BIOPHYSICAL CHARACTERISTICS OF THE NESTING SITE OF LEATHERBACK TURTLES (*DERMOCHELYS CORIACEA*) AND OLIVE RIDLEY TURTLES (*LEPIDOCHELYS OLIVACEA*) ON LHOKNGA BEACH OF ACEH BESAR

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Abstract: Leatherback turtle (*Dermochelys coriaceae*) and olive ridley turtle (*Lepidochelys olivaceae*) are endangered turtle species that continue to experience population decline due to various factors, one of which is the degradation of nesting habitats. A coastal area is commonly used by turtles as a nesting ground as it is associated with the characteristics of the bio-physical environment required for the successful hatching of their eggs. The present study aims to explore turtle nesting habitats related to the bio-physical features of Lhoknga Beach in Aceh Besar. An exploratory survey method was employed. A descriptive data analysis was conducted on the number of eggs and environmental parameters. Around the coastal area, the sand temperature ranges from 28.25 to 28.76ºC, the sand humidity ranges from 44% to 52%, the beach width is 15.35 to 27.49 m, the beach slope is 1.68º–4.41º (categorized as gently sloping), and medium-sized sand sediments dominate the beach. Based on the number of turtle nests and eggs, the findings reveal 14 nests and 878 eggs of the leatherback and 5 nests and 533 eggs of the olive ridley turtle. The whole turtles' nesting habitats and activities discovered on Lhoknga Beach are supported by the favourable biophysical conditions of the coast. A total of 8 species of coastal vegetation and 4 predators are located in the area. Based on the characteristics of the coast, it can be concluded that Lhoknga Beach has suitable coastal features for turtle habitats and can potentially be utilized as a conservation area in Aceh Besar Regency.

Keywords: Sea Turtle; Sea Turtle Nesting Habitat; Lhoknga Beach

Abstrak: Penyu belimbing (*Dermochelys coriaceae*) dan penyu lekang (*Lepidochelys olivaceae*) merupakan jenis penyu yang terancam punah terus mengalami penurunan populasi yang disebabkan oleh berbagai faktor diantaranya yaitu degradasi habitat peneluran. Kawasan pesisir pantai dimanfaatkan penyu sebagai tempat peneluran (*nesting ground*) yang berkaitan dengan karakteristik lingkungan bio-fisik pantai berperan penting dalam keberhasilan penetasan telur penyu. Tujuan dari penelitian ini adalah untuk mengetahui kajian habitat peneluran penyu terkait dengan karakteristik bio-fisik pantai di kawasan Pantai Lhoknga Kabupaten Aceh Besar. Penelitian ini dilakukan dengan metode *survey exploratif* dan analisis data dilakukan secara deskriptif terhadap jumlah telur dan parameter lingkungan. Kondisi suhu pasir pantai berkisar antara 28,25–28,76ºC, kelembapan pasir 44%–52%, lebar pantai 15,35 m–27,49 m, kemiringan pantai

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1,68º–4,41º (berkategori landai) dan didominasi sedimen pasir dengan ukuran sedang. Berdasarkan jumlah sarang dan telur penyu, ditemukan sebanyak 14 sarang dengan 878 telur pada penyu belimbing dan 5 sarang dengan 533 telur pada penyu lekang. Aktivitas peneluran tersebut didukung dengan kondisi karakteristik biofisik pantai yang dimiliki Pantai Loknga mendukung sebagai habitat peneluran penyu. Vegetasi pantai yang ditemukan terdapat 8 spesies dan predator rantai makanan 4 spesies. Berdasarkan karakteristik pantai yang ditemukan dapat disimpulkan bahwa kawasan Pantai Lhoknga memiliki karakteristik pantai yang sesuai sebagai habitat peneluran penyu dan berpotensi untuk dijadikan sebagai kawasan konservasi penyu di Kabupaten Aceh Besar.
Kata kunci: Penyu; Habitat Peneluran Penyu; Pantai Lhoknga

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Introduction

Turtles are a type of marine reptile that inhabits tropical and subtropical areas. Their population, however, has been declining over the years. Based on the Convention on International Trade in Endangered Species (CITES), the appendix criteria of turtles are categorised into appendix I. They are on the red list of the International Union for The Conservation of Nature (IUCN), meaning that their existence around the globe is so endangered that all forms of use and distribution of turtles require serious attention (CITES, 2019; IUCN, 2019).

The leatherback (Dermochelys coriacea) and olive ridley (*Lepidochelys olivacea*) possess features that differentiate them from the other types of turtles. Leatherback turtles are characterized by their star-fruit-shaped carapaces consisting of seven white lines, as well as their body size as the largest of all turtles. Olive ridley turtles can be specifically identified as having the highest number of carapace scales.

Both types are spread in Indonesian waters along with the others, including green turtles (Chelonia mydas), hawksbill turtles (Eretmochelys imbracata), loggerhead turtles (Caretta caretta), and flatback turtles (*Natator depressus*) (Mulyana & Dermawan, 2008). The turtle population in Indonesia continues to decline, so the government decided to undertake conservation efforts, including establishing nesting habitats and feeding grounds for the turtles and their offspring as protected aquatic biota (Mangunjaya et al., 2017).

Turtles live in two different habitats, i.e. land and sea. Their typical habitat on land covers coastal areas, particularly used as nesting ground, while the ocean is the main environment for their entire lifetime (Buhang et al., 2016). The territories on land selected by turtles for nesting purposes must be associated with certain characteristics owned by the coastal biophysical environment.

Favourable beach conditions that are suitable and safe for turtle nesting processes affect the increase in turtle populations worldwide. Meanwhile, the low percentage of turtles successfully hatching and reaching open waters is potentially caused by several factors, including failure to hatch and threats from predators such as crabs, ants, birds, and other reptiles (Ario et al., 2016). Other factors have also been responsible for the degradation of nesting habitat, i.e. natural disasters and various human activities.

Not all Indonesian shores are picked by turtles as their nesting grounds; only those with suitable coastal biophysical characteristics are. According to Setyawatiningsih et al. (2011), beach conditions preferred by sea turtles for this purpose include a sloping area, clean sand, a minimum of 30 m long and 10 m wide, and a substrate temperature of 29–31^{o}C. Moreover, turtles favor nest substrates with a texture dominated by coarse sand measuring 1.67–1.73 mm and nest humidity in the range of 36.96–48.26%. These conditions are currently found on a large number of turtle-nesting beaches throughout Indonesia, one of which is located in the coastal area of Aceh Province.

One of the natural nesting sites for the leatherback and olive ridley in Aceh Besar Regency is Lhoknga Beach (Hindar et al., 2018). The turtle nesting activities have been going on for a long time but were stopped for a while since December 2004 due to the tsunami, a natural disaster that hugely damaged the coastal area. Several disadvantages have emerged ever since, including the beach becoming narrower or having more contact with tidal activities (the ebb and flow of sea water); frequent coastal erosion; constantly changing beach slopes; little coastal vegetation; and a large amount of sand mixed with waste such as metal, rubbish, and rock fractions (Novita Siregar et al., 2016).

The nesting activities started again from 2006 to date. The Lhoknga coastal area has the potential for natural turtle nests due to its favourable conditions, indicated by a lot of nesting and egg-laying activities every season. One effort to save turtles from extinction is to determine and protect their nesting habitats so that the turtle population remains maintained. Based on the description above, a study on the turtle nesting habitat associated with the coastal biophysical characteristics must be conducted, hopefully resulting in providing sufficient information regarding the attempts to conserve the habitats of leatherback and olive ridley turtles.

Methodology

Study Site

The study was conducted at coordinates (N 05°27’29.29” E 095^{o}14’38.30”), the Lhoknga Beach area, Mon Ikeun Village, Lhoknga District, Aceh Besar Regency, Aceh Province (Figure 1). It is known as a coastal tourist attraction area and is located outside the beach area for regular observation or conservation of turtle populations.

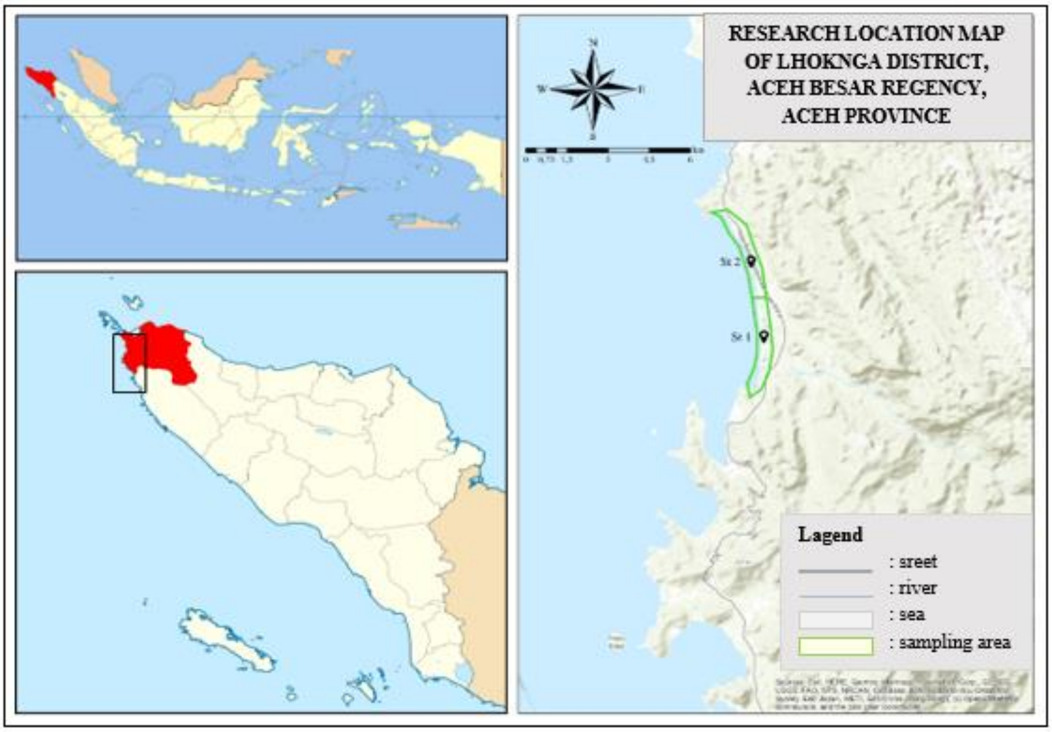

Figure 1. Lhoknga Beach Area

Materials and Tools

Several tools were utilized in the study, i.e. a GPS (Garmin 62s) to set the location coordinates, a rolling meter (Magnum 50 m) to measure the research area, wooden pegs to mark the research area boundary, plastic ropes (Sea Gull Q-rope 8 mm) to measure the beach slope, a waterpass (D-Xplore 18 inch) to find out the coastal surface slope, a scaling stick (2 m long) to measure the height of the beach slope, a digital thermometer (Hanna Hi8424) to investigate the temperature of the sand, a soil tester (Takemura) to measure sand humidity and pH, mini shovels (Mizu sukoppu) to scoop the sand, shieve shaker (Mesh 4.750 mm–0.075 mm) to determine the diameter of the sand, a camera (Fujifilm X-A3) to take pictures as documentation, a garden scissor (Prohex) to identify the sample, flashlights (Dony KL 158) to help with night vision, batteries (ABC alkaline) to power the flashlights, and stationery (Faber Castell) to record the data. Several materials were employed, including plastic bags to store the sand and label papers to mark the sample.

Data Collection

The study was conducted during the turtle nesting season, i.e. between December 2020 and February 2021, using the exploratory survey method, which means eliciting data by recording information related to specific events at a limited time and place and population to provide an overview of the local situation and conditions (Hadi, 1986). The stations of the research location were determined based on the differences in environmental baseline (purposive sampling). Station 1 was assigned to the location with a lot of community activity, close access to the main road, and little vegetation. Station 2 covers the location with no community activities, distant access to the main road, and a lot of vegetation. Each station was equipped with 10 transects that were perpendicular to the shoreline, 20 m x 10 m long (depending on the highest tides), and 100 m apart from each other (Setyawatiningsih et al., 2011).

Determining the transect location at each station was based on both the turtle nesting area of the previous year and random appointment (purposive random sampling). On each transect, 3 plots were placed, determined by the distance between the highest tide and the outermost coastal vegetation (plot 1 = 0–5 m; plot 2 = 5–10 m; and plot 3 = 10–15 m). Biophysical measurements were conducted in each plot, including the number of turtle nests, predatory animals, vegetation, and sand conditions (temperature, humidity, and structure), every morning, afternoon, and evening at a depth of 30 cm (condition inside the nests) (Satriadi A., et al., 2003). Also, sand sedimentation and coastal width and slope were measured. The width and slope of the beach were investigated by observing the distance between the highest sea tide and the outermost coastal vegetation (Dermawan et al., 2009). The sand sedimentation was measured by applying the stratified filtering method, using a sieve shaker, guided by the diagram introduced by Folk & Ward (1957).

Parameters

The parameters in this study encompass several biophysical characteristics of the turtle nesting beach. They consist of biological factors including the amount of nests, vegetation, and predatory animals; and physical factors including the sand humidity, sand temperature, sand structure, beach width, and beach slope. Sampling points for all of the parameters were determined using the exploratory survey method on the plots of each transect (a total of 20 transects and 60 plots). The observations were conducted in the morning, afternoon and evening.

Measuring the sand, including its condition (temperature and humidity) and structure, was undertaken at a depth of 30 cm from the surface of the beach (nests' natural state). The sand condition was measured using a digital thermometer (temperature measurement) and soil tester (humidity measurement). Meanwhile, the sand structure was examined for its diameter using the sand sieving method, with a tool named sieve shaker Mesh (4.750 mm–0.075 mm).

Moreover, the width and slope of the beach were measured on each transect by involving the distance between the highest tide and the outermost coastal vegetation. A scaling stick was set vertically at the points representing the highest tide, from which the roll meter was pulled to the outermost vegetation at a 90^{o} angle, and a waterpass was utilized to maintain the straightness of the meter (Putra et al., 2014). To calculate the beach slope, the following formula was employed:

$$\tan\alpha = \frac{a}{b} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

$$\alpha = \text{Arc } \tan\frac{a}{b} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

in which:

α = beach slope angle (º);

a = beach height (m), measured with a 2-meter scaling stick; and

b = total flat distance of the beach (m), measured with a roll meter.

Data Analysis

The collected data were analysed descriptively. The approach was employed as the present analyses were aimed at constructing a description of the situation and events systematically by elaborating the results of calculations both in the field and in the laboratory.

Findings and Discussion

The amount of turtle nests found in the beach nesting area

The turtle nesting activities taking place on Lhoknga Beach are the ones that occur naturally, excluded from the turtle conservation area. The total number of turtle nests found on Lhoknga Beach is described in Table 1.

Table 1. Number of turtle nests in the Lhoknga Beach area

Type of Turtle	Station	Nest	Number of eggs	Distance (m)	Type of Turtle	Station	Nest	Number of eggs	Distance (m)
Leather back	I	S1T6P3	75	16.40	Olive Ridley	I	S1T3P3	95	50.40
		S1T7P3	45	28.80			S1T3P3	123	55.40
		S1T8P3	80	18.46			S1T3P3	121	67.80
		S1T10P3	65	27.52					
	II	S2T2P3	65	16.56		II	S2T4P3	82	68.80
		S2T2P3	53	18.10			S2T10P3	112	71.40
		S2T2P3	72	17.20					
		S2T3P3	68	12.34					
		S2T4P3	52	14.21					
		S2T4P3	48	12.84					
		S2T5P3	42	22.54					
		S2T5P3	72	20.87					
		S2T5P3	65	21.30					
		S2T5P3	76	22.10					
Total		14 nests	878				5 nests	533	
Average number of eggs			63 eggs					107 eggs	
Range of eggs in a nest			42–80 eggs					82–123 eggs	
Average nest distance (m)				19.23					17.29

Note: S = Station; T = Point; and P = Plot

The turtle nesting activities on Lhoknga Beach happen naturally without any handling or assistance from external factors. Observations conducted over the past 4 months, particularly 8 hours after sunset, reveal that there are 19 turtle nests with a total of 1,411 eggs. Classified according to the types, the leatherback turtles

(*Dermochelis coriacea*) site 14 nests and lay 878 eggs; while the olive ridley (*Lepidochelys olivacea*) occupy 5 nests with 533 eggs (Figure 2 and Table 1). The entire observation period was carried out during the turtle nesting season so that no turtle chicks or hatchlings were found in the nests.

The number of eggs found in leatherback turtle nests on Lhoknga Beach ranges from 42 to 80, with an average of 63 eggs; while the olive ridley 82–123, with an average of 107 eggs. This indicates that the nesting activities in this area are considered normal, referring to the average number of eggs per nest being set at 81.5 ± 3.6 for leatherback and 109.9 ± 1.8 for olive ridley turtles (Dermawan et al., 2009).

In the nesting area on Jamursba Medi Beach, West Papua, leatherback turtles lay between 26 and 161 eggs per nest, with an average number of 75 eggs (Trianto, 2008). The number of olive ridley eggs in the nesting area at Taman Kili-Kili Beach, East Java, is 69-305 per nest, with an average of 143 eggs. (Darmawan et al., 2020). The number of eggs in a nest influences the total number of eggs laid by a type of turtle. This is because turtles can lay eggs 1–7 times in a single nesting cycle (Adnyana et al., 2009).

The number of nests and eggs discovered is based on the direct observations and findings conducted on the entire turtle nesting activities. However, the limitations of tagging equipment for turtles result in that few turtles' activities cannot be precisely tracked and, therefore, affect the overall data on the turtle eggs and nests on Lhoknga Beach.

The distances of nests from each other at one station are found to be distinctive from the others. This is due to the differences in the measure of the highest tide at each station, depending on the turtle morphology and coastal slope. The nests located too close to the highest tide have a high potential for the sand inside the nest to be submerged over time which can cause the eggs to rot. The findings show that the average distance from the leatherback turtle nests to the highest tide point is 19.23 m, and that of olive ridley turtle nests is 17.29 m. It can be seen that there is a difference in the average distance from the nests to the highest tide for each turtle type. The farthest distance is detected in the leatherback because their bodies and limbs are larger than those of the olive ridley. Nevertheless, turtle body size is not a factor influencing the number of eggs produced (Ibrahim et al., 2016).

The turtle nesting activities on Lhoknga Beach are dominated by the leatherback instead of olive ridley. Observation records, however, mention that the last time leatherback turtles nested on Lhoknga Beach was in 2017 and only returned in 2020-2021, while olive ridley can be noticed almost every nesting season. The leatherback turtles' less frequent nesting activities compared to the olive ridley in this coastal area are influenced by their status, i.e. more threatened than olive ridley turtles. The more threatened a turtle species is, the smaller its population and the harder it is to find. This is mentioned in the list issued by the

IUCN that leatherback turtles are already included as the endangered status, while olive ridley are categorized as vulnerable (IUCN, 2019).

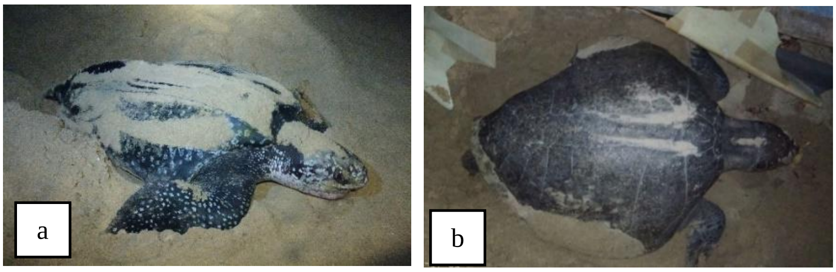

Figure 2. Turtle nesting activities on Lhoknga Beach: a) leatherback and b) olive ridley

Characteristics of the turtle nesting beach

Biological conditions of the turtle nesting beach

A total of 8 plant species are found on Lhoknga Beach, consisting of 8 different families. The species include Australian pines (*Casuarina equisetifolia*), *Lannea nigritana*, coast cottonwoods (*Hibiscus tiliaceus*), beach cabbage (*Scaevola taccada*), screw pines (*Pandanus tectorius*), *Ischaemum muticum*, green carpetweed (*Mollugo verticillate*), and bayhops (*Ipomoea pes-caprae*). Of all the species discovered at each observation point of turtle nests, Australian pines and bay hops dominate the area. Also, screwpines (*Pandanus tectorius*) are located there, having the typical characteristic of coastal vegetation as well as a distinctive attraction for turtles. Bustard (1972) in Nuitja (1992) suggest that *Pandanus tectorius* affects turtles' instinct to lay eggs.

Several turtle nests are seen in the vegetation covers as their roots can bind sand grains and prevent sand collapse. This can make it easier for turtles to carry out the excavation and egg-laying processes. Additionally, both temperature and humidity around the vegetation are relatively stable, with indirect sunlight hitting the sand surface, making it favourable for turtle eggs during the incubation period. According to Nugroho (2016), the presence of vegetation affects the length of the incubation period of turtle eggs in terms of the required average incubation time in open fields is shorter than in areas covered by plants. Meanwhile, some nests are found in open areas as well, without shade from any vegetation. This is because not every turtle species prefers vegetated areas, including olive ridley turtles which prefer open land to build their nests (Satriadi et al., 2003).

Turtle eggs in natural nests can fail to hatch, commonly caused by various aspects, one of which is the threat from predators. The predatory animals include crabs, ants, birds, and a few types of reptiles (Ario et al., 2016). The findings reveal 4 predatory species inhabiting Lhoknga Beach, i.e. crabs (*Ocypoda* sp), red ants (*Oecophylla smaragdina*), monitor lizards (*Varanus salfator*), and dogs (*Canis familaris*). Crabs (*Ocypoda* sp) are considered the most likely predators of turtles, indicated by their high occurrence rate at each observation point of the turtle nests at every station. This is in line with Márquez-M (2004) suggesting that the damage caused by crabs is by creating holes in turtle nests, leading to an increase in the incubation period and consequently damage to the eggs (egg spoilage).

Moreover, monitor lizards, red ants, and dogs are potential predators of turtle eggs and hatchlings (Márquez-M, 2004). Similarly, Manurung et al. (2015) state that natural threats to turtle life come from the food chain cycles in the ecosystem, including monitor lizards that have been recorded to commonly prey on turtle eggs as well as crabs on turtle chicks. The imbalance in the number of predators and turtle eggs that are only laid during the season (once a year) adds to the reasons for the declining number of turtle eggs on Lhoknga Beach. The threats to turtle eggs and hatchlings are to be faced not only at the nesting phase on shore, but also when the hatchlings reach the ocean for the next stage of life and during the growth period as they can be infected with various diseases (Chapman et al., 2017), contaminated by marine pollution (Setywatiningsih et al., 2011), and entangled in tuna longline bycatch (Nugraha et al., 2017).

In addition to predators around the beach, excessive activities carried out by humans, especially in coastal communities, ultimately hurt coastal ecosystems. The biggest threat remains human actions and behaviour (Verissimo et al., 2019). One of the factors contributing to the threat of extinction of sea turtles is their eggs' failure to hatch. This can be caused by human actions and behaviour (Phillott & Parmenter, 2001 in Nursanty et al., 2019). The observations conducted during the nesting season show that human hunting activities can be noticed at all observation points of turtle nests. Although the hunters only track the eggs, this action still greatly disrupts the overall nesting and egg-laying process in each nesting area on Lhoknga Beach.

Physical conditions of the turtle nesting beach

Turtle nesting is influenced by certain conditions and characteristics of the coast. Lhoknga Beach, in particular, measures ± 2 km long and ± 18 m wide. Featured with white sand and a scenic landscape, the coastal area has become one of the tourist attractions in Aceh Besar Regency. The physical characteristics of the turtle nesting area on Lhoknga Beach can be seen in Table 2.

Table 2. The average parameter for measuring the physical characteristics of Lhoknga Beach as the turtle nesting area

Parameter	Time (GMT +7)	Lhoknga				Tolerance limit
		Station 1 (x) ± SD		Station 2 (x) ± SD		
Sand Temperature (°C)	06:00	28.25	0.45	28.44	0.37	24–33 °C
	14:00	28.69	0.59	28.38	0.92	
	22:00	28.76	0.57	28.61	0.54	
Sand Humidity (%)	06:00	47%	0.12	47%	0.08	40–60 %
	14:00	44%	0.09	46%	0.07	

Parameter	**Time (GMT +7)**	**Lhoknga**				Tolerance limit
		Station 1 (x) ± SD		**Station 2 (x) ± SD**		
	22:00	52%	0.09	51%	0.06	
Beach Width (m)	06:00	22.96	7.05	15.35	4.77	30–80 m
	14:00	27.49	4.02	19.65	2.72	
	22:00	23.32	5.60	16.93	4.92	
Beach Slope (^{o})	06:00	1.79	0.52	3.94	0.88	<30 ^{o}
	14:00	1.68	0.53	3.27	0.59	
	22:00	2.12	0.52	4.41	0.98	
Sand Structure	Size	0.26 mm		0.42 mm		Medium sand (0.25–0.5 mm)
	Type	Slightly Gravelly Sand		Slightly Gravelly Sand		Dominated by sand instead of gravel and mud

The average sand temperature of Lhoknga Beach ranges from 28.25 ± 0.45 to 28.76 ± 0.57. Station 1 has an average temperature of 28.25 ± 0.45 ^{o}C in morning hours, with a temperature range of 27.73–29.07 ^{o}C; 28.69 ± 0.59 ^{o}C in afternoon hours, with a temperature range of 27.73–30.05 ^{o}C; and 28.76 ± 6.03 ^{o}C in evening hours, with a temperature range of 27.37–29.68 ^{o}C. Meanwhile, at station 2 the average temperature is 28.44 ± 0.37 ^{o}C in morning hours, with a temperature range of 27.64–29.17 ^{o}C; 28.38 ± 0.92 ^{o}C in afternoon hours, with a temperature range of 25.36–29.31 ^{o}C; and 28.61 ± 0.54 ^{o}C in evening hours, with a temperature range of 27.53–29.64 ^{o}C (see Table 2).

The sand temperature of Lhoknga Beach is regarded as within the tolerance limit for the turtles to nest and lay eggs. According to Yusuf (2000), the required temperature for proper turtle embryo growth is 24–33°C. Based on the observations, the sand temperature in this area does not exhibit a significant change, regardless of the changing period (from morning to afternoon to evening). This is because the sand temperature measurement is carried out on the inside of the nest (at a depth of 30 cm) to obtain a temperature resembling that of natural turtle nests. As mentioned by Oktavi et al., (2019), sand temperature measurements at a depth of 30–50 cm indicate an optimal and relatively stable temperature for turtle egg incubation.

Meanwhile, the sand on the surface experiences temperature fluctuations due to the direct influence of intense sunlight as well as other environmental factors such as climate change, rainfall, and wind, so the surface easily loses the ability to store temperature compared to the sand inside the turtle nests. This is in line with Nybakken (1992) mentioning that the surface of beach sand that is exposed to direct sunlight experiences big temperature changes. The turtle nests at a depth of 15 cm and below experience temperature fluctuations; and the deeper it goes, the lower the temperature (Susilowati, 2002).

Sand temperature affects the turtle egg incubation process and determines the sex of the hatchlings. Thus, the hatchlings on Lhoknga Beach must be dominated by males. This refers to research by Khaisu (2013) and Crews et al., (2001) in Hindar et al., (2018), suggesting that if a turtle's eggs incubate >30°C, the hatchlings will potentially be female; and if the eggs incubate <30°C, the hatchlings will potentially be male.

The average sand humidity of Lhoknga Beach ranges between 44% ± 0.09 and 52% ± 0.09. At station 1 the average humidity is 47% ± 0.12 in morning hours, with a humidity range of 22–63%; 44% ± 0.09 in afternoon hours, with a humidity range of 23–55%; and 52% ± 0.09 in evening hours, with a humidity range of 30–65%. Meanwhile, at station 2 the average humidity is 47% ± 0.08 in morning hours, with a humidity range of 34–63%; 46% ± 0.07 in afternoon hours, with a humidity range of 34–60%; and 51% ± 0.06 in evening hours, with a humidity range of 40–59% (see Table 2).

The sand humidity of Lhoknga Beach demonstrates a daily change as each day goes by. The highest sand humidity at stations 1 and 2 is found to happen in the evening, i.e. 52% and 51%, respectively; and the lowest humidity occurs in the afternoon, i.e. 44% and 46%.

This change in sand humidity is still considered within the tolerance limit for turtle nesting activities, which is 40–60% (Ackerman, 1997). It is certainly influenced by several environmental factors, including the air circulation around the nests, both outside and inside the nest (Nybakken, 1992); intensity of sunlight that can induce evaporation; selection of nest position for laying eggs associated with tidal activities; and type of sand (Setyawatiningsih et al., 2011). If the beach sand is dominated by small and fine grains, it is relatively denser and, therefore, more effective at preventing seawater from seeping and entering turtle nests; on the contrary, coarse-grained sand makes it easier for seawater to reach the inside of the nests. The coarse texture of the sand is more draining than holding water as it has larger pores (Nybakken, 1992; Satriadi, 2003 in Setiawan et al., 2018).

Accurate humidity in turtles' nests strongly contributes to the normal development of their fetus. It is needed for fetal development as well as biochemical reactions that take place in the eggs. Bustard (1972) in Nyoman et al., (2018) state that if the humidity inside the nest is too low or reaches very dry conditions, this can cause fluid to leak from the eggs, making it difficult for hatchlings to come out of their shells; or worse, they may run out of energy to open their shells. Eventually, the hatchlings will die before even leaving their nests (death-in-nest condition). However, too high humidity inside and around the nest increases the growth of fungi and bacteria that will potentially cover the pores of the eggshell. The blockage interferes with the egg respiration process and, therefore, prevents the embryos from growing properly and can even result in death (Solomon dan Baird, 1980 in

Rudiana et al., 2004). This surely affects the hatchability of turtle eggs on Lhoknga Beach.

Beach width is another factor influencing turtles' decision to build their nests. The wider a beach is, the more turtles feel safe to undertake nesting activities on the coast. The average width of Lhoknga Beach ranges from 15.35 ± 4.77 m to 27.49 ± 4.02 m. Station 1 has an average beach width of 22.96 ± 7.05 m in morning hours, with a wide range of 13.74–38.20 m; 27.49 ± 4.02 m in afternoon hours, with a wide range of 24.78–36.42 m; and 23.32 ± 5.60 m in evening hours, with a wide range of 14.01–31.38 m. Meanwhile, at station 2, the average beach width is 15.35 ± 4.77 m in morning hours, with a wide range of 9.09–25.40 m; 19.65 ± 2.72 m in afternoon hours, with a wide range of 13.99–24.36 m; and 16.93 ± 4.92 m in evening hours, with a wide range of 9.89–26.71 m.

On Lhoknga Beach, the highest average width occurs during the afternoon and keeps lowering through the evening and morning. The difference in beach width is caused by several factors, one of which is tidal activities. When the tide is low, the width of the beach gets higher; conversely, when the tide is high, the beach width gets lower. The measurement of coastal width was executed from the outermost vegetation boundary to the highest tide point.

The tidal activities on Lhoknga Beach demonstrate a semi-diurnal tidal type, meaning that the tide cycle includes two high tides and two low tides in 24 hours. This proves that the beach area is at the low tide period during the afternoon so the highest beach width can be seen during that time.

How wide a coastal area is can greatly affect turtles' accessibility towards it and their consideration for making nests. The areas regarded as suitable for turtles building nests are those with dry conditions and not affected by tides, which represent supratidal coasts (Arifianti, 2011). If a shore is frequently exposed to sea waves, its sand will increasingly experience temperature and humidity dynamics which have a disadvantageous impact on the egg incubation process. (Darmawan et al., 2020).

The ideal width of a beach for turtles' nesting habitat is 30–80 m (Nuitja, 1992). The observations show that the average width of Lhoknga Beach is less than 30 m, which means it is not ideal for turtle nesting activities. However, although the beach is excluded from the ideal category, the nesting activities are still going on there. This is by López Castro et al. (2004) in Alli et al. (2017), suggesting that olive ridley turtles lay their eggs on beaches 20–30 m wide measured from the coastline when the tide is low.

The chance of the nests being submerged by sea water will be reduced if they are not exposed to tidal waves and not too close to the body of water. The potential for turtle nests to be submerged by seawater will be reduced if the nests are not exposed to tidal waves and not too close to the seawater bodies. This is evidenced by the observations conducted, indicating that a majority of turtle nests are located in plot 3 (≥15 meters away from the highest tide). If the nests are too close to the highest tide, they will most likely be exposed to the waves or seawater and eventually the sand around the nest will be submerged and, therefore, lead to egg spoilage inside the nest. This is in line with Benni et al. (2017) who mention that turtles will choose the safest place to store their eggs to avoid the highest tides.

The slope of Lhoknga Beach has an average of 1.68 ± 0.53^{o}–4.41 ± 0.98^{o}. At station 1, the average slope is 1.79 ± 0.52^{o} in the morning, with a slope range of 1.11–2.76^{o}; 1.68 ± 0.53^{o} in the afternoon, with a slope range of 0.69–2.34^{o}; and 2.12 $\pm$ 0.52^{o} in the evening, with a slope range of 1.32–2.94^{o}. Meanwhile, at station 2, the average slope is 3.94 ± 0.88^{o} in the morning, with a slope range of 3.06–6.33^{o}; 3.27 ± 0.59^{o} in the afternoon, with a slope range of 2.50–4.68^{o}; and 4.41 ± 0.98^{o} in the evening, with a slope range of 3.08–6.81^{o} (See Table 2).

Lhoknga Beach is classified as a sloping beach, referring to the coastal slope criteria described as follows. The slope of 0–2% (0–1.14^{o}) is categorized as flat; the slope of 2–7% (1^{o}–5^{o}) as mild slope; 7–15% (5^{o}–9^{o}) wavy; 15–25% (9^{o}–14^{o}) steep; 25–45% (14^{o}–24^{o}) very steep; and the slope of >45% is categorized as precipitous (Putra et al., 2014). Accordingly, the slope of Lhoknga Beach is still within the optimum limit for the turtle nesting process, i.e. <30^{o}. To lay their eggs, turtles instinctively tend to choose shores with mild slope, adequate width, and position on the upper coast with a slope of 30^{o} (Nuitja, 1992).

Coastal slope constitutes a factor that highly influences turtles' ability to access the proper sites for laying eggs. The steeper the coast, the more energy it takes for them to climb up and lay their eggs. Besides, a steep beach causes turtles' vision of distant objects in the front to be obstructed (Dharmadi & Wiadnyana, 2017). This is due to turtles' eye morphology which only accommodates a vision at an angle of 150° or less (Putra et al., 2014).

Sand is the main constituent of the texture of turtle nests. It must consist of grains of the appropriate size for nest construction to facilitate air diffusion so that the eggs can grow well (Miller, 1997; Lutz, 1997 in Nugroho et al., 2016). Based on the analyses conducted on the sand structure of the turtle nesting area on Lhoknga Beach, it is found that the average sand sediment encompasses 0.93% gravel, 97.32% sand, and 1.75% mud at station 1; and 1.81% gravel, 96.87% sand, and 1.32% mud at station 2.

Both stations represent a coastal area that is mostly composed of sand, while gravel and mud are the minority components. Therefore, the structural sand sediment at each station is categorized as the slightly gravelly sand type. The sand, clay, and dust affect the temperature of the nest. If a nest consists of a small amount of sand and a large amount of dust and clay, this may cause eggs to decay in the nest (Nuitja, 1983). Conversely, a large amount of sand prevents the nest from puddles that might form around it; instead, the water coming towards it will easily sip through the large amount of beach sand, without being held back, and this can keep the temperature warm for the nest, which is beneficial for embryonic development.

The results of the sand structure analysis revealed that the average sand size is in the medium category, i.e. 0.26 mm and 0.42 mm at Station 1 and Station 2 respectively. This refers to the grain size category of sand sediments as follows. Gravel is 2 mm, very coarse sand is 1 mm, coarse sand 0.5 mm, medium sand 0.25 mm, fine sand 0.125 mm, very fine sand 0.063 mm, and silt is 0.038 mm (Setiawan et al., 2013). The sand structure discovered on Lhoknga Beach is considered good for the turtle nesting process since it is dominated by the sand itself rather than gravel and mud. This is by Zakyah (2016), states that the highest hatching success is obtained from the sand treatment with medium-sized grains (0.25-0.5 mm), i.e. 100%; while the second best success is treated with fine sand (<0.25 mm), i.e. 99%; and the lowest success is from the sand treatment with coarse grains (>0.5 mm), i.e. namely 97.30%.

Furthermore, sand structure influences turtles in determining their nesting habitat. According to Bustard (1972), the sand category suitable for turtle nests is medium (0.21 – 0.50 mm); while fine sand (0.10 – 0.21 mm) is considered fairly suitable. This is because when the sand is too fine, turtles will face difficulties in building their nests as they may easily slide and crumble (Nuitja, 1992). The sand structure is associated with the ease with which turtles dig their nests. If the sand is too fine, the nests will easily slide; while coarse sand can also make it difficult for the mother turtles to dig. In the present research, the sand size of all sites is categorized as medium, making the area suitable for turtle nesting activities. A beach dominated by a large amount of sand prevents the nest from puddles that might be formed around it. Rather, as the water can be easily absorbed by a large amount of sand, this will help to keep the temperature warm for the nest, which is advantageous for embryonic development. On the contrary, coarse sand is less able to retain water than fine sand as it features larger pores.

Conclusion

The turtle nesting area on Lhoknga Beach in Aceh Besar Regency has the potential to be a turtle conservation area, characterized by the coastal biophysical characteristics which support turtle nesting habitat. This includes the sufficient length and width, gentle slope, and presence of several coastal vegetation that supports turtle nesting activities. Furthermore, the beach sand which is medium in size and dominated by sand sediments can optimally provide temperature and humidity for the turtle nesting process.

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