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Prediction of Suitable Habitat Locations for Sea Turtle Nesting Using Maximum Entropy Along the Coast of Kretek Subdistrict, Bantul Regency

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KEYWORDS
The suitability of nesting sea turtles; Maximum Entropy (maxent); Remote sensing.

ABSTRACT
Development along the southern coast of the Special Region of Yogyakarta, particularly in tourism zones, increasingly threatens sea turtle conservation and reduces the availability of suitable nesting sites. This study aims to model the suitability of sea turtle nesting habitats, analyze environmental variables influencing nesting preferences, and evaluate prediction results along the Kretek District coastline using Species Distribution Modeling (SDM) with the MaxEnt algorithm. Eleven environmental variables—such as slope, distance to vegetation, dunes, built-up areas, fallow land, agricultural land, roads, rivers, fishponds, and proximity to the sea—were derived from remote sensing data. The model produced an elongated suitability pattern along stretches of sand and fallow land, indicating that Depok, Pelangi, Cemara Sewu, Barchan, and Parangkusumo Beaches are generally suitable for nesting, while Parangtritis Beach is unsuitable due to intense human activity. The model achieved very high accuracy (AUC 0.981), with distance from sand being the most influential variable (66.5% contribution; 63.6% permutation importance). Evaluation results showed that increased human disturbance correlates with fewer nesting sites; Depok and Parangtritis Beaches had the lowest presence, while Pelangi Beach recorded the highest nesting activity with 43 locations.

INTRODUCTION

Turtles are long-lived organisms with a long lifespan but slow reproductive cycles, so the growth rate of their populations does not keep pace with their rate of extinction. These animals are globally targeted for conservation. According to the Regulation of the Minister of Environment and Forestry of the Republic of Indonesia (MoEF) Number 106 of 2018, which amends the Ministerial Regulation Number 20 of 2018 concerning Protected Species of Plants and Animals, all types of turtles in Indonesia are fully protected. Since 1975, based on the International Union for Conservation of Nature (IUCN) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), all species of wild turtles have been listed in Appendix I, indicating their status at high risk of extinction worldwide. Consequently, international trade and use of these animals are prohibited (Fourcade et al., 2014; Hafizt et al., 2017; Huijbers et al., 2015).

Turtle nesting habitats are located in coastal regions. Of the seven species of sea turtles globally, six are found in Indonesian waters. According to the environmental and strategic study document (KLHS) on the Zoning Plan for Coastal Areas and Small Islands (*RZWP3K*) by the Yogyakarta Marine and Fisheries Service (2018), four species commonly nest along the coast of the Special Region of Yogyakarta: Green Turtles (*Chelonia mydas*), Hawksbill Turtles (*Eretmochelys imbricata*), Olive Ridley Turtles (*Lepidochelys olivacea*), and Leatherback Turtles (*Dermochelys coriacea*). Nesting sites occur at six locations along this coast: Pelangi Beach, Samas Beach, Goa Cemara Beach, and Pandansimo Beach in Bantul Regency, as well as Trisik Beach in Kulon Progo Regency and Drini Beach in Gunungkidul Regency.

Environmental conditions at Pelangi Beach and surrounding areas in Kretek Subdistrict, Bantul Regency, significantly influence turtle nesting habitats and hatchling success. This is reinforced by Regional Regulation Number 9 of 2018 on the *RZWP3K* of DIY, which designates several beaches in Kretek as Conservation Areas, prohibiting destructive activities, changes in land use, and removal of coastal vegetation. Threats to turtles arise from natural sources such as abrasion, obstructive vegetation, and predators, as well as from human activities including theft, illegal fishing, trade in eggs and shells, bombing, use of potassium-based poisons, habitat pollution, and loss of nesting grounds. According to the Marine and Fisheries Service (2018), ecological degradation along the southern coast of Yogyakarta, caused by resource exploitation and land-use changes driven by human activity, has led to declining habitat quality and reduced nesting potential. Data from BKSDA (2011) and Bappeda (2017) show that turtle landing sites at Depok Beach declined from five points in 2011 to only two in 2017, underscoring the urgency for systematic conservation despite limited data availability. Rapid coastal development related to settlements, fisheries, and ports increases ecological pressures, threatening ecosystem sustainability both directly through land conversion and indirectly through pollution. Protective and rehabilitative measures are therefore needed.

Turtles exhibit a strong homing instinct, migrating between feeding and breeding grounds and consistently returning to the same nesting sites, making the protection of nesting beaches crucial. Nest-site selection depends on environmental heterogeneity, preferring substrates with at least 90% sand Nuitja & Uchida, (1983) and beach slopes of 3–16%, which facilitate access. During high tide, turtles undergo a sequence of nesting behaviors: crawling ashore, creating body and nest holes, laying eggs, covering and camouflaging nests, and returning to the sea. Nest success is influenced by proximity to the sea with nests closer to the shoreline producing higher hatching rates Nurhidayata, (2013) and by land cover, as shaded areas improve hatching time and success.

Various studies have analyzed turtle nesting habitats using different methods. Fathin (2016) conducted a land suitability analysis for nesting on Pelangi Beach, identifying key physical parameters such as sand texture and beach slope. Wichaksono (2018) studied nesting dynamics on Cemara Beach, Banyuwangi, highlighting human impacts on nesting frequency. Spanier (2010) and Wood et al. (2000) emphasized the importance of beach morphology and environmental variables such as temperature and moisture in nest selection. Mazaris et al. (2006) and Hart et al. (2014) applied spatial analysis to model nesting preferences, noting the significance of distance-based variables such as proximity to vegetation and human disturbances. However, these studies often used limited spatial data and did not fully utilize advanced modeling techniques like MaxEnt combined with high-resolution remote sensing.

Despite previous research, comprehensive spatial modeling that integrates high-resolution remote sensing data with advanced algorithms like MaxEnt to predict suitable nesting habitats along the coast of Kretek Subdistrict remains lacking (Arslan et al., 2023; Dunkin et al., 2016; Hu et al., 2025; Putra & Mustika, 2021). This study addresses this gap by using PlanetScope imagery and DEM ALOS PALSAR data to derive critical environmental variables including slope, distance to vegetation, sand dunes, and human infrastructure. By integrating Species Distribution Modeling (SDM) with Geographic Information Systems (GIS), the study aims to produce detailed and accurate predictions of suitable nesting habitats, providing a scientific foundation for targeted conservation strategies. The findings are expected to enhance turtle conservation efforts in the region, supporting the preservation of these endangered species amid increasing anthropogenic pressures.

These characteristics serve as a basic reference for analyzing species distribution based on measurable environmental variables. In GIS modeling, environmental variables must have congruent geographic data and extent as polygons or pixels. This data becomes the environmental variables used to predict species distribution and habitat suitability. Spatial distribution modeling methods have been widely developed, with Maximum Entropy (MaxEnt) analysis being one commonly used approach. MaxEnt estimates the distribution probability of species by identifying the distribution with maximum entropy among subjects (pixels) and projecting values for other pixels in the study area. MaxEnt uses presence-only data as samples for environmental variables to estimate likelihoods of species distribution nearby.

Remote sensing provides up-to-date land use information which is crucial for assessing turtle nesting habitat suitability. This technology has been extensively applied in monitoring coastal environments. This study examines habitat suitability through land use and slope variables against the backdrop of declining turtle landing sites caused by land degradation, conversion, and anthropogenic threats.

Since turtles exhibit strong homing instincts and tend to return to the same nesting sites, protecting these habitats is vital. However, field surveys often face challenges due to limited data, land use changes, and turtles' sensitivity to human presence. To overcome this, this study uses Species Distribution Modeling (SDM) with Maximum Entropy (MaxEnt) and GIS to predict suitable turtle nesting habitats along the coast of Kretek Subdistrict, Bantul Regency. Environmental variables extracted from high-resolution PlanetScope imagery for land cover/use and DEM ALOS PALSAR imagery for slope serve as spatial inputs to understand habitat selection patterns. The study formulates spatial prediction objectives, evaluates influential variables, and analyzes habitat suitability distribution. Its outputs include habitat prediction maps, key variable information, and distribution patterns, providing benefits for field monitoring, identification of threats, and potential application in other regions.

METHOD

This research was conducted along the coast of Kretek District, Bantul Regency, Yogyakarta, which administratively included five villages characterized by sandy coastal areas near sand dunes and predominantly regosol soil. The study area encompassed important turtle landing and nesting beaches such as Depok Beach, Pelangi, Cemara Sewu, Barchan, and Parangkusumo.

The methodology employed ArcGIS software for spatial data processing and MaxEnt for species distribution modeling. Fieldwork involved tools like GPS, soil survey instruments, thermo-hygrometers, laser range finders, cameras, and checklists to measure and verify habitat physical conditions. The main datasets comprised PlanetScope imagery for land cover and land use, DEM ALOS PALSAR for slope data, and existing turtle nesting locations used as presence points in the modelling (Ramadhan & Waty M., 2025).

Data processing involved three key stages: data preparation (image and DEM correction and organization), determination of environmental variables (land cover classification, slope mapping, and distance calculations to features such as sea, vegetation, roads, and built-up areas), and field sampling using stratified random sampling to test land cover accuracy, as well as purposive sampling to update turtle nest locations (Sumatriani & Aisyah, 2018).

Spatial modeling to predict turtle nesting habitat suitability was performed with MaxEnt using presence data and environmental variables formatted as ASCII rasters, with standard parameters including regularization multiplier, number of background points, replications, iterations, and probability threshold. Model performance was evaluated with the area under the curve (AUC) of the receiver operating characteristic (ROC) curve. Variable contributions were analyzed using jackknife tests and response curves. Finally, predictions were verified through spatial overlays with field data to assess the accuracy of the predicted distribution patterns of turtle nesting habitats.

Table 1. Area of Kretek District by Village

No	Village	Area (Ha)	Area Percentage (%)	The Number of Hamlets
1	Tirtohargo	362	13,52	6
2	Parangtritis	1.187	44,34	11
3	Donotirto	470	17,56	13
4	Tirtosari	239	8,39	7
5	Tirtomulyo	419	15,65	15
	Sum	**2.677**	**100**	**52**

RESULTS AND DISCUSSION

Environmental variables of the location of suitability for turtle nesting from extraction from DEM ALOS PALSAR and Citra PlanetScope

Spatial modeling in this study requires several variables obtained from primary and secondary data. These variables consist of bound variables and independent variables. Bound variables are used as presence data, while independent variables consist of environmental variables obtained from remote sensing data extraction which will later be used as input as MaxEnt models. Bound variables are variables that have a value dependent on the value of an independent variable which is also called a point of presence. The variables tied to this study are data on turtle nesting locations that have been carried out by the Yogyakarta Natural Resources Conservation Agency (BKSDA) in October-November 2011 and the Bantul Regency Regional Development Planning Agency (Bappeda) in August 2017.

The free variable is an environmental variable used to compile spatial modeling related to the location of turtle nesting suitability along the coast of Kretek District, Bantul Regency. These environmental variables are in the form of slope slope, distance of nests to vegetation, sand beds, sand dunes, built-up land, fallow land, agricultural land, roads, rivers, fishponds, and the sea. These environmental variables were extracted from remote sensing data, namely DEM ALOS PALSAR data and PlanetScope imagery. The DEM ALOS PALSAR data lowers the slope slope information, while the PlanetScope image lowers the land cover/use data that is derived back to the nest distance variable to vegetation, sand beds, dune dunes, built-up land, fallow land, agricultural land, roads, rivers, fishponds, and the sea.

Cover Classification/Land Use

The classification of cover/land use is carried out by visual interpretation on the PlanetScope composite image 321 (true color) through digitization on the computer screen. The covering/land use class is prepared according to SNI 7645:2010 which is adjusted to the coastal conditions of Kretek District, and is grouped into vegetation (agricultural and non-agricultural), non-vegetation (expanses of sand, dunes, fallow land, built-up land, roads, fishponds), and waters (rivers and seas). Class recognition is based on hue/color, texture, pattern, and site/association; For example, sand dunes and expanses of sand are both grayish-brown in color but are distinguished by texture and pattern, while the main differentiator between water bodies (sea, river, fishpond) is the context of the water.

Table 2. Characteristics of Cover Class/Land Use along the Coast of Kretek District

Land Cover		Information
Vegetated areas	Agricultural areas	In the form of rice fields, fields, and land planted by other types of vegetables and plants that are classified as agricultural land
	Non-agricultural areas	In the form of coastal vegetation, natural forests, mixed gardens, shrubs classified into Vegetation
Non-vegetated areas	Fallow land	In the form of land that is not overgrown with vegetation and is not a settlement, and is not covered with water, which is classified into sand dunes, sand dunes, and fallow land
	Residential and non-residential land	Residential land in the form of housing, offices, and buildings is classified as built-up land. Non-residential land is in the form of land that is built but not buildings, so it is classified into fishpond class and road class
	Waters (bodies of water)	In the form of land that is completely covered by water, so it is classified into rivers and seas.

Source: Visual interpretation (2020)

Spatially, the coast of Kretek District is dominated by marine classes and vegetation, followed by stretches of sand that extend along six beaches (Depok, Pelangi, Cemara Sewu, Barchan, Parangkusumo, Parangtritis). Certain coastal parts, especially parts of Parangkusumo Beach, Depok Beach, and Parangtritis Beach, show a higher intensity of built-up land due to the existence of settlements, tourist facilities, and economic activities. The results of the classification were then tested for accuracy through comparison with field conditions using Google Street View, and compiled in a confusion matrix; The overall accuracy value is 91.43% with most classes having producer and user accuracy >85%, so the cover/land use map is considered suitable for Euclidean distance analysis and subsequent modeling.

Table 3. Visual recognition of cover/land use type in composite PlanetScope 321 imagery

Land cover/use	Image Interpretation			
	Color/hue	**Texture**	**Pattern**	**Sites/associations**
Sand dunes	Gray brown	Rough	Irregular	Sea
Sand	Gray brown	Soft	Orderly	Sea

Land cover/use	Image Interpretation			
	Color/hue	Texture	Pattern	Sites/associations
Road	Gray	Soft	Orderly	Built-up land
Fallow land	Gray brown	Soft	Irregular	Built-up land
Agricultural land	Light dark green	Soft	Orderly	Rice fields and settlements
Built-up land	Bright gray, white	Rough	Orderly	Road
Water body	Dark blue	Smooth-coarse	Orderly	Sand
River	Dark blue	Soft	Orderly	Fallow land and settlements
Fishpond	Dark blue, bright white	Soft	Orderly	Sea
Vegetation	Dark green	Rough	Irregular	Sea and Hills

Source: visual interpretation (2020)

Slope Slope Mapping

The slope map is compiled from DEM ALOS PALSAR data using the Slope function in ArcGIS so that it produces slope classes in degrees that are then converted to percent. Referring to Van Zuidam's (1989) classification, slopes are divided into six classes: flat, sloping, sloping–steep, steep, steep–steep, and steep. In the coastal area of Kretek District, especially in the research areas of Depok Beach, Pelangi, Cemara Sewu, Barchan, Parangkusumo, and Parangtritis, the range of slopes that appear is in the range of 0°-16°, which means that it is dominated by flat slopes to light steep.

In general, flat and sloping zones are associated with sand dunes near the coastline, while more sloping slopes tend to appear at the transition between sand dunes and dunes, fallow land, built-up land, or vegetation at the back of the coast. This condition reflects the dynamic nature of the coast due to tidal processes and sediment accumulation/erosion that affect the shape of the slope. The slope slope map is then used as one of the environmental (continuous) variables in MaxEnt modeling to explain turtles' preference for coastal topographic characters when selecting a search location.

Variable Bound MaxEnt Model Input (Attendance Data Compilation)

The bound variable in the MaxEnt model is in the form of turtle presence data represented by the coordinates of the search nest. This study used 27 documented nesting locations in the 2011–2017 period, spread across Depok Beach, Pelangi Beach, and Cemara Sewu Beach. The data was collected from the Yogyakarta BKSDA and the Bantul Regency Bappeda, then compiled in CSV format with three main columns, namely species, longitude, and latitude using Microsoft Excel.

Table 4. Coordinates of Turtle Nesting Locations to Build a Model

No	Beach	Year	Coordinate		Source
			Longitude	Latitude	
1	Depok Beach	October - November 2011	110.28630	-8.01238	BKSDA
2	Depok Beach	October - November 2011	110.28788	-8.01268	BKSDA
3	Depok Beach	October - November 2011	110.28905	-8.01270	BKSDA

No	Beach	Year	Coordinate		Source
			Longitude	Latitude	
4	Depok Beach	October - November 2011	110.29038	-8.01303	BKSDA
5	Depok Beach	October - November 2011	110.29147	-8.01345	BKSDA
6	Depok Beach	August 2017	110.29464	-8.01428	Bappeda
7	Depok Beach	August 2017	110.28611	-8.01219	Bappeda
8	Pelangi Beach	October - November 2011	110.29747	-8.01453	BKSDA
9	Pelangi Beach	October - November 2011	110.29955	-8.01517	BKSDA
10	Pelangi Beach	October - November 2011	110.30192	-8.01653	BKSDA
11	Pelangi Beach	October - November 2011	110.30972	-8.01868	BKSDA
12	Pelangi Beach	August 2017	110.30038	-8.01607	Bappeda
13	Pelangi Beach	August 2017	110.30276	-8.01676	Bappeda
14	Pelangi Beach	August 2017	110.30331	-8.01679	Bappeda
15	Pelangi Beach	August 2017	110.30542	-8.01741	Bappeda
16	Pelangi Beach	August 2017	110.30663	-8.01791	Bappeda
17	Pelangi Beach	August 2017	110.30845	-8.01834	Bappeda
18	Pelangi Beach	August 2017	110.30927	-8.01879	Bappeda
19	Pelangi Beach	August 2017	110.31049	-8.01896	Bappeda
20	Cemara Sewu Beach	October - November 2011	110.31257	-8.01953	BKSDA
21	Cemara Sewu Beach	October - November 2011	110.31510	-8.02040	BKSDA
22	Cemara Sewu Beach	October - November 2011	110.31548	-8.02053	BKSDA
23	Cemara Sewu Beach	October - November 2011	110.31592	-8.02063	BKSDA
24	Cemara Sewu Beach	August 2017	110.31396	-8.01987	Bappeda
25	Cemara Sewu Beach	August 2017	110.31430	-8.02007	Bappeda
26	Cemara Sewu Beach	August 2017	110.31479	-8.02034	Bappeda
27	Cemara Sewu Beach	August 2017	110.31522	-8.02056	Bappeda

Source: BKSDA Yogyakarta (2011), Bappeda of Bantul Regency (2017)

All points are listed in a geographic coordinate system so that they can be directly used as spatial inputs in MaxEnt. The temporal (2011 and 2017) and spatial (several different beaches) distributions of these attendance data help to represent the variation in nesting habitat conditions along the coast of Kretek District. This dataset is an important basis for training the model in recognizing combinations of environmental variables related to the actual nesting location.

Independent Variable MaxEnt Model Input (Environmental Variable Feeding)

The independent variables in MaxEnt modeling consist of slope slope and a set of distance variables to different cover/land use classes. All environmental variables are processed in the form of an ASCII raster with a uniform spatial resolution of 12.5 m and the same extent, using a geographic coordinate system. The slope slope is extracted from the DEM ALOS PALSAR (TIFF format) which is then converted to ASCII via ArcGIS 10.7.1, and is used as a continuous variable to represent changes in the topography of the coast.

Other biophysical components are derived from the results of the cover/land use classification through Euclidean distance analysis in ArcGIS for each class: sand beds, dunes, fallow land, built-up land, agricultural land, roads, seas, rivers, fishponds, and vegetation. The result is ten distance maps (in meters) that depict how close or distant each grid location is to these features. All eleven environmental variables (1 slope + 10 distance) were then used as MaxEnt inputs, based on previous theories and references that showed that the combination of topographic factors, proximity to the sea and sand beds, and intensity of human activities strongly determined the suitability of turtle nesting habitats.

Table 5. Environmental variables used in modeling

No.	Environmental Variables	Unit	Name on the model	Reference sources
1	Slope Slope	Degree (°)	slope	Garmestani *et al*. 2000; Wood *et al*. 2000; Spanier, 2009
2	Distance from vegetation	m	vegetasi	Hays & Speakman, 1993; Hart *et al*., 2014; dan Huijbers *et al*., 2015
3	Distance from the fishpond	m	tambak	Huijbers *et al*, 2015
4	Distance from the river	m	river	
5	Distance from built-up land	m	lterbangun	
6	Distance from agricultural land	m	lpertanian	
7	Distance from fallow land	m	lBlank	
8	Distance from the water body	m	loud	
9	Distance from the road	m	road	
10	Distance from the sand dunes	m	hpasir	Garmestani *et al*. 2000; Wood *et al*. 2000; Barik *et al*. 2014, and Huijbers *et al*, 2015
11	Distance from the sand dunes	m	Sand	Hays & Speakman, 1993; Mazaris *et al*. 2006; Witherington *et al*. 2011; dan Huijbers *et al*., 2015

Model Performance and Evaluation

The model's performance in predicting the location of turtle nesting suitability along the coast of Kretek District can be seen from the MaxEnt output, namely (1) the average omission and predicted area curve, and (2) the sensitivity and specificity curve. The average omission and predicted area curves will show the accuracy of the model, while the sensitivity and specificity curves will show the results of the model evaluation. The average omission curve and predicted area as shown in Figure 4.8a in this study shows that there is a close relationship between attendance data and prediction results. This also proves the accuracy of the resulting model.

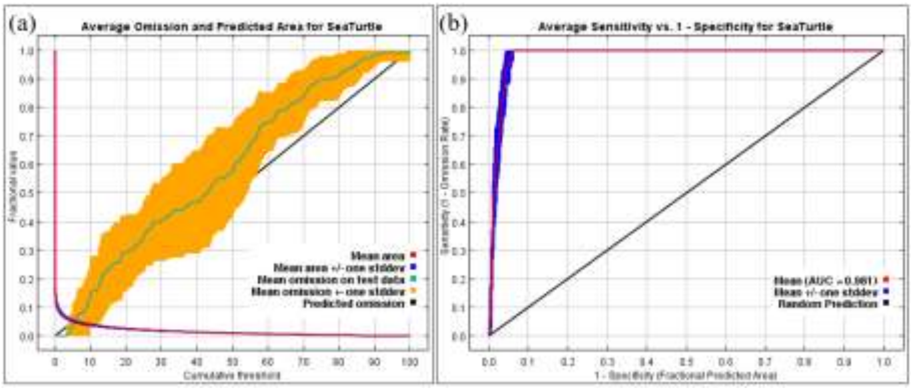

Figure 1. (a) Curve average omission and predicted area, (b) Curve Sensitivity and specificity

Model evaluation is a model validation that is carried out by looking at *the Area Under Curve* (AUC) value of Maxent processing. The sample used in conducting this evaluation used 30% of the data on the presence of turtles. Where, in the collection of data on the location of attendance there were 27 samples. Thus, 70% of the sample is used to build the model and 30% is used for molecular validation. Based on the model created using the MaxEnt algorithm, the accuracy test in predicting the location of turtle nesting habitat suitability has an AUC value of 0.981 with a standard deviation of 0.004. These results illustrate that the accuracy of the model performed is acceptable with very high accuracy. Figure 4.8b shows the model evaluation curve where the red line shows the average value of AUC, while the blue line shows the average value of the standard deviation. The smaller the standard deviation value, the better the model performance.

Response Curve on MaxEnt Model

The MaxEnt response curve describes the relationship between the probability of the suitability of the turtle nesting location and the value of each environmental variable. In general, the probability of conformity tends to be high (above 0.5) in a combination of supportive conditions, such as slope slope of less than 10° (about 3–16%), proximity to sand and sea, and relative distance from roads, agricultural land, and built-up land. Sloping to sloping beach conditions make it easy for sea turtles to climb to shore and dig nests, while the presence of certain coastal stretches and vegetation (e.g. in the shade of sea pandanus) provides an ideal substrate and moisture for egg hatching.

Conversely, the probability of conformity decreases when the location is closer to sources of disturbance such as roads, built-up land, fishponds, and agricultural activities that reflect high levels of human activity. The average nest distance of hundreds of meters from these features indicates the turtle's tendency to avoid crowded areas. The response curve also shows that turtles choose the optimal distance from the sea line: not too close to avoid tidal inundation, but still close enough to make it easier for the mother to return to the sea after laying eggs. This response pattern emphasizes the importance of a combination of topographic factors, substrates, and human disturbances in determining the suitability of search habitats.

Prediction of Turtle Nesting Suitability Location

Based on the AUC value and the contribution of environmental variables, the MaxEnt model produces a prediction map of the location of turtle nesting habitat along the coast of Kretek District with a probability value between 0 to around 0.75. The value was then classified into suitable and inappropriate habitats using the 10 percentile training presence logistic threshold of 0.324. Areas with predicted values below the threshold are represented as non-conforming zones, while areas with values above the threshold as suitable habitats are indicated by darkening color gradations as the probability of conformity increases (Figure 2).

Spatially, the high suitability zone forms an elongated pattern over sand and fallow land on beaches that are relatively quiet and have little human activity, such as Pelangi Beach, Cemara Sewu, and Barchan. On the other hand, Parangtritis Beach was identified as an unsuitable area due to the dominance of built-up land, agricultural land, and high intensity of human activities, as well as the absence of records of the presence of turtles laying eggs at the location. The strong homing instinct factor in turtles tends to return to the same nesting location further strengthens the possibility that beaches with a history of nesting in Kretek District will continue to be the main location, while beaches that have been fragmented and crowded with human activities tend not to be used as nesting sites.

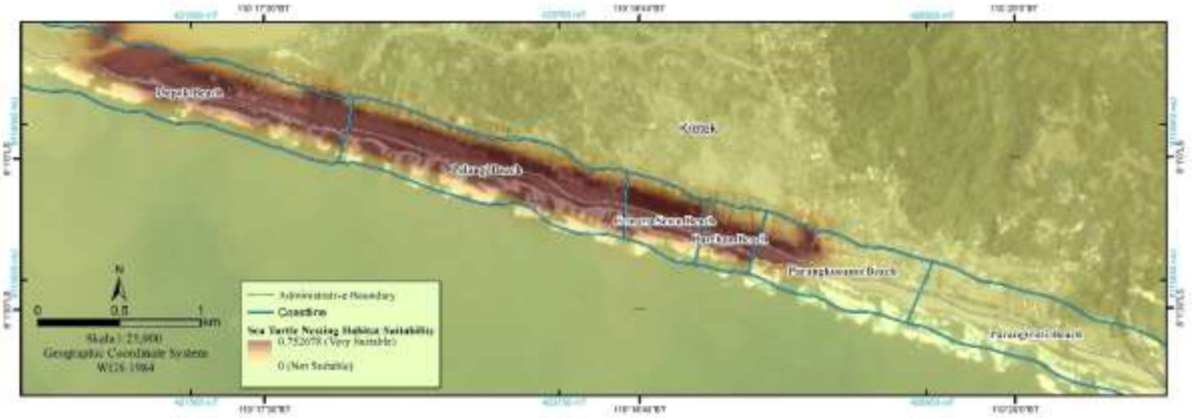

Figure 2. Predicted Habitat Suitability Map For Sea Sea Turtle Nesting Along the Coastline of Kretek Subdistrict

Evaluation of Prediction Results related to the Distribution of Turtle Nesting Habitat Suitability Locations based on Physical Characteristics

Evaluation of Prediction Results with Field Survey Results

Measurements and field observations in this study were carried out to determine the predictions and suitability of turtle nesting locations from the model produced with actual conditions in the field, as well as to assess the comparison of the predictive results of the findings of the presence of turtles laying eggs in the field in 2011-2017 with the findings of the presence of turtles laying eggs in the field in 2018-2019 which was carried out during the observation in 2020 along the coast of Kretek District. Based on Figure 4.27, it can be analyzed that the prediction of turtle nesting locations based on data from 2011-2017 can be appropriate and accurate in predicting the location of turtles laying eggs in 2018-2019. This study used modeling inputs of 27 turtle nesting locations (attendance data) spread throughout the research area. To find out the level of accuracy of the modeling prediction results based on field surveys that have been carried out by overlaying *the* prediction map with the location of the turtle nesting point (*according to* the March 2020 survey).

The turtle nesting location points that indicate the probability level value are presented in Table 4.9. Based on the table, it can be analyzed that as many as 62 turtle nesting locations were found in 2018-2019. The data was obtained based on field surveys and interview reports with the head of the Pelangi Beach turtle conservation manager. A total of 62 findings were in locations that were predicted to have high attendance rates and moderate to high suitability levels. This proves that *MaxEnt*'s turtle nesting location prediction has a fairly good model performance by showing a level of accuracy in predicting presence and absence.

Table 6. Probability Value for Turtle Nesting Location

No	Beach	Year	Coordinate		Probability Value
			X	Y	
1	Pelangi Beach	March 2020	422625	9113941	0.6815
2	Pelangi Beach	March 2020	422659	9113930	0.6856

3	Pelangi Beach	March 2020	422722	9113910	0.6785
4	Pelangi Beach	March 2020	422783	9113900	0.6960
5	Pelangi Beach	March 2020	422818	9113887	0.6978
6	Pelangi Beach	March 2020	422843	9113885	0.7044
7	Pelangi Beach	March 2020	422876	9113870	0.7015
8	Pelangi Beach	March 2020	422925	9113858	0.7061
9	Pelangi Beach	March 2020	422959	9113850	0.7076
10	Pelangi Beach	March 2020	423001	9113837	0.7068
11	Pelangi Beach	March 2020	423048	9113822	0.7002
12	Pelangi Beach	March 2020	423060	9113815	0.6994
13	Pelangi Beach	March 2020	423088	9113803	0.6880
14	Pelangi Beach	March 2020	423118	9113800	0.6851
15	Pelangi Beach	March 2020	423138	9113797	0.6814
16	Pelangi Beach	March 2020	423787	9113608	0.7285
17	Pelangi Beach	March 2020	423245	9113743	0.6790
18	Pelangi Beach	March 2020	423314	9113727	0.6848
19	Pelangi Beach	March 2020	423339	9113714	0.6811
20	Pelangi Beach	March 2020	423378	9113715	0.6838
21	Pelangi Beach	March 2020	423405	9113713	0.6890
22	Pelangi Beach	March 2020	423426	9113713	0.6924
23	Pelangi Beach	March 2020	423442	9113704	0.6902
24	Pelangi Beach	March 2020	423464	9113705	0.6913
25	Pelangi Beach	March 2020	423488	9113694	0.6897
26	Pelangi Beach	March 2020	423554	9113678	0.6938
27	Pelangi Beach	March 2020	423596	9113664	0.6988
28	Pelangi Beach	March 2020	423611	9113659	0.6956
29	Pelangi Beach	March 2020	423725	9113632	0.7257
30	Pelangi Beach	March 2020	423737	9113626	0.7283
31	Pelangi Beach	March 2020	423762	9113612	0.7229
32	Pelangi Beach	March 2020	424147	9113486	0.7317
33	Pelangi Beach	March 2020	424123	9113495	0.7351
34	Pelangi Beach	March 2020	424084	9113511	0.7425
35	Pelangi Beach	March 2020	424076	9113514	0.7415
36	Pelangi Beach	March 2020	424053	9113524	0.7412
37	Pelangi Beach	March 2020	424022	9113530	0.7395
38	Pelangi Beach	March 2020	424000	9113540	0.7392
39	Pelangi Beach	March 2020	423978	9113553	0.7383
40	Pelangi Beach	March 2020	423950	9113555	0.7323
41	Pelangi Beach	March 2020	423912	9113574	0.7339
42	Pelangi Beach	March 2020	423903	9113576	0.7346
43	Pelangi Beach	March 2020	423867	9113580	0.7277
44	Cemara Sewu Beach	March 2020	424319	9113455	0.6929
45	Cemara Sewu Beach	March 2020	424272	9113463	0.7108
46	Cemara Sewu Beach	March 2020	424189	9113481	0.7317

47	Cemara Sewu Beach	March 2020	424170	9113487	0.7324
48	Cemara Sewu Beach	March 2020	424585	9113366	0.6000
49	Cemara Sewu Beach	March 2020	424543	9113377	0.6039
50	Cemara Sewu Beach	March 2020	424505	9113388	0.6093
51	Barchan Beach	March 2020	424820	9113302	0.5645
52	Barchan Beach	March 2020	424765	9113320	0.5788
53	Barchan Beach	March 2020	424719	9113340	0.5886

Source: Virgin processing and field survey (2020)

Data shows that turtle nesting locations on the coast of Kretek District are dominated by Pelangi Beach, Cemara Sewu, Barchan, and Parangkusumo, but based on Regional Regulation No. 9 of 2018 RZWP3K DIY, only Pelangi Beach is included in the Conservation Zone so all activities that damage the ecosystem, convert land, or cut down coastal vegetation are prohibited, especially due to the strong homing instinct nature of turtles that will return to the same location to lay eggs. Of the six beaches studied (Depok, Pelangi, Cemara Sewu, Barchan, Parangkusumo, Parangtritis), Depok Beach experienced a decrease in turtle landing due to its function as a fish landing port and tourist area that triggered egg theft, fishermen's bycatch, and habitat change, although the model is still categorized as appropriate because it was once a nesting location in 2011 and the environmental variables are still supportive so that the potential for nesting in the future remains. On the other hand, Parangtritis Beach which has long been a tourist area has almost never been a turtle landing site due to the intensity of human activities, light, and noise at night, exacerbated by the hunt for turtle eggs and body parts, as well as the fact that turtles will only return to the beach known as the nesting site so that the absence of a long-term landing history makes this beach not "registered" in the turtle's navigation memory.

Spatial Distribution of Turtle Nesting Locations

Based on the results of interviews with the manager of the Pelangi Beach turtle conservation area, document studies, and field surveys show that there are 89 turtle nesting locations along the coast of Kretek District. The details related to the beach with the number of nesting locations can be seen in Table 4.10. *Point plotting* or point recording based on coordinates has been carried out in October-November 2011 by the Yogyakarta Natural Resources Conservation Center (BKSDA) and in August 2017 by the Regional Development Planning Agency (Bappeda) of Bantul Regency. So, in March 2020, *an update* was carried out regarding the location of the turtle nesting.

Table 7. List of Beach Names and Number of Turtle Nesting Locations

Beach Name	**Number of Turtle Nesting Locations**			
	Oct – Nov 2011	**August 2017**	**March 2020**	**Sum**
Depok Beach	5	2	0	7
Pelangi Beach	4	8	43	55
Cemara Sewu Beach	4	4	7	15
Barchan Beach	0	0	8	8
Parangkusumo Beach	0	0	4	4
Parangtritis Beach	0	0	0	0

Sum	13	14	62	89

Source: Document Study and Field Survey (2020)

The data in Table 7 shows that throughout October 2011 to August 2017, turtle nesting locations were only found on three beaches, namely Depok Beach, Pelangi Beach, and Cemara Sewu Beach, with 13 points in 2011 where Depok Beach was the dominant location and 14 points in 2017, when Pelangi Beach was the location with the most landings. However, from 2017 to 2020, Depok Beach experienced a drastic decline in nesting activities due to the high level of human activity as a fish landing center as well as a tourist area, which caused turtles to feel threatened so that they no longer landed, as evidenced by a March 2020 field survey that did not find turtle nests. The 2020 nesting data update shows that the presence of turtles generally occurs in April-August, in line with the dry season when rainfall is low so that sand conditions are more stable, as recorded the highest rainfall in January 2019 (427 mm) and the highest number of rainy days in the same month. Based on the last field survey, there were 62 nesting points with a dominance of 43 points at Pelangi Beach, while the four beaches that became nesting locations were Pelangi Beach, Cemara Sewu, Barchan, and Parangkusumo; while Parangtritis Beach has consistently never been a nesting location due to the high intensity of tourists, land conversion, and high human activity that disturbs animals that are sensitive to light and sound. Spatially, mother turtles tend to nest in areas somewhat far from the coastline towards the boundary of coastal vegetation, as seen in the distribution of points.

Analysis of Physical Characteristics of Turtle Nesting Sites

According to information from the manager of the Pelangi Beach turtle conservation area, the turtles that are most often found landing in certain locations are the type of Leatherback Turtle/Gray Turtle (*Lepidochelys olivacea*). The identification of the Loggerhead Turtle can be seen from the external shape (morphology), especially the shape of the carapace, traces of the presence and size of the nest, and the physical characteristics of the habitat. The Lekang turtle has a high dome-like carapace shape (consisting of five pairs of *coastal Scutes*), with a dark green carapace color, and the bottom is yellow and the head of this type of turtle is relatively large. The width of this turtle's footprint is approximately 80cm, with a shallow shortcut shape and diagonal marks made by its front limbs that are asymmetrical.

The turtles that make the landing are female turtles, where the male turtles are in subtidal areas. Each species of turtle has a different nesting time (*timing*) from each other. Loggerhead turtles have a nesting time at night around 20.00 to 24.00, but it is possible that loggerhead turtles can lay eggs outside of that time. This shows that turtles landing to lay eggs need a place that is completely suitable and safe from various kinds of disturbances.

The existence of an environmental carrying capacity that is in accordance with the turtle nesting habitat, both biotic and abiotic, will affect the location used as a turtle nesting ground. The biotic factor in question is a human factor that tends not to do excessive activity and disturb the search habitat. As in these four beaches, namely Pelangi Beach, Cemara Sewu Beach, Barchan Beach, and Parangkusumo Beach. In this location, human activity is very rare compared to other beaches that have developed into tourist attractions, such as Depok Beach and Parangtritis Beach (Figure 3).

Figure 3. The condition of Parangtritis Beach has human activities

(Source: Field Survey, 2020)

Human activities have a direct effect on the presence of turtles, where the farther the nest location from the built-up land or road, the turtles will feel safer to land and lay eggs, while the proximity to residential areas, agriculture, or human activity centers makes turtles reluctant to appear, as seen in Depok Beach, Parangkusumo, and especially Parangtritis which have never been found as a search location. On the other hand, Pelangi Beach, Cemara Sewu, and Barchan have a long distance from built-up land and agriculture and are supported by the existence of coastal vegetation such as pandanes and creeping plants that help maintain the stability of sand temperatures, so that these three beaches are ideal locations for turtles to lay eggs. The average data of nests are more than 100 meters from the built-up land and are just above the sand bed, except for a few points in Pelangi and Cemara Sewu which are under vegetation, while changes in land use caused the loss of nests on Depok Beach in 2020. In terms of abiotic factors, all beaches in Kretek District have a slope of <10°, in accordance with the requirements of the turtle nesting habitat, and although the daytime temperature is relatively high due to measurements at the time of sun exposure, the nocturnal conditions indicate a suitable temperature range for embryonic development. The length of the coastline also affects the number of nests, for example, Pelangi Beach which is 1,812 meters long can accommodate more nesting sites than Cemara Sewu and Barchan which are shorter, while Parangtritis Beach despite having a beach length of 1,637 meters is still not used by turtles due to the pressure of human activities and high changes in land function.

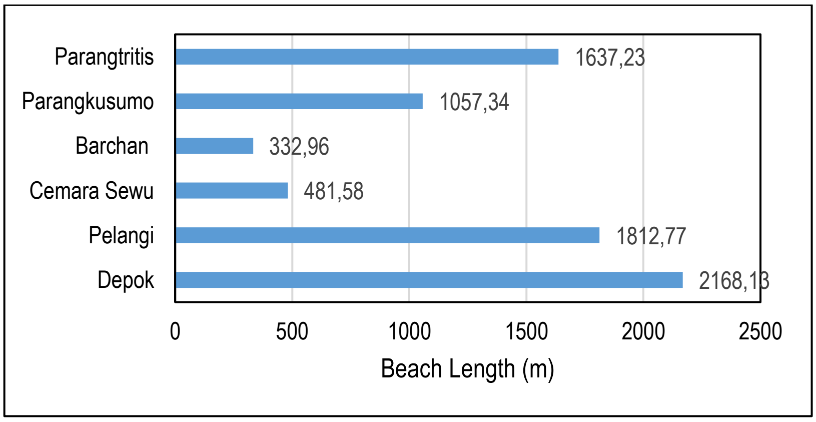

Figure 4. The length of each beach along the coast of Kretek District

Directions for Managing Turtle Nesting Habitat Suitability Locations

The coastal area of Kretek District, Bantul Regency is an important habitat for turtles to lay eggs, but the pressure of human activities causes a decrease in the quality and quantity of habitat, so more intensive protection efforts are needed. Various steps have been taken, such as patrolling, monitoring, and zoning determination through Regional Regulation No. 9 of 2018 which regulates tourist areas, ports, and conservation—with Pelangi Beach as the only official conservation area. The protection of turtles is crucial given its long life cycle and vulnerability to disturbances, so conservation management must be carried out comprehensively, systematically, and involving various parties (Babu & Sudhakar B., 2015; Lee, 2015; Niyonizera & Wabala S., 2025). Predicting the location of nesting habitat suitability using the MaxEnt model is an important basis for sustainable management planning, identifying areas that are highly suitable to those that are not suitable for turtles. The government and the community play a role in supervising the use of coastal space through information exchange, report follow-up, and coaching, accompanied by conservation education to the community, especially on beaches that have high nesting potential such as Pelangi, Cemara Sewu, Barchan, and Parangkusumo. The results of the 2020 survey show that there were 62 turtle landing points in the 2018-2019 period on the four beaches, although the conservation area is only designated at Pelangi Beach so that this beach receives special management facilities under the Bantul BKSDA.

Figure 5. Turtle Conservation Area at Pelangi Beach and Pelangi Conservation Management Office

Turtle conservation activities in the Pelangi Beach conservation area include monitoring the theft and capture of turtles, collecting data on turtles that land and lay eggs, recording the number of eggs hatched, relocating eggs to safer nests, and releasing hatchlings, and this effort should ideally also be applied to Cemara Sewu, Barchan, and Parangkusumo Beaches which have high potential as nesting locations so that they can increase turtle populations and preserve their habitats (Agusta et al., 2025; Zhou Wang Y. & Ding L., 2024). Although the environmental variables on Parangtritis Beach show physical suitability, light and sound pressure from settlements and roads make this beach never a location for searching, so ecotourism-based management of special interest needs to be considered with turtle-friendly spatial arrangement. Based on these conditions, management recommendations include reviewing conservation zoning, increasing supervision and law enforcement, rehabilitating degraded habitats, building turtle management facilities and information centers, and widespread socialization through various media and related institutions so that turtle populations can increase and avoid various threats.

CONCLUSION

The MaxEnt model developed to predict turtle nesting habitat suitability along the coast of Kretek District demonstrated excellent accuracy (AUC 0.981), identifying an elongated suitable pattern primarily associated with sandy and fallow land areas at Depok, Pelangi, Cemara Sewu, Barthan, and Parangkusumo beaches, while Parangtritis Beach was found unsuitable. The distance from sand expanses was the most influential environmental variable, contributing 66.5% to the model's formation. Field data revealed variability in nesting site numbers, with Pelangi Beach having the highest concentration (43 points) and few or none at Depok and Parangtritis Beaches. This model can guide targeted conservation efforts by delineating suitable nesting habitats for turtle protection. Future research should enhance the model by incorporating additional variables such as land and sea surface temperatures, wind direction, tides, and more detailed turtle presence data (including timing of nesting activities). Expanding the study area and aligning field surveys with nesting seasons and natural conditions would also improve accuracy. Furthermore, improving survey tools and data collection timing—especially for temperature measurements—will strengthen field data quality, supporting more effective habitat management and population conservation in the region.

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