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Research Article

VEGETATION AND TEMPERATURE AS DETERMINANTS IN THE EGG-LAYING BEHAVIOR OF HAWKSBILL TURTLES (ERETMOCHELYS IMBRICATA) AND LOGGERHEAD TURTLES (CARETTA CARETTA)

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Abstract

Vegetation and temperature are biophysical parameters that affect sea turtle nesting behavior. Coastal vegetation is essential to the nesting behavior of Loggerhead sea turtles. In contrast to Hawksbill sea turtles, Loggerhead sea turtles preferentially select sandy beaches for nesting. The study aimed to measure the impact of vegetation and temperature on sea turtle nesting behaviors and to offer detailed insights on adaptation and enhanced conservation techniques to save sea turtles from environmental changes. The study was performed on Popaya Island, within the Nature Reserve of Mas Popaya Raja Island, North Gorontalo, from January to March 2023. Identification of population and sample using the purposive sampling method for all turtles observed throughout the observation phase. The findings indicated that Hawksbill turtles (Eretmochelys imbricata) favored nesting in locations characterized by greater plant diversity and density, averaging 195 eggs per nest. Loggerhead turtles (Caretta caretta) deposited a comparatively lower number of eggs (88 eggs) than at other locations (96 - 108 eggs). Some eggs were found in places with no surrounding vegetation. The nesting activity of loggerheads in non-vegetated regions may have been affected by the shallowness of the holes and their comparatively broader width. The sand surface temperature in areas with dense flora and biodiversity decreases, impacting egg-laying activity as one moves further from the vegetation's border.

Keywords: Biophysical Parameters; Sandy Beach; Egg Laying; Turtle Behavior

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INTRODUCTION

Sea turtles are marine reptiles with considerable economic value that are threatened with extinction (Pittman et al., 2024). This condition is caused by various factors, including predatory animals, the gathering of eggs for trade, the hunting of young turtles for meat, environmental contamination, and habitat deterioration (Itoh et al., 2024). The proper microclimate for incubating sea turtle eggs is formed through interactions between the physical qualities of the material (Beaumont & Glavovic, 2024), the composition of the beach, the local climate, and the eggs in the nest.

Hawksbill turtles (Eretmochelys imbricata) are characterized by a beak-shaped snout, an upper jaw that slopes downward and is quite sharp like an older bird (Ghermandi & Sinclair, 2024). Hawksbill turtles are scattered across Indonesia, especially on small isolated islands (Arkema et al., 2024). Hawksbill nesting habitat is impacted by various environmental conditions, including beach vegetation and sand surface temperature (Boumans et al., 2024), which play an essential role in Hawksbill nesting.

Loggerhead turtles (Caretta caretta) spend most of their life in shallow coastal waters and the open ocean (Bozzeda et al., 2025). They rarely reach the shore except when the female needs to build her nest and lay eggs. The waters where they reside have surface temperatures that range from 13.30C - 280C during the non-nesting season. When females create nests and deposit eggs, temperatures between 240C - 260C normally produce males, while temperatures between 320C - 340C likely to produce females (Shennan & Crabbe, 2024). Loggerhead turtles have specific adaptations for swimming and diving, as well as the capacity to handle salt water without dehydration (Edworthy & Tagliarolo, 2025). All these help them live in varied situations (Biswas et al., 2025). In turtles, sex is not decided by chromosomes like in humans but by the environmental conditions in which their eggs are incubated (Shennan & Crabbe, 2024). Warmer temperatures normally create females, whereas lower temperatures produce males (Bischof, 2025). Studies demonstrate that greater temperatures can lead to an imbalance in the turtle population, with more females than males (Benjamin et al., 2025). This could be a severe problem as males are vital for the reproduction and sustainability of the species (Defeo & McLachlan, 2025). Climate change resulting to increased temperatures can significantly influence sea turtle populations.

Loggerhead turtles tend to choose sandy beaches as nesting locations (Langdon, 2025). Sandy beaches function as natural incubators and provide a good environment for turtle embryo development (Lepage et al., 2025). By understanding these elements, we can more effectively protect loggerhead turtles and ensure the sustainability of coastal ecosystems (Deb et al., 2024). Coastal vegetation plays an essential effect in nesting behavior for loggerhead turtles (Xie et al., 2025). Unlike the Hawksbill turtle, the Loggerhead turtle tends to choose sandy beaches as nesting locations (Kianfar, 2025). This study aims to see the level of influence of vegetation and temperature on turtle nesting activities.

In addition, it provides insight into the adaptation of sea turtles to environmental changes (Vadivel et al., 2025). Coastal vegetation maintains air temperature and nest temperature stability and shields predators that attack sea turtles when they land on the beach (Trevisiol et al., 2024). By understanding the effects of vegetation and temperature, we can build more effective conservation measures to conserve sea turtles and nesting places and sustain coastal ecosystems (Fariq et al., 2024). This study is the first step to conserving sea turtles and the coastal environment, especially in Pulau Mas Popaya Raja Nature Reserve located in North Gorontalo Regency, Gorontalo Province, which has a diverse ecosystem and vegetation from other nature reserves (Maes et al., 2024). This is also the theme of novelty research undertaken in that place.

Besides protecting the diversity of plants and animals and their ecosystems, this conservation area also works as a life support system area (Hlaing et al., 2024). Geophysically, Mas, Popaya, and Raja Islands are dissimilar (Bauer et al., 2024). Mas Island is a land constructed on a rock with an altitude of ± 10 meters above sea level, and on the east and south are sandy.

Popaya Island is mainly sandy and flat at an altitude of ± 2 meters above sea level, surrounded by sandy beaches (Nasution et al., 2024). At the same time, Raja Island is the largest island with topographic characteristics that vary from pleasant to very steep. The beach is sandy in the southern section of the island, ,while the northern part is rocky.

RESEARCH METHOD

Research Design

The study was conducted at Popaya Island, Mas Popaya Raja Island Nature Reserve, located in Dunu Village, Anggrek District, North Gorontalo Regency, from January to March 2023. The research method used in determining the observation sample was the purposive sampling method.

Research Target/Subject

The research samples consisted of turtles identified during the observation and data collection phases. Simultaneously, the population represented the total number of turtles located within the Pulau Mas Popaya Raja Nature Reserve Area.

Research Procedure

The fundamental instruments utilized in this research, including stationery, roll meter, stopwatch, GPS, digital camera, camera trap, and soil thermometer, were useful in data collecting. The utilized materials, including conservation area maps, the PlanSnap program, and the observation tally sheet, were pivotal in the organization and analysis of the gathered data.

Instruments, and Data Collection Techniques

The data collection on turtle nesting behavior and the measurement of physical features of nesting locations employed observational and measuring techniques. Observations were conducted from 19:00 to 05:00 WITA at the research site during a duration of two months. Observation techniques encompassed beach observation, involving direct monitoring of turtle nesting activities and the identification of vegetation (Deng et al., 2024). The observations encompassed nesting duration, nest site, and turtle behavior during egg deposition. The dimensions of the turtle's carapace were assessed to determine the species of the particular turtle. Assessment of sand temperature surrounding the turtle nest, which influences embryo development. Assessment of nest depth and diameter to comprehend nest circumstances and determinants influencing hatching. calculating the eggs in the nest to assess hatching efficacy.

The study used a purposive sampling technique. The observation point was divided into 4 observation points (stations), and at each sampling point, a camera trap was installed at a distance of 20-25 meters from the edge of the beach. The criteria for each observation station in the field are as follows: Station 1 (East) has a coastline that is not long. Station 2 (South) has a short coastline, frequent abrasion and many fallen trees. Station 3 (West) has a longer coastline than the east and south stations. Station 4 (North) has the longest coastline.

In the initial observation, the vegetation found included Coconut (Cocos nucifera L), Tropical Almond (Terminallia catappa L), Australian pine tree (Casuarina equisetifolia), Pandan thorn leaf (Pandanus tectorius), Japanese celery (Angelica keiskei) and Beach naupaka (Scaevola taccada). Tree structures in the vegetation found include trees, poles and saplings. A map of the research location and observation stations can be seen in Figure 1.

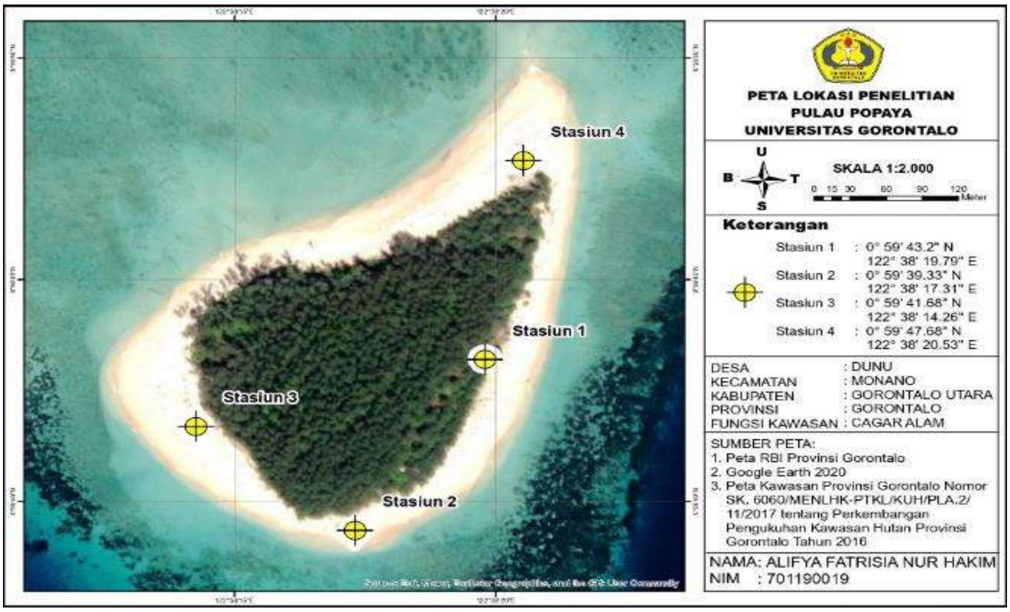

Figure 1. Map of Research Location and Observation Stations

Data Analysis Technique

Observation data was collected and documented in a tally sheet; the results were analyzed descriptively and qualitatively based on the observations and measurements, specifically describing and explaining all stages undertaken by turtles during the egg-laying process, which encompasses the turtle's landing phase (emerging from the sea and returning to it), searching for nesting sites, excavating nests, depositing eggs, creating camouflage in the sand, and sealing the egg cavity (Steward et al., 2024). Factors like as plant kind and structure, together with temperature, affect the success of sea turtle nesting behavior. The relationship between biophysical parameters and turtle nesting behavior was examined by quantitative principal component analysis.

RESULTS AND DISCUSSION

The analysis of species dominance within the vegetation structure at each observation station indicates that the Australian pine tree (Casuarina equisetifolia) is the prevailing vegetation type in the pole structure. The activity and behavior of sea turtles exhibit a significant correlation with vegetation and temperature, which are critical factors in facilitating the egg-laying process in nests. The condition of biophysical factors in regulating temperature and humidity around the nest will be significantly influenced by vegetation factors. The prevalence of species within the Australian pine tree vegetation on the pole structure significantly influences the egg-laying behavior of turtles during the incubation phase.

The data presented in Table 1 categorizes the vegetation of the beach into three distinct groups: saplings, poles, and trees. The Australian pine tree (Casuarina equisetifolia) represents a significant species within the pole category in the turtle nesting area, exhibiting an INP of 134.365, which surpasses that of other vegetation types. The number of tree-category vegetation types is less than that of other categories. The interaction between the Australian pine tree and other plant species is likely to significantly impact the behavior of sea turtles during their egg-laying process.

Table 1. Species Dominance in Vegetation Structure of Turtle Egg Laying Areas

Vegetation/species	Station I	Station II	Station III	Station IV	INP	Structure
Coconut (*Cocos nucifera* L)	3.92	-	-	-	22,665	Tree
Tropical Almond (*Terminallia catappa* L)	19.61	21.43	21.76	-	94,223	Tree
Australian pine tree (*Casuarina equisetifolia*)	23.53	23.81	26.08	-	134,365	Pole
Pandan thorn leaf (*Pandanus tectorius*)	7.84	-	-	-	34,050	Pole
Japanese celery (*Angelica keiskei*)	21.57	26.19	26.08	-	101,007	Sapling
Beach Naupaka (*Scaevola taccada*)	23.53	28.57	26.08	-	107,173	Sapling

The overall vegetation structure affects turtle nesting behavior by offering an appropriate location and shielding the nest from environmental stressors. The Australian pine tree (Casuarina equisetifolia) has varying INP values, with station I measuring 23.53 and station III measuring 26.08. This species stabilizes sand on the beach and offers a secure nesting location. Additional plant species identified at each observation station include Beach Naupaka (Scaevola taccada) (INP 107.173), Japanese Celery (Angelica keiskei) (101.007), and Tropical Almond (Terminalia catappa L.) (94.223), which are also prevalent species. Coconut plants (Cocos nucifera L) and Pandan Thorn leaves (Pandanus tectorius) exhibit low INP values of 22.665 and 34.050, respectively.

All vegetation was located at Station I, exhibiting varying levels of dominance along the periphery of the turtle egg-laying zone, whereas Stations II and III contained just 4 (four) dominant species out of the 6 types of vegetation identified in the turtle nesting area. Station 4 (North) possesses the most extensive coastline, resulting in a nesting habitat accessible to sea turtles, unencumbered by the vegetation types present on Popaya Island, Mas Popaya Raja Island Nature Reserve, Dunu Village, Anggrek District, North Gorontalo Regency.

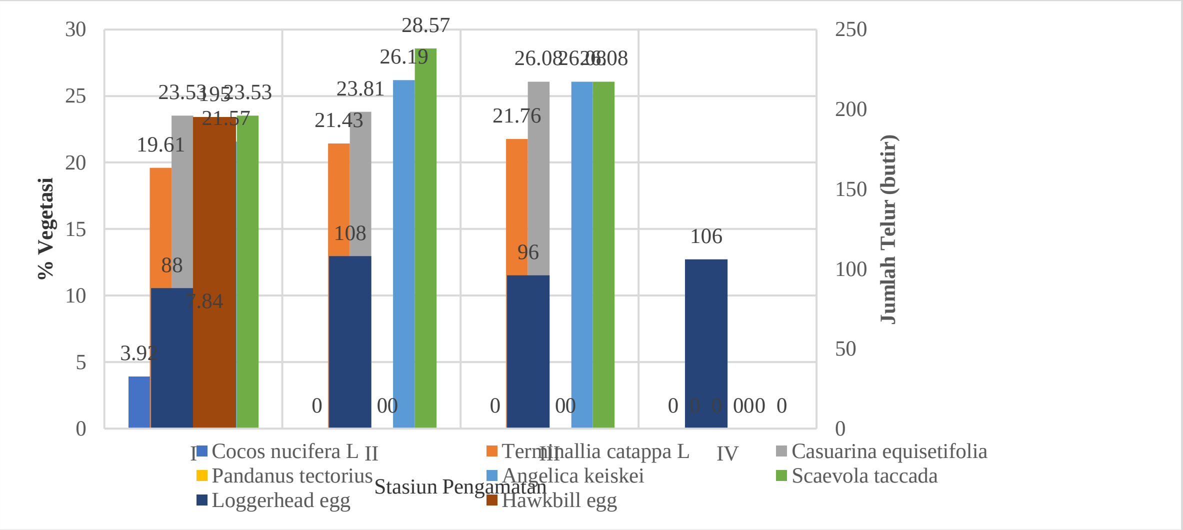

Figure 2. Influence of Vegetation on the Number of Loggerhead and Hawksbill Turtle Eggs

Figure 2 indicates that Hawksbill (Eretmochelys imbricata) and Loggerhead (Caretta caretta) turtles exhibit distinct preferences for nesting locations. This disparity arises from potential temperature and humidity variations between places with sparse and dense vegetation. The temperature of the nest influences the hatching success of Loggerhead turtle eggs. Hawksbill turtles (Eretmochelys imbricata) favor nesting in areas characterized by more vegetation diversity and density, typically depositing an average of 195 eggs. Eggs of this turtle species were exclusively discovered at Station 1, which exhibited greater vegetation compared to other stations (Andrade et al., 2025). Conversely, Loggerhead turtles (Caretta caretta) in areas with varied and dense flora typically lay fewer eggs, averaging 88, compared to other locations where the average ranges from 96 to 108 eggs. Even in locations devoid of adjacent vegetation, eggs were discovered.

The optimal temperature for incubating Loggerhead turtle eggs is from 29 to 32°C, with humidity levels between 67 and 80%. The depth of the sand influences the hatching success of Loggerhead turtle eggs. Research indicates that Loggerhead turtles select nests with appropriate sand depth for egg incubation, influencing the temperature and humidity within the nest. In summary, environmental factors influencing Hawksbill turtle egg hatching pertain mostly to nest architecture and egg strata, whereas those impacting Loggerhead turtles are predominantly associated with temperature, humidity, water availability, and sand pH.

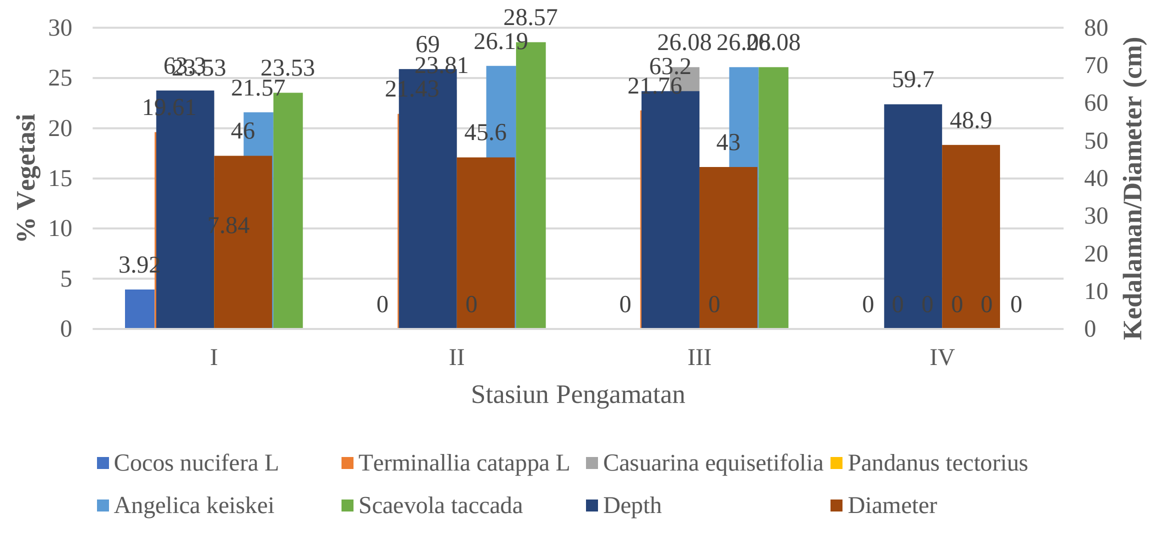

Figure 3: Effect of Vegetation on the Depth and Diameter of Sea Turtle Nesting Holes

The depth of the hole correlates with the turtle's capacity to excavate the nesting cavity. Loggerhead turtles possess a comparatively lower hole depth and a broader hole diameter (Figure 3). Studies indicate that vegetation influences egg-laying behavior, with certain species, including the Green Turtle (Chelonia mydas), selecting vegetated areas for nesting. Research data indicates that the majority of green turtles construct nests in regions characterized by flora, including fulen plants, matting, beach tobacco, beach iron, fish eyes, cassowary, and kelap (M.F. Babarro et al., 2024). Coastal vegetation plays a crucial role in safeguarding sea turtle eggs from direct sunlight, mitigating abrupt temperature fluctuations, deterring predators, and influencing humidity, temperature, and sand stability, thereby ensuring safety during nest excavation.

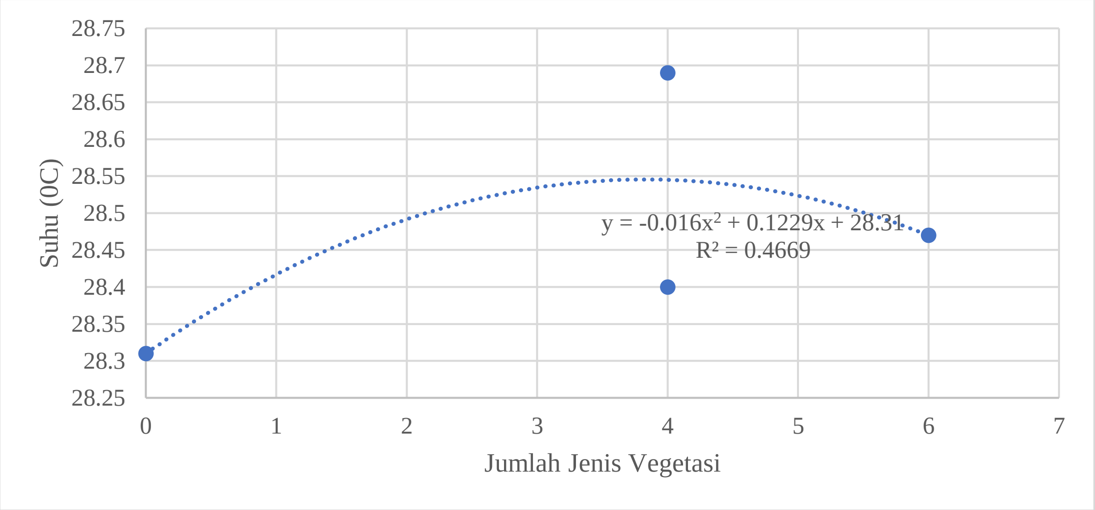

Figure 4: Effect of Vegetation on the Temperature of Sea Turtle Nesting Holes

Vegetation types significantly influence turtle breeding habitats. Vegetation offers shade for turtle nests, mitigating sunlight that can elevate nest temperatures and jeopardize embryos. Moreover, flora serves as a natural barrier for the egg hatching process against disturbances from sea waves, humans, or predatory animals (Neumann et al., 2024).

Vegetation typically reduces surface temperature. A higher population density correlates with a reduction in temperature, influencing turtles' nesting habits. The impact of hole temperature on nesting activity is generally consistent (refer to Figure 4). The amount of dense vegetation often lowers the surface temperature, with the coefficient of determination (r^2) at 0.4669, indicating that around 46.69% of the vegetation's quantity and type influences the temperature. This number demonstrates the inadequately strong impact of vegetation on temperature conditions in the nesting areas (Figure 4).

Table 2 indicates that Hawksbill turtle nesting sites are situated at a greater distance (183 m), approximately twice that of Loggerhead turtles, which average 87.25 m from the beach. Nonetheless, it is hypothesized that this distance is also influenced by the behaviors of the two turtle species. Diversity of vegetation influences the lay of eggs by Hawksbill and Loggerhead turtles. In denser and more diversified vegetation, both turtle species may lay eggs at varying distances.

Table 2: Effect of Vegetation on the Distance of Sea Turtle Nesting Nests from the Coastline

Description	Station			
	I	II	III	IV
Coconut	3.92	0	0	0
Tropical Almond	19.61	21.43	21.76	0
Australian Pine tree	23.53	23.81	26.08	0
Pandan thorn leaf	7.84	0	0	0
Japanese celery	21.57	26.19	26.08	0
Beach naupaka	23.53	28.57	26.08	0
Distance nest of Hawkbill	183	0	0	0
Distance nest of Loggerhead	90	92	80	87

Notes: Data after processing, 2024

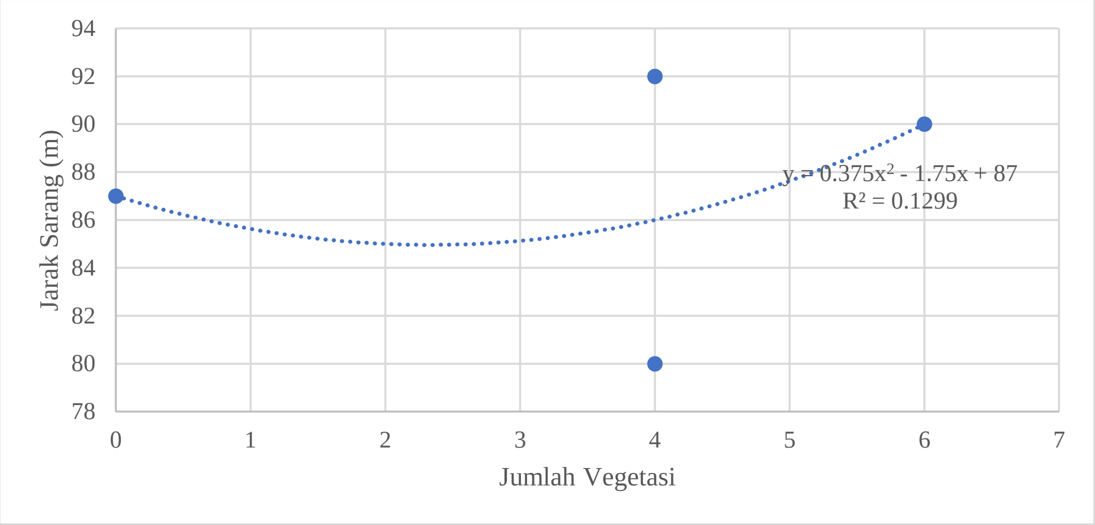

Figure 5: Correlation between the amount of vegetation and the distance between turtle nests

The correlation between vegetation and the distance of turtle nesting is significant. Coastal vegetation protects turtle eggs, mitigating the threats posed by waves and predatory species. Moreover, vegetation might affect environmental circumstances that facilitate the nesting process (Bilkovic et al., 2025). Research indicates that several plant species, including Pandanus tectorius, Baringtonia asiatica, and Hibiscus tilaceus, positively correlate with Green turtle (Chelonia mydas) nesting behavior (Dupont et al., 2025). A greater number of turtle nests were discovered in areas with vegetative habitats. Figure 5 illustrates a minimal link between vegetation density and the distance of turtle nests (r2 = 0.1299); nonetheless, relatively, populations with greater vegetation tend to be situated farther from turtle nesting sites. Vegetation significantly influences nest presence and the nesting process.

The influence of temperature on turtle activity and egg quantity is minimal and varies in both Hawksbill and Loggerhead turtles. There is a propensity for the quantity of eggs in each turtle to be inversely proportionate between the two kinds of turtles (Figure 6). An elevation in temperature affects the egg-laying behaviors and site selection of Hawksbill and Loggerhead turtles differently.

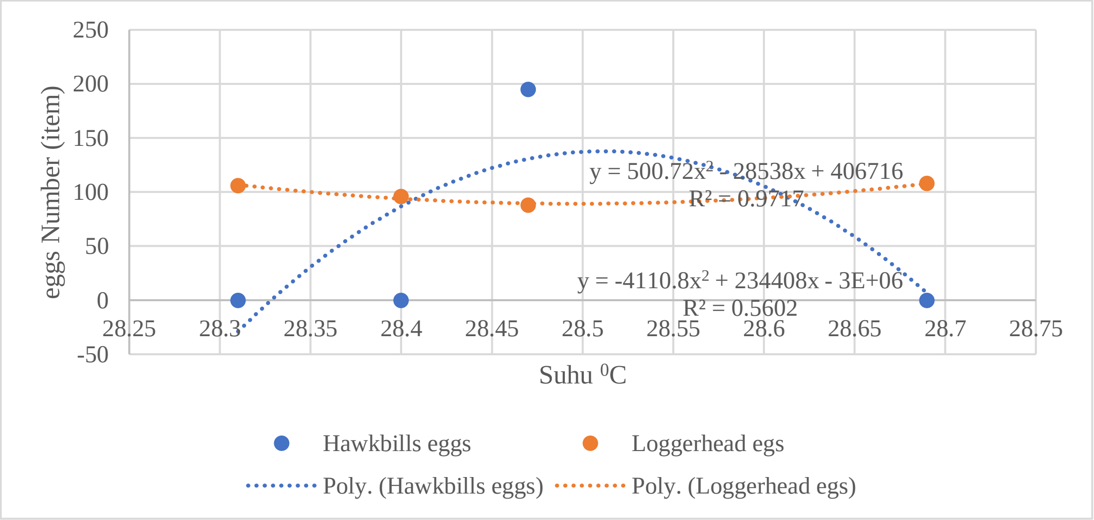

Figure 6: Effect of Temperature on the Number of Turtle Eggs

The rise in temperature has a reduced impact on the decline of Hawksbill turtle eggs, but a non-significant trend suggests that elevated temperatures may be associated with an increase in the reproductive output of Loggerhead turtles. The effect of elevated temperatures was markedly more pronounced in Loggerhead turtles ($r^2 = 0.9747$) than in Hawksbill turtles ($r^2 = 0.5602$). The nesting habit of the Hawksbill turtle is influenced by several primary factors, but the Loggerhead turtle's laying of eggs, comprising 97.47% of its reproductive yield, is predominantly determined by temperature. Kasmeri et al. (2022) contend that an increase in temperature does not directly affect the egg production of Hawksbill and Loggerhead turtles.

Figure 7 demonstrates that the depth of the hole substantially affects the egg count, comprising around 88.07%, but the diameter has a minimal impact, contributing at about 18.15% to the egg number. The depth of the hole construction will affect the egg-laying behavior of turtles. The depth of the hole will affect the temperature and humidity of the nesting location, thereby establishing stable and suitable conditions for turtles to lay their eggs (Rigo et al., 2024). The diameter of the hole is dictated by the characteristics of each turtle, namely the measurements of the carapace and plastron.

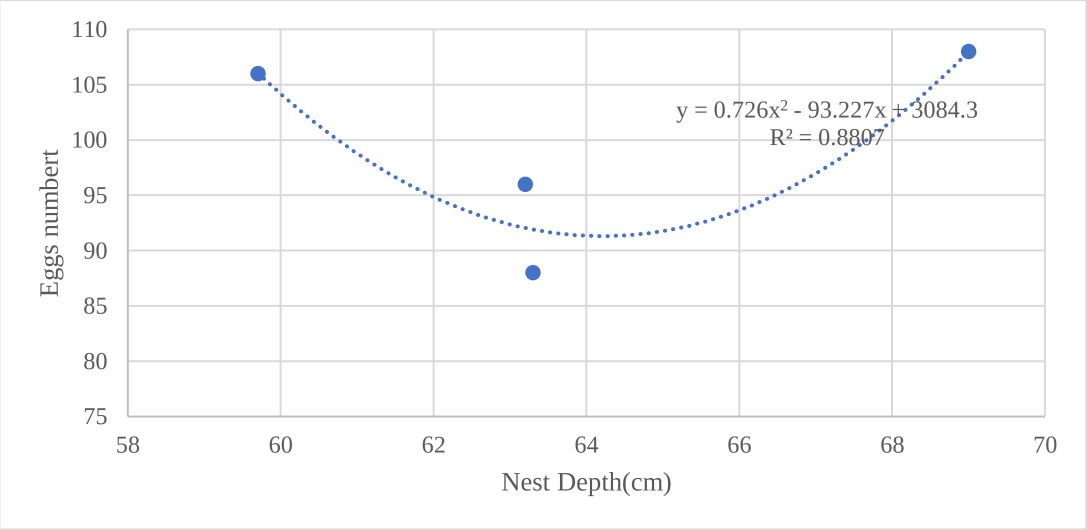

Figure 7a. Effect of Nest Depth on the Number of Turtle Eggs

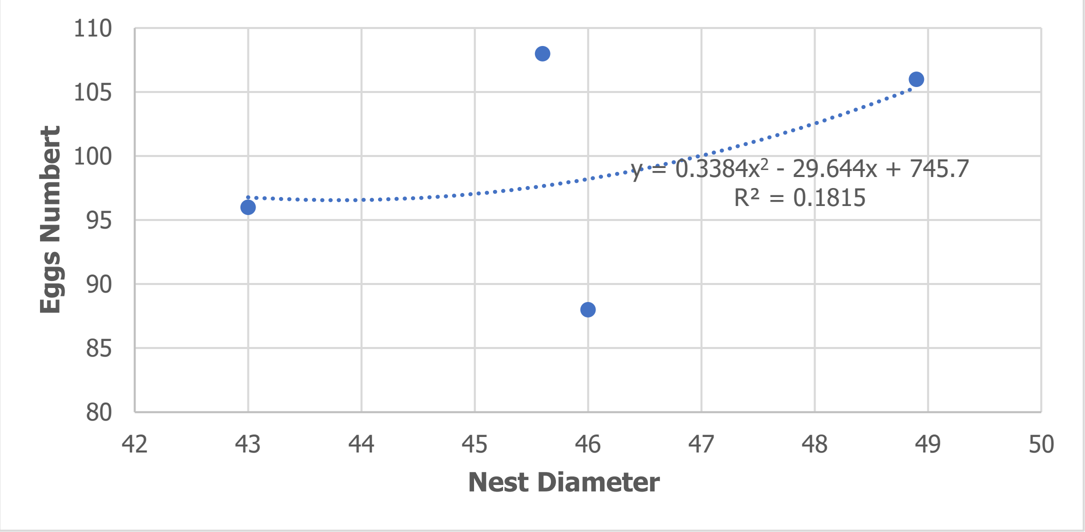

Figure 7b. Effect of Nest Diameter on the Number of Turtle Eggs

Preserving the physical conditions of the nesting area in accordance with the needs of sea turtles is essential for preserving their number and ensuring successful egg-laying. This includes efforts to ensure that the depth and diameter of nesting holes adhere to research-based standards.

CONCLUSION

The findings demonstrated the preference of Hawksbill turtles (Eretmochelys imbricata) for laying their eggs in areas surrounded by denser and more varied vegetation. Compared to other locations, loggerhead sea turtles (Caretta caretta) lay comparatively less eggs in areas with a high density and quantity of vegetation. In places where there was no vegetation nearby, some eggs were discovered.

Relatively shallow hole depths and comparatively broader diameters were the results of loggerhead nesting activity in unvegetated locations. The farther from the edge of the vegetation, the lower the temperature is on the sand surface, which impacts egg laying activity in regions with a lot of plant and diversity.

For both Hawksbill and Loggerhead turtle species, the impact of temperature on turtle activity and egg counts was comparatively minor and variable. In contrast to Hawksbill turtles, who are less affected by temperature increases, Loggerhead turtles are more likely to lay more eggs when temperatures rise, however this effect is not statistically significant.

AUTHOR CONTRIBUTIONS

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.

Author 2: Conceptualization; Data curation; Writing.

Author 3: Data curation; Investigation.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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