BIODIVERSITAS
Volume 25, Number 9, September 2024
Pages: 3246-3253

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d250947

Spatial modeling of the use probability for Pig-nosed turtles (*Carettochelys insculpta*) in South Papua, Indonesia

PURNAMA GRAHA[1,♥], MIRZA D. KUSRINI[2], SYARTINILIA[3], RICHARD GATOT NUGROHO TRIANTORO[4]

[1]Natural Resources and Environmental Management Study Program, Institut Pertanian Bogor. Gedung SPS 2nd Floor Kampus IPB Barangsiang, Bogor 16144, West Java, Indonesia. Tel./fax.: +62-251-8332779, ♥email: purnamagraha@apps.ipb.ac.id
[2]Forest Resources Conservation and Ecotourism, Institut Pertanian Bogor. Kampus IPB Dramaga, Bogor 16680, West Java, Indonesia
[3]Landscape Architecture, Institut Pertanian Bogor. Kampus IPB Dramaga, Bogor 16680, West Java, Indonesia
[4]Forestry Service of West Papua Province. Jl. Brigjend Abraham O. Atururi, Arfai, Manokwari 98315, West Papua, Indonesia

Manuscript received: 11 July 2024. Revision accepted: 19 September 2024.

Abstract. *Graha P, Kusrini MD, Syartinilia, Triantoro RGN. 2024. Spatial modeling of the use probability for Pig-nosed turtles (*Carettochelys insculpta*) in South Papua, Indonesia. Biodiversitas 25: 3246-3253.* The uncontrolled use of natural resources can threaten species' survival and negatively impact ecosystems, potentially affecting the economy and its service to humans. One species that requires attention is the Pig-nosed turtle (*Carettochelys insculpta* Ramsay, 1886), the sole surviving member of the Carettochelyidae family and is only found in rivers of southern New Guinea and the northern regions of Australia. Pig-nosed turtles have been harvested intensively in Papua for their eggs and are considered vulnerable based on the International Union for Conservation of Nature red list assessment. Developing a spatial distribution model to determine the probability of use of *C. insculpta* priority areas is crucial to safeguard the essential areas necessary for its life cycle. This research utilized the Ecological Niche Modeling at The Metaland EcologyLab to assess use probability and identify potential conservation risks. Results of the probability of use model analysis in South Papua Province revealed that the region with the highest use probability of *C. insculpta* is Boven Digoel District, accounting for a significant land area of 496,019.61 hectares. In comparison, moderate use was noted in Asmat District, encompassing 921,830.76 hectares, whereas low use was recorded in the same district, covering 695,466.10 hectares. The use probability was influenced by multiple factors, with the most significant contributions stemming from the occurrence of water (41%), distance from the settlement (21%), distance from road (14%), land cover (13%), river density (6%), and slope (5%).

Keywords: *Carettochelys insculpta*, conservation risks, probability, spatial distribution model, use

INTRODUCTION

The Pig-nosed turtle, *Carettochelys insculpta* Ramsay, 1886, is a unique species. It was first identified in 1886 by Australian zoologist Edward Pierson Ramsay, with the initial specimen collected in Strickland River, a tributary of the Fly River located in Papua New Guinea (Ramsay 1887). This species is the only surviving member of the Carettochelyidae family, making it a significant part of the ecosystem (Joyce 2014). The *C. insculpta* is a Cryptodira, or hidden neck, suborder of the Carretoch elyidae family, and according to the cladogram of extant turtle family members, it is the oldest living species, from 200 million to 150 million BC (Vitt and Caldwell 2014). In Papua, Indonesia, *C. insculpta* is not as famous as sea turtles but holds significant cultural value and contributes significantly to human sustenance. In the vicinity of Vriendschap River, Asmat District, South Papua Province, Indonesia, *C. insculpta* is even used as part of dowries, underscoring their deep cultural significance in local communities (Triantoro et al. 2017). For centuries, these turtles have served as a food source for local populations, providing eggs and meat in several regions across Papua, Indonesia (Eisemberg et al. 2018). However, *the C. insculpta* population is under increasing pressure due to habitat degradation and climate change, with commercial exploitation being a primary threat (Burgess and Lilley 2014; Samedi 2000). These threats underline the urgent need for conservation efforts.

The Pig-nosed turtle is a protected and endangered species in Indonesia, and it is also included in CITES Appendix II (Eisemberg et al. 2018; Indonesian Government 2018). Human use, specifically illegal trade, is the biggest threat to *C. insculpta* in Indonesia. The species is in high demand for exotic pets, food markets, and traditional healing practices, leading to intensive exploitation in Papua. From 2013 to 2020, there were 20 reported illegal cases (Shepherd et al. 2020). Indonesian export data from 2000 to 2015 showed that individuals bred in captivity were sold as pets for prices ranging from $100 to $300 in the Japanese market and $100 to $500 in the U.S. market (Andersen et al. 2021). The high economic value of *C. insculpta* has led to illegal trade with significant negative impacts. Although the Indonesian Government has implemented a limited quota system for the use of wild eggs (Indonesian Government 2022), this only applies to the Asmat District. Legal breeding is only available in Asmat, so *C. insculpta* from Boven Digoel District and other areas in South Papua Province is considered illegal and may be sold to unregistered companies. However, this trade benefits the local communities economically (Kusrini et al. 2024).

In a time characterized by growing human influence on the environment, securing ecological stability is vital for sustainable development and has garnered global attention (Liu et al. 2022). Understanding the interaction between human activities and wildlife is crucial for effective conservation strategies and management (Marsh et al. 2022; Bramorska et al. 2024). This research delved into the potential and relevance of socio-economic factors in modeling species distribution, explicitly focusing on their impact on the habitat of *C. insculpta* in South Papua Province, Indonesia. A more comprehensive approach to species distribution modeling, integrating human socio-economic dynamics, can significantly enhance our understanding of the factors influencing biodiversity (Bramorska et al. 2024). Monitoring its intensive harvest is crucial to maintaining and protecting the vital feeding and nesting areas of *C. insculpta.* These areas shift based on food availability and environmental degradation (Eisemberg et al. 2015). This underscores the importance of sustainable development and the need to model the distribution of use probabilities, a practical implication of our research. Involving communities in conservation program planning is also essential, ensuring their needs and interests are accommodated. By fostering strong partnerships among communities, governments, and conservation organizations, long-term solutions can be created to protect and manage priorities sustainably (van Zinnicq Bergmann et al. 2022). The analysis results using probability modeling and identification of conservation risks can develop effective conservation strategies for managing *C. insculpta* areas and encourage the sustainable use of natural resources. These strategies promise to improve the local area's welfare, instilling a sense of hope and optimism in the local stakeholders.

MATERIALS AND METHODS

Study area

According to Eisemberg et al. (2018), *C. insculpta* primarily inhabits rivers, including deltas, estuaries, grassy lagoons, swamps, and lakes, in the southern lowlands of New Guinea, spanning from Papua Indonesia to Papua New Guinea. To model this species' probability of use, we focused study area in South Papua Province, with a buffer zone of 4 km from the river bank (Figure 1).

Procedures

Data collection and preprocessing

The species use probability model relies on two main types of data: response variable data, which consists of *C. insculpta* egg use points, and environmental variable data (Table 1). Response variable data were collected through research conducted in Boven Digoel District, South Papua Province, in 2022 and 2023, and Asmat District, South Papua Province, in 2011 and 2012. This model used 720 use points of *C. insculpta* eggs, providing latitude-longitude coordinates in decimal degrees based on the 1984 World Geodetic System data.

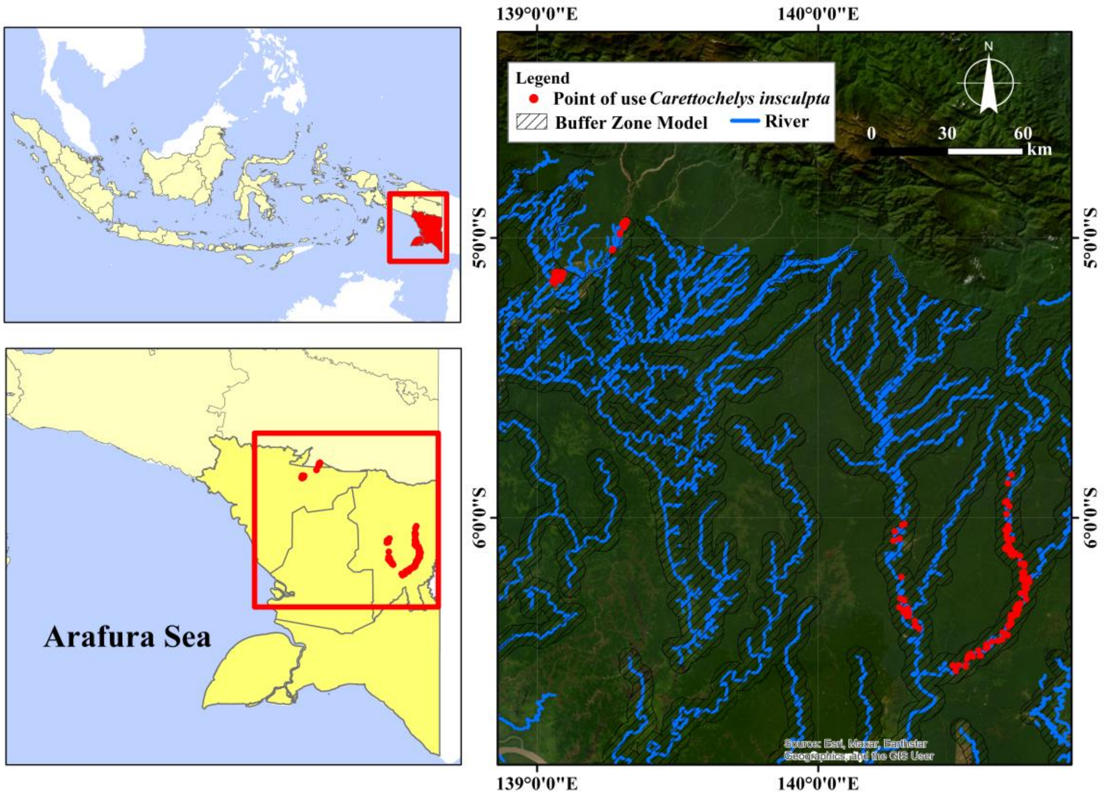

Figure 1. Location of the buffer zone for the spatial modeling of the use probability for *Carettochelys insculpta* in South Papua Province, Indonesia

Table 1. Response variable and environmental variables affecting the use probability model of *Carettochelys insculpta* in South Papua Province, Indonesia

Data	Data source	Data type
C. insculpta egg use points	Data 2011 and 2012 (Triantoro 2012), data 2022 (Kusrini et al. 2024), observation data for 2023	Point
Occurrence water	Global Surface Water, dataset 1984-2021 (Pekel et al. 2016), Url: https://global-surface-water.appspot.com/download	Raster
River density	Indonesia's Earth Shape in 2022	Vector
Distance from river to settlement	Indonesia's Earth Shape in 2022	Vector
Distance from river to road	Indonesia's Earth Shape in 2022	Vector
Land cover	Land Cover in 2022, Indonesian Ministry of Environment and Forestry	Vector
Slope	SRTM 1 Arc-Second Global, URL: https://earthexplorer.usgs.gov	Raster

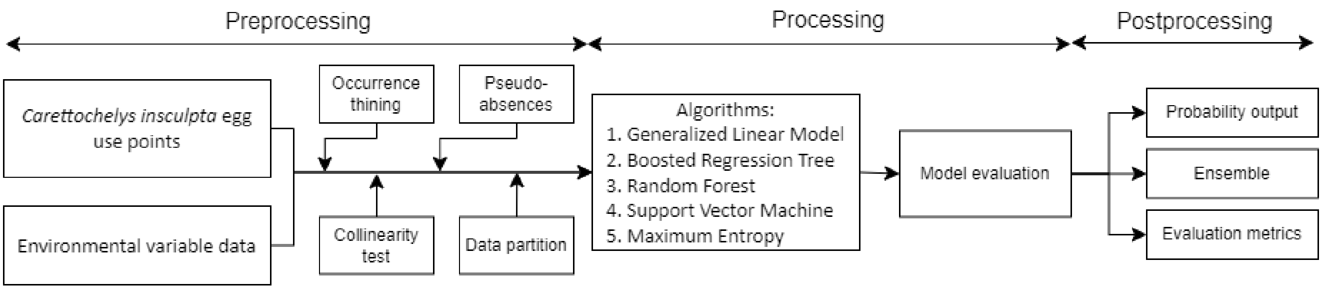

Figure 2. The research flowchart of the species uses probability-model analysis

This research models the probability of species using a direct analytical approach that avoids preconceived assumptions about data distribution (Wikle 2015). This research utilizes data on environmental variables such as the presence of water to conduct a comprehensive analysis and compile various aspects of human-animal interactions, measured through surface water occurrence, quantifying the frequency of water presence on the surface over 38 years (from March 1984 to December 2021), normalized for seasonal variations, and visually represented to show areas of permanent and occasional water occurrence (Pekel et al. 2016). Besides that, there were river density, Euclidean distance from river to settlement, and Euclidean distance from river to road, land cover, and slope were also observed. Before analysis, environmental variable data were preprocessed into necessary variables using ArcGIS software and obtained at a spatial resolution of 50 m (≈1.627 arcsec).

Data analysis

Species use probability-model analysis

This research utilized the Ecological Niche Modeling at the Metaland Ecology Lab (ENMTML) package to analyze the species using a probability model. Developed by the Laboratory of Prof. Paulo De Marco at Universidade Federal de Goiás, Brazil, ENMTML is a comprehensive R package that simplifies the complexity of ENM methodology into a single function. The primary function of ENMTML includes several arguments that users must specify according to their modeling needs. Detailed information about this function can be found at the following link: https://andrefaa.github.io/ENMTML.With ENMTML, users can easily adjust, project, evaluate models and present results. The package also offers a range of alternatives for different methodological steps, such as variable collinearity control, bias control, and accessible region restrictions. ENMTML allows users to handle overprediction, create model ensembles, and project to different time/spatial periods (De Andrade et al. 2020).

The ENMTML package and analysis process consists of three main stages: preprocessing, processing, and postprocessing (Figure 2). During data preprocessing, response variables with <10 events are excluded from the analysis to ensure the required model accuracy for the sample size (van Proosdij et al. 2016). Thereafter, an event thinning analysis is conducted using the Cellsize method in the spThin ENMTML package to reduce autocorrelation and possible sampling bias by maintaining unique cells in a grid that are twice the size of the original cells (Velazco et al. 2019). Collinearity between environmental variables is analyzed by a Pearson correlation test with a threshold of 0.7 (De Marco and Nóbrega 2018). In the research on pseudo-absences and background points, a random method is used to allocate pseudo-absences throughout the area used for model fitting (Leroy 2023). A data set is necessary whose datasets are independent of the events used to fit the model to evaluate the ideal model. Event data were divided into two parts for model calibration and testing. The dataset is divided into a selected number of folds, and at each run, the model is fitted using k-1 folds and evaluated on the remaining folds. This robust and thorough evaluation process is repeated for all folds, and the results are combined to assess overall model performance (De Andrade et al. 2020). Predictions were generated based on the level of conformity of the survey results' use of data points with a probability model using accuracy measures (Araújo et al. 2019). The K-fold method with five folds was used in this research for model evaluation (Jung and Hu 2015).

During processing, the algorithm fine-tunes the model and generates a suitability map. This research utilized 5 of 13 available algorithms for model fitting, namely, Generalized Linear Model (GLM) (Agresti 2015), boosted regression tree (BRT) (Yu et al. 2020), Random Forest (RDF) (Simon et al. 2023), Support Vector Machine (SVM) (Ara et al. 2021), and default feature maximum entropy (MXD) (Phillips et al. 2017). The research also employed an ensemble model, combining multiple algorithms to enhance prediction performance and stability. Therefore, to create a binary map, the ensemble method used a principal component analysis basis with an above-average sensitivity and specificity threshold, returning the eigenvalue of the first principal component. The research model utilized the threshold at which the sum of sensitivity and specificity is at its maximum (Norberg et al. 2019).

During postprocessing, suitability maps produced by several algorithms underwent evaluation through a comprehensive set of five distinct metrics: Area Under the Curve (AUC), True Skill Statistics (TSS), κ, Jaccard and Sorensen. The outcomes of this evaluation represent the mean and standard deviation of the partial model. Postprocessing also involves the creation of binary maps utilizing five varying thresholds and five unique methods for generating ensemble models. These features are conveniently organized within a single function available through the R package ENMTML (De Andrade et al. 2020). The quantile distribution (Q) was employed using the ArcGIS application, resulting in three classes to classify the probability values. Quantile classification is a method that categorizes data distribution by weighing the distances of each observation component from the quantile in question (Hennig and Viroli 2016). The first class (low) is either 0 or Q1, the second class (medium) is >Q1 to Q2, and the third class (high) is >Q2 to 1.

Identification of species conservation risks

Identifying species conservation risks involves analyzing species' probability of use, its response to environmental factors, and the contribution of each variable. A statistical zonal analysis was conducted using ArcGIS to determine species conservation risks based on the use of probability model analysis. The stage yielded various summary statistics for each reference zone, including the mean of the data attributes, the size of data dispersion, the minimum and maximum values of the data attributes, the total number of data attributes, the number of data entities used in the calculation, and the most common (majority) and rare (minority). These statistical results are presented in a tabular format, allowing a better understanding of how data attributes vary across different areas (Yan et al. 2020).

RESULTS AND DISCUSSION

Carettochelys insculpta uses probability model analysis

A Pearson correlation test with a threshold of 0.7 was conducted to assess the collinearity among environmental variables. Results showed no collinearity among the variables. The *C. insculpta* use probability model was evaluated for performance using five discrimination metrics (Table 2).

According to the probability model for using *C. insculpta*, the RDF algorithm yields the most favorable outcomes compared to other algorithms, including ensembles (Table 2). Results indicated that the RDF algorithm surpassed others in terms of the Sorensen value. Hence, the research opted to use the RDF algorithm to model the use of *C. insculpta*, which produced a binary map depicting their probability of use.

Figure 3 displays the outcomes of the RDF model and the distribution of low (no use occurs) to high (use occurs) probabilities of use for each South Papua Province district. Table 3 summarizes the results of the calculation for the probability of use of *C. insculpta* in each district of South Papua Province.

Table 2. Results of the use of probability model analysis of *Carettochelys insculpta* based on various algorithms

Algorithm	AUC	κ	TSS	Jaccard	Sorensen
BRT	1.00	0.96	0.96	0.96	0.98
GLM	0.98	0.89	0.89	0.89	0.94
MXD	0.99	0.95	0.95	0.95	0.98
Ensemble	1.00	0.97	0.97	0.97	0.98
RDF	1.00	0.97	0.97	0.97	0.99
SVM	0.99	0.94	0.94	0.94	0.97

Table 3. Spatial area of the RDF model for the use probability for *Carettochelys insculpta* in various districts of South Papua Province, Indonesia

RDF Model for the probability	District							
	Asmat		Boven Digoel		Mappi		Merauke	
	Hectare	%	Hectare	%	Hectare	%	Hectare	%
Low	695,466.10	34	78,626.53	6	303,711.07	28	201,369.94	23
Moderate	921,830.76	44	698,603.91	55	508,411.58	46	431,780.00	50
High	459,706.51	22	496,019.61	39	290,205.73	26	238,418.10	27
Total area model	2,077,003.37	100	1,273,250.05	100	1,102,328.38	100	871,568.04	100

Table 4. Variable importance for the use probability for *Carettochelys insculpta* based on various algorithms

Environmental variable	Contribution (%)					
	BRT	MXD	GLM	RDF	SVM	Ensemble
Distance from road	8	18	15	14	20	15
Distance from settlement	6	16	22	21	23	18
River density	5	3	5	6	3	4
Slope	0	7	9	5	8	6
Land cover	1	22	4	13	15	11
Occurrence water	80	34	45	41	31	46

Table 5. Characteristics of environmental variables based on various probability of use classes by *Carettochelys insculpta* in South Papua Province, Indonesia

RDF Model for the probability	Euclidean distance from road (km)	Euclidean distance from settlement (km)	River density (km/km^2)	Slope (%)	Land cover	Occurrence water (%)
	$\bar{x}$	$\bar{x}$	$\bar{x}$	$\bar{x}$	Majority	$\bar{x}$
Low	6.46	11.73	1.03	4.85	Primary swamp forest	0
Moderate	7.53	14.65	1.50	6.36	Primary dryland forest	0
High	9.31	21.29	1.72	6.09	Primary dryland forest	10.64

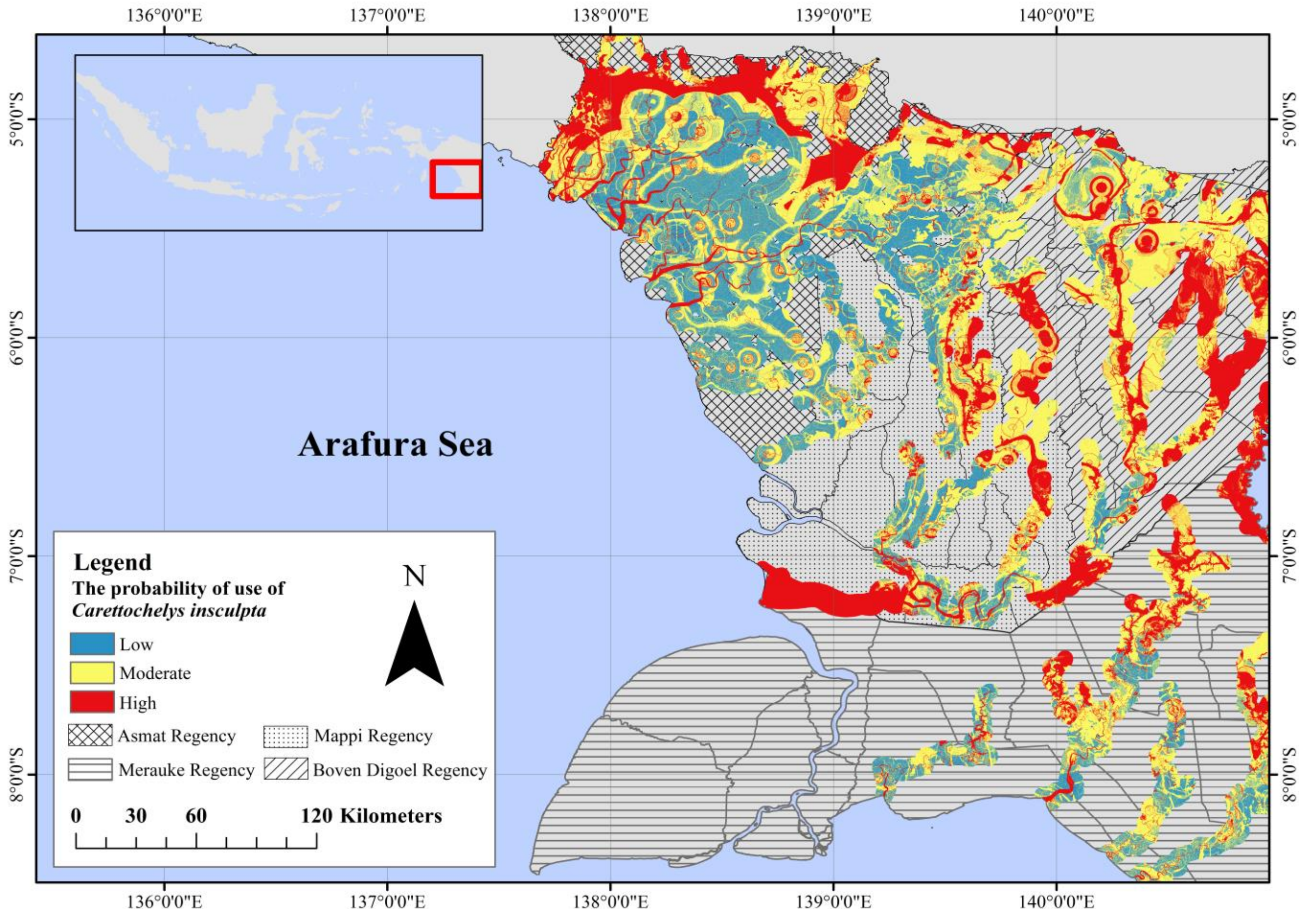

Figure 3. RDF model for the use probability for *Carettochelys insculpta* in South Papua Province, Indonesia

Table 3, the region with the highest *C. insculpta* probability of use in South Papua Province is Boven Digoel District, accounting for a significant land area of 496,019.61 hectares. In comparison, moderate use was noted in Asmat District, encompassing 921,830.76 hectares, whereas low use is recorded in the same district, covering 695,466.10 hectares. The graphical representation of the use concentration for each of these categories in every district is illustrated in Figure 3.

Identification of species conservation risks

Various environmental factors influence the probability of using *C. insculpta* in South Papua Province, as analyzed using models based on the RDF algorithm (Table 4). Of these factors, the occurrence of water had the highest impact at 41%, followed by distance from the settlement at 21%, distance from the road at 14%, land cover at 13%, river density at 6%, and slope at 5%.

Table 5 provides information on the characteristics of environmental variables based on various probability classes by *C. insculpta* in South Papua Province. The characteristics of environmental variables for the use model were derived from the results of zonal analysis comparing the use model with various environmental variables utilized in the research.

Research areas with a high probability of use exhibited distinct environmental characteristics. These characteristics included being located further away from roads and settlements (with a mean distance of 9.31 km and 21.29 km) and having a higher density of rivers (with a mean of 1.72 km/km^2). These areas had a flat slope classification (0%-8%), with a mean value of 6.09%. Most of the land cover was primary dryland forest, and the frequency of surface water presence was also relatively high, with an overall mean of 10.64%.

Discussion

Key spatial factors influencing the use of *C. insculpta* in environmental modeling include water availability, river density, proximity to settlements and roads, land cover, and terrain slope. Water availability is a critical biological factor for *C. insculpta* as it is predominantly aquatic. However, it also facilitates human access to the species. Pekel et al. (2016) noted that a value of 100% indicates an area is constantly inundated with water. Eisemberg et al. (2011), in their research in Papua New Guinea, reported that a combination of flooding and human egg harvesting resulted in a 92% loss of *C. insculpta* nests.

Except for water availability, other factors mentioned beforehand align with Bennett and Robinson's (2000) framework on determinants of the sustainability of hunting or wildlife use in a given region, which may have independent or cumulative effects. The primary factors that influence the sustainability of hunting or use can be classified into five main categories, including physical and geographical factors (i.e., distance from source areas and affordability), biological factors (i.e., biological production and susceptibility to harvest), social factors (i.e., human settlement and migration patterns), cultural and religious factors (i.e., hunting practices and technology), and economic factors (i.e., commercialization of animal harvesters, market value for animals, and income of hunters and consumers). In the research on human-animal interactions, various environmental factors are considered, including accessibility as determined by distance from road and river density. Burgess and Lilley (2014) found that water transportation and increased motorboat use intensify the use of *C. insculpta*. Other factors included distance from the settlement, which reflects the level of human interaction, social activities, and land slope, affecting the carrying capacity and accessibility. Land cover is also considered for its impact on ecological sustainability, agricultural productivity, and the types of human activities possible in the area. Lastly, the occurrence of water describes the condition of water in the area and its impact on accessibility.

Accurately assessing the probability of use and identifying potential threats to the conservation of *C. insculpta* is essential to maintain the sustainability of its lifecycle within and beyond protected areas. This research evaluated the use of probabilities, environmental variables, and characteristics that contribute to the use of *C. insculpta* in South Papua Province. The research proposed simplifying the complexity of ENM methodology into a single function called ENMTML package that adjusts, projects, evaluates models, and presents model results (De Andrade et al. 2020). The use probability model of *C. insculpta* in research using the RDF algorithm yielded better results than other algorithms regarding discrimination metrics. The RDF algorithm produced an AUC of 1.00, κ of 0.97, TSS of 0.97, Jaccard of 0.97, and Sorensen of 0.99. Evaluation of model results using the RDF algorithm indicated good predictive performance, with all five discrimination values exceeding 0.5. A value near one accurately reflects the model's ability to estimate species prevalence based on the modeled species distribution (Burkov 2019). Although the ensemble algorithm and the RDF algorithm have equal AUC, κ, TSS, and Jaccard values, the ensemble algorithm has a lower Sorensen index score. Leroy et al. (2018) suggested that the Sorensen discrimination metric is more suitable for assessing a model's ability to accurately classify the presence and absence of existence, as it is not affected by prevalence. RDF is an effective machine learning algorithm because it reduces variance (or overfitting) without impacting biased distributed data and different nonhomogeneous variables (Burkov 2019).

This research revealed that the probability of the high use of *C. insculpta* (Pig-nosed turtle) eggs in South Papua Province is influenced by several environmental factors. The three most significant factors were the presence of surface water, distance from human settlements, and proximity to roads. The presence of surface water was assessed based on data from 1984-2021, which recorded how frequently water appeared on the surface each month (Pekel et al. 2016). The study found that areas with an average surface water presence probability of 10.64% had a higher likelihood of being used by turtles. The Pig-nosed turtle's survival is closely tied to water availability, with males and juveniles being mostly aquatic, while mature females migrate to riverbanks and sandy areas during nesting seasons (Eisemberg et al. 2011; Burgess and Lilley 2014). Therefore, the year-round availability of surface water is essential for the species' survival, particularly for successful reproduction and egg-laying.

Local communities have turned to hunting the species' eggs as a significant source of income (Triantoro et al. 2017), although it contributes to the decline of this already endangered species. The distance from settlements and roads was found to influence the likelihood of egg harvesting, with shorter distances increasing the probability of harvest. Although harvesting in remote areas during nesting seasons involves traveling by motorized boats and using temporary bivouacs (huts) (Triantoro et al. 2017), the further the harvesting area is from settlements, the higher the associated costs. Additionally, watersheds near settlements face more significant pressure from human activities, which can lead to increased pollution and habitat alteration.

According to Kusrini et al. (2024), the traditional ownership of *C. insculpta* breeding areas in Boven Digoel District has provided economic benefits for the local community and holds promise for future prosperity. Kusrini et al. (2024) noted that the number of *C. insculpta* eggs harvested during the breeding season remained consistent, averaging 69,000 eggs per season, except during the coronavirus disease 2019 pandemic from 2020 to 2021. Breeding activities in Boven Digoel District are not yet officially recognized by law. The estimated number of eggs harvested in Kao River (Boven Digoel District) exceeds the recommended national quota. The gap between the quota and the natural egg population has led to continued illegal egg harvesting and the trade of *C. insculpta* hatchlings. The Indonesian Government is taking steps to protect and prevent the extinction of *C. insculpta* from overexploitation by designating them as hunted animals (Indonesian Government 2021). Eggs can be harvested from the wild for ranching through strict quota systems. Currently, legal ranching is given to CV. Alam Nusantara in Mimika District, Central Papua Province, for 10,000 eggs. Half of the quota (50%) can be exported, but the remaining 50% must be released back into their natural habitat (Indonesian Government 2022).

The importance of establishing egg farming areas in other districts highlights the high probability of use of *C. insculpta*, especially in Boven Digoel District, followed by Asmat, Mappi, and Merauke Districts. Although quota allocation and breeding efforts are focused solely on Asmat District, the widespread probability of use suggests that this issue transcends administrative boundaries. Although Mappi and Merauke Districts have not been significantly affected like Boven Digoel and Asmat, it is crucial to emphasize the need for monitoring and appropriate preventive measures in these districts to prevent a decline in the *C. insculpta* population. Therefore, to reduce overexploitation and protect wildlife populations, egg ranching locations must be facilitated in various districts of South Papua Province. Egg ranching will have several benefits, including the ability to adjust egg collection intensity, implement proper monitoring and control (Siroski et al. 2024), diversify conservation sites to mitigate the risk of failure in any one area, and empower local communities by creating economic incentives to protect wildlife and their habitats.

According to the IPBES (2022) report on reptiles, ranching programs are highly effective methods for sustainable use. These programs improve the survival rates of harvested eggs and offer incentives for indigenous peoples and local communities to preserve the entire managed ecosystem. However, successful implementation necessitates supporting approaches such as incentives, a robust legal framework including governmental support for producer groups, trade and processing, market access, premium pricing through certification, tax breaks, and outreach and education on pertinent policies and regulations related to use. Therefore, practitioners and policymakers may wish to consider the practical implications of these findings in their efforts to balance species utilization and environmental protection.

Effective strategies can be developed to protect *C. insculpta* and support regional management by identifying conservation risks and using probability models. This is important for the welfare of local areas, maintaining biodiversity, and encouraging environmental sustainability. Protecting threatened species helps prevent ecological disruption and preserve genetic resources for future generations (Ceballos et al. 2017). It is our collective responsibility to take action, ensuring the survival of this unique and valuable species, with our contributions playing a key role in its protection.

ACKNOWLEDGEMENTS

We sincerely thank all the institutions and individuals who contributed to this research. This study was made possible with the support of the Korindo Group (PT. Tunas Sawa Erma and PT. Inocin Abadi) under the MoU between PT. Tunas Sawa Erma and the Faculty of Forestry and Environmental Studies, Institut Pertanian Bogor, Indonesia (No. 0101/KG-TSE/JKT/VII/2022). We would like to express our appreciation to the Papua Natural Resources Conservation Agency (Regional Division I Merauke, SKW I Agats, SKW II Timika) for granting research permits and providing invaluable information and to the Yasa Agats Community-based Organization and the Faculty of Planology, Universitas Cendrawasih, Indonesia, for their valuable support and information. We also thank Kim Namhong, Winarjanto Isok, Vinoba Tjandra, and Ary Wibowo for their support throughout the research process. Furthermore, we are grateful to Paulus Kafiar for his assistance and guidance in the field, Aryo Adhi Condro, Ramdani Manurung, and Morgan W. Sawaki for their assistance in field preparations and processes, Bryan and Reza for field documentation, and Herlin for permit preparation, and Lusiana Dyah and Arif Hassan for assistance in arranging meetings and communications with local government agencies and institutions.

REFERENCES

Agresti A. 2015. Foundations of Linear and Generalized Linear Models. John Wiley & Sons, Inc., New Jersey.

Andersen SK, Staerk J, Kalhor E, Natusch DJD, da Silva R, Pfau B, Conde DA. 2021. Economics, life history and international trade data for seven turtle species in Indonesian and Malaysian farms. Data Brief 34: 106708. DOI: 10.1016/j.dib.2020.106708.

Ara A, Maia M, Louzada F, Macêdo S. 2021. Random machines: A bagged-weighted support vector model with free kernel choice. J Data Sci 19 (3): 409-428. DOI: 10.6339/21-JDS1014.

Araújo MB, Anderson RP, Márcia Barbosa AM, Beale CM, Dormann CF, Early R, Garcia RA, Guisan A, Maiorano L, Naimi B, O'Hara RB, Zimmermann NE, Rahbek C. 2019. Standards for distribution models in biodiversity assessments. Sci Adv 5 (1): eaat4858. DOI: 10.1126/sciadv.aat4858.

Bennett EL, Robinson JG. 2000. Hunting of Wildlife in Tropical Forests: Implications for Biodiversity and Forest Peoples. Environment Department Paper, Biodiversity Series-Impact Studies. The World Bank Institute, Washington, USA.

Bramorska B, Komar E, Maugeri L, Ruczyński I, Żmihorski M. 2024. Socio-economic variables improve accuracy and change spatial predictions in species distribution models. Sci Total Environ 924: 171588. DOI: 10.1016/j.scitotenv.2024.171588.

Burgess EA, Lilley R. 2014. Assessing the Trade in Pig-nosed Turtles *Carettochelys insculpta* in Papua, Indonesia. Traffic, Petaling Jaya, Malaysia.

Burkov A. 2019. The Hundred-Page Macine Learning Book. https://books.google.co.id/books?id=ZF3KwQEACAAJ.

Ceballos G, Ehrlich PR, Dirzo R. 2017. Biological annihilation via the ongoing sixth mass extinction signaled by vertebrate population losses and declines. Proc Natl Acad Sci 114 (30): E6089-E6096. DOI: 10.1073/pnas.1704949114.

De Andrade AFA, Velazco SJE, De Marco Júnior P. 2020. ENMTML: An R package for a straightforward construction of complex ecological niche models. Environ Model Softw 125: 104615. DOI: 10.1016/j.envsoft.2019.104615.

De Marco P, Nóbrega CC. 2018. Evaluating collinearity effects on species distribution models: An approach based on virtual species simulation. PLOS ONE 13 (9): e0202403. DOI: 10.1371/journal.pone.0202403.

Eisemberg C, van Dijk PP, Georges AP, Amepou Y. 2018. *Carettochelys insculpta*. The IUCN Red List of Threatened Species. DOI: 10.2305/IUCN.UK.2018-2.RLTS.T3898A2884984.en.

Eisemberg CC, Amepou Y, Rose M, Yaru B, Georges A. 2015. Defining priority areas through social and biological data for the Pig-nosed turtle (*Carettochelys insculpta*) conservation program in the Kikori region, Papua New Guinea. J Nat Conserv 28: 19-25. DOI: 10.1016/j.jnc.2015.08.003.

Eisemberg CC, Rose M, Yaru B, Georges A. 2011. Demonstrating decline of an iconic species under sustained indigenous harvest - the Pig-nosed turtle (*Carettochelys insculpta*) in Papua New Guinea. Biol Conserv 144 (9): 2282-2288. DOI: 10.1016/j.biocon.2011.06.005.

Hennig C, Viroli C. 2016. Quantile-based classifiers. Biometrika 103 (2): 435-446. DOI: 10.1093/biomet/asw015.

Indonesian Government. 2018. Regulation of the Minister of Environment and Forestry No. P.106/MENLHK/SETJEN/KUM.1/12/2018. Concerning Management of Wild Plant and Animal Species. Minister of Environment and Forestry, Jakarta. [Indonesian]

Indonesian Government. 2021. Decree No. 65. MENLHK/KSDAE/KSA.2/3/2021 Concerning Determination of The Eggs of The Pig-nosed Turtle (Carettochelys insculpta) in Papua Province as A Game Animal. Minister of Environment and Forestry, Jakarta. [Indonesian]

Indonesian Government. 2022. Decree No. SK.2/KSDAE/KKH/KSA.2/1/2022. Concerning Quotas for the Collection of Natural Plants and the Capture of Wild Animals for the Period 2022. Minister of Environment and Forestry, Jakarta. [Indonesian]

IPBES. 2022. Thematic Assessment Report on the Sustainable Use of Wild Species of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). DOI: 10.5281/zenodo.6448567.

Joyce WG. 2014. A review of the fossil record of turtles of the clade pan-Carettochelys. Bull Peabody Museum Nat Hist 55 (1): 3-33. DOI: 10.3374/014.055.0102.

Jung Y, Hu J. 2015. A K-fold averaging cross-validation procedure. J Nonparametr Stat 27 (2): 167-179. DOI: 10.1080/10485252.2015.1010532.

Kusrini MD, Triantoro RGN, Manurung R, Setiawan RA, Kim N. 2024. Local harvest of Pig-nosed turtle (*Carettochelys insculpta*) in the Kao River. Boven Digoel District, South Papua, Indonesia. Biodiversitas 25 (2): 522-532. DOI: 10.13057/biodiv/d250211.

Leroy B, Delsol R, Hugueny B, Meynard CN, Barhoumi C, Barbet-Massin M, Bellard C. 2018. Without quality presence–absence data, discrimination metrics such as TSS can be misleading measures of model performance. J Biogeogr 45 (9): 1994-2002. DOI: 10.1111/jbi.13402.

Leroy B. 2023. Choosing presence-only species distribution models. J Biogeogr 50 (1): 247-250. DOI: 10.1111/jbi.14505.

Liu C, Li W, Xu J, Zhou H, Li C, Wang W. 2022. Global trends and characteristics of ecological security research in the early 21st century: A literature review and bibliometric analysis. Ecol Indic 137: 108734. DOI: 10.1016/j.ecolind.2022.108734.

Marsh SME, Hoffmann M, Burgess ND, Brooks TM, Challender DWS, Cremona PJ, Hilton-Taylor C, de Micheaux FL, Lichtenstein G, Roe D, Böhm M. 2022. Prevalence of sustainable and unsustainable use of wild species inferred from the IUCN Red List of threatened species. Conserv Biol 36 (2): e13844. DOI: 10.1111/cobi.13844.

Norberg A, Abrego N, Blanchet FG et al. 2019. A comprehensive evaluation of predictive performance of 33 species distribution models at species and community levels. Ecol Monogr 89 (3): e01370. DOI: 10.1002/ecm.1370.

Pekel JF, Cottam A, Gorelick N, Belward AS. 2016. High-resolution mapping of global surface water and its long-term changes. Nature 540 (7633): 418-422. DOI: 10.1038/nature20584.

Phillips SJ, Anderson RP, Dudík M, Schapire RE, Blair ME. 2017. Opening the black box: an open-source release of maxent. Ecography 40 (7): 887-893. DOI: 10.1111/ecog.03049.

Ramsay EP. 1887. On a new genus and species of fresh water tortoise from the Fly River, new Guinea. Proceedings of the Linnaean Society of New South Wales.

Samedi IDT. 2000. Freshwater turtle and tortoise conservation and utilization in Indonesia. In: Paul P, van Djik SBL, Rhodin AGJ (eds). Asian Turtle Trade. Proceedings of a Workshop on Conservation and Trade of Freshwater Turtles and Tortoises in Asia. Phnom Penh, Cambodia, 1-4 December 1999. Cambodia.

Shepherd CR, Gomez L, Nijman V. 2020. Illegal wildlife trade, seizures and prosecutions: A 7.5-year analysis of trade in Pig-nosed turtles *Carettochelys insculpta* in and from Indonesia. Glob Ecol Conserv 24: e01249. DOI: 10.1016/j.gecco.2020.e01249.

Simon SM, Glaum P, Valdovinos FS. 2023. Interpreting random forest analysis of ecological models to move from prediction to explanation. Sci Rep 13 (1): 3881. DOI: 10.1038/s41598-023-30313-8.

Siroski PA, Ciocan H, Hilevski S, Larriera A. 2024. Increasing population status of broad-snouted caiman (*Caiman latirostris*) based on sustainable use strategies in a managed protected area in Santa Fe, Argentina. Animals 14 (9): 1288. DOI: 10.3390/ani14091288.

Triantoro RGN, Kusrini MD, Prasetyo LB. 2017. Intensitas perburuan dan pola perdagangan kura-kura moncong babi di Sungai Vriendschap, Kabupaten Asmat. Prosiding Seminar Nasional Masyarakat Biodiversitas Indonesia 3 (3): 339-344. DOI: 10.13057/psnmbi/m030309. [Indonesian]

Triantoro RGN. 2012. Ekologi peneluran dan intensitas Pemanfaatan labi-labi Moncong Babi (*Carettochelys insculpta* Ramsay 1886) di sungai vriendschap Kabupaten. Asmat, Papua. [Dissertation]. IPB University, Bogor. [Indonesian]

van Proosdij ASJ, Sosef MSM, Wieringa JJ, Raes N. 2016. Minimum required number of specimen records to develop accurate species distribution models. Ecography 39 (6): 542-552. DOI: 10.1111/ecog.01509.

van Zinnicq Bergmann MPM, Guttridge TL, Smukall MJ, Adams VM, Bond ME, Burke PJ, Fuentes MMPB, Heinrich DDU, Huveneers C, Gruber SH, Papastamatiou YP. 2022. Using movement models and systematic conservation planning to inform marine protected area design for a multi-species predator community. Biol Conserv 266: 109469. DOI: 10.1016/j.biocon.2022.109469.

Velazco SJE, Villalobos F, Galvão F, De Marco Júnior P. 2019. A dark scenario for cerrado plant species: effects of future climate, land use and protected areas ineffectiveness. Divers Distrib 25 (4): 660-673. DOI: 10.1111/ddi.12886.

Vitt LJ, Caldwell JP. 2014. Herpetology. Elsevier, Amsterdam. DOI: 10.1016/b978-0-12-386919-7.00018-6.

Wikle CK. 2015. Modern perspectives on statistics for spatio-temporal data. WIREs Comput Stat 7 (1): 86-98. DOI: 10.1002/wics.1341.

Yan H, Feng L, Zhao Y, Feng L, Wu D, Zhu C. 2020. Prediction of the spatial distribution of *Alternanthera philoxeroides* in China based on Arcgis and Maxent. Glob Ecol Conserv 21: e00856. DOI: 10.1016/j.gecco.2019.e00856.

Yu H, Cooper AR, Infante DM. 2020. Improving species distribution model predictive accuracy using species abundance: Application with boosted regression trees. Ecol Model 432: 109202. DOI: 10.1016/j.ecolmodel.2020.109202.