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Original Article

Spatial Distribution and Suitability of the Endemic Babirusa Habitat (*Babyrousa babyrussa*) on Buru Island, Maluku using Maximum Entropy

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Abstract. Buru Island is the endemic habitat of the Babirusa (*Babyrousa babyrussa*), facing pressures from human activities and habitat fragmentation. This study used the Maximum Entropy (MaxEnt) modeling method to map the spatial distribution and assess the habitat suitability of Babirusa based on environmental variables including elevation, slope, temperature, land cover, distance to water, and distance from built-up areas. The results show that the habitat is divided into four main classes: Very Low at 24.95%, Low at 31.67%, Moderate at 29.71%, and High at 13.68% of the total island area, which requires more intensive management and protection. Elevation and distance from settlements have an influence but with relatively small contributions, indicating the species' tolerance to elevation variation. This model provides a scientific basis for integrated conservation strategies, including habitat management, reduction of anthropogenic pressures, and sustainable spatial planning based on habitat suitability to ensure the long-term survival of Babirusa on Buru Island.

Keywords: *Babyrousa babyrussa*; Buru Island; Maximum Entropy; Spatial Distribution

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INTRODUCTION

The Buru babirusa (*Babyrousa babyrussa*) is an endemic species found only on Buru Island and two other islands in the Maluku archipelago, Mangole and Taliabu (Macdonald et al., 2008; Macdonald, 2021). This babirusa is unique among its relatives due to its relatively long and thick body hair. It is believed that the Buru babirusa originated from mainland Sulawesi and then dispersed to the Maluku islands where it now resides. In 2021, the Maluku Natural Resources Conservation Agency confirmed the existence of babirusa on Buru Island through camera trap installations, dispelling the myth that the species was only folklore in the region (Paino, 2021). However, the babirusa population in Buru faces threats from illegal hunting for consumption, bycatch from snares set for agricultural pests, and habitat loss.

The Buru babirusa (*Babyrousa babyrussa*) holds significant conservation value due to its vulnerable population, threatened by habitat pressure and illegal hunting, necessitating focused study and protection to ensure its survival (Jati et al., 2024). Its habitat primarily consists of tropical rainforests with abundant natural vegetation cover, including rivers and swamps that provide food sources and shelter. On Buru Island, babirusa distribution is influenced by environmental factors such as topography and vegetation cover, as well as human activities causing significant habitat fragmentation (Wibowo, 2021). The availability of suitable habitat is a crucial factor in maintaining stable babirusa populations.

The main threats to the babirusa are habitat loss caused by land clearing for agriculture and plantations, and ongoing illegal hunting. Although babirusa are listed as a protected species, weak law enforcement results in continued threats to their survival (Macdonald, 2017). Furthermore, their low reproductive rate makes population recovery more difficult without adequate habitat protection (Mustari et al., 2013).

In the context of habitat mapping and conservation, the Maximum Entropy (MaxEnt) distribution modeling approach is a proven effective method to predict species habitat suitability using environmental and species presence data (Phillips et al., 2006; Ngarega et al., 2021; de Oliveira Sousa et al., 2025). This method is particularly suitable for species with limited presence data, such as the babirusa, to identify the most potential and critical habitat areas on Buru Island (González et al., 2021). MaxEnt modeling enables the management of spatial environmental data such as vegetation indices (NDVI), elevation, river density, and land cover types to estimate the spatial distribution of the babirusa (Ahmadi et al., 2023). The modeling results provide habitat suitability maps that play a crucial role in conservation decision-making, such as determining protected zones and prioritizing area management (Jeong et al., 2024).

Understanding the habitat suitability and distribution of the Maluku babirusa is crucial for developing effective conservation strategies. This research provides valuable insights into the ecological needs of the species and highlights areas requiring protection. Conservation efforts should focus on preserving high-quality habitats and mitigating threats such as habitat degradation and illegal hunting. Utilizing MaxEnt modeling, this study aims to contribute to the long-term survival of the Maluku babirusa and the overall biodiversity of Buru Island. The spatial distribution and habitat suitability data generated can serve as a basis for spatial planning and conservation management in Maluku, promoting a balance between development and environmental preservation.

With this background, this study aims to map the spatial distribution and assess the habitat suitability of the Babirusa using the MaxEnt method on Buru Island, Maluku. The expected results will provide a deeper understanding of the babirusa's habitat patterns, serving as a strong foundation for conservation efforts, protection, and habitat management to ensure the species' sustainability in the future.

MATERIALS AND METHODS

This research was conducted on Buru Island, Maluku Province, Indonesia (Figure 1). Geographically, the island is situated between the Banda Sea to the south and the Seram Sea to the north, to the west of Ambon and Seram Islands. The coordinates of Buru Island are approximately 3°25′30″ South Latitude and 126°40′03″ East Longitude. The environmental parameters used in this study consist of six variables: elevation, slope, temperature, land cover, distance to water, and distance from built-up areas.

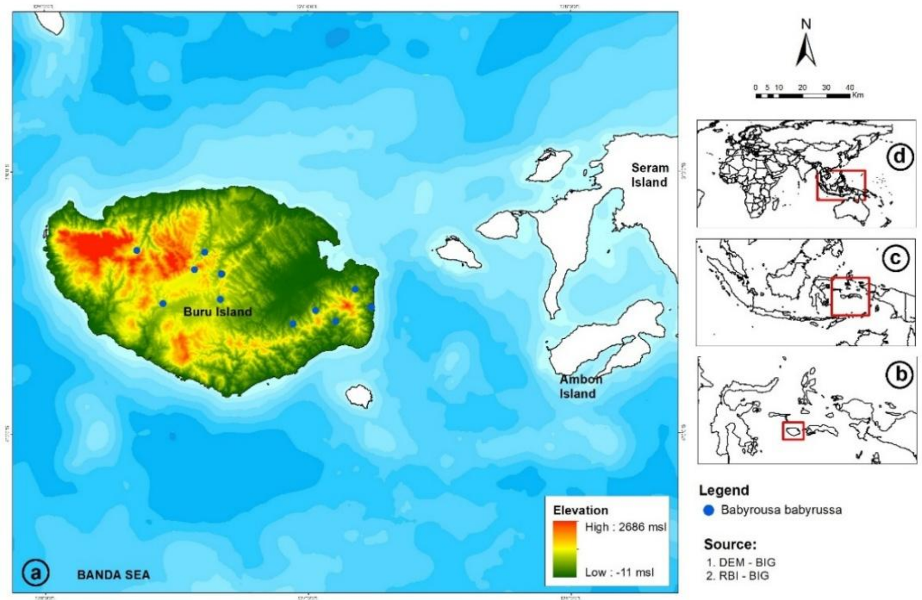

Figure 1. Research Location; (a) Buru Island, (b) Buru Island on the Map of Maluku Province, (c) Maluku Province on the Map of Indonesia, (d) Indonesia on the World Map

Environmental variables were obtained from official government agencies and international remote sensing data providers. The elevation and slope variables were derived from the National DEM data analysis with an 8-meter spatial resolution provided by the Indonesian Geospatial Information Agency (BIG). The temperature variable was obtained from the MOD11A1 Version 6 dataset, a satellite image product from NASA that provides daily land surface temperature (LST) and soil emissivity data at a 1-kilometer spatial resolution. Land cover data were acquired from high-resolution satellite image interpretation of PlanetScope with a 3-meter spatial resolution, sourced from Planet Labs. Distance to rivers was calculated using buffer analysis of river networks obtained from the Geospatial Information Agency. Distance from built-up land was derived from buffer analysis of built-up land data based on the 2025 land cover variable. In addition to environmental variables, this study also used 11 presence points of *Babyrousa babyrussa* obtained from various high-accuracy international databases, including the Global Biodiversity Information Facility (GBIF), IUCN Red List, BirdLife International, iNaturalist, data from the Maluku Natural Resources Conservation Agency, and literature studies. The complete classification of environmental variables can be seen in Table 1.

Table 1. Environmental Habitat Variables of *Babyrousa babyrussa*

No	Variable	Classification	Code	Source
1	Elevation	0-100 msl	1	Analysis and classification of National DEM data - BIG
		100-300 msl	2	
		300 – 500 msl	3	
		500-700 msl	4	
		>700 msl	5	
2	Slope	<5°	1	Analysis and classification of National DEM data - BIG
		5-10°	2	
		10-15°	3	
		15-20°	4	
		>20%	5	
3	Temperature	<14 °C	1	Analysis and classification of MOD11A1 Version 6 satellite imagery product - NASA
		14-18 °C	2	
		18-22 °C	3	
		22-26 °C	4	
		>26 °C	5	
4	Land Cover	Built Area	1	Interpretation of Planet Scope satellite imagery recorded on 14.08.2025 - Planet
		Crops	2	
		Flooded Vegetation	3	
		Rangeland	4	
		Trees	5	
		Water	6	

5	Distance to Water	>100 100-200 m 200-500m 500-100m >1000	1 2 3 4 5	Buffer analysis of rivers – BIG
6	Distance from built-up land	>100 100-200 m 200-500m 500-100m >1000	1 2 3 4 5	Buffer Distance Analysis from Built-up Land - Results of Planet Scope Satellite Imagery Interpretation

This study employs an ecological spatial modeling approach using the Maximum Entropy (MaxEnt) method to predict the spatial distribution and habitat suitability of the endemic Babirusa (*Babyrousa babyrussa*) on Buru Island. MaxEnt is a popular machine learning-based modeling technique for spatial distribution and habitat suitability analysis, particularly suitable for endemic species with limited presence data like the Babirusa (Wibowo, 2021). The core principle of MaxEnt is to maximize the entropy (disorder) of the model subject to constraints derived from actual environmental conditions where the species is found, thus producing the most uniform probability distribution of habitat while remaining consistent with known environmental data (K. Zhang et al., 2018). This method's advantages include its ability to model habitats using presence-only data without the need for absence data and its flexibility in integrating complex environmental variables (Astudillo et al., 2024). MaxEnt models have proven to provide accurate habitat suitability predictions and support conservation decision-making effectively (Luo et al., 2024).

Environmental variables were processed using ArcGIS and QGIS software, ensuring that all variables were presented in raster format with uniform spatial resolution. Values from these variables were then extracted at each Babirusa presence location and at several randomly selected background points across the study area to capture environmental variability. All these variables were compiled in raster format with consistent projection and resolution, then converted into ASCII (.asc) format for processing in MaxEnt software. These variables were selected because they are key factors influencing Babirusa habitat viability and provide rich ecological information for the modeling.

The modeling process began by splitting the babirusa occurrence data into two subsets: 75% of the locations were used as training data and 25% as testing data. The MaxEnt model was run using 5,000 iterations to estimate the probabilistic relationship between species occurrence and environmental variables. Model validation was conducted using the Area Under the Curve (AUC) value from the Receiver Operating Characteristic (ROC) curve. An AUC value close to 1 indicates a well-performing model, whereas a value below 0.5 suggests a poorly performing model (Zhang et al., 2025).

The output from MaxEnt is a probability map of the babirusa habitat distribution, depicting habitat suitability values ranging from 0 to 1 (Su et al., 2024). Values approaching 1 indicate highly suitable and potential habitats for babirusa presence. Additionally, a sensitivity analysis of environmental variables is performed to identify which factors most significantly influence babirusa distribution on Buru Island. This information is valuable for conservation strategies focused on protecting this endemic species. The MaxEnt method is widely used in endemic species conservation studies due to its effectiveness and reliability. The full workflow of this research can be seen in Figure 2.

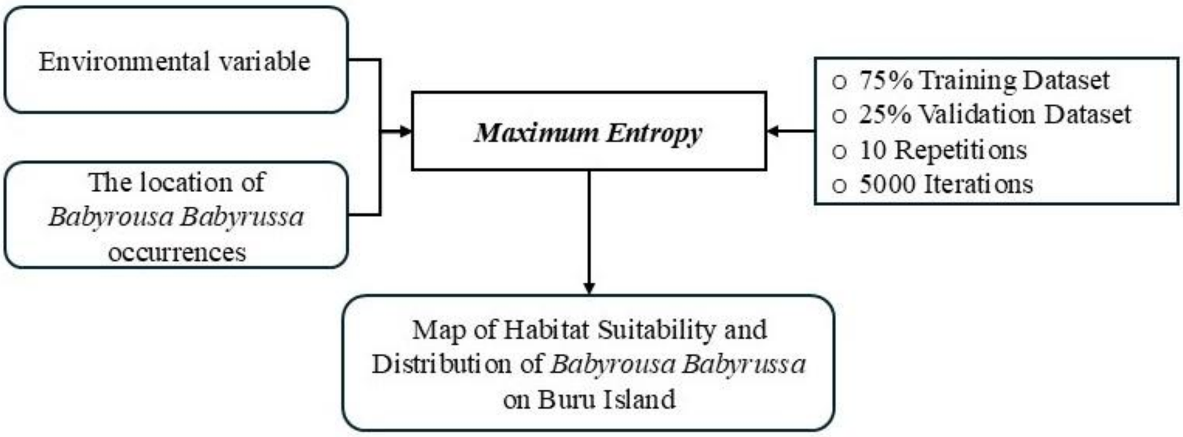

Figure 2. The MaxEnt method is widely used in endemic species conservation studies due to its effectiveness and reliability

RESULTS AND DISCUSSION

The occurrence of *Babyrousa babyrussa* on Buru Island.

The presence of *Babyrousa babyrussa* on Buru Island, Maluku, was confirmed through intensive surveys using camera traps installed by the Maluku Natural Resources Conservation Agency (BKSDA) in 2021 within the Masbait Nature Reserve area. Out of ten cameras placed along wildlife trails and activity areas such as wallowing spots and salt licks, nearly all recorded babirusa activity (Figure 3), confirming the species' natural habitat on Buru Island (Paino, 2021). This finding represents the first direct evidence since intensive surveys began in 1995, prior to which only tracks and skulls of babirusa had been found in the region.

Additional information from the local community supports that babirusa indeed inhabit the hill and mountain forests of Buru Island, with local myths reinforcing its presence as a guide for lost people. Although surveys by BKSDA between 2011 and 2013 did not find direct evidence, the discovery of babirusa bones in 2019 sparked increased conservation efforts through patrols and habitat monitoring (Setiyani et al., 2023). The main threats facing the babirusa population on Buru Island are illegal hunting and habitat fragmentation caused by human activities.

From a taxonomic and evolutionary perspective, the babirusa in Maluku, including those on Buru Island, belong to a group that is paleoecologically and geologically closely linked to Sulawesi, which was connected by land approximately 14 million years ago. The Buru Island babirusa, *Babyrousa babyrussa*, is one of three recognized subspecies, showing distinct morphological differences compared to the babirusa species from mainland Sulawesi (Babyrousa celebensis) and the Togian Islands (Setiyani et al., 2023). This differentiation is based on physical traits such as dense hair and tusk size, indicating species diversification driven by geographic isolation.

Figure 3. Documentation photo of the Babirusa observed on Buru Island, Maluku, through camera trap installation from April to June 2021. Source: Documentation of the Ministry of Environment and Forestry/Natural Resources Conservation Agency Maluku. (Paino, 2021)

Ecologically, the Buru babirusa is known as the "hairy babirusa" due to its long fur and smaller body size compared to the Sulawesi babirusa (Setiyani et al., 2023). The upper canine teeth of the males differ from those found in Sulawesi. This study emphasizes the importance of habitat protection to sustain the population of this endemic species, alongside conservation efforts involving increased patrolling, community education, and continuous monitoring using camera trap technology to ensure the survival of this rare species on Buru Island.

Environmental Variables and Habitat of *Babyrousa babyrussa*

Environmental variables affect the habitat of the Babirusa (*Babyrousa babyrussa*) on Buru Island with varying contributions: elevation (3.1%) and slope (1.1%) have minor influence as Babirusa can live in diverse altitudes and slopes due to their flexible mobility. Temperature (24.1%) and land cover (27.4%) significantly impact habitat suitability since Babirusa require optimal temperatures and forest habitats that provide food and shelter. Distance to water sources (0.7%) is important for drinking and bathing, though its contribution is small likely because of widely available water. The most dominant factor is distance from human settlements (43.6%), indicating that Babirusa strongly avoid human disturbance to survive safely in their natural habitat. The detailed contribution of environmental variables can be seen in Table 2.

Table 2. Contribution of Environmental Variables

No	Variable	Percentage Contribution
1	Elevation	3,1%
2	Slope	1,1%
3	Temperature	24,1%
4	Land Cover	27,4%
5	Distance to Water	0,7%
6	Distance from built-up land	43,6%

Elevation plays an important role in determining the habitat distribution of the Babirusa (*Babyrousa babyrussa*) on Buru Island through its influence on vegetation type and quality as well as the available microclimate. Buru Island, characterized by karst topography and mountainous terrain, sees Babirusa mostly found at mid to high elevations, avoiding low coastal areas densely populated by humans. However, the contribution of elevation to the Babirusa habitat distribution model is relatively small, indicating the species' wide tolerance for altitude variation as long as other habitat needs are met (Rosyidy & Wibowo, 2020). Spatially, elevation is visible on the habitat distribution map (Figure 4.a), and its contribution across elevation classes is shown in Figure 5.a This condition aligns with findings that Babirusa occupy upland forests and mountainous areas, with the best habitats typically located in regions of relatively intact primary forest cover and dense vegetation that support feeding and shelter needs. Therefore, although elevation is not the primary factor, the presence of Babirusa is strongly tied to ecological conditions shaped by elevation, including soil moisture and microclimate supporting vegetation that provides its food sources.

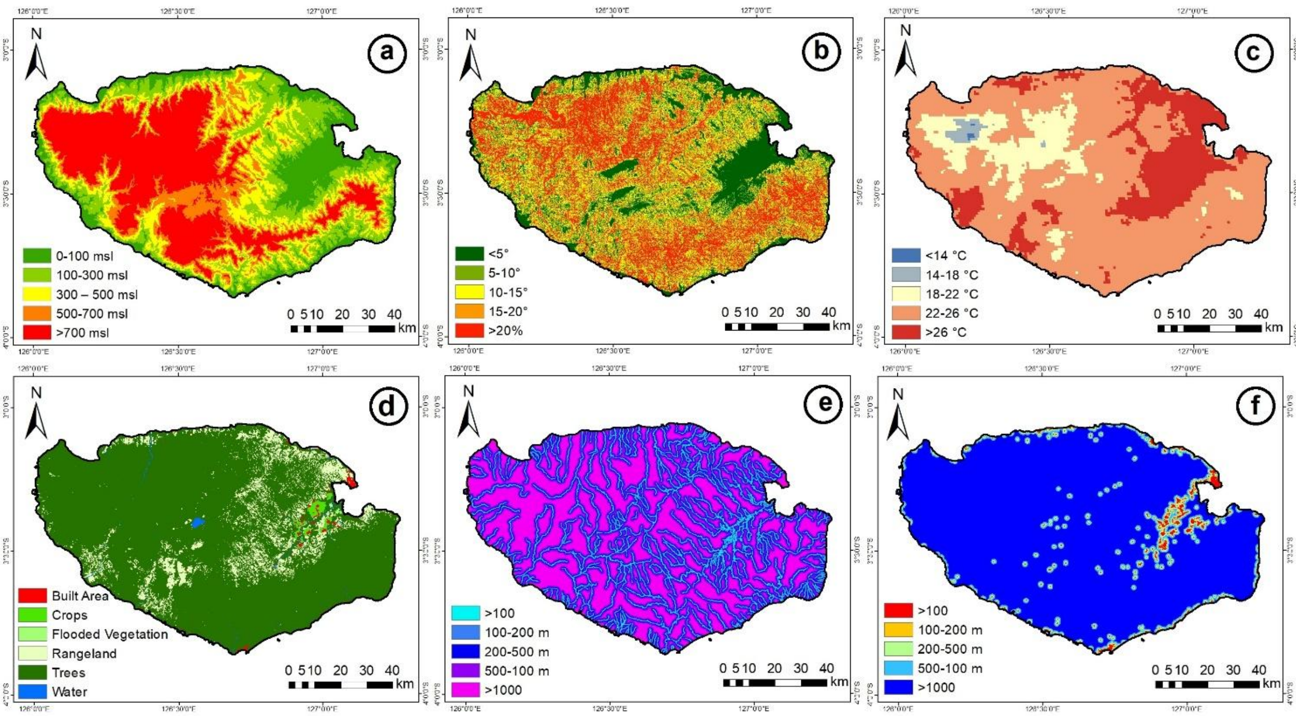

Figure 4. Environmental Variables: (a) Elevation, (b) Slope, (c) Temperature, (d) Land Cover, (e) Distance to Water, (f) Distance from Built-up Land

Slope plays a role in the mobility and habitat selection of the Babirusa (*Babyrousa babyrussa*), as steep slopes are generally less favored due to difficulties in movement and food searching (Figure 4.a). On Buru Island, slope contributes minimally to habitat distribution, indicating it is not a major limiting factor for Babirusa. This may be because most ideal habitats for Babirusa are in areas with gentle to moderate slopes that allow free movement and access to food sources (Ferretti et al., 2021). The contribution curve for slope classes (Figure 5.e) shows that Babirusa tend to prefer habitats with low to moderate slopes, supporting their ecological activities without significant topographic barriers (Wibowo, 2021). Therefore, although slope is not a dominant variable, understanding it remains important for conservation and habitat management on Buru Island, particularly in maintaining connectivity and availability of suitable areas for the well-being of this species (Figure 5.b).

Environmental temperature significantly influences the survival of Babirusa (*Babyrousa babyrussa*) because this species depends on the stable conditions of wet tropical forest habitats (Figure 4.c). Temperature changes can directly affect Babirusa's physiological activities and behaviors, including food consumption and their ability to regulate body temperature (Fischer, 2002). The high contribution of temperature (24.1%) in the habitat distribution model indicates it is a major limiting factor for Babirusa, as it affects their metabolism and the availability of vegetation as a food source (Rosyidy & Wibowo, 2020). Ideal Babirusa habitats typically feature tropical temperatures that support a microclimate with dense vegetation and ample water supply, essential for wallowing and skin care. The temperature contribution curve across various classes (Figure 5.f) shows Babirusa preference for temperature ranges that support their natural survival. Unsuitable temperature conditions can cause physiological stress and reduce the abundance of viable habitats for this species, making temperature a critical variable for conserving and managing Babirusa habitat on Buru Island (Wibowo, 2021).

Land cover type is a key factor determining the suitability of habitat for the Babirusa (*Babyrousa babyrussa*) on Buru Island, with a strong preference for primary and secondary forests that provide essential food sources, shelter, and ecological protection (Figure 4.d) (Wibowo, 2021). Primary forests, with their complex vegetation structure and high ecosystem stability, offer the optimal habitat for Babirusa feeding and activities. Secondary forests can still support Babirusa presence, although with slightly lower habitat quality. Land cover disturbances from forest conversion into settlements, plantations, or agricultural land cause significant habitat fragmentation, reducing habitat suitability and continuity vital for maintaining Babirusa populations. The significant contribution of the land cover variable in the model (27.4%) reflects Babirusa's high sensitivity to landscape changes that can lead to habitat degradation and hinder movement and ecological interactions (Figure 5.b). Therefore, conservation of both primary and secondary forest habitats is a top priority in preserving Babirusa, especially given the increasing threats from deforestation and land-use changes on Buru Island (Setiyani et al., 2023).

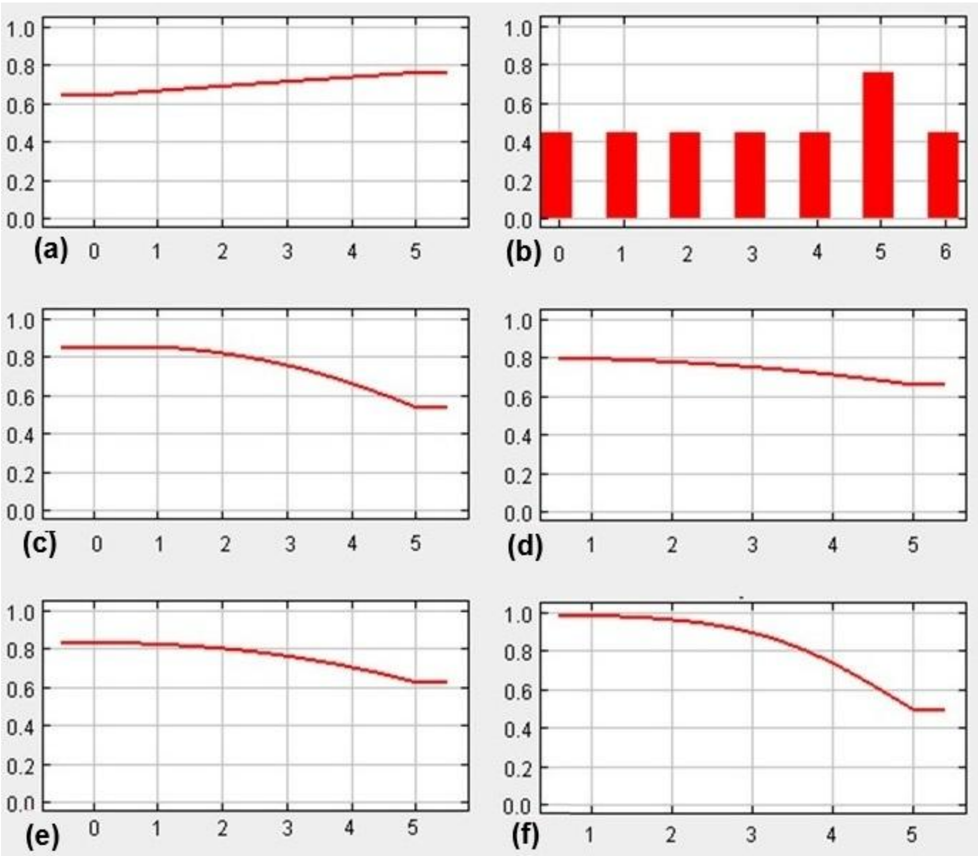

Figure 5. Variable Contribution Curve; (a) Distance from built-up land, (b) Land Cover, (c) Distance to Water, (d) Slope, (e) Elevation, (f) Temperature.

Babirusa (*Babyrousa babyrussa*) heavily rely on the availability of water sources for critical needs such as drinking, bathing, and wallowing, which serve to regulate body temperature (thermoregulation) and remove parasites (Wibowo, 2021). On Buru Island, the variable distance to water sources contributes relatively little to the habitat distribution model, likely because water sources are fairly evenly distributed throughout their habitat or because babirusas can access water sources located away from their main activity areas. Spatially, the distance from rivers and water sources can be observed in Figure 4.e, while its contribution curve to water distance classes is shown in Figure 5.c. This indicates that although water is an essential ecological requirement, babirusas on Buru Island have adaptive flexibility regarding water distance, allowing them to survive in landscapes with uneven water distribution (Macdonald et al., 2008). This capability is an important survival strategy for babirusas amid habitat changes and fluctuating natural resource availability.

The variable "distance from built-up land" contributes the most to determining the habitat distribution of Babirusa (*Babyrousa babyrussa*) on Buru Island, indicating that this species strongly avoids areas close to human settlements or activities. Anthropogenic disturbances such as deforestation, hunting, and land conversion to residential or agricultural use cause significant habitat fragmentation and reduce the quality of suitable habitats (Macdonald, 2017). Therefore, distance from densely populated areas is a key factor in predicting the presence and survival of Babirusa, as areas far from human disturbance provide safe space for feeding, sheltering, and breeding activities. Spatially, this variable can be observed on the habitat distribution map (Figure 4.f), and the contribution curve of distance from built-up land is shown in Figure 5.a. This condition underscores the importance of managing buffer zones around settlements to reduce human pressure and preserve natural Babirusa habitats while maintaining ecosystem connectivity crucial for the mobility of this species (Mustari et al., 2013). Conservation of Babirusa on Buru Island requires an approach that integrates habitat protection from human disturbance as a primary step to safeguard the population and ecological sustainability.

Land Suitability Model for *Babyrousa babyrussa* Habitat

The habitat suitability model for *Babyrousa babyrussa* on Buru Island, developed using Maximum Entropy modeling, classifies the habitat into four main categories with varying extents and qualities that have different implications for species survival. The "Very Low" suitability class covers about 210,749.84 hectares (24.95%) of the area and represents regions highly unsuitable for babirusa. These regions typically consist of open or fragmented land, areas with high human disturbance, or unfavorable environmental conditions such as extreme elevations, temperatures, and inadequate vegetation cover. In these habitats, the likelihood of babirusa population persistence is minimal, necessitating management efforts aimed at habitat protection or restoration. Spatial distribution of habitat suitability can be visualized in Figure 6.

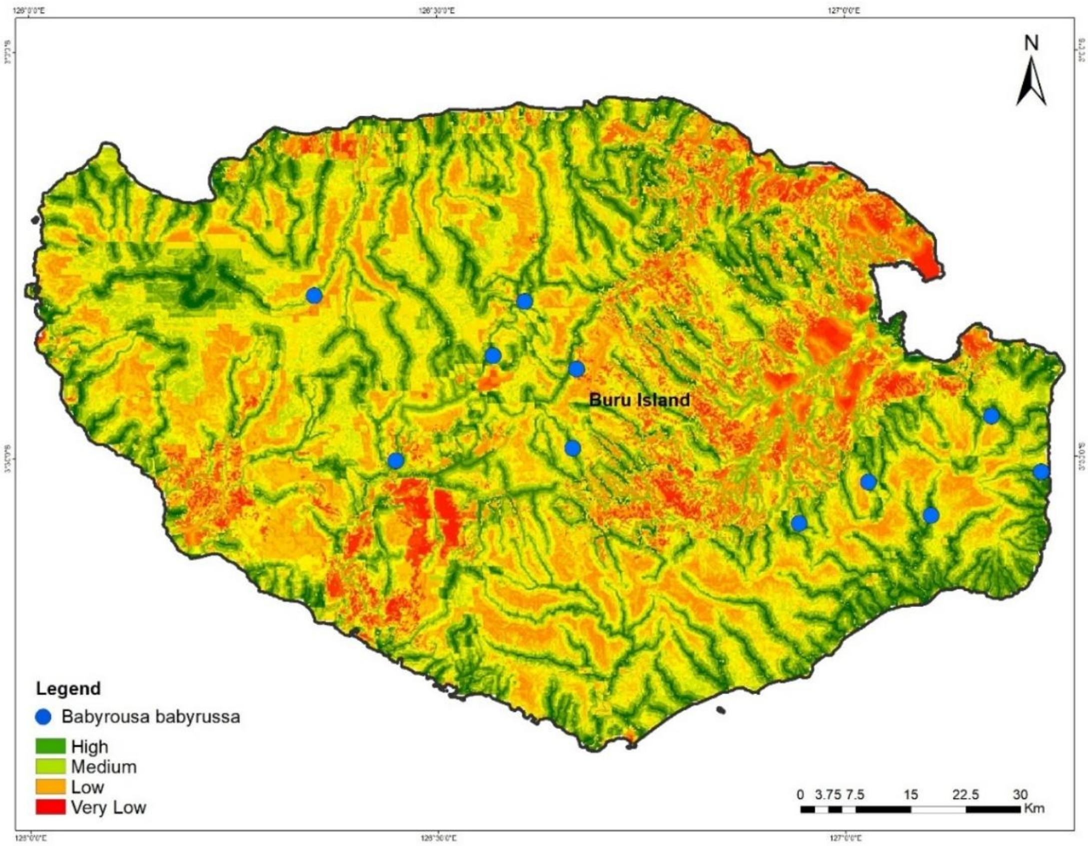

Figure 6. Spatial Distribution and Habitat Suitability of the Endemic Babirusa (*Babyrousa babyrussa*) on Buru Island, Maluku Province, Indonesia

The Low class covers an area of 267,519.19 hectares (31.67%) and represents zones with low habitat suitability, where environmental factors become more conducive but still have limitations, such as proximity to settlements or vehicle routes, steep slopes, and a mix of primary and secondary forest cover. In this zone, babirusa may still exist in small populations, so it is important to enhance protection and reduce anthropogenic pressures. The Moderate class, covering 250,997.69 hectares (29.71%), indicates moderate habitat suitability with relatively favorable environmental conditions such as supportive elevation, good forest cover, stable temperature, and proximity to water sources. These habitats are potentially important corridors for babirusa population movement and need to be maintained to prevent degradation. This class is ideal for ecosystem-based conservation and population monitoring programs. The High class, with an area of 115,565.26 hectares (13.68%), represents the best habitat suitability for *Babyrousa babyrussa*. Characteristics of this zone include dense primary forest cover, abundant water sources, distance from human activity and settlements, and ideal topography combined with optimal temperature (Wibowo, 2021). This area is vital for the species' survival and is a high priority in conservation strategies, wildlife protection, and further research on babirusa habitat and behavior.

In the habitat suitability model for babirusa created, accuracy testing and model validation were conducted to assess the predictive strength using cross-validation on the testing and training data. Validation involved comparing a 70% training data split with 30% testing data, chosen due to limited babirusa presence data. Model validation was measured using the Area Under the Curve (AUC) value, categorized according to Zhang et al., (2018). The validation results for the babirusa habitat suitability model are presented in Figure 7.

Figure 7(a) shows the error rate and the area predicted as a cumulative threshold. The curve indicates that the error rate for the training data closely matches the predicted model error, consistent with Phillips et al., (2006), where a smaller difference between training data error and model prediction error signifies lower overall error and stronger model performance.

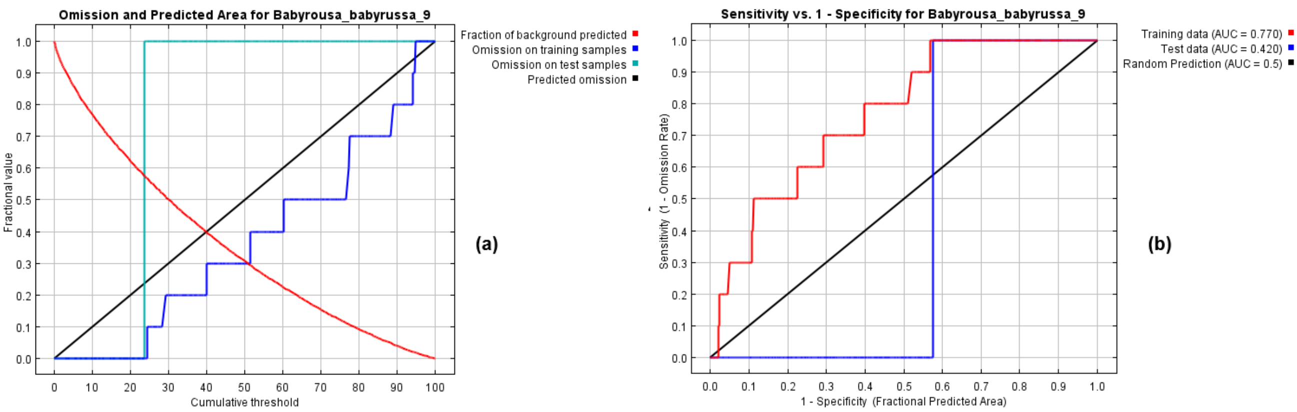

Figure 7. ROC-AUC Curve (a) Error Area and Prediction; (b) Sensitivity

Figure 7(b) displays the Receiver Operating Characteristic (ROC) curve for the same dataset. Specificity is based on the predicted area results (Phillips et al., 2006). The highest AUC value achieved by this model is 0.770, indicating positive accuracy. According to Phillips et al., (2006), this falls into the high accuracy category. Therefore, the babirusa habitat suitability prediction model demonstrates good discrimination between suitable and unsuitable habitats, providing strong confidence in the modeling results.

Policy Recommendations

Conservation policy recommendations for *Babyrousa babyrussa* on Buru Island should focus on protecting natural habitats and mitigating threats from human activities. Firstly, government and conservation agencies need to strengthen law enforcement against forest encroachment, illegal logging, and wildlife poaching through regular patrols involving local communities as voluntary monitors (Clayton et al., 2000). Additionally, habitat restoration and rehabilitation programs should be implemented in fragmented areas to maintain ecological corridors that support the survival and movement of babirusa populations (Wibowo, 2021). Raising awareness and educating local communities about the importance of babirusa conservation and the benefits of preserving nature should be an integral part of these policies to encourage active community participation (Fischer, 2002). This strategy aligns with the National Babirusa Conservation Action Plan established by the Ministry of Environment and Forestry of Indonesia (KLHK) and developed through multi-stakeholder coordination from 2013 to 2022 (Setiyani et al., 2023).

Secondly, ongoing monitoring using technologies such as camera traps should be prioritized to obtain up-to-date data on the distribution, density, and behavior of babirusa in their natural habitat. This information can provide a scientific basis for updating habitat maps and assessing the effectiveness of implemented conservation policies. Furthermore, establishing special conservation areas and designating protection zones in high habitat suitability areas are strategic steps to secure long-term protection. Collaborative research with universities and international conservation organizations is highly encouraged to deepen studies on the genetics, ecology, and adaptation of this endemic species. These policies support efforts to preserve biodiversity in the Wallacea region and fulfill Indonesia's obligations to protect species listed as Vulnerable by the IUCN and included in CITES Appendix I (Wibowo, 2021).

CONCLUSION

The conclusion of this study indicates that the habitat distribution of Babirusa (*Babyrousa babyrussa*) on Buru Island is greatly influenced by environmental variables such as elevation and distance from residential areas. Although these factors do not dominate, they indicate a broad tolerance of the species to these variables. Areas with high and moderate suitability levels cover most of the habitat capable of supporting the species' survival, making management and protection of habitats in these zones a top priority. The MaxEnt modeling provides an effective spatial representation that serves as a foundation for sustainable and environmentally focused conservation decision-making, as well as a critical tool in developing biodiversity strategies and optimizing conservation area management on Buru Island.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this manuscript.

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