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Spatial Distribution and the Influence of Surface Temperature and Green Area on Sea Turtle Nesting Sites in Peninsular Malaysia

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Abstract. Malaysia is home to four of the seven sea turtles in the world, with Malaysian islands being one of the potential areas for sea turtle landing and nesting. However, sea turtles are classified as endangered species because they face extinction mainly due to land use changes, human marine activities, and environmental factors. As a result, they are now among the most important resources for ecotourism. Green turtles are the most prevalent species (endangered), while the hawksbill turtle is one of the world's most seriously endangered marine turtle species today. Hence, considering the importance of improving turtle habitat in Malaysia, this study investigated the sea turtle's nesting site preference in Peninsular Malaysia using spatial analysis. The objectives of this study are (1) to map sea turtle nesting sites in Peninsular Malaysia for five years (from 2017-2021) and (2) to identify the influence of surface temperature and landscape characteristics on sea turtle nesting habitats. This study used the binomial regression method to determine the significant environmental factors such as temperature, distance from the green area and the coastal line that could influence the preference for sea turtle habitat. The results show a positive relationship between temperature and that more sea turtles will nest and land in the area with the higher temperature. Also, more sea turtles prefer to land and nest near green areas. These findings confirmed the influence of green areas in turtle nesting sites in Peninsular Malaysia. It could assist the authorities in further understanding the importance of green areas in turtle nesting site preference and developing a mitigation plan to protect sea turtle habitat.

1. Introduction

Four of the seven sea turtle species in the world reside in Malaysia [1]. They are the *Chelonia mydas* (also known as a green turtle), *Eretmochelys imbricata* (hawksbill), *Lepidochelys olivacea* (olive ridley), and *Dermochelys coriacea* (leatherback). Malaysia is also recognised as one of the world's important nesting rookeries for sea turtles [1]. The leatherback turtle (*D. coriacea*) eggs on Terengganu's mainland beaches, primarily along a 15-kilometre stretch near Rantau Abang. The green turtle (*C. mydas*) is more extensively dispersed, with the most important nesting populations on the Sabah and Sarawak Turtle Islands. Only two significant nesting populations of the hawksbill turtle (*E. imbricata*) remain, in the Sabah Turtle Islands (primarily Gulisaan Island) and Melaka, with remnant populations in Terengganu,

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Johor, and elsewhere. The olive ridley turtle (*L. olivacea*) nesting status is patchy, with sporadic examples of nesting documented in Penang, Kelantan, Terengganu, and Sarawak Turtle Islands [2].

The green turtle is the most prevalent sea turtle species in Malaysia, nesting in Sabah and Sarawak, Perak, Terengganu, Pahang, and Johor. One of the most extensive green turtle nesting areas in Peninsular Malaysia is Redang Island in Terengganu, with 1,000–2,500 nests annually. In comparison, hawksbill turtle nest in Sabah, Melaka, Terengganu, and Johor. The green and hawksbill turtles have been classified as severely endangered by the International Union for Conservation of Nature (IUCN) [3]. Mostly, some wildlife is under threat of extinction, including sea turtles. Many factors contribute to their extinction, such as habitat loss and degradation, climate change, fisheries bycatch, and wasteful use of turtle eggs, meat, and other animal parts. Sea turtles have been integral to many communities' cultures, livelihoods, and economies. Their eggs are used for food, traditional medicine, and trading. With rising demand from the wildlife trade sector, conventional subsistence turtle egg gathering has primarily developed into income-driven commercial exploitation in many world regions [4].

In general, many studies have been conducted to identify the environmental factors of sea turtle nesting preference worldwide using statistical and geographic information systems [5,6,7,8]. Environmental parameters, particularly temperature, can be utilised to forecast nesting seasons [9]. While others prefer open sand, some sea turtles (hawksbill) tend to nest in or near vegetation, preferring forested areas. Many sea turtle populations nest in various habitats, including sandy beaches and more densely forested regions [9,10,11]. Quantifying the relationship between nest temperature and vegetation cover is especially significant since sea turtles lay huge clutches of 100 to 200 eggs, causing nests to warm [10]. Also, the incubation temperature of the nests, which varies according to the area of the beach, can reveal the phenotypic sex of sea turtle embryos [12]. In addition to preventing disorientation in hatchlings, dune vegetation can assist sea turtles in other ways. Climate change is more pronounced in marine turtle eggs, where sex determination is temperature-dependent and increases the proportion of female hatchlings as temperatures rise. Sex ratios may be less skewed towards females if nests are shaded by coastal flora like sea grapes [13]. Another study found that nest site selection in sea turtles is sometimes heavily influenced by offshore cues and beach characteristics. Nesting near the water increases the risk of inundation and egg loss due to erosion. On the other hand, the possibility of desiccation, hatchling disorientation, and predation on nesting females, eggs, and hatchlings increases when nests are placed further inland. [14]. The sand temperature has been identified as significantly influencing the turtles nesting in the area as the temperature will affect their eggs [15]. For example, a temperature around 25–30 °C [15] is perfect for turtle eggs, but high-temperature readings will cause egg-hatching and destroy them. This type of sand is also vital for turtle nesting on the beach site because the turtles will choose moist and soft sand to make it easy for them to make their nests.

In Malaysia, a previous study by [16] analysed the spatial distribution of hawksbill turtles in Melaka. A previous study by [17] investigated the influence of green areas and highlighted the importance of Merambong trees in Penang beach areas for green turtle nesting sites. However, there is a lack of analysis investigating the influence of landscape characteristics (distance to green area and coastline) in other sea turtle nesting sites in Peninsular Malaysia.

2. Aim and Objectives

This study aims to investigate the five-year spatial distribution of nesting sites and the influence of landscape on sea turtle nesting sites in Peninsular Malaysia using the binomial regression model from 2017 to 2021. These are the objectives that must be achieved by the end of this study:

i. To map sea turtles' distribution in Peninsular Malaysia for five years
ii. To identify the influence of surface temperature and landscape characteristics on sea turtle nesting habitats

3. Methodology

The sea turtle nesting preference factors in Peninsular Malaysia were determined using spatial regression. In this study, binomial regression was chosen to analyse the factors influencing sea turtle

nesting sites using SPSS software. The collected data on sea turtles were used to create distribution maps of sea turtles in Peninsular Malaysia for five years, from 2017 to 2021. This study consists of four phases: (i) Phase 1: Preliminary study, (ii) Phase 2: Data collection, (iii) Phase 3: Data processing, and (iv) Phase 4: Results and analysis. Figure 1 shows the workflow of the methodology of this study.

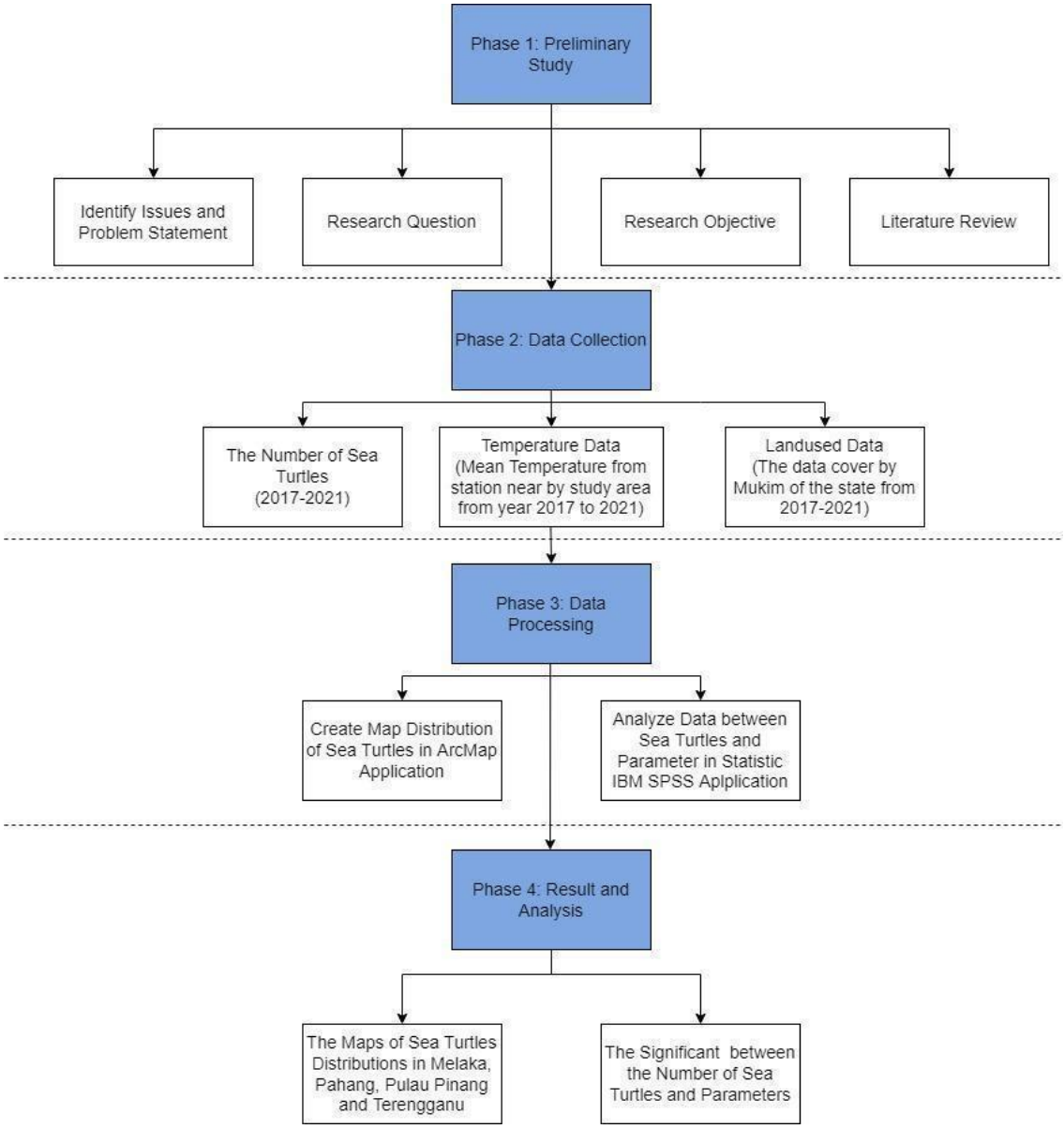

Figure 1. Workflow of methodology

3.1 Preliminary Study

This phase is related to issues and problem statements related to the topic covered in this study, which is the sea turtle nesting preference in Peninsular Malaysia using a spatial regression model. This phase also includes the purpose of this study, its objectives, research questions, and the scope of the study. This study aims to investigate the five-year spatial distribution of nesting sites and the influence of landscape on sea turtle nesting sites in Peninsular Malaysia using the binomial regression model from 2017 to 2021.

3.2 Data Collection

The data used are sea turtles, temperature, and land use data. The sea turtle data were applied from the SWOT open-source platform of the State of the World's Sea Turtles (https://seamap.env.duke.edu/swot) [18]. Several agencies supplied the data, including WWF-Malaysia, via visual sighting from vessels/aeroplanes, GPS tagging, photo identification and passive acoustic detection. The turtle species were drawn from the green, hawksbill, olive ridley, and leatherback turtles. Meanwhile, the temperature data were collected from the Malaysian Meteorological Department (MetMalaysia), and the land use data were acquired from PLANMalaysia. The green area was categorised from the values of land use that represent grass, bushes, or mangrove area. Table 1 shows the dependent and independent variables employed in this study.

Table 1. The dependent and independent variables analysed in this study

Dependent variable	Independent variables
Number of turtles	Temperature
	Distance from green area
	Distance from coastline

3.3 Data Processing

Data processing includes several stages as follows:

i. Develop distribution maps. Distribution maps show the location of any feature in a given area. Distribution maps can be qualitative, such as those that show a region's vegetation or soil, or quantitative, such as those that represent the population. Dots can mean the population distribution, each representing a certain number of people [19].
ii. Preprocessing land use data was conducted to compute the distance of turtle nest points from the green area and coastal line using the 'near distance tool' in ArcGIS software.
iii. Develop a binomial regression model. The negative binomial distribution is a model for counting the number of events. The negative binomial distribution is widely used in the classic distribution approach, a Bernoulli experiment sequence. The model assumes the variable has a gamma distribution with a mean of 1 and a variance of $1/\theta\acute{\imath}$. Therefore, $E(\delta\acute{\imath}) = 1$ if the parameter $\beta = \theta\acute{\imath}$ is part of the mean from the Poisson distribution [20].

4. Results and Discussion

4.1 Sea Turtle Distribution Map

This section elaborates on sea turtle distribution maps in Peninsular Malaysia. Based on the sea turtle data gathered from the SWOT organisation, the sea turtle distribution in Peninsular Malaysia decreased throughout the five years from 2017 to 2021 (Figure 2).

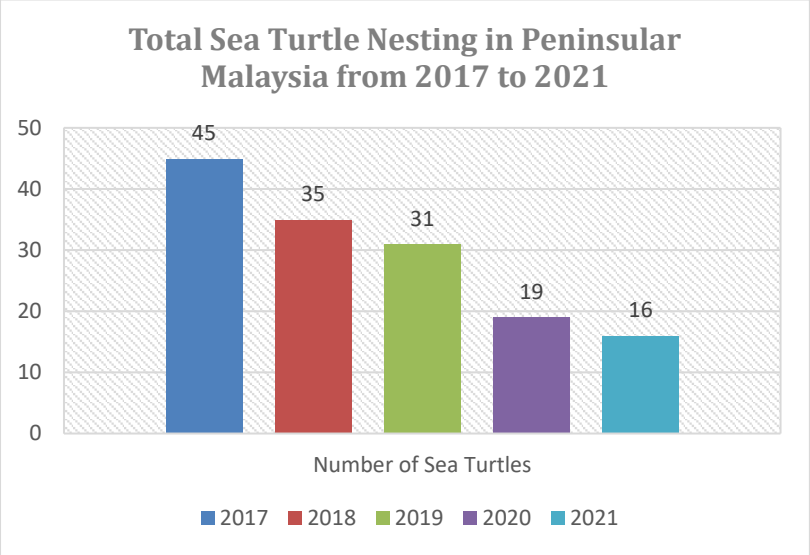

Figure 2. Total sea turtle nesting in Peninsular Malaysia in 2017–2021

Over the five years, 146 sea turtles were nested in Peninsular Malaysia's coastline. In 2017 and 2018, 45 and 35 sea turtles were nested in Peninsular Malaysia's coastal area, respectively. It means the number of sea turtles decreased compared to the previous year. Similarly, the number of sea turtles nesting in Peninsular Malaysia's coastal area decreased throughout 2019–2021. The information was then used to map sea turtle distribution. From the data, only four states in Peninsular Malaysia have been the preferred locations for sea turtle nesting: Melaka, Pahang, Terengganu, and Penang.

Figure 3 shows increased sea turtles nesting in Melaka for five years. In 2017, there were no sea turtle landing and nesting in the coastal area of Melaka. In 2018, 1–2 sea turtles landed and nested in the same area. In 2019–2021, the distribution of sea turtle landing and nesting in the coastal area of Melaka was consistent, with 3–5 sea turtles.

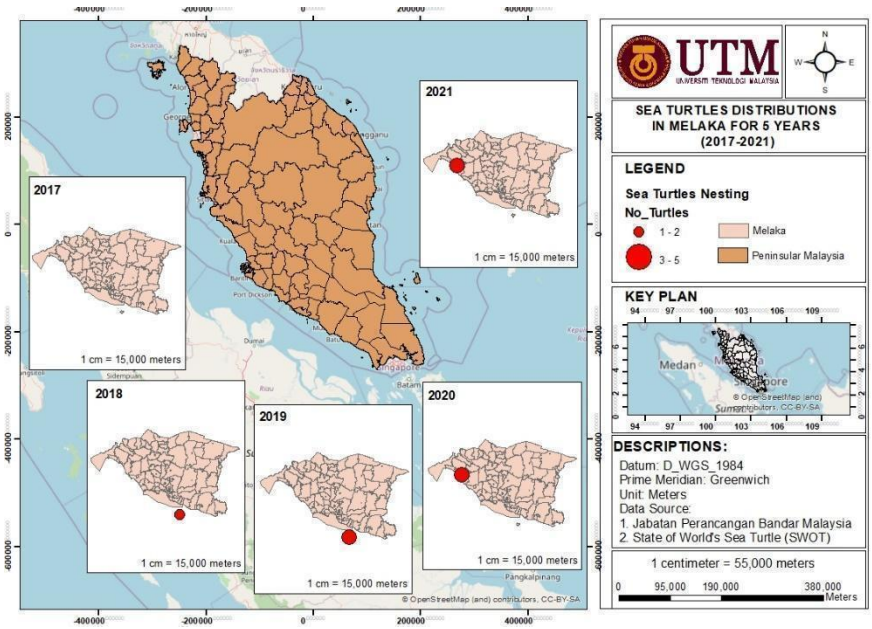

Figure 3. Sea turtle distribution in Melaka for five years (2017–2021)

Figure 4 illustrates a distribution map of sea turtles in Pahang, concentrated on Tioman Island. The distribution map shows that the number of sea turtles on Tioman Island has declined. In 2017 and 2018, the distribution of sea turtles in Tioman Island saw 3–5 sea turtles landing and nesting. However, the distribution of sea turtles began to decline in 2019, 2020, and 2021.

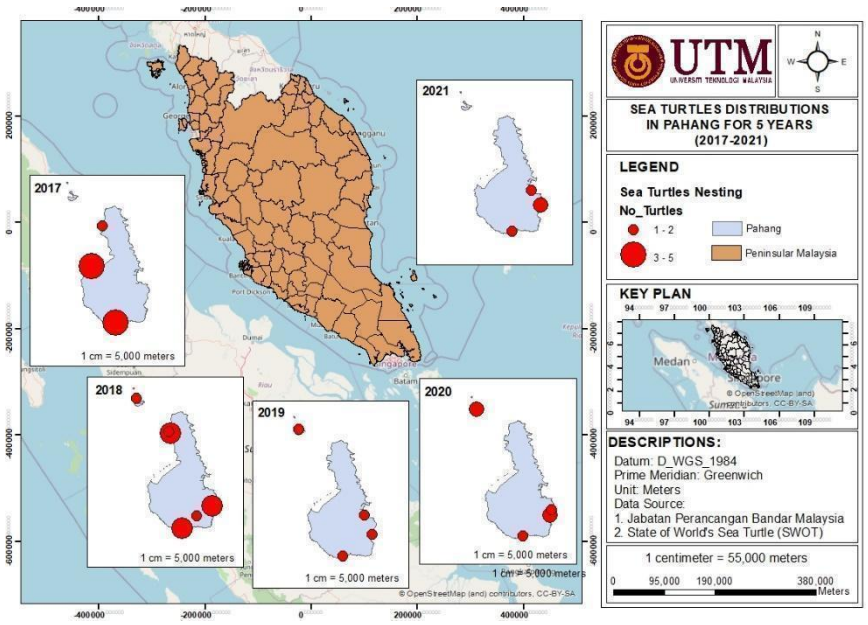

Figure 4. Sea turtle distribution in Pahang for five years (2017–2021)

Figure 5 represents a distribution map of sea turtles in Terengganu. Terengganu is famous for sea turtle landing and nesting in their coastal area. In 2017, sea turtle landing and nesting sites were detected in every coastal region of Terengganu. In 2018, the distribution of sea turtle landings and nesting in Terengganu decreased to 3-5 turtles. However, in 2019–2021, the distribution of sea turtle landing and nesting in Terengganu started to decline.

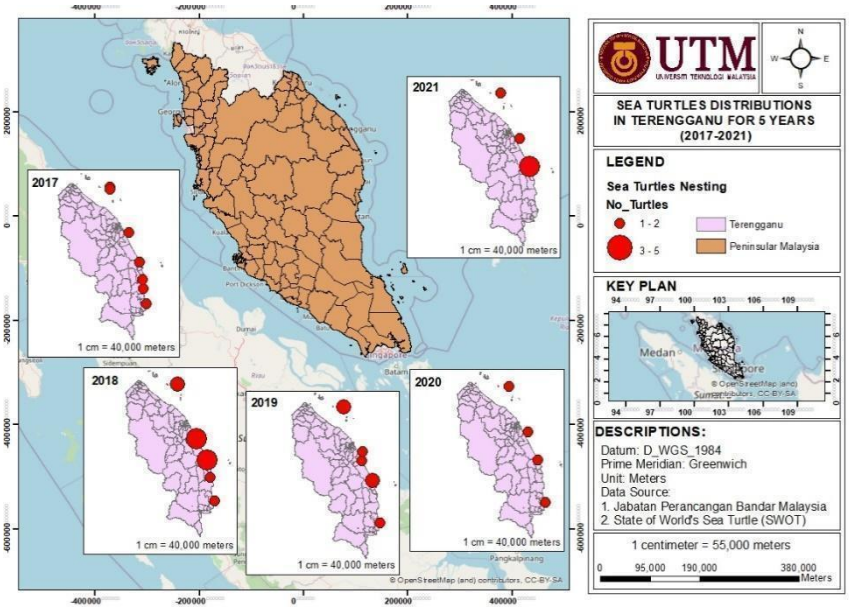

Figure 5. Sea turtle distribution in Terengganu for five years (2017–2021)

Figure 6 shows a distribution map of sea turtles in Penang. The distribution of sea turtles in Penang clearly shows the decline of sea turtle landing and nesting in the state. In 2017 and 2018, the coastal area of Penang was preferred for sea turtles to land and nest there. However, starting in 2019, sea turtle landing and nesting in the coastal regions of Penang decreased significantly. Meanwhile, in 2020 and 2021, no more sea turtles landed and nested on the Penang coastline.

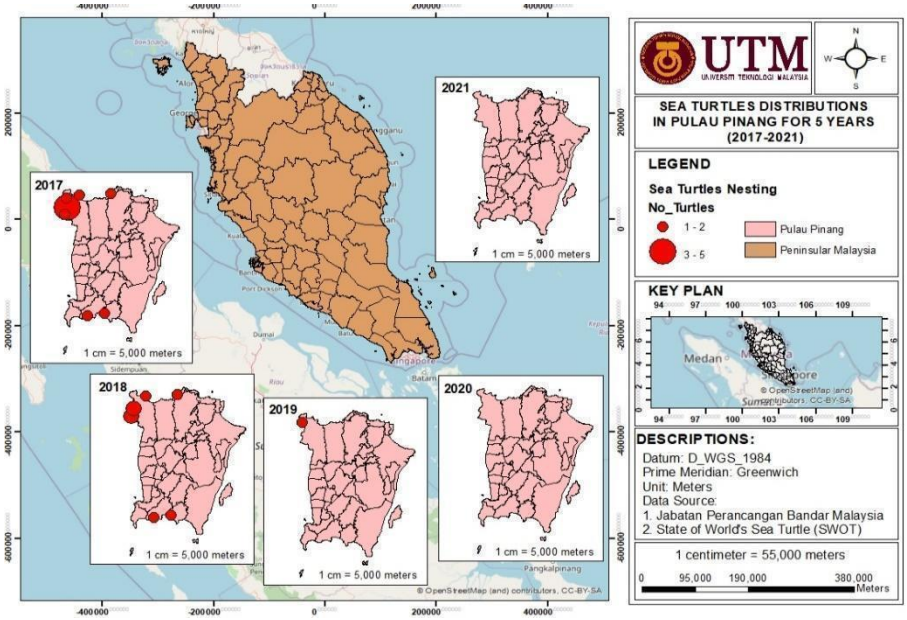

Figure 6. Sea turtle distribution in Penang for five years (2017–2021)

These findings show that the distribution of sea turtles in Peninsular Malaysia mainly focuses on the coastal area, especially in Terengganu, Pahang, Melaka, and Penang. It is common knowledge that Terengganu is one of the popular states for sea turtles nesting and landing in coastal areas, such as Rantau Abang, Pulau Kapas and Pulau Redang. In Pahang, Tioman Island is only the area for sea turtle nests and landing. Sea turtles have preferred several areas in Penang to nest and land: Teluk Kemuning, Teluk Belimbing, and Pantai Kerachut. Finally, the sea turtle landing and nesting in Melaka started in 2018 along the coast of Selat Melaka in the district of Pengkalan Balak as the preferred area.

The results of the distribution maps of sea turtles for these four states clearly showed that the distribution of sea turtles that land and nest in the areas started to decrease yearly. In Melaka, the presence of sea turtles in the state's coastal regions is still consistent, but not for Pahang, Penang, and Terengganu. In Pahang and Terengganu, sea turtles still land and nest in the coastal areas, and the decrease in the frequency of sea turtle landing and nesting is not too drastic. However, no sea turtle landing was recorded in Penang starting in 2019. Several environmental factors may have influenced sea turtles' preference to nest and land on a beach.

4.2 Identification of Surface Temperature and Landscape Characteristics Influence Sea Turtle Distributions and Populations

This study uses binomial regression to model the factors influencing sea turtle nesting preference in Peninsular Malaysia. The modelling approach is based on stepwise regression, which begins with all variables and eliminates non-significant variables with *p*-values of more than 0.05 at each step. The Akaike information criterion (AIC) and Bayesian information criterion (BIC) values are used to evaluate the model. These two criteria, which add a complexity-penalising factor to the log-likelihood, are better appropriate for quantifying the relative quality of regression models while accounting for the number of parameters [21]. AIC is utilised in the considered model selection algorithms to pick binomial regression models with varying numbers of predictors.

Initial analysis showed the predictor with the highest value of R^2 is the temperature (p<0.05, R^2 = 62). It means that the temperature explains more than half of the variance in the environmental factors influencing sea turtle nesting preference, which is about 62%. It shows that the temperature may provide a particular influence in defining the number of sea turtle nesting and landing in Peninsular Malaysia. This is followed by the distance from the green area (p<0.05, R^2 = 45.2). It means that the distance from the green area explains approximately one-third of the variance in the environmental factors influencing sea turtle nesting preference, which is about 45%. Meanwhile, the distance from the coastline has an R^2 value of 44.14 at p>0.05, which is not a significant variable. Thus, it can be concluded that two predictors have a more substantial influence on sea turtles nesting preference in Peninsular Malaysia. The lowest and highest coastal temperatures reported in this study are 28.5 and 30.3 °C, respectively, with an average temperature of 29.5 °C. The average distance between the green areas and the nesting site is 10.5 m, with the smallest and maximum distances being 7.2 and 14.7 m, respectively. The coastline's minimum, average, and maximum distances from the nesting sites are 9.1, 12.1, and 19.8 m, respectively.

However, explaining R^2 values without analysing the normal probability and scatter plots of fitted vs observed values is incomplete. [22] indicated that it is biased to only consider R^2 values without analysing the residual plot. Thus, Figures 7 and 8 show the residual plots of the two main predictors, temperature and the distance from the green area, respectively. Next, the pattern in the residual vs fitted plots is analysed. Even if the R^2 value is high, if the data is not randomly scattered, it indicates a poor fit. Figures 7 and 8 illustrate the patterns of the residual vs fitted plots for temperature and the distance from the green area, respectively, which are randomly scattered.

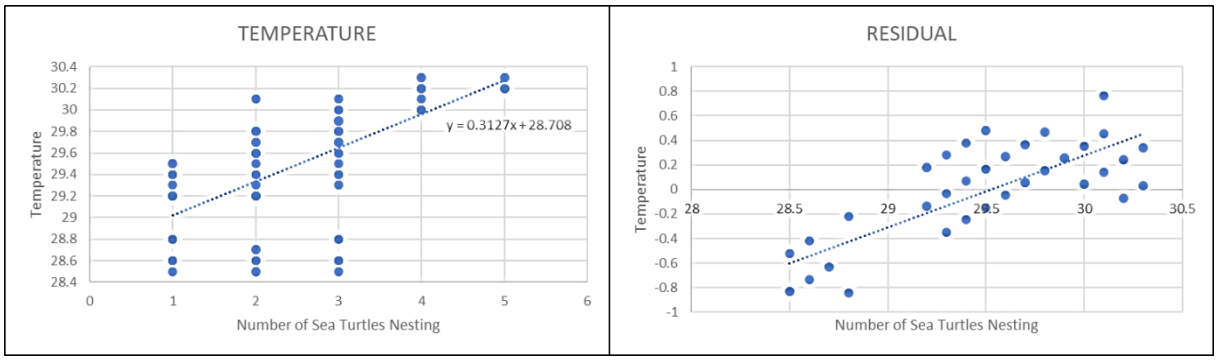

Figure 7. Residual plot of temperature

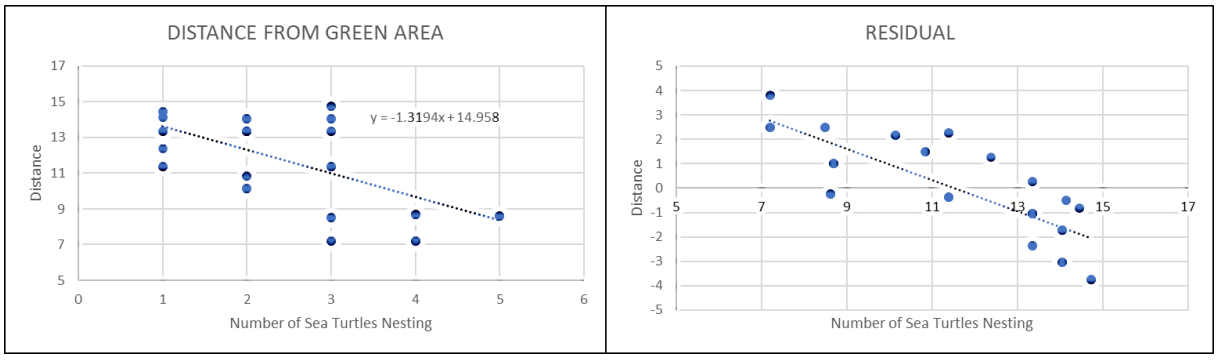

Figure 8. Residual plot of distance from the green area

The temperature of the coastal environment is one of the environmental factors influencing sea turtle preference for nesting and landing sites. The ideal temperature for sea turtles to nest and eggs hatch is between 25 and 35 °C [23]. The eggs will not be destroyed at these temperatures and will hatch successfully. The average temperature of 29.5 °C has been determined in this study from the five years

of data as a significant variable that affects the number of sea turtles in the nesting sites. At the same time, nearby green areas have been identified as one of the dominant landscape factors influencing the increased number of sea turtles. A lower vegetation area (dune) is the most popular spot for the oviposition process to hide the eggs from their enemies [24]. Nearby green areas could balance the surrounding temperature to the ideal hatching temperature and be suitable for a nesting site for sea turtles, where they dig holes in the sand and eggs hatch. However, the distance from the coastline does not significantly influence the selection of sea turtle nesting sites. This is in line with a study by [25] that highlighted that in Mexico, the dune area was the most popular nesting spot compared to sites near the tidal area. The landing and nesting of sea turtles near the coast will threaten the species due to the occurrence of tidal phenomena. These phenomena will destroy sea turtle nesting sites and eggs, and when the tide rises, sea turtle eggs will be swallowed up by the water.

5. Conclusions

The spatial analysis of the five-year sea turtle distribution in the four states of Peninsular Malaysia that have been hotspots for sea turtle nesting places shows that the distribution of sea turtles that land and nest in the areas has begun to drop from year to year. In Melaka, the presence of sea turtles in the state's coastal regions is still consistent, but not for Pahang, Terengganu, and Penang. In Pahang and Terengganu, sea turtles still land and nest in the coastal areas, and the decrease in the frequency of sea turtle landing and nesting is not too drastic. However, no sea turtle landing was recorded in Penang starting in 2019. Environmental factors may have influenced sea turtles' preference to nest and land on a beach.

To research the links between the quantity of sea turtles and the environmental factors influencing sea turtle nesting site preferences, three environmental parameters (temperature, green area, and coastline) were examined. This study discovered a positive association between temperature, with more sea turtles nesting and landing in warmer regions, and a negative relationship between the number of sea turtles to distance from the green areas. This study confirmed that sea turtles commonly landed in Peninsular Malaysia prefer sites near green areas to the near coastal line. These findings may help authorities better understand sea turtle environmental factors and nesting preferences and build a mitigation plan to conserve sea turtle habitat.

However, there are limitations to this study. This analysis could be biased because it does not include other factors such as marine pollution, sand temperature, and different beach zones and differentiate the result according to turtle species. The data is also limited to the year 2017-2021. Furthermore, the turtle observation data extracted from the SWOT database were collected from selected agencies and crowdsourced data. Hence, several recommendations are suggested to increase the quality of the results. This study considers the surface temperature from the MetMalaysia weather station. Future work may consider the sand temperatures for better precise findings. Marine pollution may also be a significant environmental factor influencing the sea turtle nesting preference in Peninsular Malaysia. So, in further studies, these variables also should be considered. Other possible variables may also be analysed, such as the type of sand, tidal data, slope and the size of the green area. Furthermore, data on sea turtles may be acquired from other credible sources with greater temporal data for the previous 10-20 years.

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