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Beach suitability for nesting Olive ridley sea turtles (Lepidochelys olivacea), Playa Malena, Azuero Peninsula, Panama

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SIT Study Abroad

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Abstract

Sea turtle species all over the world are facing continuous declines in their populations partly due to diminished viable nesting habitat. Understanding sea turtle nesting preferences and the suitability of beaches for reproductive success is necessary in order to sustain their populations and ensure their conservation. Olive ridley sea turtles (*Lepidochelys olivacea*) are one of the species experiencing this trend, especially in the Eastern Pacific. This study examined the beach suitability of a site known as Playa Malena in the Azuero Peninsula in Panama for Olive ridley nesting. This site was compared to the suitability of 7 other surveyed beaches along the same coast with nesting populations of Olive ridley sea turtles. Since the microhabitat of a beach is an important determinant of successful nesting for sea turtles, this study aimed to identify the influence of certain beach characteristics on completed nests with deposited eggs compared to aborted nesting attempts. It was found that Olive ridley females strongly prefer sandy beach sediment over gravel and pebbles to lay their eggs. The physical beach suitability and the level of human impact for each site was assessed using the Sea Turtle Nesting Beach Indicator Tool and compared to identify areas in need of future monitoring and conservation. Suggestions are made about future applications of the Indicator Tool in the face of rapidly degrading nesting habitat worldwide.

Acknowledgements

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Figure 1: Playa Malena during sunset at low tide.

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Introduction

Ecology of Olive Ridley Sea Turtles

Sea turtles species around the world have faced continued threats of extinction with 5 of the 7 species listed in the U.S Endangered Species Act (ESA) as threatened or endangered (Valdivia et al., 2019). One of these species is the Olive ridley sea turtle (*Lepidochelys olivacea*), which has experienced a continuous decline in their population over the years and is currently listed as vulnerable on the IUCN Red List despite being the most abundant sea turtle species (Valverde et al., 2012). Olive ridley sea turtles are most commonly found in the Indian and Pacific oceans, and less commonly, in parts of the South Atlantic (Barrientos-Muñoz and Ramirez-Gallego, 2014). The nesting population of the these turtles has been especially decimated in Mesoamerican countries in comparison to Indian and Western Pacific sites, which highlights a need for monitoring and conservation of females and their hatchlings at nesting sites in countries such as Panama (Valverde et al., 2012).

The *Lepidochelys* genus is characterized by both synchronous mass nesting events known as *arribadas* and solitary nesting activity, with most of the recent research focusing on the ecology and behavior of the turtles within the *arribadas* (Williamson et al., 2019). The *arribada* phenomenon is unique to the Olive ridley and Kemp's ridley sea turtles (*Lepidochelys kempii*) and much is still unknown about the evolution and adaptive significance of this behavior in these specific turtle species (Plotkin, 2007). *Arribada* nesting behavior in Olive ridley sea turtles has been extensively studied in comparison to solitary nesting despite it being far less common (Matos et al., 2012). Hundreds of thousands of turtles aggregate on a few select beaches in the world to synchronously nest together during these few days, whereas solitary nesting occurs on numerous beaches all throughout the nesting season which extends from July to November (Behera et al., 2010; Dornfeld et al., 2015). There are only a few remaining rookeries on the East Pacific where females still participate in *arribadas*, which may indicate that solitary nesting behavior is more important than previously thought in contributing to the revitalization of the population (Dornfeld et al., 2015). This argument is supported by statistics from Eastern Pacific sites that report a range of 74-81% hatching success at solitary beaches compared to range of 0-32% hatching success at *arribada* beaches (Bézy et al., 2014). With diminishing *arribada* nesting, solitary nesters may become the key to sustaining Olive ridley populations in the Eastern Pacific.

Although Olive ridley sea turtles are not considered endangered yet, they still face a multitude of threats that have contributed to a gradual decline in their abundance (Barrientos-Muñoz and Ramirez-Gallego, 2014). Despite this fact, there are little monitoring and conservation efforts directed towards this species (Dornfeld et al., 2015). There are legally operated egg harvests of turtle eggs on beaches such as Ostional Beach in Costa Rica and Isla Cañas in Panama where large-scale *arribadas* occur (Flores et al., 2021; Valverde et al., 2012). In places where only solitary nesting occurs, there is even less information about the status of the population and the hatchling success on these beaches. A study done in El Valle beach in Colombia noted that monitoring of the Olive ridley turtle solitary nesting beaches had only recently begun and there were illegal take of eggs and direct capture of the nesting females

(Barrientos-Muñoz and Ramirez-Gallego, 2014). Conservation of this species must begin before they are critically endangered, so drastic measures do not need to be taken hastily.

Site Description

The Eastern Tropical Pacific (ETP) is a region of reproductive importance for the Olive ridley sea turtles and extends from Mexico to Peru (Rodríguez-Zárate et al., 2018). However, much remains unknown about the nesting distribution, abundance, and preference of the Olive ridley turtles due to inaccessibility of coasts and potential nesting beaches (Flores et al., 2021). There is a lack of data about nesting beaches in Panama in particular, partly because of the deficiency of beach surveys and partly because of limited accessibility to the potential nesting areas (Flores et al., 2021). Recently Flores et al. (2021), conducted a study on previously un-surveyed beaches on the Azuero Peninsula of Panama that used local ecological knowledge to identify sea turtle nesting sites and populations, including the Olive ridley species. The Azuero Peninsula is characterized as a rural, agriculturally dominated, and sparsely populated area of the country with little information about sea turtle abundance and activity (Araúz et al., 2017). The Azuero Peninsula is affected by multiple ocean currents which circulate nutrients and enable certain oceanographic conditions that provide both spatial and temporal habitats for various sea turtle species such as the Olive ridley (Flores et al., 2021; Rodríguez-Zárate et al., 2018). The study site, Playa Malena, is located on the western coast of the Azuero Peninsula, approximately 80km from the island of Coiba, which is an important foraging ground for many species of sea turtles (Llamas et al., 2017). Playa Malena has a long-term ongoing conservation program run by the local community that deals primarily with nesting Olive ridley sea turtles and their hatchlings (Flores et al., 2021).

Olive Ridley Nesting Characteristics

For all sea turtle species, nesting occurs along the coastlines of tropical and some temperate regions (Cousins et al., 2017). A successful nest requires certain physical requirements in order to produce an abundance of hatching. These include a sediment that will maintain the structure of the nest throughout the incubation period, a far enough distance from the tide line so as not to inundate the eggs, and a low salinity, high humidity, perfect temperature, and well-ventilated substrate that allows the eggs to develop properly (Cousins et al., 2017). Olive ridley sea turtles prefer to place their nest on beaches with relatively high humidity levels on tropical mainland shores and they are usually located near river mouths or estuaries (López-Castro et al., 2004). López-Castro et al. (2004) found that Olive ridley nests were typically placed in areas with a superficial humidity of <1% and a superficial temperature close to 32°C, which are both factors that vary depending on the distance from the tide line. Olive ridleys display temperature-dependent sex determination (TSD), meaning that the critical temperature range to get a 1:1 sex ratio in each clutch, is between 30°C and 31°C, which is the highest in all sea turtle species (Eich et al., 2012). However, these turtles lay relatively shallow nests in comparison to other species (around 34-60cm deep), which can cause greater temperature fluctuations than in deeper nests (Dornfeld, 2011). Olive ridleys also tend to nest on mud banks or sloping areas of open sandy beaches (Cousins et al., 2017; Flores et al., 2021). Because of their smaller size compared to other turtle species, Olive ridleys require beaches with a gentle slope and no beach wall that would prevent them from crawling beyond the high tide line (Reichart, 1993).

Threats to Nesting

Since Olive ridley sea turtles are considered vulnerable by the IUCN, nesting and hatchling success are essential to their population's continued existence. However, there are still several threats to nesting populations that influence the growth of the population. One of the most influential factors affecting all sea turtle species is human activity through egg harvesting, egg predation by domesticated animals, beach degradation by coastal development, and turtle hunting (Oliver de la Esperanza et al., 2017). Coastal development is one anthropogenic activity that is directly affecting the reproductive success of sea turtles all over the world (Oliver de la Esperanza et al., 2017). Not only does it limit the potential nesting areas on beaches, but it also contributes to beach erosion, direct tourism pressure, and increases the amount of light pollution on the beach and shoreline (Oliver de la Esperanza et al., 2017). Light pollution has been shown to decrease nest density, limit the nest site selection of females, and increase the rate of nest abandonment by females (Kamrowski et al., 2014). This could be due to the disruptive effects of light pollution on hatchling orientation when they are trying to crawl to the ocean, which would significantly influence hatchling mortality and the females' reproductive success (Kamrowski et al., 2014). Light pollution from coastal development and human activity is a major threat to the availability of suitable sea turtle nesting beaches along coasts worldwide.

Predation is also a threat to nesting and a consideration when females select a nest site. Particularly, the presence of *arribada* behavior in Olive ridley populations suggests that aggregate nesting is used to overwhelm predators and maximize hatchling success (Dornfeld, 2011). The Predator-Satiation Hypothesis states that there is a finite number of predators on an *arribada* beach and the overabundance of food from the high density of nests will allow for the predators to have their fill and leave most of the nests untouched (Dornfeld, 2011). However, for solitary nesters, predators such as crabs (*Gecarcinus ruricola, Ocypode quadrata*) prey on the hatchlings and have been recorded as attacking up to 60% of the nests in a single season (Varela-Acevedo et al., 2009). While crabs are ferocious natural predators, invasive or exotic species are becoming increasingly problematic for hatchling survival and reproductive success. Domestic dogs (*Canis familiaris*) are considered to be one of the most abundant carnivore species in the world and they prey on a variety of animals, including being well-known scavengers of sea turtle nests (Ruiz-Izaguirre et al., 2015). Human presence and coastal development facilitates the influx of domestic dogs into sea turtle nesting beaches and increases the amount of predation pressure on the hatchlings (Ruiz-Izaguirre et al., 2015). Enclosed hatcheries have been used to increase hatchling success rates and decrease the amount predation from predators like crabs and dogs, however, ant predation has become a new and unmatched threat to this conservation strategy (Korgaonkar et al., 2020). Red ants (*Dorylus orientalis*) are becoming an increasing concern for the successful protection and conservation of sea turtle nests because they significantly decrease the emergence rates of hatchlings (Korgaonkar et al., 2020). Olive ridley nests on the coast of India saw an average 35-50% ant infestation rate with a 0-10% emergence rate over the course of 7 years (Korgaonkar et al., 2020). Sea turtles face a multitude of predation threats—both anthropogenic and natural—which threaten their reproductive success and population size.

Effects of Climate Change on Nesting

One of the largest threats to the viability of sea turtle populations around the world is the indirect and direct effects of climate change (Varela et al., 2019). Sea turtle nesting grounds will—if they have not already—be affected by multiple climatic processes such as temperature increases, enhanced storm frequencies, and sea level rise (Fuentes et al., 2011). These processes will affect all areas of the world, but they are especially influential in the tropics and subtropics, where sea turtles reside, because of the high variability in climatic conditions between seasons (Rivas et al., 2018). Since sea turtles are ectotherms and their reproductive output is directly affected by temperature, the global warming of the planet is thought to be the most significant threat to sea turtle populations (Fuentes et al., 2011). Sex determination in sea turtle embryos is temperature dependent, meaning that there is a 'pivotal temperature' at which the sex ratio is 1:1, and incubation temperatures below this point will be more male-dominated and incubation temperature higher will be more female-dominated (Eich et al., 2012). Scientists in Australia have reported high female-biased sex ratios in nests along the northern Great Barrier Reef over the past 20 years and they believe that complete feminization of the population could occur in the near future (Jensen et al., 2018). Along with skewing the sex ratio in sea turtle populations, increased temperature is predicted to cause more hatchling mortality since embryos are extremely sensitive to thermal changes (Fuentes et al., 2011).

While the increase in heavy precipitation events due to climate change can mitigate the increase in air and sand temperature that affects sex ratios in sea turtles, it also threatens to flood nests and increase embryo mortality by changing the hydric conditions (Rivas et al., 2018). Excessive precipitation affects female nesting behavior by both decreasing the potential nesting areas and increasing the number of flooded nests (Rivas et al., 2018). Heavy precipitation has also caused more coastal erosion on nesting beaches, which rapidly changes the beach composition, structure, and suitability for nesting females (Rivas et al., 2018). The increase in the frequency and magnitude of storms, such as cyclones or hurricanes, due to global warming has also affected beach suitability for sea turtles (Dewald & Pike, 2014). Hurricanes have affected nearly 97% of sea turtle nesting beaches over the past half century and they can affect the quality of these areas by flooding or eroding nests, scattering debris, and causing sand erosion or accretion (Dewald & Pike, 2014). Storm surges also negatively affect the reproductive output of turtles by decreasing hatching success and the emergence rate of neonates (Pike & Stiner, 2007).

Along with temperature inflations and increased storm surges, sea level rise is a concerning by-product of climate change for sea turtle nesting beaches and their reproductive success. Sea turtle nesting areas are primarily located in low-lying coastal habitats that are most vulnerable to frequent flooding and erosion by rising sea levels, which could affect the beach suitability of particular sea turtle species (Pike et al., 2015). Embryos are especially vulnerable to sea level rise because saltwater inundation can induce hypoxia and cause significant rates of hatchling mortality (Pike et al., 2015). While sea turtles have shown to be resilient creatures in the face of climate change, the rate of sea level rise is unprecedented, and scientists argue it is too rapid for the species to adapt (Varela et al., 2019). Sea level rise is also causing a 'coastal squeeze' because it is shortening the amount of suitable beach for nesting and coastal development is preventing upward landward migration of the beach (Katselidis et al., 2014). This is limiting the area of available nesting habitat for sea turtles, and therefore decreasing their potential reproductive output (Katselidis et al., 2014).

Importance of Nest Placement

The nesting placement of sea turtles is extremely important in maximizing offspring survival and the reproductive fitness of the nesting females (Zavaleta-Lizárraga & Morales-Mávil, 2013). Since sea turtles do not provide parental care to their offspring, the physical characteristics of the nest site are paramount in determining the success of their hatchlings (Zavaleta-Lizárraga & Morales-Mávil, 2013). The environmental factors of the beach can also influence the size, growth, and behavior of the neonates (Wood & Bjorndal, 2000). Females press their heads into the sand as they make their way up the beach when selecting a nest site as a way to detect microhabitat characteristics suitable for their eggs (Wood & Bjorndal, 2000). One important variable in nesting placement is the distance that the nest is placed from the ocean, which has been shown to be strongly correlated to hatchling survival. (Hays & Speakman, 1993). Nests placed too close to the ocean could be flooded by storm surges or tides and the hatchlings can be suffocated, whereas nests placed farther inland force hatchlings to crawl for longer to reach the ocean which increases the risk of heat stroke, misorientation, or predation (Hays & Speakman, 1993). The sand characteristics are also important factors in nest placement because they help moderate the gas exchange within the nest, which has significant implications for embryo development and mortality (Clusella Trullas & Paladino, 2007). There are several other environmental cues that help sea turtles select a preferable nest sight, but in a study done on loggerhead turtles (*Caretta caretta*), researchers found that the slope of the beach had the greatest influence on nest site selection (Wood & Bjorndal, 2000). The slope of the beach can determine the level of exposure of a nest to predation, how far a female will crawl to nest depending on energy expenditure, and the reproductive cost of finding a suitable incubation site for the eggs (Varela-Acevedo et al., 2009). All these factors are assessed by each female every time they nest in order to maximize their clutch's success rate, as well as minimize any potential threats that would affect the survival of the hatchlings. For this reason, it is also important to identify the factors that cause a female to abort a nesting event and leave the beach. A comparison between favorable and unfavorable nesting characteristics can give insight into the most influential microhabitat properties, as well as which sections of the beach are most suitable for successful nesting.

Research Question

What is the beach suitability for the nest placement of Olive ridley sea turtles (*Lepidochelys olivacea*) on Playa Malena in the Azuero Peninsula of Panama?

Methods

Study Site

The study site is located at Playa Malena (7.576232N, 80.966923W) in the Mariato District of the Azuero Peninsula in Panama (Figure 2). Playa Malena is approximately 851 m long black sand beach with a river located at the north end of the beach that flows into the ocean and is surrounded by pebbles and gravel. Nearly the entire community of Malena participates in a sea turtle conservation group called Malena Beach Conservation Association, which operates a hatchery for three different species of turtle hatchlings throughout the year: Green turtles

(*Chelonia mydas*), Hawksbill turtles (*Eretmochelys imbricata*), and Olive ridley turtles (*Lepidochelys olivacea)*. The nesting of Olive ridley turtles at this beach is of the solitary type, meaning no *arribadas* occur on the beach. Throughout the nesting season, community volunteers patrol the beach daily—once at dusk and once at dawn—looking for nests. The eggs are dug up and transferred to the enclosed hatchery located near the beach entrance about 669 m away from the river and monitored until they hatch, wherein the neonates are released.

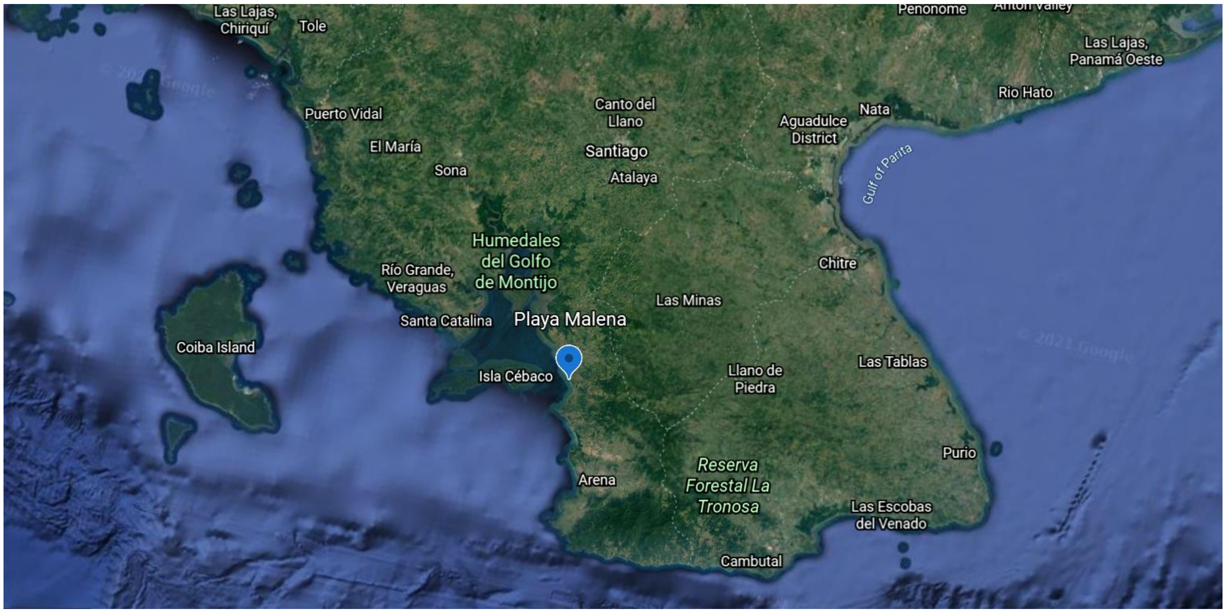

Figure 2. Location of Playa Malena on the western coast of the Azuero Peninsula in Panama.

<u>Locating the Nests</u>

Beach patrols were conducted on foot every night starting November 20th, 2021, to December 2nd, 2021, which is at the very end of the nesting season for Olive ridleys. The length of the beach for the study was from the river mouth (7.577739N, -80.969348W) until the south end where fishing boats are parked (7.572617N, -80.963689W). Patrols usually started at 9pm and last until approximately 2am to 3am or until maximum high tide. During beach patrols, the length of the beach was surveyed, sticking close to the tide line, using red light to search for turtle tracks on the sand (Flores et al., 2021). The turtle tracks would lead to either a completed nest or an aborted nest. Completed nests were identified by following the tracks to a disturbed area known as the 'body pit' made by the underside of the turtle's shell when she fills in the egg chamber and packs it down (Varela-Acevedo et al., 2009). A long, study stick was used to poke holes into the flat patch until the loosely compacted sand around the egg chamber was found (Flores et al., 2021). The eggs were excavated and transferred to another nest in the hatchery by my companion working on behalf of Malena's conservation association. Aborted nests were identified by turtle tracks leading to uncovered, half-dug holes in the sand or by turtle tracks that head back to the ocean, uninterrupted (Varela-Acevedo et al., 2009). At each location—completed or aborted nest—the GPS location was recorded, along with several beach characteristics outlined in the Sea Turtle Nesting Beach Indicator Tool (Cousins et al., 2017).

Quantifying Beach Suitability

The Sea Turtle Nesting Beach Indicator Tool is provided freely by Bluedot Associates online and was used to quantify the beach suitability of Playa Malena for Olive ridley sea turtles during the study period (Campbell, 2019). The microhabitat characteristics that were measured for the assessment included beach sediment, beach elevation, beach width, and beach slope. Beach sediment was classified in levels of how much sand or gravel was present. The exact beach elevation was recorded using a GPS, but the Indicator Tool categorized elevation into 3 ranks: <0.5m, between 0.5m and 1.5m, and >1.5 m. Beach width was calculated using a GPS and measured as the distance from the ocean to the vegetation behind the beach. Beach width was also split into 4 categories within the Indicator Tool: 0m, <5m, between 5m and 15m, and >15m. Beach length was measured from the designated start point at the river mouth to the designated end point at the other end of the beach using a GPS. The Indicator Tool categorizes beach length as <200m, between 200m and 1km, and >1km. Beach slope was measure using a clinometer app on a smartphone and recorded at each nest. The Indicator Tool categorizes beach slope as low and moderate/steep. The exact values were separated into these 2 categories based on if the slope was >5° or <5° based on the Slope Steepness Index. These microhabitat characteristics were recorded for each of the completed and aborted nests to understand the differences in suitability for Olive ridley female nesters within Playa Malena. They were then averaged to come up with a singular value for each characteristic, since the Nesting Beach Indicator Tool assesses an entire beach as a whole. The Nesting Beach Indicator Tool provided a singular beach suitability score for Playa Malena based on the data collected over the 2-week study period.

Along with a beach suitability assessment, the Nesting Beach Indicator Tool provided a human impact assessment based on 4 categories that are graded between 0 and 5, with 0 being the least impactful and 5 being the most (Cousins et al., 2017). The 4 categories the beach is graded on are: development behind the beach, obstructions on the beach, disturbances on the beach, and evidence of light pollution on the beach. Each category is given a score and then the Indicator Tool provides a star rating based on how impacted the beach is by human activity. The star rating is between 1 star (the most impact/worst rating) and 5 stars (the least impact/best rating).

Comparing Beach Suitability Across Sites

The Nesting Beach Indicator Tool was also used to generate scores for other beaches along the southwestern coast of the Azuero Peninsula. Beach survey data from 7 beaches with nesting Olive ridleys was obtained from Flores et al. (2021). Flores et al. (2021) carried out 39 total patrols at all the nesting beach sites to identify the species of sea turtle present. They also recorded the beach characteristics of each site, which were categorized and input into the Indicator Tool in order to generate a beach suitability score. These scores were then compared across the sites, including Playa Malena, to understand where Olive ridley sea turtles would potentially nest, and which beach should be focused on for future conservation efforts depending on the level of suitability. Flores et al. (2021) also recorded human activity impacts for each beach that they surveyed, which allowed the human impact assessment portion of the Nesting Beach Indicator Tool to be applied and compared between sites.

Data Analysis

The beach characteristics of the completed nests and the aborted nests were compared, and a Chi-square test was performed to find any significant differences between the number of nests found within each of the categorizations for beach suitability characteristics as defined by the Nesting Beach Indicator Tool. Playa Malena was also scored based on its beach suitability using the Nesting Beach Indicator Tool and its grading scale. Its score was then compared to the scores of other Olive ridley nesting beaches along the coast of the Azuero Peninsula using data from Flores et al. (2021). The human impact assessment of the Nesting Beach Indicator Tool was also applied to these same beaches and compared across the sites. Each beach was given a star rating based on the human activity already present and its effects on the existing sea turtle nesting populations.

Ethics

This study did not include any human subjects, nor was anyone interviewed for the purposes of the experiment. Every precaution was taken to minimize any risk to the female Olive ridley (*Lepidochelys olivacea*) nesters and their eggs. Data was not taken on the female nesters themselves, so they were not approached or disturbed in any way. Data was taken during the night to identify turtle tracks and nests before the tide, debris, or human traffic erased any trace of them. Because of this, a red light was used to patrol the beach to avoid light pollution and walks were done as close to the tide line to avoid disturbing potentially nesting females. When a nest was located, the excavation and transferring of the eggs to the hatchery was done by a volunteer from the Malena conservation association using proper techniques. Whenever turtle eggs were handled, latex gloves were worn so as to avoid introducing any foreign microorganisms or bacteria that could potentially affect the survival or fitness of the hatchlings. Gloves were changed between each individual clutch.

Results

Over the 13 nights that patrols were conducted, 12 completed nests with deposited eggs and 10 aborted nests were found, totaling to 22 nesting events detected overall. An average of 1.69 nests were located per night (completed and aborted combined). Playa Malena is a primarily sandy beach with gravel and pebbles found within 321m of the river mouth (start point). The beach sediment of the remaining 530m of the beach is composed of only sand. There were 11 nests found in the gravel/pebbles area (50%) and 11 nests (50%) found in the sandy area. Of the 10 aborted nests, 90% of them were found within the gravel/pebble boundaries. Of the 12 completed nests, 83.3% of them were found in the sandy sediment more than 321m away from the river. There were no nests found in the last 116m of the beach, despite it being entirely sandy. A Chi-square test indicated a significant difference ($p < .05$) between the type of nesting event and the type of beach sediment it occurred in (Figure 3).

Figure 3. Locations of the completed and aborted nests on Playa Malena. The river is located on the upper left corner on the map with the shaded polygon designating the area of gravel and pebbles.

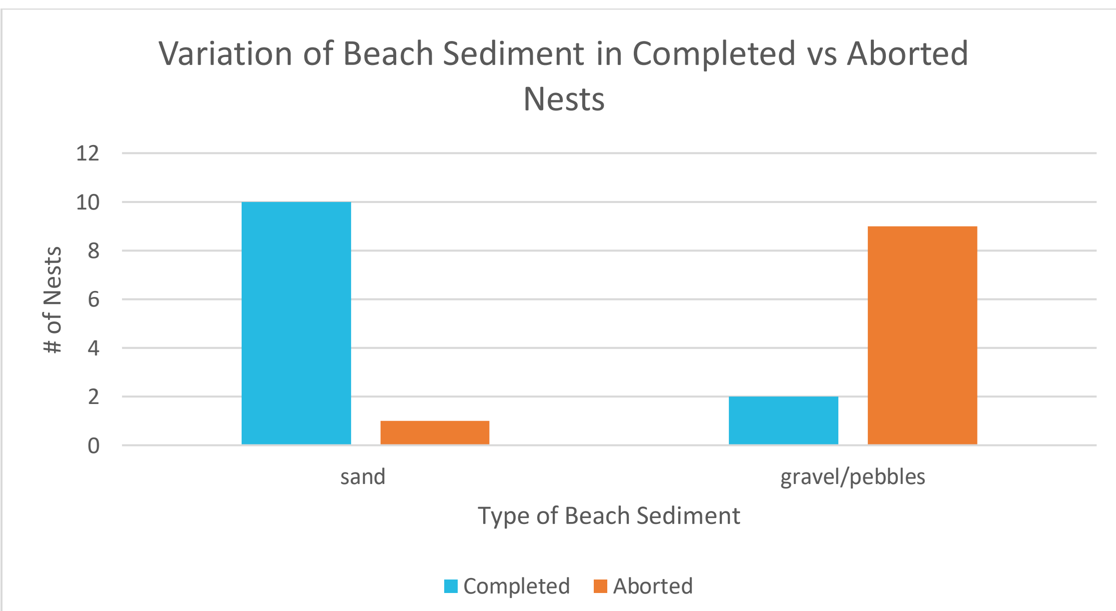

Figure 4. The number of nests found in each sediment type categorized by the type of nesting event, X^2 (1, N = 22) = 11.73, p = 0.0006.

The mean slope for the completed nests was 7.09° and the mean slope for the aborted nests was 6.15°. There were 10 nesting events categorized as having 'low' slope and 12 nesting events categorized as having 'moderate/steep' slope. Of the aborted nests, 60% were given a ‘low’ slope rating and 40% were given a ‘moderate/steep’ rating. Of the completed nests, 33.3% had a ‘low’ slope, and 66.6% had a ‘moderate/steep’ slope. A Chi-square test found there was not a significant difference ($p > .05$) between the type of nest and the slope categorization (Figure 4).

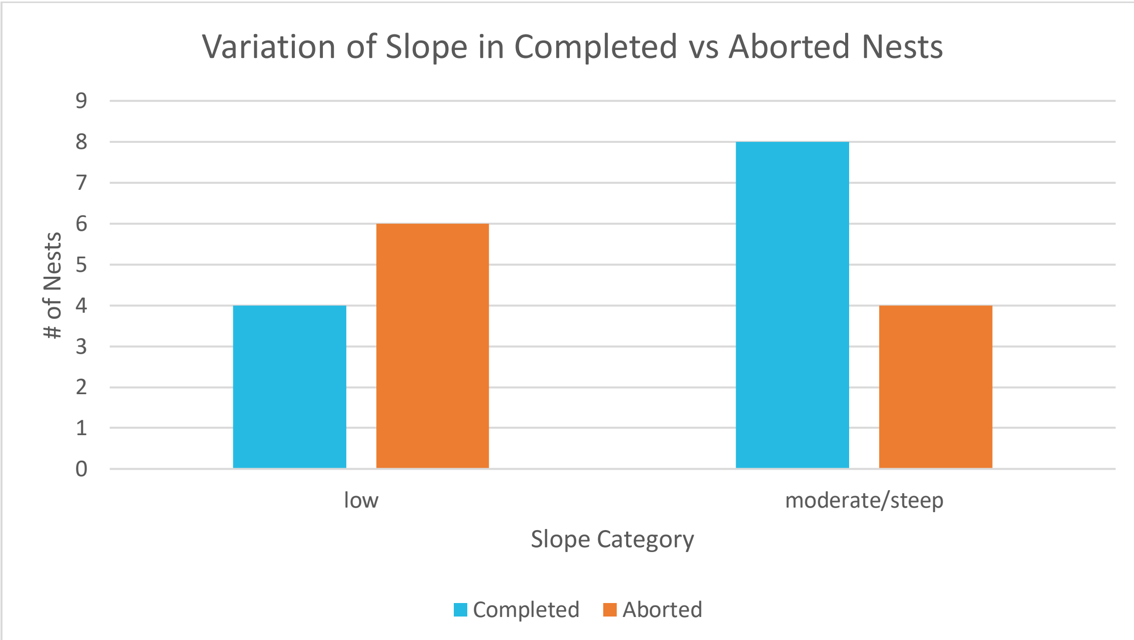

Figure 5. The number of nests of each nesting type, categorized by the steepness of their slope, $X^2\,(1, N = 22) = 1.56$, $p = 0.21$.

The Sea Turtle Nesting Beach Indicator Tool was applied to Playa Malena using averaged beach characteristics taken from all the nesting events that were measured over the course of the study period. The other beaches along the Azuero Peninsula coast were scored based on the literature from Flores et al. (2021). Table 1 summarizes the scores for each of the beaches. The criteria behind the scores given for each characteristic is provided in Appendix 1. The Nesting Beach Indicator Tool defines a score above 70 as a “typical beach to have regular nesting”, which each beach is designated as. Playa Malena has a median score of 85 based primarily on its beach sediment (mostly sand with gravel) and its moderate/steep beach slope, and its shorter beach length compared to the other beaches. Playa Cascajilloso had the lowest score of 80, while Playa Horcones had the highest score of 100.

Table 1: A summary of the Sea Turtle Nesting Beach Indicator Tool beach suitability scores for beaches along the southwestern coast of the Azuero Peninsula with nesting Olive ridley populations.

Beach	Beach Sediment	Beach Elevation	Beach Width	Beach Slope	Beach Length	Score
Malena	20	15	25	15	10	85
Cascajilloso	20	15	25	5	15	80
El Gato	30	15	25	5	10	85
Colorado	20	15	25	15	10	85

Granada	20	15	25	15	10	95
Verde	20	15	25	15	10	85
Horcones	30	15	25	15	15	100

The Human Impact Assessment section of the Sea Turtle Nesting Beach Indicator Tool was also applied to the same beaches above. They were given a star rating based on the level of human activity impacting the beach. Table 2 summarizes the grades and subsequent star ratings given to each beach. Most beaches were given a 3-star rating, including Playa Malena, which is defined as "human impact may already be affecting nesting activity" by the Nesting Beach Indicator Tool. Only Playa Verde received a 4-star rating primarily because of the minimal amount of disturbance and other human activities found on the beach. 4-star ratings are defined as "human impact is unlikely to already be affecting nesting activity".

Table 2: A summary of the star ratings given by the Human Impact Assessment section of the Sea Turtle Nesting Beach Indicator Tool for each beach.

Beach	Fixed or semi-fixed development behind beach	Obstructions on beach	Disturbances on the beach	Evidence of light pollution on the beach	Star Rating
Malena	1	2	3	1	3
Cascajilloso	1	1	4	1	3
El Gato	3	1	4	2	3
Colorado	1	4	3	1	3
Granada	1	1	3	1	3
Verde	1	1	1	1	4
Horcones	3	1	4	2	3

Discussion

Beach Suitability of Playa Malena

Playa Malena was determined to be a suitable beach for Olive ridley nesting based on the score and designation provided by the Sea Turtle Nesting Beach Indicator Tool. This assessment characterized Playa Malena as a mostly sandy beach with some gravel and pebbles that is moderately long, wider than 15m, and a moderate to steep slope. Based on previous research, Olive ridley prefer to nest on the steep sloping areas of an open sandy beach or on the mud banks of a river mouth or estuary (Cousins et al., 2017; Flores et al., 2021). Playa Malena was shown to have all these preferred characteristics, including having a river at the far end of the beach. However, even though, Olive ridleys prefer to nest near estuaries, there were more aborted nests found closer to the river, and more completed nests found farther down the beach. This suggests that the large area of gravel and pebbles present around the river mouth and extending down the beach, has a significant influence on Olive ridley nesting females and plays a heightened role in determining the nesting suitability of a beach. This is consistent with Campbell (2019) findings about the beach suitability of Armila Beach in Guna Yala for leatherback (*Dermochelys coriacea*) sea turtles. He determined that there was a significant difference in the amount of nests laid in sand compared to the amount of nests laid in the gravel sections of the beach, which suggests that sandy beach sediment composition is an extremely important factor for nest site selection across different species of sea turtles (Campbell, 2019). The type of beach sediment determines the success of the egg chamber excavation by a nesting female because dry, coarse sand makes it difficult to dig (Varela-Acevedo et al., 2009). It is also a key variable for hatchling success since it can influence the nest temperature and rate of emergence of the hatchlings (Varela-Acevedo et al., 2009). The gravel found at Playa Malena was rough to the touch and was observed to be loose and dry compared to the sand on the beach, which the females may have noticed when they started to dig their nests, and at which point, they decided to abort. Conservation of open sandy areas should be a priority for maintaining the Olive ridley sea turtle population at Playa Malena.

Over the course of the 2-week study period, the river at Playa Malena shifted a considerable amount, effectively shortening the beach by 90m by the conclusion of the experiment. This also extended the area of the gravel and pebbles further down the beach as the flow of the river pushed more of the coarse sediment onto its banks. Based on the results from the study, Olive ridley sea turtles prefer to deposit their eggs in sand rather than in gravel or pebbles, so the beach suitability of Playa Malena was slightly affected when the river rapidly changed the structure and composition of the beach. This may have wider implications for all sea turtle nesting beaches that are experiencing accelerated rates of change in their physical characteristics due to climate change (Oliver de la Esperanza et al., 2017; Rivas et al., 2018). If the beach suitability can change rapidly over a 2-week period, there are concerns about how much it could change over the course of several months during an Olive ridley nesting season, and how that would affect the reproductive success of the females and subsequent conservation strategies. Artificially maintaining the location and trajectory of the river flow throughout the nesting season might be a viable strategy in limiting the area of gravel and pebbles on Playa Malena and increasing the amount of suitable nesting habitat for the sea turtles. Long term beach surveys combined with beach management and conservation planning could also be a solution to this issue (Butt et al., 2016). By continually assessing the long-term beach suitability of sea turtle nesting areas, more effective conservation plans can be implemented to maximize the reproductive output of the nesting females and ensure the success of their hatchlings.

The human impact assessment of Playa Malena determined that human impact may already be affecting the nesting area, however most of the aborted nests were found near the river and away from most of the human activity that occurs on the beach. Human activity on Playa Malena is mostly confined to the areas closest to the beach entrance on the south end, and consists of small housing structures toward the back of the beach with some outdoor lighting. People often make campfires at a rancho located right next to the hatchery on the beach. Most of the completed nests were found closer to this area than the aborted nests, which suggests that human activity is not as much of a deterrent to nesting as the physical characteristics of the beach, such as sediment composition. However, when the physical properties of the beach are ideal and uniform across an area, human activity could become a deterrent for the female nesters and lead to increased aborted nest attempts (Weishampel et al., 2003). In the last 36m of Playa Malena at the south end, there are fishing boats with flashing lights parked on the beach where many dogs and crabs can be found scavenging for fish parts. There were no nests or nesting attempts found in this area over the course of the study period, despite it being an open, sloping, sandy part of the beach. This suggests that the heightened human activity that caused obstructions, predator influx, and increased light pollution, dissuaded the females from nesting in a suitable area, which effectively diminished the potential reproductive habitat of the Olive ridley females on Playa Malena. This is consistent with previous studies that found human pressures from multiple activities, such as coastal development and light pollution, were directly responsible for nesting habitat degradation and disappearance (Oliver de la Esperanza et al., 2017). These activities should be avoided or minimized in the future to decrease the disturbance to nesting females and increase the amount of viable nesting grounds.

Comparing Suitability Across Nesting Beaches

A comparison of the beach suitability across surveyed beaches in the western Azuero Peninsula found that all of them are considered ‘typical beaches for regular nesting’ which is plausible considering each one was found to have Olive ridley nesters present. There was no variation in the beach width and the beach elevation between the 8 beaches, but there was a some of variation in the sediment, and slope between all the beaches. Considering sandy beach sediment was determined to be a significant factor in nest site selection for Olive ridley sea turtles at Playa Malena, it may be an important influence on the level of nesting activity and their reproductive success at the other beaches along the same coast. Compared to the other sites, Playa Malena is the only beach where a conservation program for Olive ridleys exists, so the reproductive success of the nesting females at the other beaches depends solely on suitability of the different physical characteristics (Flores et al., 2021). This suggests beaches with only sand may be more suitable to the nesting preferences of Olive ridley sea turtles compared to the beaches with sand and gravel, and therefore conservation efforts should prioritize those beaches (Playa Horcones and Playa El Gato).

There was little variation in the overall beach suitability scores with most receiving a score between an 80 and 85, however, Playa Horcones received a perfect score for its physical characteristics. Further research is needed to determine if there is a significant difference between the number of Olive ridley nests on this beach compared to the other beaches with less ideal physical conditions. Interestingly, Playa Horcones received a 3-star rating for its human impact assessment, indicating that the human activity present on the beach could be negatively affecting the nesting suitability for the sea turtles. Playa Verde received a score of 85 for its physical suitability, but 4 stars for its lesser human impact suggesting it may be more preferable for nesting than Playa Horcones. The Sea Turtle Nesting Beach Indicator does not combine the physical suitability and the human impact assessments to generate an overall nesting suitability rating, so the intersectional effects cannot be determined, despite being inextricably intertwined. Human activity affects the physical characteristics of a beach both indirectly, through climate change, and directly, through such enterprises like coastal development, which shortens the beach width (Oliver de la Esperanza et al., 2017). Therefore, understanding patterns of sea turtle nesting activity is dependent on both the physical suitability of the beach and level of human activity affecting the area over time. In order to effectively implement a long-term conservation solution, future research needs to focus on the human impact on physical beach suitability instead of treating them as separate determinants.

Potential Sources of Error

The Olive ridley nesting season typically lasts until November, so this study was conducted at the very end of when the majority of females arrive onshore to nest. This resulted in the occurrence of very few nesting events and a small sample size to make definitive conclusions about. For this reason, there could be some sample bias since the females that did nest were outliers. In the future, it would be better to conduct this experiment over the course of an entire nesting season to ensure an adequate sample size. Additionally, there is the possibility that some nesting events were missed due to overlooked turtle tracks and nests from it either being too dark to identify or from the tide washing the tracks away. However, members of the Malena conservation group would patrol the beach once at dawn looking for any nests that were missed during the previous night and they would inform if any were found. Occasionally, it was difficult to decern what was an aborted nesting event and what was a nest with deposited eggs, however a stick was used to find any possible pockets in the sand where a nest was thought to have been laid before it was classified as an aborted attempt.

Conclusion

The aim of this study was to assess the beach suitability of Playa Malena for the nesting placement of Olive ridley sea turtles and compare it to the suitability of 7 other surveyed beaches along the southwestern coast of the Azuero Peninsula. This was successfully achieved using the framework of the Sea Turtle Nesting Beach Indicator Tool to rapidly assess the physical characteristics and human impact of each site. The beach sediment composition was determined to be the most significant factor in determining the successful nesting of eggs for Olive ridleys on Playa Malena, with the sea turtles preferring sand over gravel. The trajectory of the gravel section further down the beach as a result of the river's movement is concerning for the future suitability of Playa Malena for sea turtle nesting. Conservation management plans for the nesting Olive ridleys on Playa Malena should include conservation of sandy beach environments and continual assessments of the physical beach characteristics to monitor any changes in nesting suitability. Human activity and human-induced climate change are also influential factors on the physical characteristics of nesting beaches, so they must be assessed in conjunction to the physical beach suitability of a site in order to identify sea turtle nesting preferences. Certain human activities may deter females from nesting despite having suitable nesting conditions on the beach. Similarly, certain human activities may have detrimental long-term impacts on the physical properties of a beach and degrade the suitability for sea turtle nesting over time. This study adds to the existing literature on Olive ridley nesting preferences and identifies beaches on the Azuero Peninsula in Panama that could potentially be important sea turtle nesting grounds in need of conservation monitoring and management.

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Appendix

Sea Turtle Nesting Beach Indicator Tool grading criteria for beach suitability characteristics from Cousins et al. (2017).

Category	Options	Max Contribution	Option Value
Beach sediment (to 50cm)[1]	Beach composed of only sand (fine to coarse)	30%	30
	Predominantly sandy beach with gravel (i.e. granule, pebble, cobble, boulder)		20
	Predominantly gravel beach with areas of sand		15
	Gravel beach		-30
Beach elevation (above high tide)[2]	Less than 0.5m	15%	5
	Between 0.5m and 1.5m		10
	Greater than 2m		15
Beach width (above high tide)	0m	25%	-15
	Less than 5m		15
	Between 5m and 15m		20
	Greater than 15m		25
Beach slope	Low	15%	5
	Moderate to steep		15
Beach length	Less than 200m	15%	5
	Between 200m and 1km		10
	Greater than 1km		15