Siamese Crocodile *(Crocodylus siamensis)* Habitat Preference in Kalimantan Timur using Maximum Entropy Modeling

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ABSTRACT

This study aims to understand the habitat preferences and environmental factors affecting the distribution of the Siamese crocodile (Crocodylus siamensis) in East Kalimantan, the presence data is taken in Mesangat Wetlands Essential Ecosystem. Collected through field observations, camera traps, and local community input from 2017 to 2022. Using the MaxEnt model, 24 environmental variables, including climatological and physical data, were analyzed. Results showed that the Bio4 variable (Seasonal temperature) significantly influenced the crocodile's distribution, with ideal temperatures between 26-27°C and annual rainfall of 2000-2500 mm/ Year. The most suitable habitats were lowland areas with high river accessibility and low land slope. Jackknife analysis confirmed climate variables had the greatest impact, while NDVI had a lower impact. The model's accuracy was high, with an AUC of 0.991. The primary habitats were in Kutai Timur Regency, classified into four categories: unsuitable, low suitability, moderate suitability, and high suitability. Conservation recommendations include improving habitat quality, strengthening conservation programs, genetic research, industry collaboration, and raising public awareness. This study provides a scientific basis for more effective conservation efforts to ensure the survival of the Siamese crocodile in the wild.

Keyword: Crocodylus siamensis, Environmental variables, Habitat preferences, MaxEnt model, Siamese crocodile

ABSTRAK

Penelitian ini bertujuan untuk memahami preferensi habitat dan faktor lingkungan yang mempengaruhi distribusi buaya siam (Crocodylus siamensis) di Kalimantan Timur, pengambilan data kehadiran di Lahan Basah Mesangat, dengan metode observasi lapangan, penggunaan kamera jebak, dan informasi dari masyarakat setempat, dari rentan waktu 2017 hingga 2022. Analisis MaxEnt yang dilakukan mengevaluasi 24 variabel lingkungan, yang meliputi data klimatologi dan fisik. Hasil menunjukkan bahwa variabel Bio4 (Suhu Musiman) memiliki pengaruh paling signifikan terhadap distribusi buaya siam, dengan rentang suhu rata-rata tahunan yang sesuai antara 26-27°C dan curah hujan tahunan 2000-2500 mm. Habitat yang paling sesuai berada di dataran rendah dengan aksesibilitas sungai yang tinggi dan kemiringan lahan yang rendah. Analisis jackknife mengkonfirmasi bahwa variabel iklim memiliki kontribusi terbesar dalam model, sedangkan NDVI menunjukkan dampak yang lebih rendah. Tingkat akurasi model sangat tinggi dengan AUC 0.991. Habitat buaya siam di Kalimantan Timur terutama berada di Kabupaten Kutai Timur, dengan kategori kesesuaian habitat yang dibagi menjadi empat kelas: tidak sesuai, kesesuaian rendah, sedang, dan tinggi. Rekomendasi untuk konservasi mencakup peningkatan kualitas habitat, penguatan program konservasi, riset genetik, kolaborasi dengan industri, dan peningkatan kesadaran publik. Hasil penelitian ini memberikan dasar ilmiah untuk upaya konservasi yang lebih efektif guna memastikan kelangsungan hidup buaya siam di alam liar.

Kata kunci: Buaya Siam, Crocodylus siamensis, Habitat preferensi, MaxEnt model, Sebaran lingkungan

INTRODUCTION

East Kalimantan, is one of the high biodiversity value in the word, provides crucial habitat for the endangered Siamese crocodile (*Crocodylus siamensis).* The presence of this species indicates healthy freshwater ecosystems, but threats like deforestation, habitat degradation, and human-wildlife conflicts have led to declines in their population. Understanding the habitat preferences and spatial distribution of *Crocodylus siamensis* is essential for effective conservation and management.

Currently, information is limited and insufficient for targeted conservation strategies. Previous studies have focused on population inventories without comprehensive predictive distribution modeling. Predictive techniques like MaxEnt are valuable for understanding habitat preferences and potential distribution by integrating environmental data and occurrence records, aiding in conservation planning. However, the data about *Crocodylus siamensis* in East Kalimantan is still limited.

This study aims to enhance our understanding of *Crocodylus siamensis's* habitat preferences and distribution in East Kalimantan using MaxEnt. By utilizing comprehensive environmental data and valid occurrence records, this research will provide insights into the environmental factors influencing the species' presence. The findings will form a basis for sustainable conservation strategies, aiding habitat protection and population recovery.

Expected outcomes include a detailed understanding of habitat preferences, accurate distribution maps, analysis of human impacts, identification of threats and challenges, and targeted conservation recommendations. The study also aims to promote collaboration among stakeholders and enhance public awareness and education about Siamese crocodile conservation. This research will deepen ecological and conservation knowledge of *Crocodylus siamensis* and generate actionable recommendations to ensure the species' future survival.

METHODS

Research Location

The MaxEnt model is taking sample in Kalimantan Province, and presence data is collected in Essential Ecosystem Area (KEE) of Mesangat Wetland. The coordinates for this location are between 00°38'40" - 00°25'54" N and 116°38'53" - 116°44'24" E.

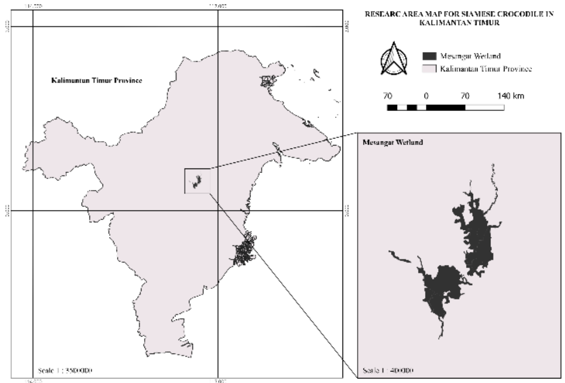

Figure 1. Research Area

Research Procedure

a. Occurrence / Presence Data

Species Presence Data: Collected for *Crocodylus siamensis* in East Kalimantan through field observations, camera traps, captures, and previous research reports from 2017-2021. Coordinates (x,y) in Mesangat Wetland and were extracted into a .csv format for spatial data processing in ArcGIS.

b. Environmental Variable

Environmental Variables for Siamese Crocodile Habitat Distribution that we considered is twenty-four environmental variables as potential predictors of the Siamese crocodile (*Crocodylus siamensis*) habitat distribution. These variables were chosen based on their biological relevance to species distributions and other habitat modeling studies (e.g., Kumar et al., 2006; Guisan et al., 2007a, b; Pearson et al., 2007; Murienne et al., 2009). Nineteen bioclimatic variables, which are biologically more meaningful for defining eco-physiological tolerances of a species (Graham and Hijmans, 2006; Murienne et al., 2009), were obtained from the WorldClim dataset (Hijmans et al., 2005; WorldClim Bioclimatic Data). Elevation data (Digital Elevation Model; DEM), with a spatial resolution of 1 km. The DEM data were used to generate slope and aspect (both in degrees) using ARC GIS version 9.2, 'Surface Analysis' function (ESRI, Redlands, California, USA). Normalized Difference Vegetation Index (NDVI) data, representing vegetation density and health, were acquired from the MODIS dataset available through the Global Land Cover Facility (GLCF), University of Maryland (GLCF NDVI Data) website. Soil data layers were not used in the analyses due to their coarse resolution. All environmental variables were resampled to a 1 km spatial resolution.

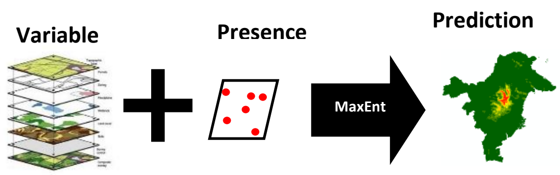

Figure 2. MaxEnt Process

Covariance index

We tested all variables for covariance and correlation matrix, ArcGIS analysis evaluates relationships between environmental variables. Higher covariance values indicating stronger relationships. In this study, 24 environmental variables were analyzed, with Bio4 (representing seasonal temperature) having the highest covariance index (-22273.9) and NDVI (Normalized Difference Vegetation Index) the lowest (-09396).

While Bio4 strongly influences Siamese crocodile distribution prediction, NDVI's lower relevance suggests its limited impact due to the crocodile's habitat preferences. Similar trends were found in previous reptile habitat studies, such as Pramatana's 2023 study on Komodo dragons and Untalan et al.'s 2019 research on the Philippine monitor lizard.

Variable Correlation

The evaluation of environmental variable correlations identified seven highly correlated variables: Bio4, Bio5, Bio6, Bio8, Bio9, Bio10, and Bio11. These variables exhibit correlation indices close to "1". Bio4 represents temperature variability, Bio5 indicates the maximum temperature of the warmest month, Bio6 represents the minimum temperature of the coldest month, Bio8 provides information on the wettest quarter's average temperature, Bio9 denotes the driest quarter's average temperature, Bio10 gives insight into the hottest quarter's average temperature, and Bio11 represents the coldest quarter's average temperature. While these correlations were noted, their influence on the modeling process will be considered further in the evaluation phase, particularly in assessing variable contribution. This will provide insights into which variables contribute most significantly to the study.

c. MaxEnt Modeling Procedure

Maximum Entropy Distribution or MaxEnt, which has demonstrated superior performance compared to various other modeling methods (Elith et al., 2006; Ortega-Huerta and Peterson, 2008). MaxEnt is particularly effective even with limited sample sizes (Hernandez et al., 2006; Pearson et al., 2007; Papes and Gaubert, 2007; Wisz et al., 2008; Benito et al., 2009). This machine learning program estimates the probability distribution of a species' occurrence based on environmental constraints (Phillips et al., 2006). MaxEnt requires only species presence data (not absence) and environmental variable layers for the study area.

We utilized the freely available MaxEnt software, version 3.4, which generates probability estimates of species presence ranging from 0 to 1, with 0 indicating the lowest and 1 indicating the highest probability. On this research we use 278 presence records and 24 environmental variable to model the potential habitat distribution for the Siamese crocodile.

We jackknife validation test required defining 'suitable' and 'unsuitable' areas using two different thresholds: the 'lowest presence threshold' (LPT, equal to the lowest probability at the species presence locations) and a fixed threshold of 0.10. For further details, refer to Pearson et al. (2007).

RESULT AND DISCUSSION

a. Habitat preference for *Crocodylus siamensis*

The processing of environmental data revealed the habitat preferences of the Siamese crocodile (*Crocodylus siamensis*) based on bioclimatic and physical factors. The suitable temperature range for Siamese crocodiles is between 26 and 27°C for the mean annual temperature, with a relatively wide daily temperature range of 40 to 55°C. This indicates a preference for habitats with significant daily temperature fluctuations, likely related to thermoregulatory activities.

Annual precipitation suitability is between 2000 and 2500 mm, with significant quarterly precipitation variations (100 to 800 mm). This suggests a preference for habitats with moderate to high humidity throughout the year, River accessibility with a suitable accessibility range between 0 and 10 meters, indicating a preference for habitats close to water sources, topography suitable slope ranges from 0 to 2%, suggesting a preference for relatively flat habitats. Suitable elevation ranges from 26 to 36 meters, indicating a preference for lowland areas. However, the involvement of rivers as the main accessibility and low NDVI values (-3 to 0.3) suggests a preference for habitats with relatively open vegetation.

b. Omission / Commission analysis

The analysis of omission/commission is an evaluation method used in MaxEnt modeling to measure how well the model predicts the presence or absence of a particular event or phenomenon. The graph below illustrates the evaluation of variables in areas predicted as a function of cumulative threshold predictions for Siamese crocodile habitat.

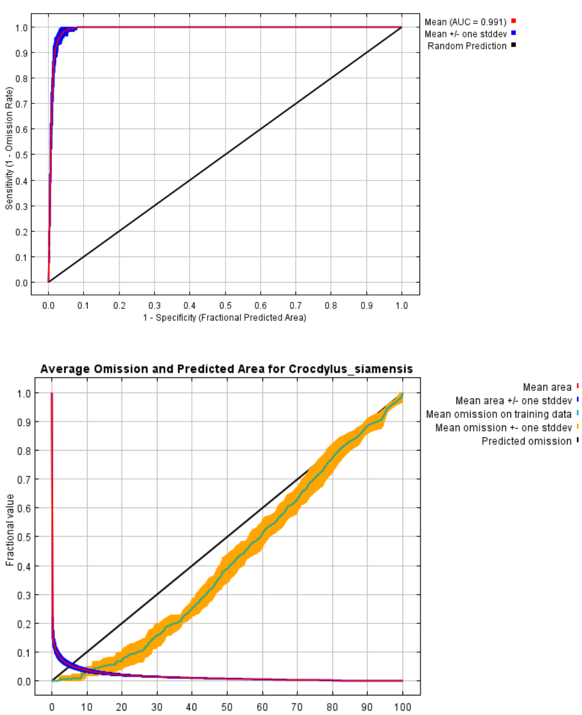

Figure 3. Response Curve

The graph above indicates that the results of the AUC analysis support the research hypothesis, where the Area Under the Curve (AUC) value obtained is **0.991**, indicating very high accuracy. The precision is calculated from the significance level set beforehand (α = 0.05) (Fielding & Bell, 1997).

c. Variable contribution

The influence of environmental variables on modeling the suitability of Siamese crocodile habitat can be seen from the results of jackknife analysis, which is a method to evaluate the relative contribution of each environmental variable to the model (Negga, 2007). The results

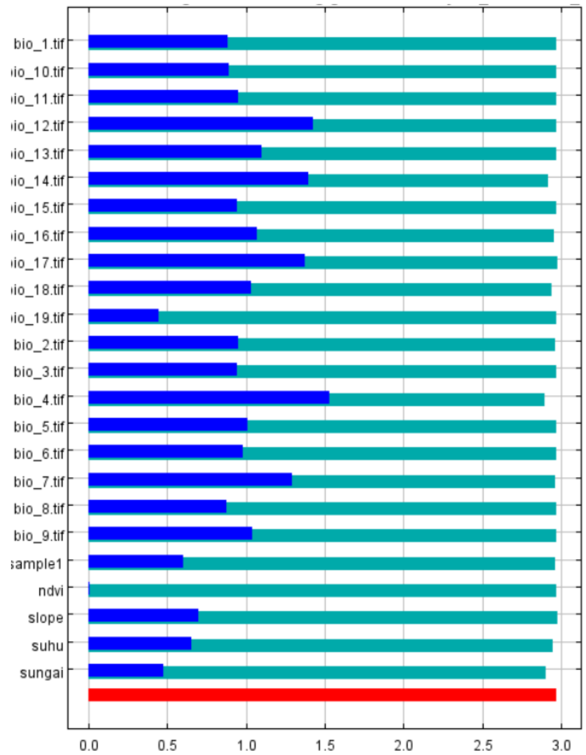

Figure 4. Jacknife evaluation for relative importances of Environmental Variable

of this operation indicate that NDVI has the lowest index value, consistent with research in reptile taxa showing that the use of NDVI (Normalized Difference Vegetation Index) exhibits a low trend compared to comparisons with other climate and physical variables.

Environmental variables with the highest gain when used individually are bio 4, which has the greatest independent value and impact, providing the most information not found in other variables. Bio 04 (Temperature Variability) with a value of 20 °C - 30 °C, provides an overview of temperature fluctuations throughout the year. This range of values reflects that temperature fluctuations are moderate. This means that the temperature difference between different seasons is not too extreme.

Areas with values between 20 to 30°C experience temperature changes between seasons that are not significantly pronounced. Although with a difference of 10°C between the rainy and hot seasons, this temperature difference is not considered extreme. This indicates that the region may have a relatively stable climate, where temperature fluctuations are not too noticeable, and it may also indicate that the region may have a more regular and consistent seasonal pattern.

d. Prediction of Siamese crocodile habitat disribution

The classes of Siamese crocodile (Crocodylus siamensis) habitat are divided into four classes based on the range of logistic distribution threshold values, namely "unsuitable," "low suitability," "moderate suitability," and "high suitability." The range of values for each suitability class is determined by considering the percentage of data present in that area from all variables, where the value starts from 0 indicating the lowest suitability up to 0.99 indicating the highest suitability taken from the AUC accuracy.

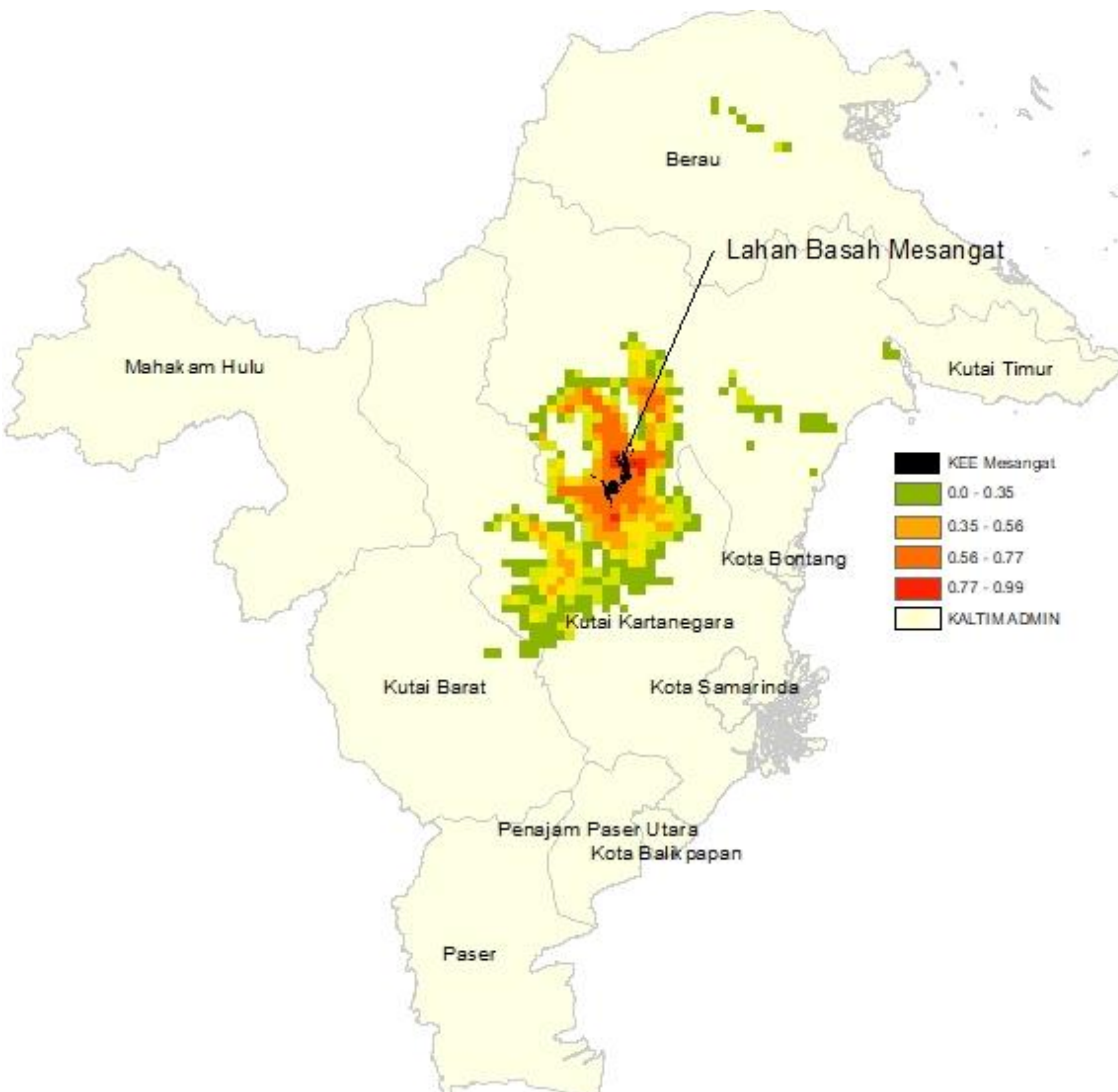

Figure 5. Prediction Habotitat Suitability of Siamese Crocodile in Kalimantan Timur using MaxEnt Modeling

Table 1. Suitability class of Siamese Crocodile in Kalimantan Timur

No	Class	Min	Max
1	Unsuitable	0	0.35
2	Low Suitability	0.35	0.56
3	Moderate Suitability	0.56	0.77
4	High Suitability	0.77	0.99

From this predictive information, it is found that this habitat is mostly distributed in East Kutai Regency, with a small portion in West Kutai, where the identified habitat forms include rivers, bodies of water, and relatively dense lowland swamp forests. An illustration of the distribution of Siamese crocodile habitat can be seen in the image above.

CONCLUSION AND RECOMMENDATION

Habitat modeling for Siamese crocodiles (*Crocodylus siamensis*) in East Kalimantan has provided valuable insights into the species' habitat preferences/ suitability. By examining various environmental variables such as temperature, rainfall, river accessibility, slope, and elevation, researchers have gained a comprehensive understanding of the characteristics of habitats favored by Siamese crocodiles. Notably, climate variables, particularly seasonal temperature variability (Bio4), have emerged as significant influencers in habitat modeling, with moderate temperature ranges between 20 to 30°C showcasing particular importance.

Furthermore, the jackknife analysis has underscored the crucial role of climate variables, especially seasonal temperature variability, in shaping habitat suitability for Siamese crocodiles. While physical factors like NDVI have shown relatively lower impacts, indicating vegetation might not be the primary determinant of habitat selection in the region. The high accuracy rate observed in omission/commission analysis, with an Area Under the Curve (AUC) reaching 0.991, confirms the efficacy of the developed model in predicting Siamese crocodile distribution accurately.

The delineation of Siamese crocodile habitat suitability into distinct classes, ranging from not suitable to highly suitable, reveals that significant portions of East Kalimantan, notably Kutai Timur Regency.

a. Recommendation

The findings of this study can serve as a basis for planning and implementing conservation strategies for Siamese crocodile habitat in East Kalimantan. Information about habitat preferences and important environmental factors can be used to determine priority locations for conservation efforts and habitat restoration. A better understanding of the impact of human activities on Siamese crocodile habitat can assist in designing sustainable management policies. This includes establishing conservation areas, regulating infrastructure development, and managing sustainable land use.

The development of sophisticated and accurate spatial models can also be used in evidence-based decision-making for habitat management and population monitoring. This enables stakeholders to make more accurate and effective decisions in conservation efforts.

• **Further studies on ecological interactions:** Further research can explore the interactions between Siamese crocodiles and other species and their surrounding environment. This includes studies on feeding behavior, reproduction, and ecological relationships with other species in freshwater ecosystems.

• **Human activity impacts:** Research can deepen understanding of the impact of human activities, such as infrastructure development and land use changes, on Siamese crocodile habitat and populations. This will help design more effective management strategies to protect and preserve Siamese crocodile habitat.

• **Variable accuracy:** detailed spatial modeling with raster accuracy and by reducing variables considered irrelevant in this study to maximize output in data processing.

• **Population genetics studies:** Research on population genetics can provide insights into population structure, genetic diversity, and habitat connectivity of Siamese crocodiles in East Kalimantan. This information is crucial for designing sustainable conservation strategies.

• **Adding impact variables:** infrastructure development or industrial development as balancing variables can understand species adaptation to human development and civilization.

By deepening our understanding of Siamese crocodile habitat and ecology and engaging in various multidisciplinary approaches, further research is expected to make a significant contribution to conservation and protection efforts for this species in East Kalimantan.

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