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Modeling Current and Future Habitat Suitability of the Sunda Pangolin (*Manis javanica*) Across Southeast Asia Using Species Distribution Modeling (SDM)

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AUTHOR BIOGRAPHY

Yoonwan Nam is a junior at UWCSEA – East Campus, Singapore, who has studied in Luxembourg, Germany, South Korea, and now Singapore, and brings an international perspective to his work. With his deep-rooted passion for Animal Science and Environmental Sustainability, he has pursued opportunities in wildlife conservation and eco-friendly innovation. Introduced to the Sunda Pangolin crisis through Singapore's *Animal Concerns Research and Education Society*, he continues his advocacy by interning at *ENTO Industries* and joining in-school conservation efforts while volunteering at SPCA and supporting WWF initiatives.

ABSTRACT

This study employs Species Distribution Modeling (SDM) to predict the current and future habitat suitability of the critically endangered Sunda Pangolin (*Manis javanica*) across Southeast Asia. By incorporating occurrence records from the Global Biodiversity Information Facility (GBIF.org) with bioclimatic variables from WorldClim, a Generalized Linear Model (GLM) is developed and validated using Receiver Operating Characteristic (ROC) analysis. The model demonstrated strong predictive performance (AUC = 0.904). Future forecasts under the SSP2-4.5 climate scenario (2061–2080) suggest potential shifts and slight expansions of suitable habitats along tropical and coastal regions, particularly in Malaysia, Thailand, and Indonesia. These results indicate that while key habitats remain stable, climate change may alter and expand them. The findings highlight the need for international conservation planning, stronger habitat protection, and continued monitoring of sensitive species. By integrating spatial data, climate modeling, and environmental awareness, this research provides a foundation for sustainable conservation of the Sunda Pangolin and provides broader biodiversity maintenance efforts in a changing climate. These insights emphasize the importance of integrating ecological modeling with long-term climate planning to anticipate future habitat shifts.

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Keywords: *Sunda Pangolin (*Manis javanica*), species distribution modeling (SDM), habitat suitability, climate change, conservation planning, biodiversity management, Southeast Asia, endangered species conservation, habitat modeling, climate projections, bioclimatic variables, generalized linear model (GLM)*

INTRODUCTION

Globally, animal species of all kinds are facing the threat of extinction. Endangered animals are species whose populations have declined to critically low levels, placing them at serious risk of disappearing from the wild (Dublin, 2018). Human activities such as deforestation, pollution, overfishing, poaching, and urban expansion are the most common roots of this biodiversity loss (IPBES, 2019). By destroying natural habitats and disrupting ecosystems, these actions have caused severe ecological imbalances. As forests are cleared, oceans are polluted, and climates change, many species are losing their homes, food sources, and breeding grounds (IPBES, 2019).

The extinction of animals is not only a struggle for nature, but it also threatens the stability of the planet's ecosystems (IPBES, 2019). Each species plays a role in keeping balance on the planet. For example, predators control the prey populations, pollinators help plants reproduce, and herbivores shape vegetation growth (Saunders et al., 2015). When species disappear, the cycle that supports life, including human life, begins to collapse. Protecting endangered animals means preserving biodiversity, which is essential for clean air, water, food security, and even medicine (IPBES, 2019). Effective conservation requires not only habitat protection—such as reducing waste, supporting wildlife conservation programs, protecting habitats, and promoting sustainable living—but also tools to predict how species distributions may shift under changing environmental conditions.

Climate change adds another layer of danger to this issue. Rising temperatures, melting ice caps, and changing weather patterns are altering habitats faster than many animals can adapt (United Nations, 2022). Therefore, working against climate change is crucial not only for human survival but also for the survival of all living creatures. Protecting natural ecosystems can help create a more sustainable future where both people and animals can thrive. Understanding and predicting the shift of the ecosystem through collected data is essential for identifying future suitable habitats and guiding conservation strategies.

Species Distribution Modeling (SDM) provides a quantitative framework to assess current habitat suitability and project future changes under climate scenarios (WorldClim, n.d.). SDMs integrate species occurrence data with environmental variables to map suitable habitats and forecast how these areas may change

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over time. By matching the already known locations of a specific species with environmental factors such as temperature, rainfall, or elevation, SDMs identify relationships that can estimate both current and potential future suitable habitats for a species under changing environmental conditions. These models are applied in ecology, conservation, and biogeography to understand biodiversity patterns, evaluate habitat suitability, and speculate the effects of environmental change on ecosystems. These models are increasingly used in conservation planning to identify priority habitats, assess vulnerability to climate change, and guide resource allocation (IPBES, 2019).

This study applies SDM to examine both current and future habitat suitability for the Sunda Pangolin (*Manis javanica*), a native species currently classified as critically endangered across Southeast Asia (IUCN, 2019). Through this approach, the study aims to provide a data-driven foundation for conservation strategies that address climate impacts and support long-term species survival.

CASE STUDY: SUNDA PANGOLIN

Among the many endangered animals in Asia, the Sunda Pangolin (*Manis javanica*) serves as a critical example of how human actions can threaten even the most peaceful creatures. Native to Southeast Asia, including Singapore, Malaysia, and Indonesia, these shy, nocturnal mammals are covered in hard keratin scales and feed mainly on ants and termites. This behaviour helps control insect populations and maintain ecological balance in forests and wetlands (AVS, 2025).

Unfortunately, the Sunda Pangolin is now classified as Critically Endangered by the IUCN Red List due to illegal trafficking and habitat loss (IUCN, 2019). Despite being legally protected under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), Sunda Pangolins continue to be hunted for their meat and scales. These products are still falsely believed to hold medicinal value in some traditional practices, particularly in China, despite the lack of scientific evidence supporting such claims (World Land Trust, 2022). Still, demand for their scales continues to drive large-scale hunting. This demand, combined with deforestation and road accidents, has caused their numbers to fall significantly across the region.

Conserving the Sunda Pangolin is crucial not only for preserving biodiversity but also for addressing misunderstandings about wildlife. Protecting their habitats, strengthening law enforcement, and educating the public about the harm caused by wildlife trade are all key steps. By challenging pseudoscientific beliefs and promoting sustainable coexistence, we can help ensure that Pangolins, and other endangered animals, continue to play their role in keeping our planet's ecosystem healthy. Furthermore, data-driven tools such as the SDMs can provide important insights into potential animal habitats under future climate conditions, providing data-driven spatial guidance for effective conservation planning.

METHODOLOGY

To construct an SDM, occurrence data were used in the form of presence or pseudo-absence points, combined with bioclimatic variables from WorldClim (WorldClim, n.d.). Pseudo-absence points are artificially generated locations where the species is predicted to be absent, usually generated by randomly sampling areas outside presence sites to provide a contrast for the model. The model then fits an algorithm to estimate the probability of species presence across geographic space. In R Studio, this process involves inspecting spatial layers, fitting the model, and assessing its performance using variables such as the True Positive Rate, False Positive Rate, and the Area Under the ROC Curve (AUC). The True Positive Rate (TPR) indicates the proportion of actual presences correctly predicted by the model, while the False Positive Rate (FPR) measures the proportion of absences that were incorrectly predicted as presences. Plotting the TPR against the FPR produces the ROC curve, which illustrates the model's ability to distinguish between suitable and unsuitable habitats. The AUC value, ranging from 0 to 1, provides an overall measure of model accuracy, with values closer to 1 indicating a stronger predictive performance. After model calibration, future projections were generated using climate-change scenarios such as Shared Socioeconomic Pathways (SSPs), which provide standardized greenhouse-gas trajectories used to model how habitat suitability may shift under different climate futures.

SDMs assess how climate change might affect future distribution of species by predicting environmental suitability under various climate scenarios. For example, a high AUC score (above 0.8) indicates that the model predicts species presence and absence with strong accuracy, meaning it effectively distinguishes between suitable and unsuitable habitats. These predictions allow researchers to identify areas where a species might lose its suitable habitat or where new suitable regions may appear in the future. The strength of SDMs is in their predictive capability, flexibility, and ability to integrate environmental datasets. However, they are limited by sampling bias, data quality, model assumptions, and uncertainty in future climate projections. Despite these challenges, SDMs contribute significantly to sustainability by guiding conservation planning, informing protected area design, prioritizing species for protection, and supporting decisions aimed at preventing biodiversity loss under changing climatic conditions.

APPLICATION OF METHODOLOGY

To assess the current and predictive distribution of Sunda Pangolins (*Manis javanica*), SDM was applied, focusing on Southeast Asia, the species' primary natural habitat as of 2019 (IUCN, 2019). This location was selected due to its ecological significance and the high pangolin occurrence density, which are important for conservation efforts. A total of 859 occurrence records of Sunda pangolin were downloaded from the Global Biodiversity Information Facility (GBIF, 2025; see References for dataset DOI). These datasets were integrated

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with environmental variables in R-Studio to generate predictive distribution maps, identifying areas of high habitat suitability and supporting evidence-based conservation planning.

DATA COLLECTION

The environmental and occurrence datasets were processed and visualized in RStudio to show the spatial variation of the Sunda Pangolin's distribution across Southeast Asia. The occurrence data were obtained from the Global Biodiversity Information Facility (GBIF), an international, government-supported biodiversity database that provides open-access species records for scientific research. These records supplied confirmed pangolin sightings, which served as *presence points* in the model. These were combined with bioclimatic variables collected from the WorldClim database, including factors such as precipitation and the annual mean temperature, which are required to determine species habitat suitability. Using RStudio's raster package, the environmental data layers were cropped to match the same location as the occurrence records, making them reliable for analysis. The processed data were then visualized on maps, highlighting trends such as higher occurrence densities in tropical forest regions and lower suitability in drier or urbanized zones. This integration of environmental and occurrence data provides a reliable representation of the Sunda Pangolin's current distribution and forms a foundation for projecting future climate conditions.

WORKFLOW AND MODEL IMPLEMENTATION

The analytic workflow followed a structured process that consisted of three main steps: visualizing bioclimatic raster layers, fitting the SDM model, and evaluating its predictive performance. Bioclimatic variables were visualized as raster layers to reveal environmental patterns. These visualizations allowed initial assessment of environmental gradients associated with known Sunda pangolin habitats. The occurrence and environmental datasets were then integrated into a Generalized Linear Model (GLM) framework to estimate the probability of suitable habitat across the study area. The GLM used a binomial distribution, relating species presence/pseudo-absence to environmental predictors. The workflow connects species occurrence data to environmental predictors, allowing the model to hypothesize where suitable conditions exist now and how they may shift under future climate scenarios.

Each figure created from the code highlights a different aspect of the species distribution modeling process, from data validation to prediction and evaluation. Maps showing presence and pseudo-absence points confirmed the spatial reliability of the dataset, while suitability maps illustrate which locations environmental conditions are suitable for the Sunda pangolin. The ROC curve and statistical tables measure model accuracy to assess confidence in the predictive ability of the analysis. These visualizations supported model validation and

interpretation by displaying spatial patterns relevant to habitat suitability.

RESULTS AND ANALYSIS

The following figures and table illustrate the key steps and outcomes of the SDM process, from data preparation to model evaluation. Each visualization represents a critical stage in linking environmental variables to the Sunda pangolin's habitat suitability across Southeast Asia. The Latitudinal distribution of Sunda Pangolin occurrence records are clustered between 0° and 10°, with very few records above 15° in northern Thailand or southern China, indicating that the Sunda pangolin is highly dependent on equatorial tropical environments corresponding to tropical lowland regions such as Malaysia, Indonesia, and Southern Vietnam (Fig. 1). The longitudinal distribution concentrates between 100° and 105°, corresponding to regions such as Malaysia and western Thailand, with a smaller cluster between 115°E and 120°E indicating populations in Borneo and the Philippines. The tabulated occurrence coordinates from GBIF, with its longitudinal coordinates ranging from 104° to 114°, and latitudinal coordinates range approximately from -7° to 12°, confirm that records span a large portion of Southeast Asia, including Thailand, Malaysia, and Indonesia (Table 1). Together, these patterns demonstrate that stable temperature and high humidity appear to be key limiting factors, meaning that climate change could significantly reduce suitable habitats and increase the species' vulnerability; such a limited geographic distribution also increases the risk of vulnerability, as environmental changes or habitat loss in these key regions could significantly impact the overall population.

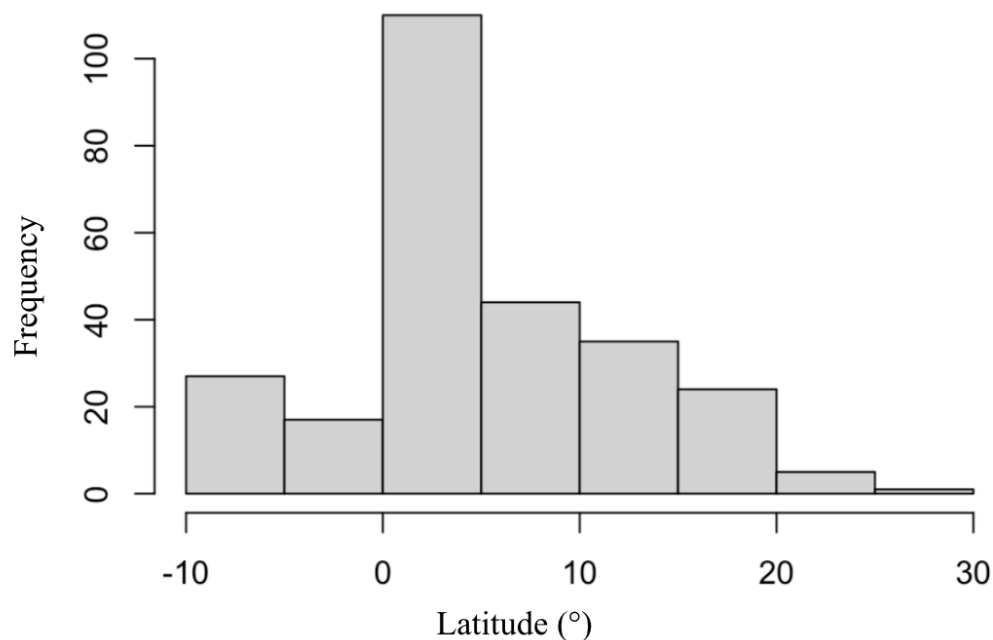
The GLM model was trained on confirmed presence records obtained from GBIF together with randomly generated pseudo-absence (background) points distributed across the region (Fig 3, Fig. 4). The inclusion of both points allowed the model to compare and contrast environmental conditions between locations where the species occurs. This improves the model's ability to distinguish suitable from unsuitable habitats, increasing prediction accuracy and overall reliability. Annual mean temperature, drawn from WorldClim, was used as an environmental predictor—suggesting that tropical regions near the equator have higher temperatures globally (Fig. 5), and the regional view confirms that Southeast Asia's consistently warm climate aligns with the area where most occurrence records are concentrated (Fig. 6). This correspondence between the predictor and the species' recorded range supports the focus on Southeast Asia's tropical climate for modeling.

The continuous current habitat suitability prediction shows the higher values are concentrated in tropical regions such as Malaysia, southern Thailand, Vietnam, and Indonesian islands, while lower values dominate northern regions such as China, India, and Myanmar (Fig. 7). The binary habitat suitability classification of these predictions shows that most observed occurrence records fall within the areas mapped as suitable, indicating good alignment between predictions and observed records (Fig. 8). This dependence on

tropical lowland environments suggests that even modest shifts in temperature or rainfall could affect future habitat availability. Under the SSP2-4.5 scenario for 2061-2080, the overall pattern of habitat suitability remains broadly similar to current conditions, with slight expansion of high-suitability areas in some tropical regions (Fig 9, Fig. 10). This stability indicates that core habitats are likely to remain suitable over time, highlighting the importance of protecting these regions to ensure long-term conservation of the species. Receiver Operating Characteristic (ROC) curve and model performance. The model achieved strong model accuracy, with an area under the ROC curve of 0.904 (Fig.11), supporting its reliability for predicting species distribution and decision-making for conservation support.

Figure 1.

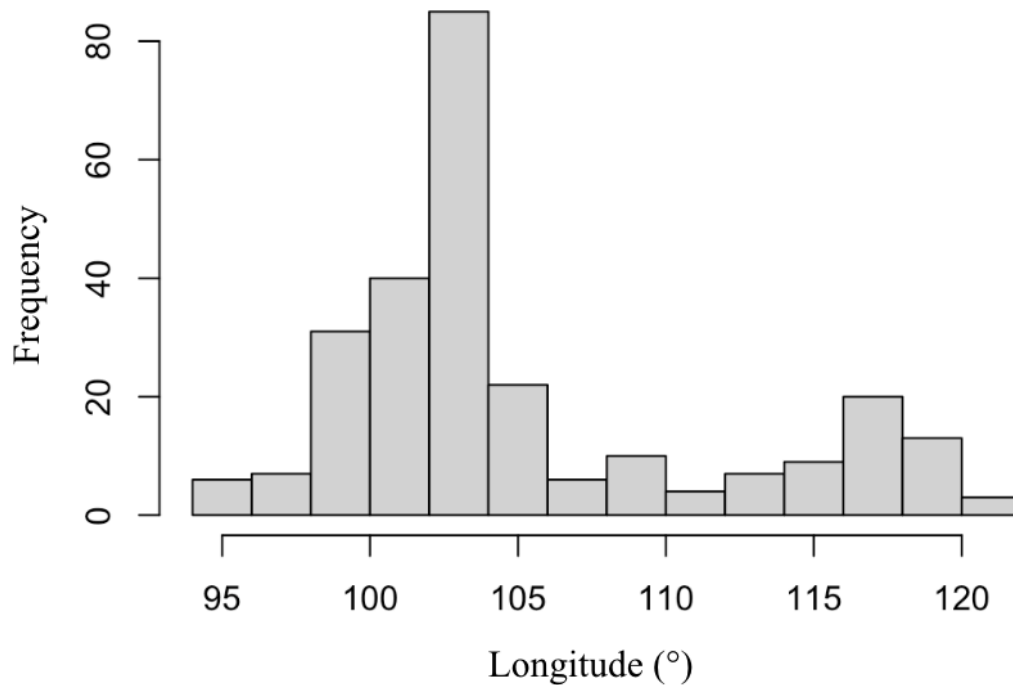
Latitudinal distribution of Sunda Pangolin occurrence records in Southeast Asia



Note. Histogram showing the distribution of Sunda pangolin occurrence records across latitude (degrees, °), ranging from approximately -10° to 30° , with frequency up to 100. Most observations are clustered between 0° and 10° , with very few records above 15° in Northern Thailand or Southern China.

Figure 2

Longitudinal distribution of Sunda pangolin occurrence records



Note. Histogram showing the distribution of occurrence records across longitude (degrees, °), ranging from approximately 95°E to 120°E, with frequency up to 80. Most observations are between 100° and 105°, corresponding to regions such as Malaysia and western Thailand, with a smaller cluster between 115°E and 120°E indicating populations in Borneo and the Philippines. Few records occur below 95°E or between 110°E and 115°E.

Table 1

Sunda pangolin occurrence coordinates (GBIF)

Data Points	Longitude (°)	Latitude (°)	Presence Absence (1=presence)
3	104.9170	11.550000	1

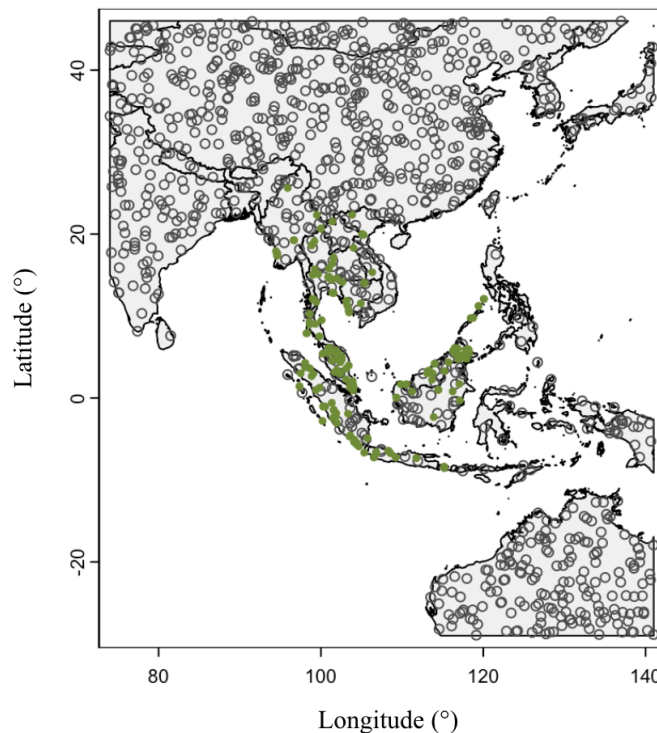
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6	106.8104	-6.801965	1
11	113.7736	3.009363	1
13	103.4296	3.961711	1
15	108.3333	-6.466667	1
16	108.3333	-6.466667	1

Note. Table showing geographic coordinates of Sunda pangolin occurrence records from GBIF, including longitude and latitude (degrees, °), and a presence indicator (pa, where 1 = observed). Longitudinal coordinates range approximately from 104° to 114°, and latitudinal coordinates range approximately from -7° to 12°, covering a large portion of Southeast Asia, including Thailand, Malaysia, and Indonesia.

Figure 3

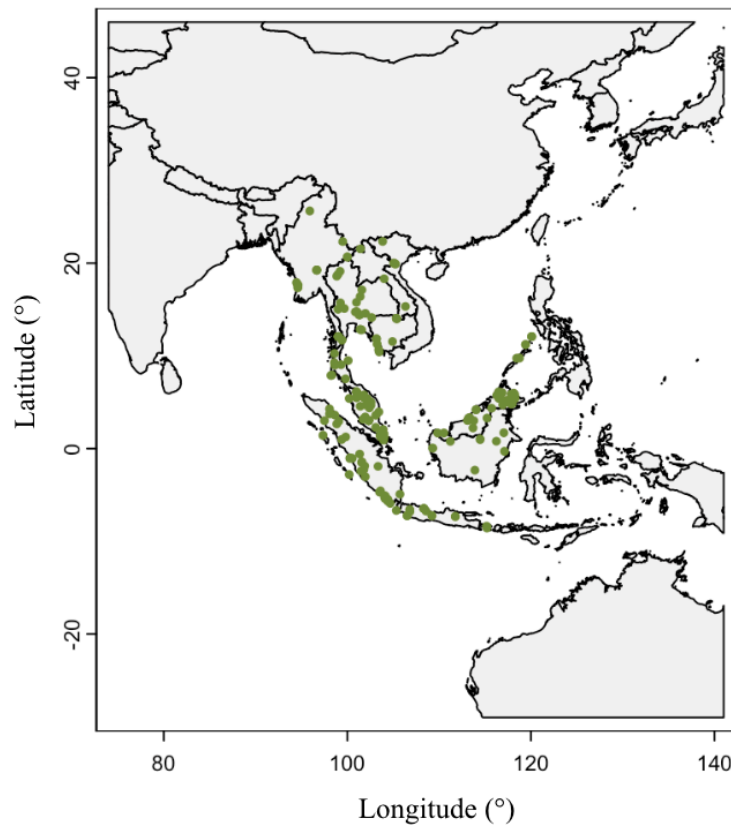
Presence and pseudo-absence (background) points across Southeast Asia



Note. Map showing Sunda pangolin presence records (green points) and randomly generated pseudo-absence/background points (grey points) across Southeast Asia. These pseudo-absence points are used alongside presence data in GLM model training to represent locations where the species is not observed.

Figure 4

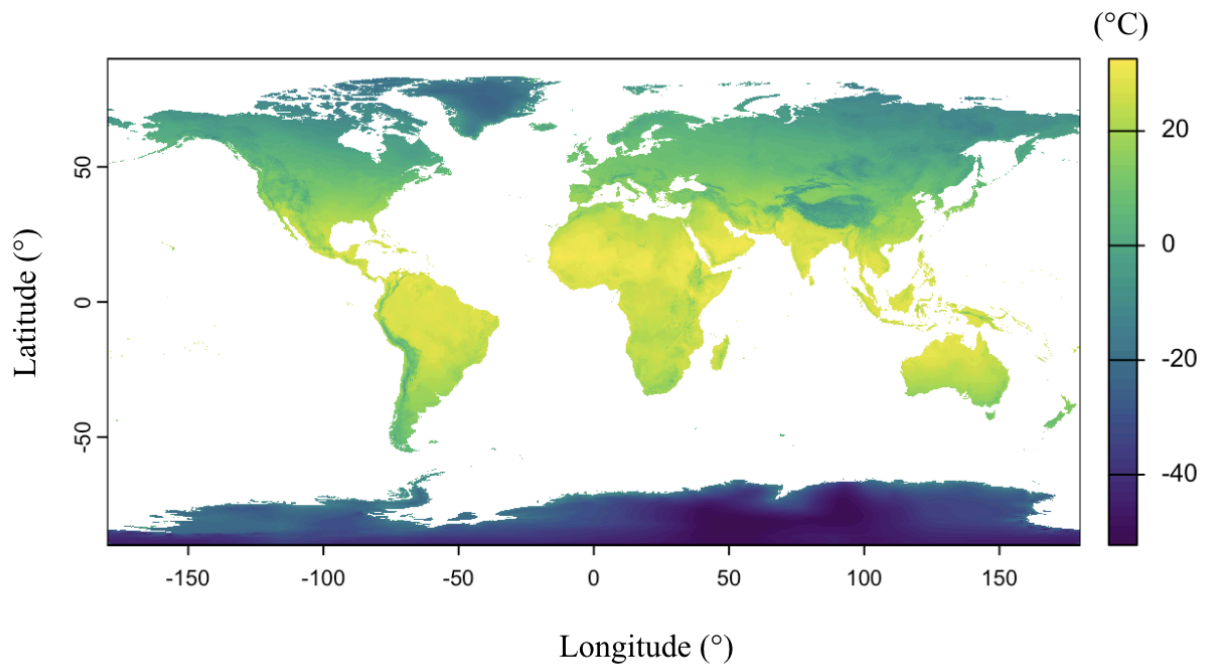
GBIF occurrence records of Sunda pangolin across Southeast Asia



Note. Map showing GBIF occurrence records of Sunda pangolin (green points) across Southeast Asia, representing confirmed presence locations used as data for model training.

Figure 5

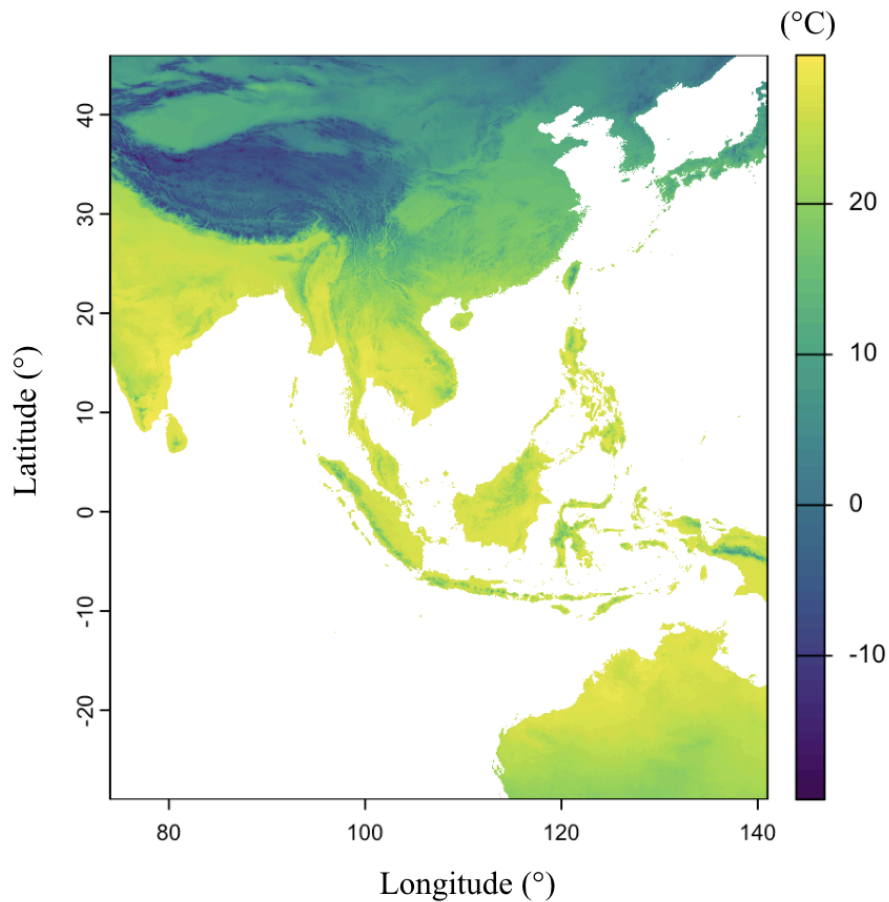
Global annual mean temperature (°C)



Note. Global map showing annual mean temperature (°C) obtained from WorldClim, used as an environmental predictor in SDM. Warmer regions (above 20°C) are shown in yellow-green, while cooler regions (below 0°C) are shown in blue-purple. This suggests that tropical regions near the equator have higher temperatures.

Figure 6

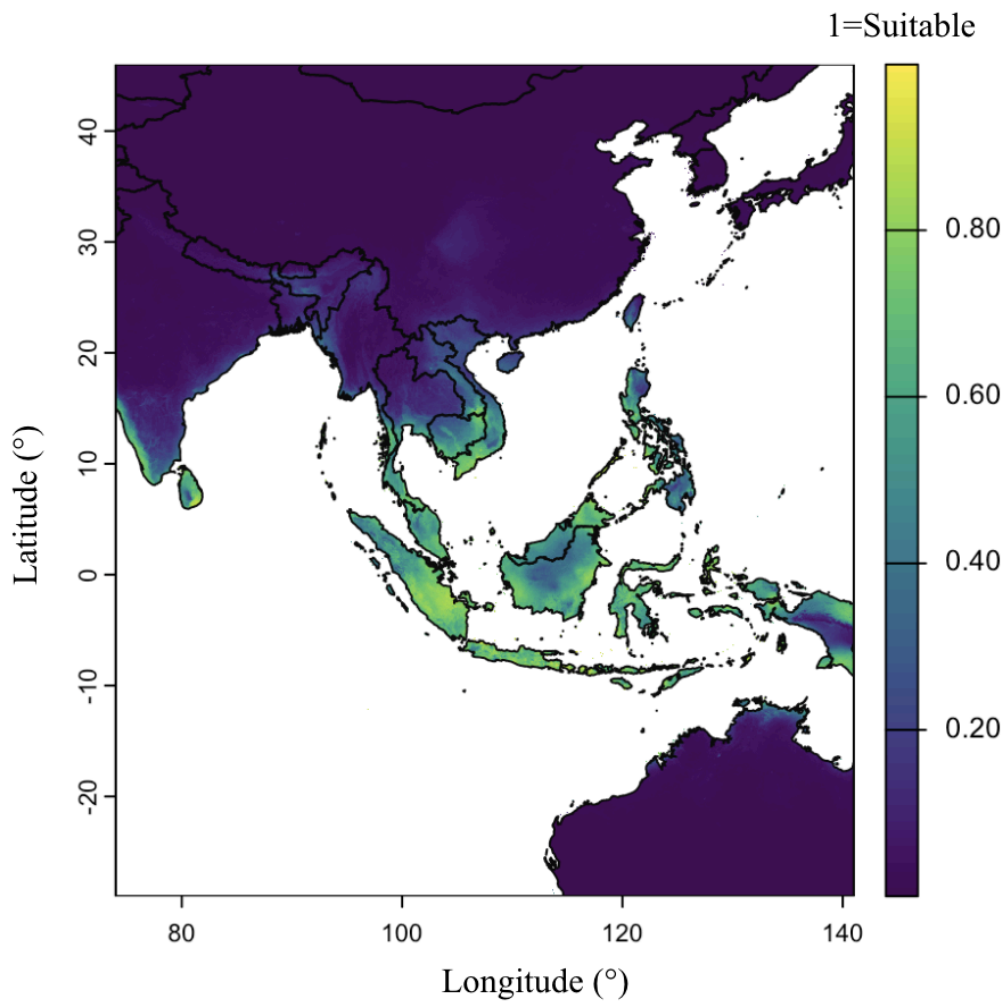
Annual mean temperature in Southeast Asia (°C)



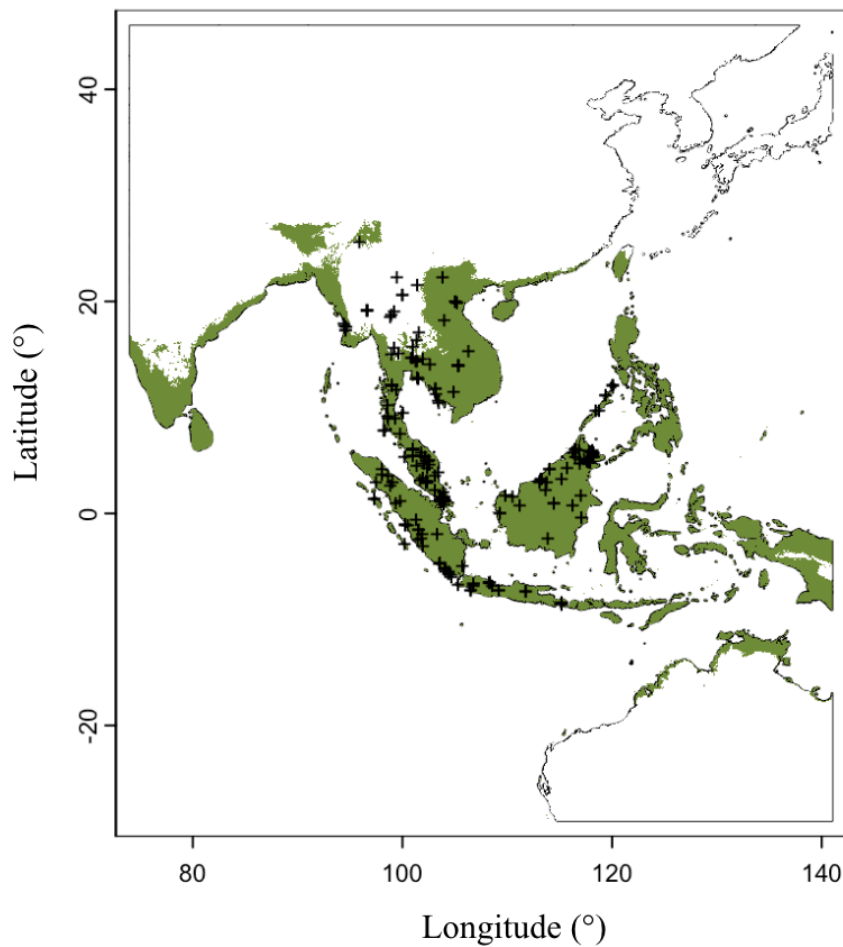
Note. Map showing annual mean temperature (°C) in Southeast Asia. Warmer regions (above 20°C) are shown in yellow-green, while cooler regions (below 0°C) are shown in blue-purple. This suggests that tropical regions near the equator have higher temperatures.

Figure 7

Current habitat suitability (continuous prediction, 0–1)



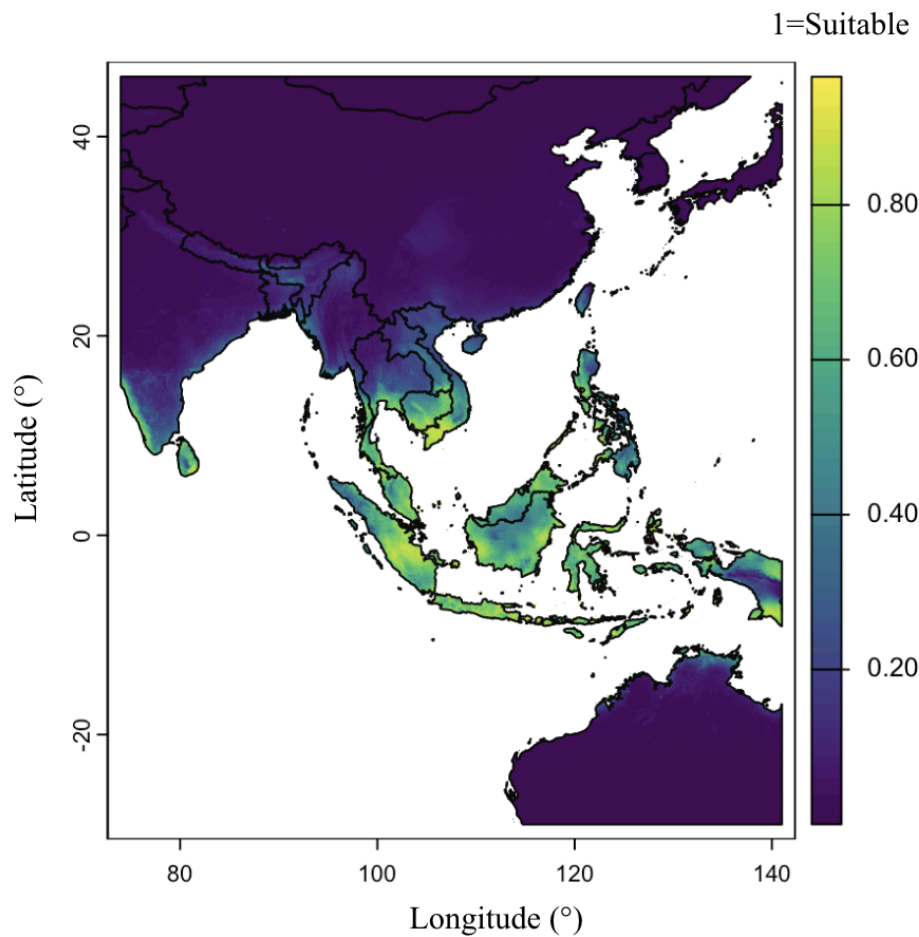
Note. Continuous map of the current habitat suitability, ranging from 0 (unsuitable) to 1 (highly suitable). Lower suitability values dominate northern regions such as China, India, and Myanmar, while higher suitability values are concentrated in tropical regions such as Malaysia, southern Thailand, Vietnam, and the Indonesian islands.

Figure 8*Binary habitat suitability classification (suitable vs. unsuitable)*

Note. Binary map classifying habitat suitability into suitable (green) and unsuitable (white) areas based on a threshold applied to continuous predictions. Black crosses represent observed occurrence records, showing that most observed points are within the suitable areas from model predictions.

Figure 9

Future habitat suitability (SSP2-4.5, 2061–2080; continuous 0–1)

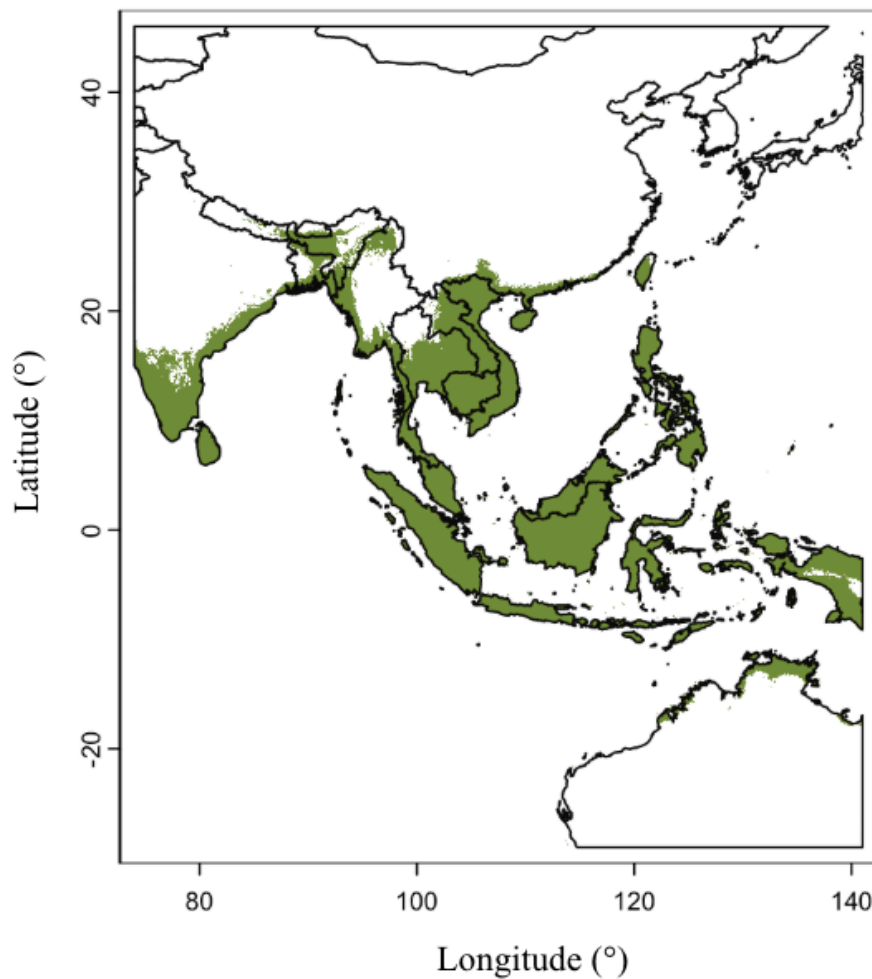


Note. Map showing projected habitat suitability for 2061–2080 under the SSP2-4.5 climate scenario, displayed on a continuous scale from 0 to 1. The overall pattern remains similar to current conditions, with slight expansion of high-suitability areas in some tropical regions.

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Figure 10

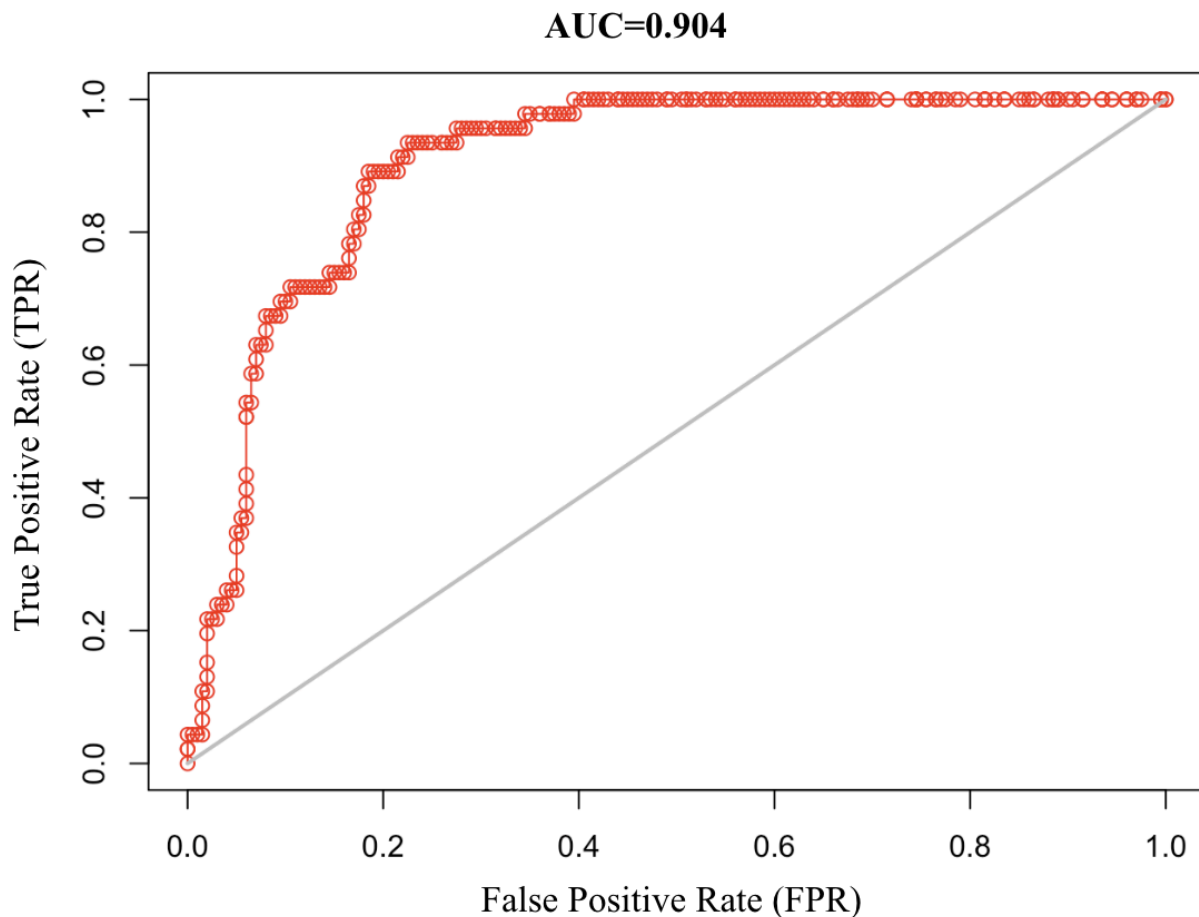
Future binary habitat suitability (SSP2-4.5, 2061–2080)



Note. Binary map showing projected suitable (green) and unsuitable (white) habitats for 2061–2080 under the SSP2-4.5 scenario. Most suitable areas overlap with current distributions, with slight expansion in some coastal regions.

Figure 11

Receiver Operating Characteristic (ROC) curve and model performance



Note. Receiver Operating Characteristic (ROC) curve showing model performance by plotting true positive rate (TPR) against false positive rate (FPR). The area under the curve (AUC = 0.904) indicates strong model accuracy.

DISCUSSION AND FUTURE DIRECTIONS

The SDM results indicate that the Sunda pangolin's (*Manis javanica*) suitable habitats are expected to remain mostly within tropical lowland regions of Southeast Asia, showing limited shifts under future climate conditions. As seen in Figures 7 and 9, high suitability is concentrated in Malaysia, southern Thailand, Vietnam,

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and Indonesia, aligning with warm and humid environments. Future projections for 2061–2080 indicate overall habitat stability with small increases along southern and coastal areas, particularly in India and China. This pattern suggests possible adaptation of future climate but highlights that the species remains vulnerable to ongoing environmental changes such as shifts in temperature, rainfall, or land use that could affect its preferred ecosystems. Since the Sunda pangolin's potential range extends across multiple national borders, effective conservation will require close coordination between Southeast Asian governments, NGOs, and international organizations to ensure habitat connectivity and lasting protection efforts.

Future research should incorporate more detailed environmental variables such as forest cover density and human activity metrics to further validate habitat predictions. Using updated, more accurate climate data should also be incorporated to help improve model precision. Additionally, incorporating other climate scenarios would provide a more comprehensive range of possible futures.

CONSERVATION RECOMMENDATIONS

Conservation efforts should prioritize protecting existing tropical forest habitats through stronger enforcement of habitat protection laws, specifically prevention of illegal logging and monitoring of land conversion, and limiting infrastructure development that threaten ecosystems. Expanding protected areas to include regions identified as suitable in both current and future models would help maintain ecological stability in changing climate conditions. Additionally, stricter enforcement of anti-poaching laws and regulation of illegal pangolin trade is necessary, particularly in countries where wildlife trafficking networks still remain active. Collaborative efforts between governments, NGOs, and local communities can strengthen legal frameworks and promote education to reduce consumer demand. Establishing wildlife corridors between fragmented habitats and implementing transboundary conservation agreements will be essential for maintaining genetic diversity and population connectivity. Cooperation across regions in Southeast Asia and ongoing habitat monitoring will be needed to support the species' survival under future climate conditions.

BROADER IMPLICATIONS

The SDM highlights how species, such as the Sunda pangolin, rely on ecosystems spanning many borders of different countries, emphasizing the need for regional collaboration in environmental conservation. Since suitable habitats occur in countries such as Malaysia, Thailand, Indonesia, and China, conservation actions must go beyond political boundaries to ensure ecological stability. This study shows how integrating spatial data, climate science, and ecological modeling can guide informed, evidence-based, and data-driven decision-making. With this approach, we can better understand how climate change shapes biodiversity and collaborate to take action in preserving vulnerable species.

LIMITATIONS

Despite its usefulness, the SDM has several limitations. First, the accuracy of predictions is constrained by sampling bias and uneven data quality in GBIF records, which may misrepresent the true distribution of the Sunda pangolin. Occurrence data are often concentrated near accessible areas such as roads and research stations, potentially underrepresenting remote habitats. Additionally, the model relies on bioclimatic variables and does not include important non-climatic factors such as land-use change, deforestation rates, or human disturbance, all of which strongly influence the species' habitat. The model also assumes that the species' climate niche remains stable over time, which may not hold true if pangolins exhibit adaptive responses to environmental change. Finally, future projections based on the SSP2-4.5 scenario come with uncertainty, since climate models and SSPs cannot perfectly represent future conditions. These limitations highlight the need to interpret model outputs with caution and to incorporate additional environmental variables in future research.

CONCLUSION

Overall, this study demonstrates the utility of Species Distribution Modeling for assessing current and projected habitat suitability of the critically endangered Sunda pangolin across Southeast Asia. Integrating spatial occurrence data with bioclimatic variables revealed areas of suitable habitat under present conditions and identified potential shifts driven by environmental change. The model achieved strong predictive performance with AUC of 0.904, indicating reliable identification of suitable habitats under current conditions. Future projections suggest moderate habitat expansion in coastal regions, though conservation efforts must address both climate-driven and human-induced threats. Although the model has certain limitations, findings establish a useful baseline for conservation planning and pinpoint regions requiring critical coordinated biodiversity conservation efforts. Continued refinement of SDMs, alongside active protection and restoration across ecosystems, will be essential to sustaining populations of endangered species, like the Sunda Pangolin.

REFERENCES

- Dublin, H. (2018). Endangered species: Definition & facts. In Encyclopædia Britannica. <https://www.britannica.com/science/endangered-species>
- Global Biodiversity Information Facility (GBIF). (2025). Occurrence download [Dataset]. <https://doi.org/10.15468/dl.5pq6jx>
- IPBES. (2019). Global assessment report on biodiversity and ecosystem services <https://www.ipbes.net/global-assessment>

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- IUCN. (2019). *Manis javanica* (Challender, D., Willcox, D.H.A., Panjang, E., Lim, N., Nash, H., Heinrich, S. & Chong, J.) [Dataset]. IUCN Red List of Threatened Species. <https://doi.org/10.2305/iucn.uk.2019-3.rlts.t12763a123584856.en>
- Animal and Veterinary Service (AVS). (2025). Pangolins in Singapore <https://avs.nparks.gov.sg/wildlife/encountering-wildlife/pangolins/>
- Saunders, M. E., Peisley, R. K., Rader, R., & Luck, G. W. (2015). Pollinators, pests, and predators: Recognizing ecological trade-offs in agroecosystems. *Ambio*, 45(1), 4–14. <https://doi.org/10.1007/s13280-015-0696-y>
- United Nations. (2022). Biodiversity - our strongest natural defense against climate change. <https://www.un.org/en/climatechange/science/climate-issues/biodiversity>
- WorldClim. (n.d.). Global climate and weather data—WorldClim 1 documentation. <https://www.worldclim.org/data/index.html>
- World Land Trust. (2022). Sunda Pangolin. <https://www.worldlandtrust.org/species/sunda-pangolin/>