm land, recreation area, etc.). The primary tree species in the red nanmu forest is the red nanmu (*Machilus thunbergii*), signifying the natural forest community at higher altitudes within evergreen broadleaf forests. The acacia forest is predominantly composed of Formosa acacia (*Acacia confusa*), with other tree species including *Ardisia sieboldii*, *Schefflera octophylla*, red nanmu, *Glochidion rubrum*, and more. This forest type undergoes a gradual transition from the reforestation with Acacia trees to eventually becoming a natural, low-altitude evergreen broadleaf forest (Chen, 2011). The water layer was provided by the Water Resources Agency in Taiwan (https://data.gov.tw, accessed 1 Feb 2018). To quantify level of human disturbance at burrow and random location, we used ArcMap 10.1 to calculate distances to the nearest road, hot spring, and human settlement. In YMSNP, hot springs are major recreational areas and closely linked to recreational activity and human food subsidies for dogs and cats (*Felis catus*) (Hu et al., 2019; Yen et al., 2019). The layer of roads, hot springs, and human settlements including buildings, farms and recreation areas, was extracted from a land-cover layer provided by the administration office of Yangmingshan National Park.

We used generalized linear model with a binomial distribution to build resource selection function (Keating and Cherry 2004) of pangolin. The dependent variable was the burrows that represent used location or random points that represent available location (set equal to 1 for "use location" and 0 for" available location"). The independent variables we considered include elevation, slope, aspect, solar radiation, NDVI, land cover, distance from water, distance from roads, distance from human settlement and distance from hot springs. We selected the best model through the forward selection method (James et al., 2021). The order in which variables were chosen indicated the extent to which they explained the model residuals, which reflected their relative importance to the dependent variable. We used the area under curve of the receiver operating characteristic (ROC) to evaluate model performance. We validated the model with burrows that were not included in the habitat selection modeling. The 1-hectare grid cells where the model predicted a pangolin usage probability greater than 50 % were classified as "used," while those with a probability less than 50 % were classified as "not used." If a burrow was in a grid cell predicted to be used by pangolins, the prediction was considered correct. We then calculated the proportion of the burrows located in grid cells where the model's prediction was correct.

To map habitat of pangolin in the YMSNP, the average environmental factors per hectare were calculated. For land cover of each grid, the dominant type of land cover (the type occupying the largest proportion of the grid) was used. The habitat selection model was then used to estimate the distribution of pangolin habitats within the park.

2.5. Effects of termite abundance on habitat use of pangolin

To understand whether food abundance affects pangolin habitat use, we conducted a termite survey in 2019, based on the data from the survey of pangolin burrow in 2018. Due to limited personnel and funding, we were unable to survey termites along all survey routes. The termite survey was carried out along six routes, three with an average of 21 burrows of pangolin (SE: 2.08) and three without any burrow of pangolin (Fig. 1).

The method for surveying termites was modified from Jones and Eggleton (2000). For each survey route, we established a 100 m $\times$ 2 m transect parallel to the route. The vegetation type of six transects were the acacia forest. Taiwan is home to 23 termite species, with foraging ranges varying from a few meters up to 100 meters. For example, *Odontotermes formosanus*, the most abundant termite species in Taiwan, forages over distances of 30–40 m (Hu et al., 2006) (Lin et al., unpublished). The *Reticulitermes* spp. reportedly forage over distances of 40–70 m (Grace, 1990; Su, 1994), while *Coptotermes* spp. has the longest foraging range in Taiwan, reaching up to 185 m (Su, 1994). Along the survey route with pangolin burrows, considering the territory size of termite in Taiwan, the termite survey transects was established at least within 100 m from the burrows. On average, 3.5 burrows were found within 100 m of each transect. All transects were placed alongside survey routes and did not intersect pangolin burrows. Given the foraging distance of termite, the presence of termite in the transects should be representative of termite within pangolin foraging areas.

To quantify termite abundance, each transect was divided into 200 one-square-meter plots. After clearing ground vegetation, termites were searched and collected in each 1 m^2 plot. Because termites typically occupy the top 0–15 cm of soil (Abe and Matsumoto, 1979), searches included decayed fallen logs, mud tubes on trees, and soil up to 15 cm deep, with the presence or absence of termites recorded for each 1 m^2 plot. We spent 1.5 mins per person per square meter effort for searching termites by using a small shovel (16 cm $\times$ 8 cm blade, weighing about 156 g, made of Chromium-molybdenum stainless steel). The number of 1 m^2 plots with termite presence served as an index of termite abundance. For example, if termites were found in 50 out of 200 plots, the termite abundance at that transect would be 50. This method allowed for standardized comparisons of termite abundance across different functional groups in the topsoil.

When termites were found, they were collected for species identification. The collected samples were preserved in 95 % alcohol, with the alcohol being replaced within a week. Species identification was based on the species identification key for termites in Taiwan (Wu and Li, 2020). We then used a *t*-test to compare termite abundance between transects with and without burrow of pangolin.

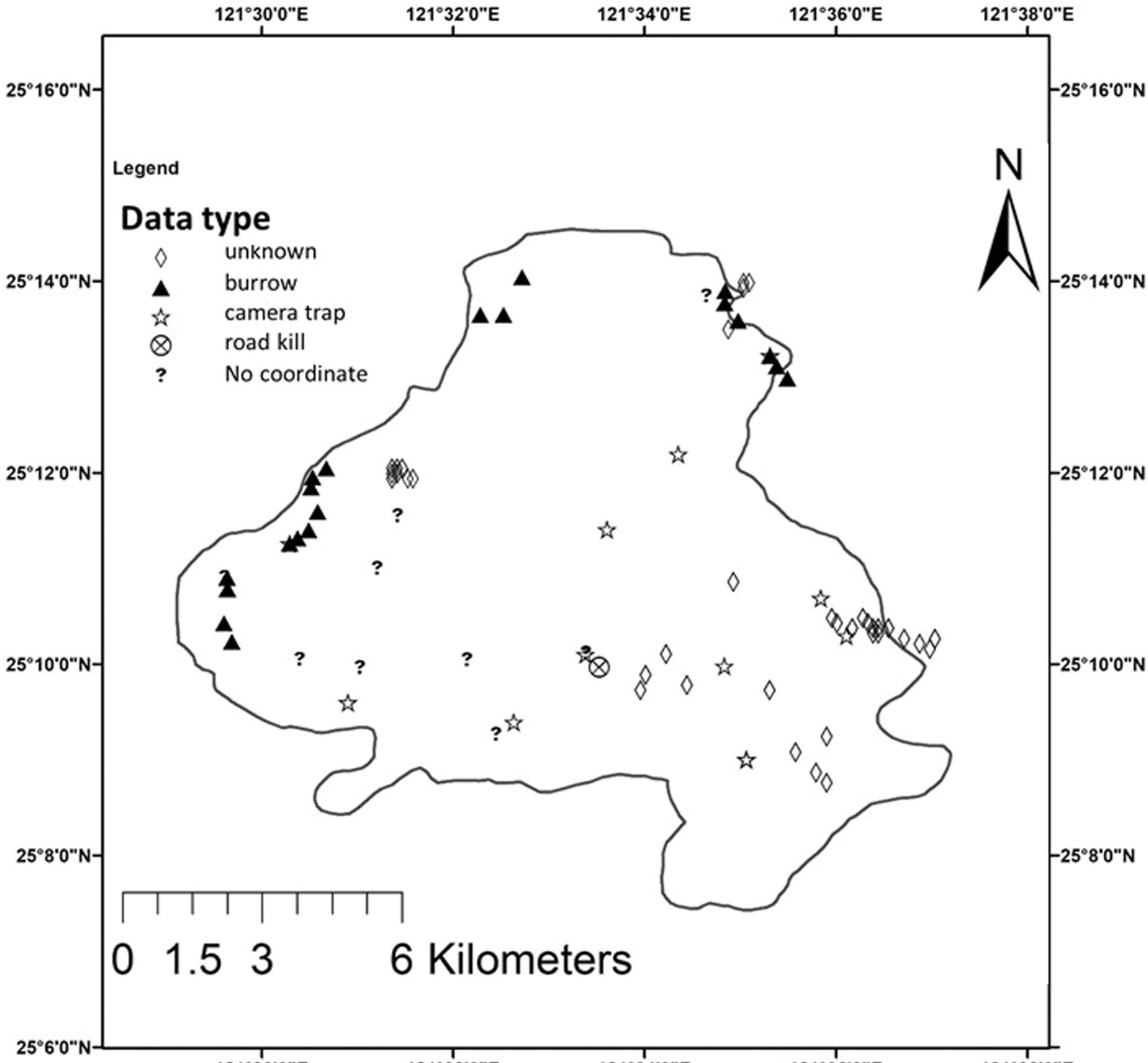

Fig. 2. Historic record of Chinese pangolins from 1995 to 2017 in Yangmingshan National Park, Taiwan.

3. Results

3.1. Historic record of pangolin

We compiled a total of 223 historic records of Chinese pangolin in the YMSNP from 1995 to 2017, including 72 historic records from 16 reports, 148 records from National Parks of Taiwan Biodiversity Database, 1 road kill record from Yangmingshan National Park Headquarter, and 2 records from personal communication (Yen and Ju, personal communication) (Fig. 2). Among these, 40 records without coordinate information were approximately marked based on descriptions in the reports. Some trails in the park extend beyond its boundaries, leading to a few pangolin records being documented outside the park. Since these trails are closely connected to the park, we did not exclude these records. The 72 records from reports include 17 camera trapping locations, 54 burrows, 1 feeding sign (Table S1). Approximately 80 % of the 223 records (n = 175) were collected between 1995 and 2010.

3.2. Distribution of burrow of pangolin

From June 2018 to November 2019, a total of 707 burrows were recorded (Fig. 3), including 506 burrows along the survey routes and 201 burrows found on the way to the survey routes or in other areas of the park. The diameter of entrance was 10–54 cm with of

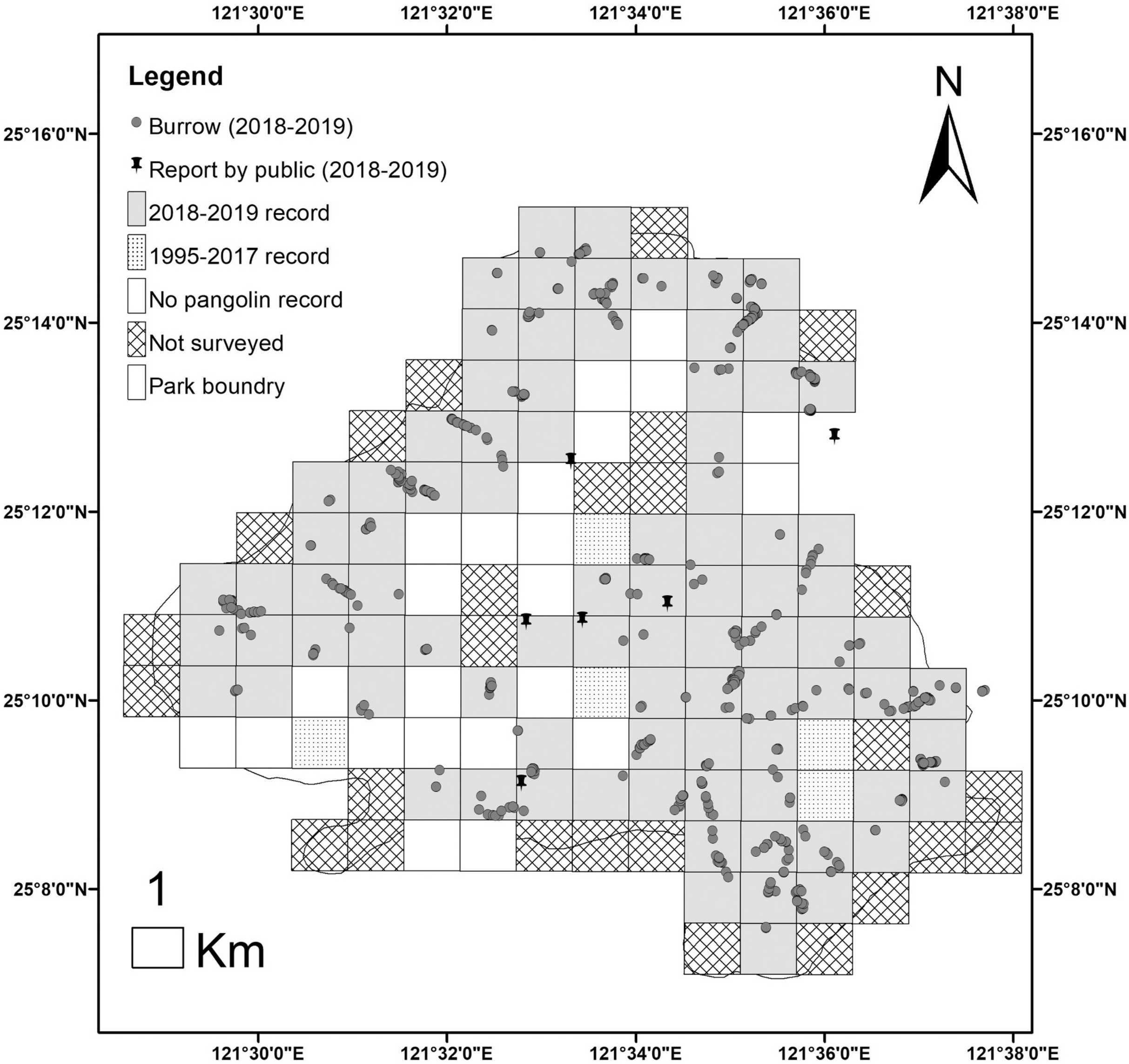

Fig. 3. Locations of sighting reports by public and burrows of Chinese pangolins in Yangmingshan National Park, Taiwan, 2018–2019.

the average of 21.31 cm (SE: 0.20). The average depth was 70.57 cm (SE: 1.60), with the maximum measurable depth of 375 cm. The average volume of excavated soil was 0.04 cubic meters (SE: 0.002). We collected 9 records of pangolin that were report by public, local government agencies and Yangmingshan National Park Headquarters (Fig. 3). Reported records included 1 of road kill, 1 of carcass, 2 of burrows, and 5 of sightings.

Burrows were found in 86 out of the 94 surveyed 1 km^2 grid cells (91.4 %) in this study. Comparing the historic records in the park from 1995 to 2017, which covered 39 grid cells, burrows were found in 34 of those grid cells. Although we did not record burrows in 5 grids with historic record, burrows were found in adjacent grids, indicating that the areas previously used by pangolins were still visited by them in 2018–2019.

3.3. *Habitat selection function and habitat map*

About half of burrows (51 %) were in Formosa acacia forest, 33 % (n = 236) were in red nanmu forest, 11.7 % (n = 87) were in other types of forest (*Fargesia* thickets, bamboos, *Cryptomeria japonica*, etc.), and only 4 % (n = 29) were in non-forest land (grass land, farm land, recreation area, etc.). The average NDVI at burrows was 0.29 (SE: 0.006). The average altitude was 474 m (SE: 6.06), with half of the burrows distributed between 353 and 588 m. The average slope at the burrow entrances was 37.08 degrees (SE: 0.88).

3.3.1. *Habitat selection function*

The environmental variables in the final habitat selection model included elevation, slope, solar radiation, land use type, and distance from hot springs. The results showed that the probability of finding a pangolin burrow decreased with increasing elevation and decreased as the slope increased. Pangolins were more likely to use habitats with higher solar radiation and were less likely to use areas closer to hot springs. Compared to red nanmu forest, pangolins prefer Formosa acacia forest and were less inclined to use other types of forest or non-forest areas (Table 1). The area under the ROC curve was 0.73. We used the 201 burrows not included in model building process to validate the model. We excluded three burrows that were out of range and, therefore, could not extract environmental variable values from the GIS layers. The results show that 77 % of burrows (n = 153) were in the grid cells that predicted to be used by pangolins.

3.3.2. *Habitat map in YMSNP*

We used the final habitat selection model to estimate the distribution of pangolin habitat within the park. Out of 12,433 one-hectare grid cells, 44 % have a probability of presence of pangolin burrow greater than 50 % (Fig. 4). These grid cells were primarily distributed in the Formosa acacia forest and red nanmu forest at elevations of 300–500 m, mainly located in the outer areas near the park's boundary.

3.4. *Effects of termite abundance on habitat use of pangolin*

Totally, three families, six genera and six species of termites were collected including *O. formosanus*, *Reticultermes flaviceps*, *Sinocapritermes mushae*, *Pericapritermes nitobei*, *Nasutitermes parvonasutus* and *Neotermes koshunensis*. Since the worker termites of *Sinocapritermes mushae* and *Pericapritermes nitobei* had similar morphology, and some samples only included workers, making it impossible to distinguish between the two species. The abundance of the two species were combined in Table 2. The average termite abundance at sites with and without burrows was 32 (SE: 6.2) and 26 (SE: 11.9) respectively (Table 2), with no significant difference ($t_2 = 0.45$, $p = 0.68$).

4. Discussion

4.1. *Distribution of pangolin*

The global population of Chinese pangolins is rapidly declining, emphasizing the urgent need for continuous monitoring of their distribution and habitat associations (Challender et al., 2019a). In this study, evidence of pangolin presence was found in over 90 % of the 94 surveyed 1-square-kilometer grid cells, suggesting a widespread distribution within the park. The primary exceptions were areas along the southern park boundary, which are more densely populated, and a military-restricted area that was surveyed only once,

Table 1
Covariate coefficient estimates from the logistic regression model for habitat selection of Chinese pangolins in Yangmingshan National Park, Taiwan, 2018-2019.

Variables	Estimate	SE	P value
Elevation (m)	−0.003	0.0005	< 0.0001
Distance from hot spring (m)	0.0002	< 0.0001	< 0.0001
Slope	−0.024	0.008	0.0036
Solar radiation (*1000)	0.0017	0.0005	0.0009
Non-forest land (Red nanmu forest as reference level)	−0.83	0.20	< 0.001
Other types of forest (Red nanmu forest as reference level)	−0.37	0.16	0.0273
Formosa acacia forest (Red nanmu forest as reference level)	0.59	0.14	< 0.0001

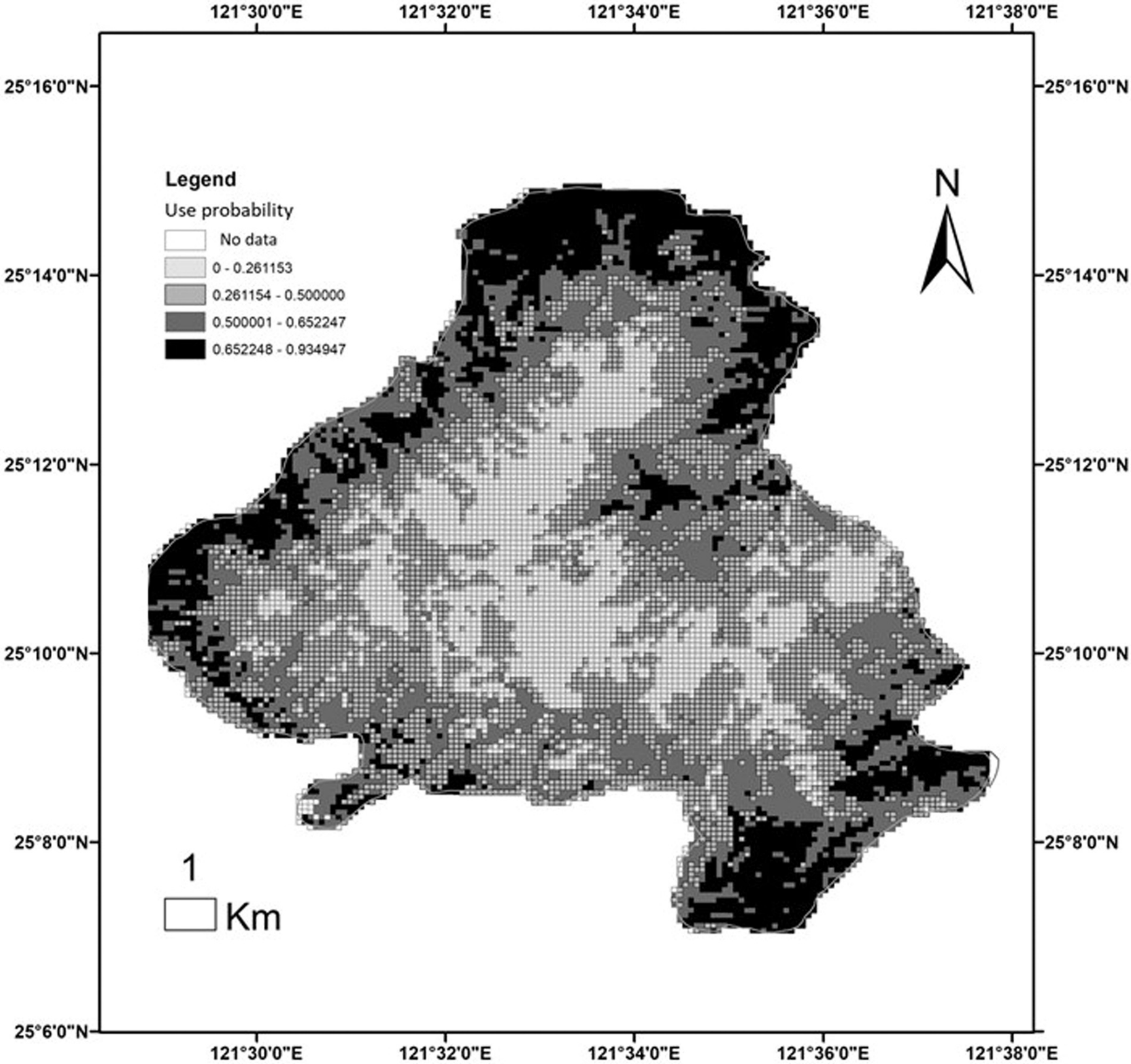

Fig. 4. Estimated use probability of Chinese pangolins in Yangmingshan National Park, Taiwan, 2018–2019.

Table 2
Species and abundance of termite at sites with burrows of Chinese pangolin and without burrows in Yangmingshan National Park, Taiwan, 2018-2019.

	With burrow			Without burrow		
	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3
Odontotermes formosanus	18	12	30	7	7	34
Reticulitermes flaviceps	2	3	6	0	0	2
Sinocapritermes mushae & *Pericapritermes nitobei*	9	13	8	2	12	15
Nasutitermes parvonasutus	1	0	7	0	1	3
Neotermes koshunensis	0	0	0	1	0	0
Termite abundance	27	24	44	10	18	49

yielding fewer pangolin records. Despite these areas, pangolins were observed in all other regions, including those with historical records of pangolin activity, suggesting that their distribution range within the park has remained stable. These findings support earlier reports, such as the 2017 International Conference on Integrated Conservation and the Analysis of Pangolin Population and Habitat Persistence (Kao et al., 2019), which indicated a positive population trend in Taiwan since 2004. (Chao et al., 2005).

4.2. Habitat selection of pangolin

Our results are consistent with earlier studies in Taiwan, which indicate that pangolins prefer low-elevation areas with gentle slopes and higher solar radiation (Chao, 1989; Fan, 2005; Lai, 2014). Similarly, in China, the burrows of the Chinese pangolin are typically located on slopes of 30–60 degrees with abundant sunlight (Wu et al., 2003; Zhang et al., 2024). Because pangolins are sensitive to cold environments, they may select high-solar-radiation areas to maintain optimal burrow temperatures (Wu et al., 2003). Interestingly, our study revealed that pangolins preferred Formosa acacia forests over red nanmu forests. This contrasts with previous research in northern Taiwan, which suggested that pangolins do not exhibit strong preferences for specific vegetation types (Fan, 2005). In southeastern Taiwan, pangolins are less inclined to prefer natural broadleaf forests (Lai, 2014). Red nanmu forests are the natural forest type in higher elevation areas of YMSNP, while Formosa acacia forests are semi-natural forests that have gradually developed from past Acacia plantations (Chen, 2011). Whether this preference indicates an affinity for plantation or secondary forests within the park requires further investigation.

Previous camera trap surveys in the park showed that the closer to human settlements, the lower the occupancy of native mammals, which in turn affects species diversity (Yen et al., 2019). However, we found that human factors, such as the distance from roads and human settlements, do not significantly affect pangolin habitat selection. In Luanshan, Taitung, southern Taiwan, pangolins prefer regions farther from major roads like provincial and county roads, but do not avoid minor roads (Lai, 2014). Additionally, newly dug burrows found in winter often appear in highly disturbed environments, though these burrows tend to be shorter and associated with small termite nests, suggesting they are primarily used for foraging (Lin, 2011). Other studies have also found pangolin burrows near trails, indicating that pangolins may use areas close to human activity (Zhang et al., 2022). In contrast, research in Nepal suggests that burrow presence decreases near trails and human settlements (Katuwal et al., 2017), while in Sri Lanka, burrow numbers increase with distance from settlements and roads (Shrestha et al., 2021). In addition to influencing habitat use, roads may pose a potential threat through wildlife-vehicle collisions. Data from the Taiwan Roadkill Observation Network (TaiRON) reported 70 pangolin roadkill incidents from 2011 to 2019, most occurring between May and September, with an increasing trend. In YMSNP, two pangolin roadkill incidents were reported between 2017 and 2018, indicating that roads could be a threat to pangolins within the park. These findings underscore the need for further research on the impact of roads on pangolin populations.

Additionally, we found that pangolins were less likely to be present near hot springs. In YMSNP, hot springs are associated with recreational activity, and food subsidies for free-roaming dogs and cats are common in these areas (Yen et al., 2019). Free-roaming dogs have negatively affected distribution and activity patterns of native mammals in the park (Yen et al., 2019). Records from the Pingtung Wildlife Rescue Center indicate that from 2006 to 2017, tail injuries—suspected to be caused by dog attacks—accounted for 20.4 % of trauma cases in Chinese pangolins (Sun et al., 2019). However, since our study did not assess dog distribution and activity along survey routes, we could not incorporate this factor into the habitat selection model. Further research is needed to determine whether pangolins avoid hot spring areas due to human disturbance, the presence of dogs, or other environmental characteristics.

4.3. Effects of termite abundance on habitat use of pangolin

The diameter of burrow entrance and depth of the burrows we recorded are similar to those found in the previous study in northern Taiwan (Fan, 2005), suggesting that most of the burrows are likely feeding burrows. In Nepal, the number of burrows increases as the distance to termite mounds decreases (Shrestha et al., 2021; Suwal et al., 2020; Tamang et al., 2022). We also found that pangolin burrows tend to be in areas with a certain level of termite abundance. Among our samples, *Odontotermes formosanus* was the most abundant termite species. Previous research has found that *O. formosanus* constitutes about 50 % of food biomass of Chinese pangolin in low-altitude areas (Sun, 2020). However, our study suggests that pangolins do not necessarily prefer areas with the highest termite abundance. During the summer, pangolins consume significantly fewer termites compared to other seasons, indicating that ants may become their primary food source during this period (Liang, 2017; Sun et al., 2020). Due to the limited number of termite survey sites, future studies should include more locations and account for ant abundance to better understand effects of food abundance on habitat selection of Chinese pangolin.

5. Conclusion

Our study provides updated information of Chinese pangolin in northern Taiwan. The results indicate the widespread distribution of the Chinese pangolin in Yangmingshan National Park, and show the habitat preference for low-elevation areas with gentle slopes, high solar radiation, and Formosa acacia forests. Despite historical population declines due to poaching and habitat loss, our findings suggest that pangolins persist in previously recorded areas, indicating a degree of stability of their distribution in the protected area. However, potential threats such as roadkill, and human disturbances near hot springs remain concerns for their conservation. While habitat selection was influenced by environmental factors, termite abundance did not appear to be a strong determinant of pangolin presence, suggesting a more complex relationship between food resources and habitat use. Given the ecological importance of pangolins and their ongoing threats, continued research and conservation efforts are essential. Future studies should focus on long-term population monitoring with baseline data from this study, the impact of human activity, and the role of food availability in habitat selection of pangolin. Effective conservation strategies, including habitat protection, mitigation of roadkill, and management of human disturbance, will be helpful in ensuring the survival of this critically endangered species.

Ethics Statement

If this manuscript involves research on animals or humans, it is imperative to disclose all approval details.
The research has been approved by Yangmingshan National Park.

CRediT authorship contribution statement

Chen: Conceptualization, Methodology, Software, Validation, Formal analysis, Visualization, Writing, Project administration, Funding acquisition. **Liao**: Investigation. **Lin**˙ Investigation, Methodology, Writing. **Li**: Validation, Editing

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used Chat GPT to improve language and readability. After using this tool, the author reviewed and edited the content as needed and take full responsibility for the content of the publication.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gecco.2025.e03521.

Data availability

Data is provided as supplementary materials

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