Patterns of foraging in Olive Ridley Sea Turtle (*Lepidochelys olivacea*) population on the east coast of India, and habitat characteristics of the arribada nesting ground at Rushikulya

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CERTIFICATE

This is to certify that **Mr. Mohit Mudliar** has carried out an original piece of research from Wildlife Institute of India, titled **"Patterns of foraging in Olive Ridley Sea Turtle (*Lepidochelys olivacea*) population on the east coast of India, and habitat characteristics of the *arribada* nesting ground at Rushikulya"**, in partial fulfilment of a Master's Degree in Wildlife Science from Saurashtra University, Rajkot, India. The study was carried out under our supervision from December 2018 to June 2019. We hereby certify that this work has not been submitted for any other degree to any University.

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Mohit Mudliar

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1. Summary

1. Olive ridley turtles (*Lepidochelys olivacea)* are known to nest solitarily as well as in *arribadas* along the east coast of India with a*rribada* nesting occurring only near two river mouth on the coast of Odisha. While multiple studies on the olive ridley exist from India, most of them are related to the *arribada* populations on the Odisha coast. However, some crucial aspects of olive ridley biology such as the ecology of solitary nesting turtles, and detailed habitat characteristics of nesting grounds of *arribada* are still poorly known. Further, knowledge of the foraging habitats of olive ridleys, nesting habitat characteristics and the microplastic prevalence in mass nesting grounds are some major gaps that are required to be studied for long term conservation of sea turtles in India.
2. In this context, this study was conducted and aimed to explore the patterns of spatial segregation of foraging olive ridley turtles which nest on two distinct nesting areas of the eastern coast of India; secondly, to examine the characteristics of mass nesting ground of Rushikulya; and lastly, to assess the status of microplastic presence in mass nesting ground.
3. Stable isotope analysis was used to explore the differences in foraging habitats of turtles from Chennai and Rushikulya. Samples from humerus bone of stranded turtles were used for stable isotope analysis using Isotope Ratio Mass Spectrometer. The stable isotope ratio for Odisha and Chennai turtles were compared.

4. Entire Rushikulya beach has various type of nesting. Of these, four sections with a different type of nesting were selected to study the beach characteristics. Five beach characteristics such as width, moisture, salinity, sand size and slope were measured. Average sand size was measured by sieving (Krumbein and Pettijohn, 1938), moisture in the sand by weight (Besley *et al*., 2016) and salinity (for 20g dry sand/100ml of water) with a salinometer. Data on beach width and beach slope (Emery, 1961) were also collected for each section of the beach. Differences in beach characteristics between the sections were analysed using ANOVA and Kruskal-Wallis tests.
5. Samples to assess the quantity of microplasic present in the nesting beach were collected from 10 points following the globally accepted protocol. Of these, five sample points were at the nesting area and five sample points at strandline. Microplastic present in the sand was extracted from 50g of dry sample and was extrapolated to get the count for one kilogram using Besley *et al*., (2016). The number of microplastic fragments and its types in each sample collected were observed under the compound microscope.
6. Carbon isotope ratios between the Rushikulya and the Chennai turtles varied significantly ($P<0.05$) when all turtle samples that were collected throughout the study period were analysed. However, there were no significant differences in the carbon isotope ratio between these two concerning turtles that got stranded during the peak nesting period, i.e. December to February ($P=0.366$).
7. Moisture contents and sand particle sizes are two important habitat variables that determine the quality of turtle nesting beaches. At Rushikulya, the moisture contents and sand particle sizes of nesting beaches of both high tide

line and nesting line were observed to be uniform. Further, the study found that the beach characteristics of island sandbar differed from all the other nesting beaches in terms of salinity, moisture content, sand particle size and slopes.

8. The study found a high level of microplastics contamination in the nesting beach at Rushikulya. The abundances of microplastic were estimated more at the strandline (1200±162 (SE) per kg) than the nesting lines (960±50 (SE) per kg). Line/ fibre was the most abundant type of microplastic found in all the samples, whereas the foam was the least abundant type.
9. In conclusion, the study found that the moisture contents and sand particle size were homogenous across the beaches of Rushikulya. The sandbar had most extreme values for four of the five studied habitat characters which might be due to surrounding waters. Sea turtles those stranded during December to February at Chennai as well as Rushikulya seems to be from a similar type of foraging areas as their carbon isotope ratio were not different. Althoug I could find a temporal difference in carbon isotope ratio values between turtles those stranded during December-February and rest of the year, I was unable to infer that this difference was due to the usage of different foraging areas or due to smaller sample size.
10. Microplastic pollution in Rushikulya was observed to be alarming when compared to other parts of the world. A high proportion of fibres which usually belongs to fishing gear and clothing was present in the samples probably due to the vicinity of only fishing village near the nesting beach and no major city along Rushikulya River.

2. Introduction

Sea turtles are amongst the largest living reptiles and are considered to fall between r and K-selected species in terms of their life history strategies. On the one hand, they take a long time to become sexually mature like K-selected species, but they produce large numbers of offspring and do not have any parental care which are traits of r-selected species (Miller, 1997). There are seven species of sea turtles and they, in order of decreasing size are Leather back sea turtle (*Dermochelys coriacea),* Green sea turtle (*Chelonia mydas*), Loggerhead sea turtle(*Caretta caretta*), Flatback sea turtle (*Natator depressus*),Hawksbill sea turtle (*Eretmochelys imbricate*), Kemp's ridley sea turtle (*Lepidochelys kempii*) and olive ridley sea turtles(*Lepidochelys olivacea*). Females lay multiple clutches during the breeding season and the number of eggs per clutch can exceed 150 (Miller, 1997) with very low hatchling survival (Chaloupka & Limpus, 2002). Hatchlings of all the species have a long oceanic phase except for *N. depressus* during which they are highly carnivorous. After attaining a certain body size, they move to the species specific foraging habitats (Plotkin, 2003). For most of the species, both the sexes migrate to offshore areas near the nesting beaches. Mating can happen at various stages of migration and differs between species (Godley *et al*., 2008).

Ridley turtles (belonging to the genus *Lepidochelys*) are evolutionarily close to loggerhead sea turtles (*Caretta caretta*) and are the smallest of all the sea turtles (Pritchard, 2007). These turtles are known for their two distinct nesting strategies. They nest solitarily similar to other species of sea turtles and also have synchronized nesting called *arribada* in which hundreds and thousands of females nest synchronously within a short duration of 5-10 days (Bernardo & Plotkin, 2007). For *L. olivacea*, large *arribadas* are known to occur in Costa Rica, Mexico and India, while *L. kempii arribadas* are recorded from Mexico only (Bernardo and Plotkin, 2007). In recent years, *L. olivacea arribadas* have also been documented from other countries in Central America on the Pacific coast and the Andaman Islands. Solitary nesting by *L. olivacea* is known to occur in South America, North America, Africa, Asia and Australia. Patterns of nesting in *arribadas* are different across areas; *L. kempii arribadas* are known to occur during the day, while *arribadas* of *L. olivacea* mostly occurs at night but daytime nesting can also be seen. In Costa Rica, *arribadas* occur multiple times through the year, while in India it occurs mostly once or twice during the breeding season. The absence of *arribada* in some years is unique to the Indian population of *L. olivacea* (Pritchard, 2007).

In India, large *arribadas* have historically been observed at three river mouths along the coast of Odisha state while solitary nesting occurs all along the Indian coast (Shanker, Ramadevi, Choudhury, Singh, & Aggarwal, 2004). While there is some knowledge of the biology of these turtles on the Odisha coast from long-term monitoring (Chandrana, Manoharakrishnan, & Shanker, 2017), satellite telemetry (S. Kumar, 2015; Behera, Tripathy, Choudhury, & Sivakumar, 2018) and studies using flipper tags (Dash & Kar, 1990; Pandav & Choudhury, 2006) not much is known about the ecology of *L. olivacea* from the rest of the coast.

Adult sea turtles move between the foraging and nesting habitat and these are the two crucial aspects that can affect their overall fitness. This makes it important to know these aspects for effective conservation of the species.

2.1 Nesting Habitat Characteristics

Nesting habitat characteristics are important as they affect the hatching success and sex ratios for all sea turtles and when compared to other species such as *C. mydas and C. caretta*, few studies deal with the nesting habitat selection *for L. olivacea*. The preference of river mouth areas by female *L. olivacea* for nesting is widely recognized (Dash & Kar, 1990; Behera, Tripathy, Sivakumar, Choudhury, & Kar, 2013, Behera *et al.*, 2013) but the reasons for selection of various river mouths for solitary nesting and specific river mouths for *arribada* nesting are unknown. In India, the Devi river mouth was known to have had *arribadas* in the past, but no *arribadas* have been observed since 1997 (Shanker, Pandav, & Choudhury, 2006). Dash and Kar (1990) observed that *L. olivacea* nest high above the tide line and prefer beaches that have less slope. López-Castro *et al*. (2004) observed that the females prefer sites with higher moisture and temperature close to 32°C for nesting. A study by (Muralidharan, Sivakumar, & Choudhury, 2009) observed the nesting locations on the beach for *L. olivacea* were significantly different in pH, slope, moisture and temperature from the locations taken along the track of female's approach.

Some areas show shifts in the *arribada*, which are well documented from Gahirmatha (Dash and Kar, 1990; Shanker, Pandav, & Choudhury, 2006). Here, *arribadas* used to take place in a stretch of 10km which shifted northward and subsequently, erosion led to the disappearance of nesting from this area. *Arribadas* now occurs only on two islets, one on the southern beach of Wheeler Island and the second on Nasi Island, which are 1km and 2km long respectively. Without knowledge about nesting habitat characteristics and due to the scarcity of baseline data, the reasons for these changes are not well understood.

These nesting habitats are also vulnerable to microplastic pollution, which is known to be increasing in oceans and beaches around the world (Van Cauwenberghe, Devriese, Galgani, Robbens, & Janssen, 2015). Microplastics are small fragments less than 5mm in size and are produced by the disintegration of plastic and by improper disposal of such raw materials from industries (Andrady, 2011; Duncan *et al*., 2018). This fragmentation can happen due to UV radiation and due to wave action in the ocean, and these fragments drift around the world's ocean facilitated by oceanic currents (Andrady, 2011). The phenomenon of microplastic contamination in the food chain is well known but additionally, these microplastics can have several damaging effects on the turtle nesting habitat. Microplastic has shown to change the physical properties of sand and alter its erosion pattern (Carson, Colbert, Kaylor, & McDermid, 2011). Microplastic can also change the temperature regime in two different ways; it can change the porosity of the sand and make it cooler or make it warmer due to its higher specific heat if present in very high amount (Duncan *et al*., 2018). (Karthik *et al*., 2018) have shown that the microplastic pollution on the Tamil Nadu coast is high and the abundance of microplastics was found to be more near river mouths. As the *arribada* nesting beaches of Odisha coast are near river mouths and are the most crucial breeding areas for Indian *L. olivacea* population, it makes it essential to examine the extent of microplastic pollution in these areas.

2.2 Foraging habitats and Migration

Sea turtles are the only reptiles known to migrate thousands of kilometres between their foraging and nesting areas (Plotkin, 2003). Interspecific differences in the migration and fidelity to the nesting and foraging areas have been studied in sea turtles. Species such as *C. mydas* and *E. imbricata* have high fidelity to their foraging grounds and have directed movement post-nesting (Balazs & Ellis, 2000; Luschi, Hays, & Papi, 2003). *L. kempii* and *N. depressus* have restricted distribution as compared to other species but can move thousands of kilometres to their foraging habitat (Godley *et al*., 2008). They have fidelity to neritic zone but not any specific area in this habitat. *D. coriacea* is the only true pelagic sea turtle but *C. carreta* and *L. olivacea* are known to use both neritic and oceanic habitats (Godley *et al*., 2008). Olive ridley turtles which nest along the Odisha coast have been observed to have three different movement patterns post-nesting; (i) in which they move directly to the eastern offshore areas of Sri Lanka, (ii) move to the Bay of Bengal, or (iii) remain closer to the eastern coast of India (Satyaranjan Behera *et al*., 2018; S. Kumar, 2015).

The patterns of movement of sea turtles can be attributed to their feeding habits. Adult *C. mydas* and *E. imbricata* feed primarily on seagrass and sponges respectively (Bjorndal, 2017) which have patchy distribution and this might explain their fidelity to these habitats. Other carnivorous sea turtles do not have static prey and thus, their movement post-nesting might depend on the availability of prey (Plotkin, 2003). Species such as *N. depressus* and *L. kempii* feed on organisms that inhabit shallow neritic areas which might be the reason for them to have fidelity to these habitats rather than to any specific areas. *D. coriacea* feeds primarily on jellyfish and thus moves to oceanic habitats and do not forage in neritic areas (Bjorndal, 2017; Plotkin, 2003; Godley *et al.*, 2008). *C. carreta* and *L. olivacea* are generalists and feed on a wide variety of food and are known either to move to open waters or inhabit nearshore areas post-nesting (Plotkin, 2003; Godley *et al.*, 2008). The movement pattern observed for the *L. olivacea* satellite tagged from Odisha coast indicates two different foraging habitats or three different foraging areas.

Satellite telemetry, stable isotope and genetic studies have provided an understanding of the pattern of migrations and fidelity to nesting and foraging sites by different sea turtle species. Satellite telemetry has shown the movement of different sea turtles between their nesting and foraging habitats for different populations around the world (Godley *et al.*, 2008). Genetic studies have demonstrated strong population structure of nesting areas for *C. mydas*, *E. imbricata* and *C. carreta* (Bowen & Karl, 1997) and ridleys as well (Bowen & Karl, 1997; Shanker *et al.*, 2004) More recently, stable isotope analysis has been used to find the different foraging areas being used by populations of sea turtles. In addition to information about foraging areas, stable isotopes also provide knowledge about foraging by these turtles which is difficult to study by either direct observation or gut analysis for oceanic turtles.

2.3 Uses of Stable Isotope Analysis in Studies Related To Foraging Ecology

Stable isotopes are extensively used for understanding the different aspects of the foraging ecology of sea turtles (Figgener, Bernardo, & Plotkin, 2019). Elements in nature are present in multiple isotopic forms and the ratio of heavy to lighter isotopes changes with geographic areas. Usually, carbon and nitrogen isotopes are used for studying the foraging ecology of organisms (Eder *et al*., 2012; Fry, 2006; Zbinden *et al*., 2011). The concentration of these isotopes in the tissue of an organism can be used to describe its trophic level, geographical area of foraging and the pathways of metabolism in its metabolic system (Fry, 2006). The isotopic ratio of carbon depends mostly upon the primary producers of the food chain and the geographical location where the animal is foraging. Nitrogen isotopes provide information on the trophic level of the organisms and also on the areas of foraging (Fry, 1988). Heavy carbon is known to be equal or in slightly higher concentration in neritic areas than oceanic areas (McClellan, Braun-McNeill, Avens, Wallace, & Read, 2010; Snover, Hohn, Crowder, & Macko, 2010; Wallace, Seminoff, Kilham, Spotila, & Dutton, 2006) Heavy nitrogen is present at higher concentration in organisms of higher trophic level and in marine systems shows a latitudinal decrease towards the poles (Fry, 2005; Snover *et al*., 2010).

Isotopic studies of sea turtles have provided much insight into their ecology. Study of isotopic concentrations from different growth rings of sea turtle bones has shown the change in feeding patterns from juvenile to adult (Avens *et al*., 2013; Eder *et al*., 2012; Ramirez, Avens, Seminoff, Goshe, & Heppell, 2015). Like in studies of many terrestrial and marine species, isotopic ratios in tissues of turtles and their prey have shown foraging niche of the different sea (Biasatti, 2004; Bolten, 2010; Godley, Thompson, Waldron, & Furness, 1998). Comparative studies of sea turtles from different ocean habitats have shown differences in their isotopic ratios and these can be due to the different nutrient cycling patterns in different areas (Wallace *et al*., 2006). Many studies have used stable isotope analysis combined with satellite telemetry to find foraging areas for different sea turtle populations (Eder *et al*., 2012; Zbinden *et al*., 2011). If the stable isotopes are used in a study without satellite telemetry, the foraging area cannot be located with any degree of certainty, but the differences in the geographical location of these areas can be accessed using cluster analysis, as was done by Vander Zanden, Bjorndal, Reich, & Bolten, (2010) for *C. caretta*. Stable isotope analysis thus provides a relatively efficient method to study the foraging ecology of sea turtles.

2.4 Objectives

There is limited information with regards to three primary aspects of olive ridley turtles for the Indian population *viz.*, the foraging ecology of solitary nesting turtles from different parts of the coast, information on the beach characteristics of *arribada* nesting areas and the microplastic presence in these beaches. Thus this study focuses on the following objectives

(i) To explore patterns of spatial segregation during foraging exist by comparing stable isotopic ratios of carbon in tissues of *L. olivacea* from different nesting areas

(ii) To examine the characteristics of olive ridley sea turtle nesting beaches in Rushikulya, Odisha.

(iii) To assess microplastic presence in the *arribada* nesting beach of Rushikulya

2.4.1 Research questions:

(i) Do animals present in different breeding areas have specific patterns of foraging?

(ii) What are the beach characteristics of nesting sites selected by olive ridley sea turtles?

(iii) What is the abundance of microplastics in the *arribada* nesting beach of Rushikulya?

3. Study Area

3.1 Beach Characteristics

To understand the beach characteristics of *arribada* nesting grounds, Rushikulya was selected as the study area. Mass nesting in Rushikulya was discovered in 1993-94 by Pandav, Choudhury, & Kar, (1994). Mass nesting in this area is observed only north of the river mouth while solitary nesting is observed on the beaches both north and south of the river mouth. This nesting beach is located in the Ganjam district of Odisha.

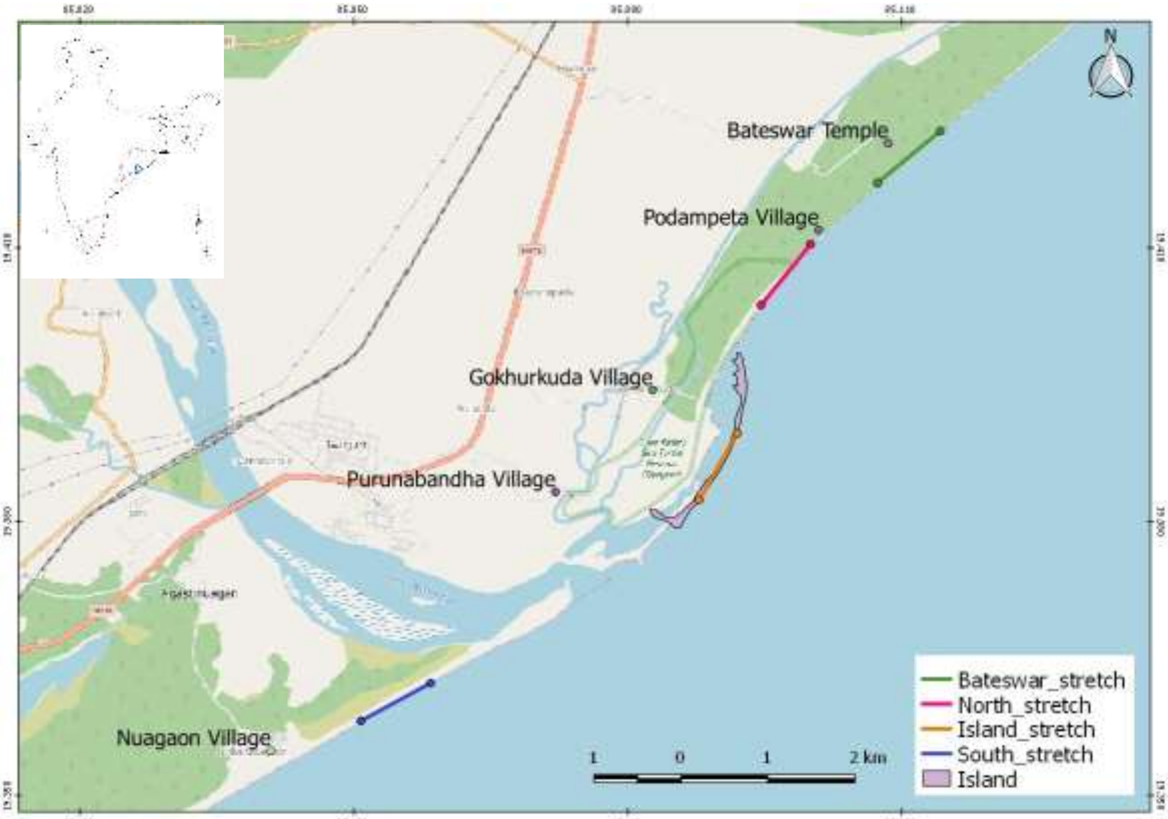

Figure 3.1: Map of the study area (Rushikulya)

The mass nesting beach is highly dynamic and changes annually. Sandbar formation on the river mouth has been observed for many years. During this study, a 3 km long sandbar was present at the river mouth. The sandbar was isolated from the main beach till February 2019 and then the northern and southern ends got connected to the mainland beach due to sand deposition. No nesting was observed on the mainland beach areas which were shielded by the sandbar.

The beaches on both the sides of the river mouth are scattered with dunes which can be more than 2 meters high in some areas. These beaches are backed by *Anacardium pes-caprae* and *Casuarina* plantation and have natural vegetation of *Ipomea pescaprae, Spinifex littoreus* and *Hydrophylax maritima.* Purunabandha, Gokhurkuda and Padampeta are the three villages north of the river mouth. On the southern side, Nuagaon village is present about 5 kilometre south of the river mouth.

Four 1 kilometre long stretches of beach were selected for intensive sampling based on their location and the type of nesting observed in previous years. The first stretch is on the southern beach of river mouth which only has solitary nesting and is referred to as “South”. The second stretch was selected on the sandbar present in front of the main nesting beach and referred to as “Sandbar”. The third stretch lies on the mass nesting beach and is referred to as “North”. The fourth stretch is further north of the mass nesting ground and near a temple called Bateshwar and is referred to as “Bateshwar”.

3.2 Microplastic Assessment

For the objective of microplastic assessment, only the main mass nesting beach was selected for intensive sampling. The Beach from Purunabandha village to Bateshwar temple was selected as the intensive sampling area. Mass nesting is usually observed on this stretch and sampling was carried out in 5 sites along this stretch.

3.3 Patterns of spatial segregation

For this objective, sampling was carried out at the nesting beaches in Rushikulya, Odisha and Chennai coast in Tamil Nadu. These beaches are more than 850 Kilometres apart, which is higher than the observed inter-nesting distance for any olive ridley turtle on the Indian coast (Tripathy & Pandav, 2008). The Chennai coast has solitary nesting and the Rushikulya coast has both solitary and arribada nesting. Sample collection in Chennai coast took place from Koovam river mouth till Neelangarai which is 14 kilometre south of this river mouth. Most of the beaches here are either public or have fishing settlements. Both Rushikulya and Chennai get dead stranded turtles along the coast. While Rushikulya does not have much trawling, Chennai has a large number of trawlers operational along the coast. Similarly, mechanised fishing in Chennai is much more than in Rushikulya (Bavinck, 2005; Tripathy & Rajasekhar, 2009)

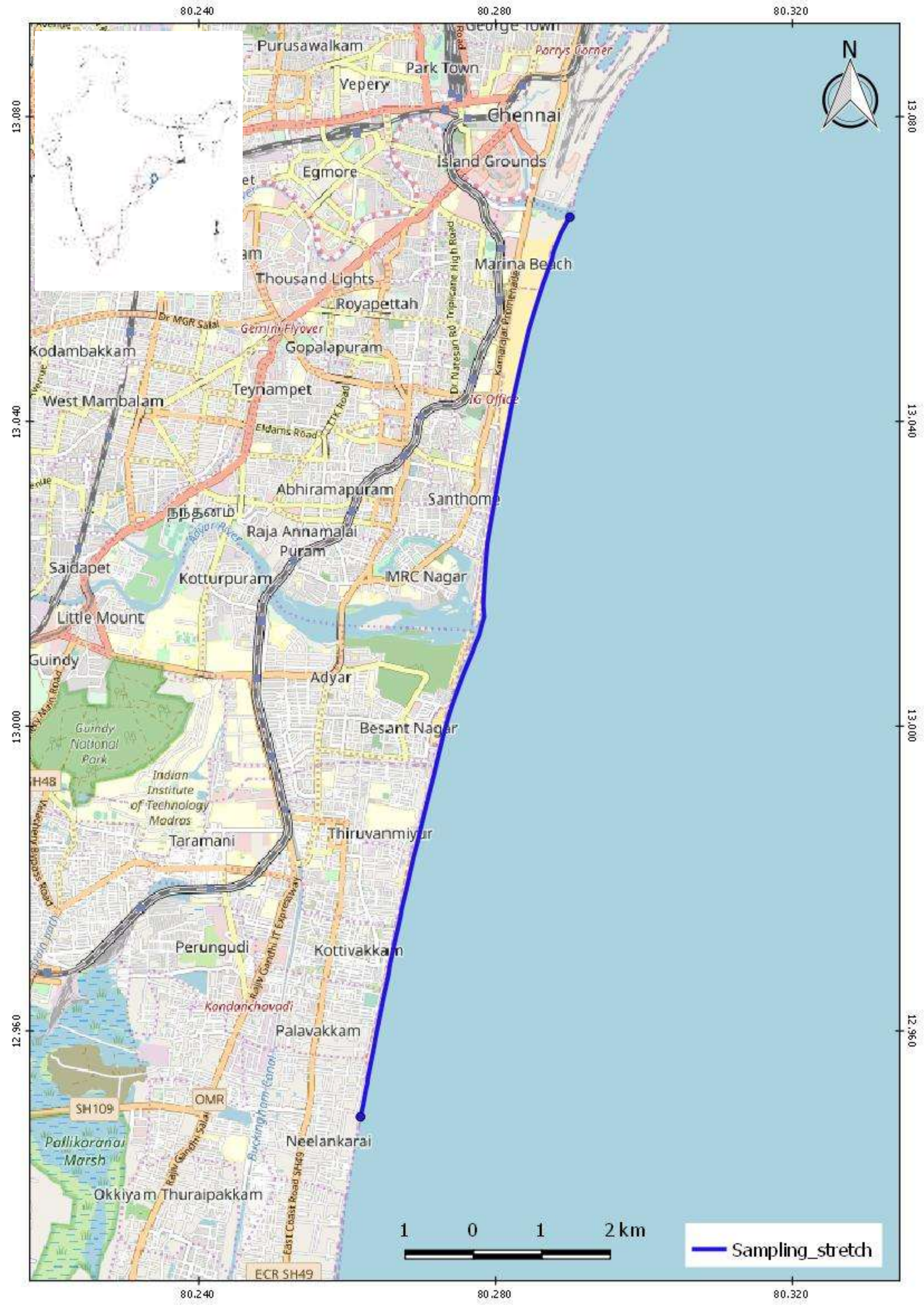

Figure 3.2: Map of the study area (Chennai)

4. Materials and Methods

4.1 Nesting habitat characteristics

4.1.1 Field Methods

To understand the nesting habitat characteristics, four sections of beaches of 1km each were selected from the study area based on their relative positions to the river mouth and the type of nesting in these areas. These intensive sampling sections were: (i) Stretch “South” - South of Rushikulya river mouth, (ii) Stretch “Sandbar”- sandbar near the river mouth which extended till 2.5 km north of the river mouth, (iii) Stretch “North”- main nesting beach which is 3 km north of the river mouth and (iv) Stretch “Bateshwar”- which was 5 km north of the river mouth. These sections of the beach were sampled at 100-meter intervals. Sand samples were collected from 3.5 meters (marked as pointA) and at 50 meters above high tideline line (marked as point B) at every 100 meters for the given stretches. For areas with beach width less than 50 m, sand sampling was done 5 meters before the vegetation line. Sand samples were taken from the sampling points at 35-45 cm depth (the average depth of *L. olivacea* nests) using a sand corer of 3cm radius and stored in airtight plastic bags for the lab analysis of moisture, salinity and average particle size.

The width of the beach at sampling locations was taken as the distance between the high tideline and the vegetation line. The method suggested by Emery (1961) was used for measuring the average slope of the beach. Metal scales of 200cm were placed every 10 meter distance from the high tide line till vegetation line. For a given height on one scale, the reading on the same horizon on the next scale was identified using a clinometer and then marked. The difference in height was measured and used for finding the slope (θ) by the following formula;

$$\theta = \tan^{-1}\left[\frac{Distance\ between\ two\ adjecent\ scales}{Difference\ in\ height}\right]$$

4.1.2 Lab Methods

About 100 gram of sand from the collected samples were dried in a hot air oven for 48 hours at 60°C. The moisture was calculated in percent weight difference.

$$Moisture\ percentage = \frac{(Moist\ weight - Dry\ weight)}{Moist\ weight} \times 100$$

The dried sand was dry sieved and the particles were categorized into size class of 2360 µm -1180 µm, 1180 µm -600 µm, 600 µm -300 µm, 300 µm -150 µm and <150µm. The mean of sand particle size for each sample was found using the arithmetic method of moment formula with f as the frequency of the size class in percentage and m as the mid-point of the class interval;

$$Mean\ particle\ size = \frac{\sum fm}{100}$$

For checking the salinity of sand, 20 gram of sand from the dried sample was mixed with 100ml distilled water and the salinity of this solution was determined using salanity meter.

4.2 Microplastic assessment

4.2.1 Field Methods

To assess the microplastic presence, only the main beach on the northern side of the river mouth was sampled. The stretch of the mainland beach from the river mouth northwards till about a distance of 10 km is known to have *arribadas* in most years during the last decade. This stretch was selected as the sampling area for microplastic abundance. Sample collection was carried out it in 5 areas which were at 10, 30, 50, 70 and 90 percent of the length of the sampling area. Samples were collected from the recent strand line and at the turtle nesting line which is ~ 50 meter above the high tideline. Sand from surface till 2cm depth was collected from a 25cmx25cm quadrat using a metal spoon and stored in air tight plastic bags.

4.2.2 Lab Methods

The samples were dried in a hot air oven at 60°C for 48 hours. 50g of the dried sample was mixed in saturated solution of sodium chloride and stirred for 2 minutes and left for settling for 6 hours. For the extraction of microplastic, the supernatant of the settled solution was filtered using filter paper of 0.45 micron pore. Three extractions from the samples were done to extract the maximum amount of microplastic present in the sample. The filter paper was observed under a microscope at different magnifications to observe the number and type of microplastic particles present in the sand sample.

4.3 Segregation during foraging

Stable isotopes from various tissues of sea turtles have been used to study different aspects of their foraging ecology. Selection of tissue for stable isotope analysis depends upon the objective of the study. Bone tissue has isotopic information stored for different years as the growth rings remain intact for certain bones. Humerus bones were collected from the Chennai coast and areas near Rushikulya river mouth. These two locations are more than 850 kilometres apart, which is greater than the observed distance travelled by female turtles within a breeding season (Tripathy and Pandav, 2008).

4.3.1 Sample Collection:

For sample collection, the beaches in the study area were regularly visited for the collection of the samples from stranded olive ridley sea turtles. Since the annual growth rings are best represented on the humerus bones, this bone was collected for the stable isotope analysis. A total of 152 and 85 carcasses were encountered during the sample collection from Rushikulya and Chennai respectively. The humerus bone from many carcasses was missing due to the predation and only 72 and 46 bones were collected from Rushikulya and Chennai respectively. Samples (n=42) from Chennai was collected between December and February 2019 as the number of turtle stranding decreased by March. In Rushikulya, samples were collected between December and February 2019 (n=33). Additionally, samples were collected from the skeleton of turtles stranded in previous years (n=11) and from freshly dead turtles during the third week of March 2019 (n=14). A serial number was given to all the collected samples using plastic tag tied to them using nylon string. Sex and the curved carapace length were recorded from the carcass with intact carapace and flippers. Sex was determined based on the tail length and curvature of the nail on the front flipper.

4.3.2 Lab Methods

The collected bones were cleaned of all the muscle tissue mechanically and then by keeping them in hot water at 60°C. The cleaned bones were dried under the sun for two to three weeks. The bone measurement *viz*. maximal length, longitudinal length, proximal width, distal width and deltopectoral width was taken with an accuracy of 0.1cm for the morphometric analysis. A section of about 3mm was taken from the diaphysis of the humerus just distal to the insertion scar using an electric saw (Hitachi PDA100M) fixed with aluminium oxide blade. Sample for the stable isotope analysis was collected from the periphery of the bone cortex on the longitudinal-axis side of the section using Bosch GSB 600 RE drill set. First, the upper surface was scraped off to avoid any impurity and then bone was scraped from 0.5mm of the outer side of the bone. 0.5 mg of the sample was used for analysing the ratio of carbon isotopes. Stable Isotope Analysis was done using Isotope Ratio Mass Spectrometer Delta V with Flash 2000 Elemental analyser at Centre for Earth Science, IISc (Bangalore).

The values for stable isotope composition are represented in standard δ notation in parts per thousand (‰) relative to international standard. IAEA glucose was used as the international standard for analysis. The following formula was used to calculate values of $\delta^{13}C$ for samples:

$$\delta^{13}C = \left[\left(\frac{R_{Sample}}{R_{Standard}}\right) - 1\right] \times 1000$$

Here, R_{Sample} is the ratio of heavy carbon to lighter carbon ($^{13}C/^{12}C$) in the sample and $R_{Standard}$ is the ratio of heavy carbon to lighter carbon ($^{13}C/^{12}C$) for an international standard.

5. Statistical Analysis

5.1 Nesting Habitat Characteristics

All the statistical analysis was implemented in R 3.4.1 software. Descriptive statistics for all the parameters were computed. Non-parametric Kruskal Wallis tests were used for the analysis of the difference in beach slope and width for different stretches. Analysis of Variance (ANOVA) was used to check if the sand characteristics were different for the different points representing samples from the high tide and nesting sites. Since there was no significant difference between these points, they were pooled to check for differences between the different stretches and tested using ANOVA.

Kruskal Wallis test was used to check the differences in salinity, moisture and average particle size of the sand samples from the four study stretches separately for the points near the high tideline (A) and the ones on turtle nesting site (B). Since the sandbar was geomorphologically different from the other three mainland beaches, the above analysis was repeated, excluding this stretch. Post-hoc pairwise comparison was done between the four stretches using Tukey's HSD test to check for the differences between each stretch.

5.2 Segregation during Foraging

Correlation for the curved carapace length (CCL) of turtles and corresponding ^{15}C were checked. While CCL was not available for all the turtles sampled, the maximal length of the humerus bone was available for these samples. As there is a high correlation between the maximal length and CCL (Kumar, Baburam, Pandav, & Mahapatra, 2014), the correlation between maximal length and ^{15}C was checked. A two Sample t-test was used to test for differences in the values of ^{15}C for the samples from Chennai and Rushikulya. First, the comparison between the two areas was conducted for the samples collected from the turtles that were stranded between December 2018 and February 2019. Then, the comparison of Chennai samples was done with the pooled data of all the Rushikulya samples.

6. Results

6.1 Nesting Habitat Characteristics

Moisture content of sand at nesting depth in both the points A (high-tide line) and B (nesting line) were observed to be uniform (ANOVA, P=0.273). Similar patterns was also observed in the case of the mean sand particle size (ANOVA, P= 0.215). However, salinity at nesting depth for the samples from the points A and B were significantly different (P<0.05)

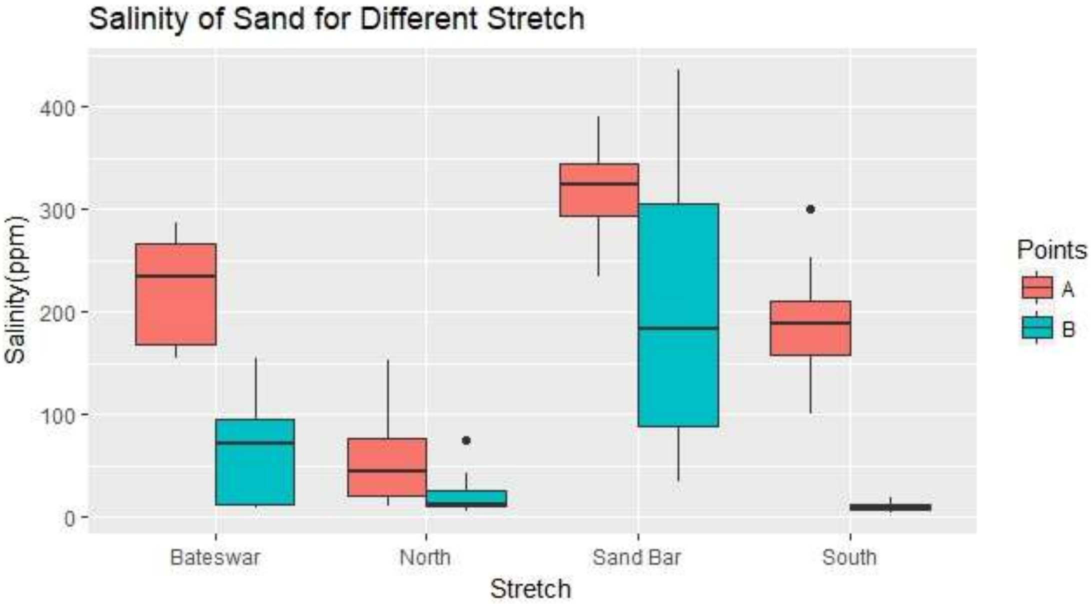

Figure 6.1: Salinity of Points A and B for the different study stretches

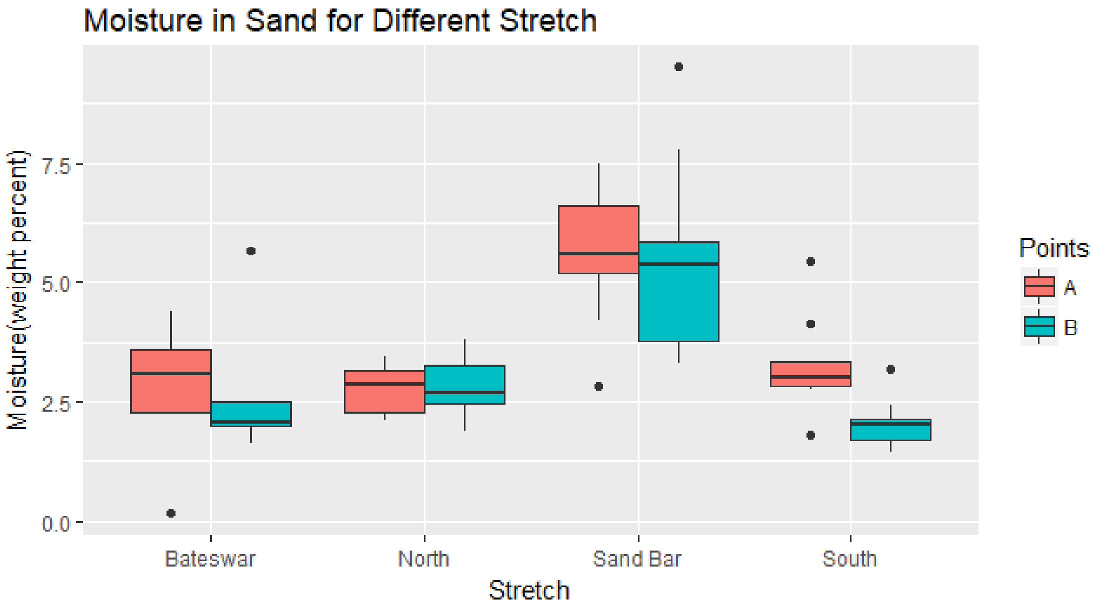

Figure 6.2: Moisture in samples of Points A and B for the different study stretches

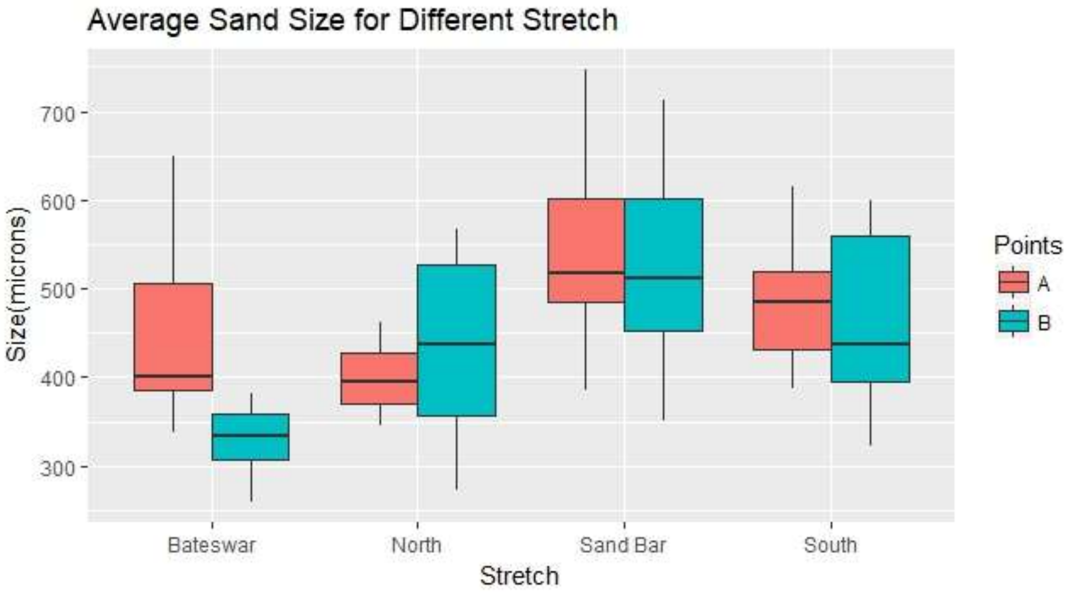

Figure 6.3: Average sand size of samples from Points A and B for the different study stretches

6.1.1 Beach width

The average widths of the nesting beach at different sections of Rushikulya were 71.8 m ±2.12 (SE), 42.21 m ±2.142 (SE), 58.3 m ±7.036 (SE) and 29.3 m ±1.844 (SE) at South, Sandbar, North and Bateshwar respectively. The beach width varied significantly at different stretches (Kruskal–Wallis H test, P <0.05). The post-hoc comparison showed a significant difference between all the four stretches (Table 6.1).

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	10344.68	3	3448.225	22.25978	2.51E-08	2.866266
Within Groups	5576.7	36	154.9083			
Total	15921.38	39				

ANOVA Table for Beach width

Between	**Adjusted P-Value**
Sandbar-Bateshwar	0.1143
North-Bateshwar	0
South-Bateshwar	0
North-Sandbar	0.0006
South-Sandbar	0
South-North	0.0061

Table 6.1: Adjusted P-values of Pairwise comparison of beach width between stretches using Tukey’s test

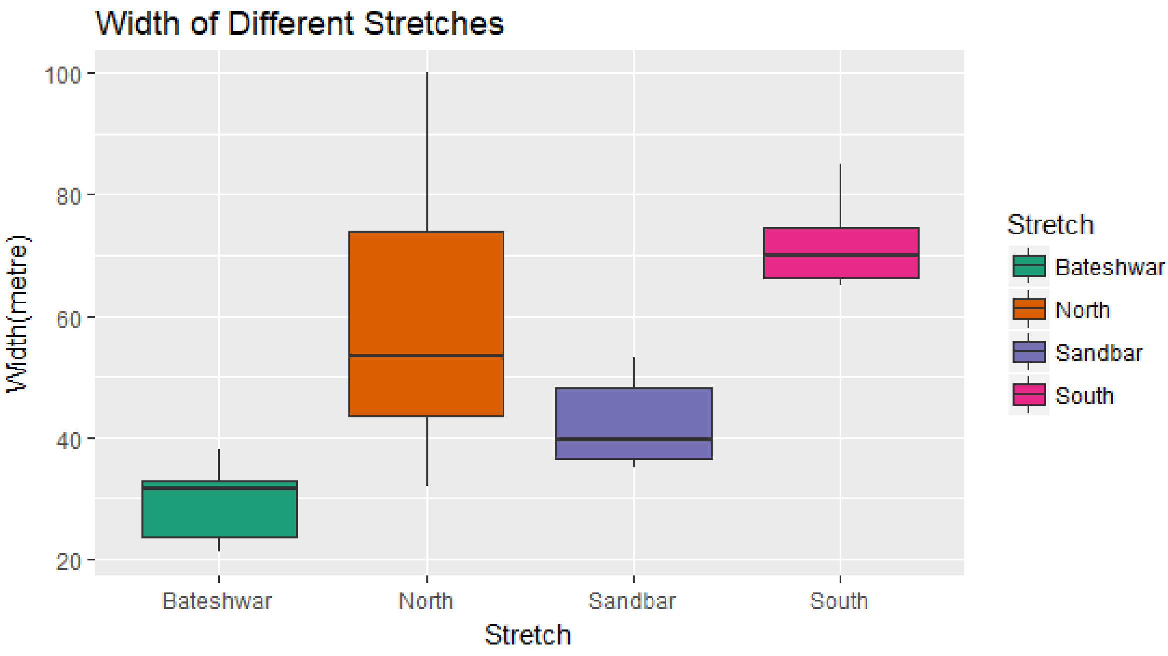

Figure 6.4: Average beach width of four study stretch in degree.

6.1.2 Slope of the beach

The average slope of the beach (in degrees) from high tide line towards the vegetation line was estimated as 0.7854 ±0.11(SE), -1.1565 ±0.142(SE), 0.573 ±0.244(SE) and 0.698 ±1.99(SE) at the stretch South, sandbar, North and Bateshwar, respectively.

Similar to beach width, the slopes also varied between stretches significantly (Kruskal–Wallis H test, P<0.05). Post-hoc pairwise comparison showed that the slope of the sandbar was significantly different from all the other beaches (see table 6.2).

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	25.68343	3	8.561145	25.98544	4.02E-09	2.866266
Within Groups	11.86053	36	0.329459			
Total	37.54397	39				

ANOVA table for beach slope

.

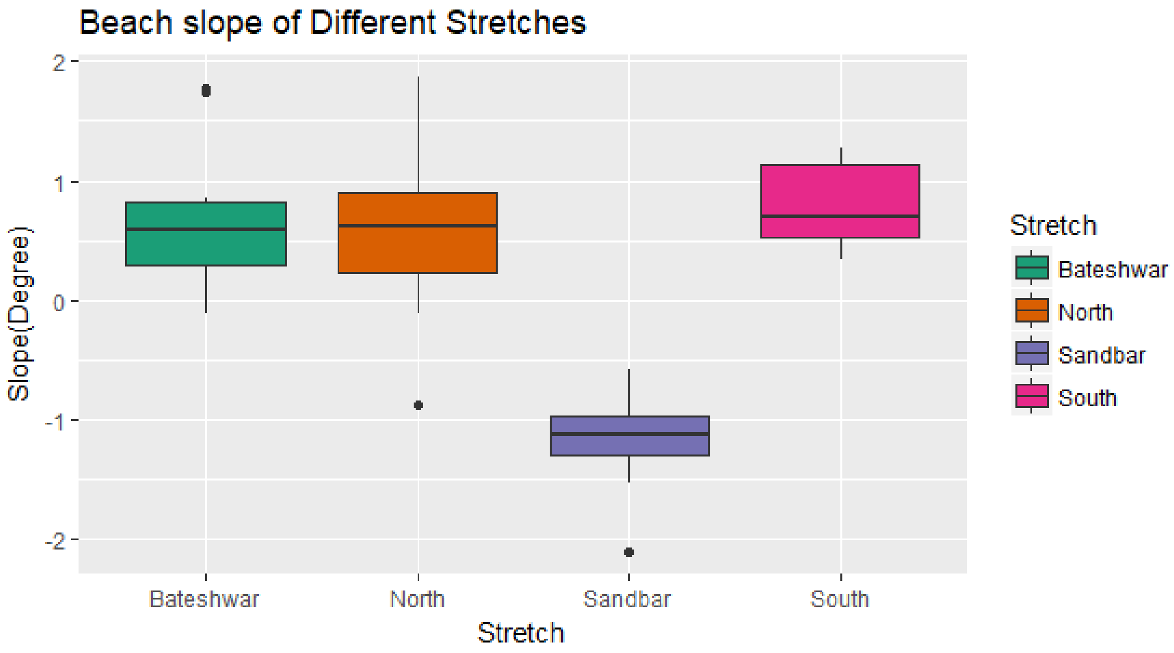

Figure 6.5: Average Slope of the beach of four study stretch in degree.

Between	**Adjusted P-Value**
Sandbar-Bateshwar	0
North-Bateshwar	0.6897
South-Bateshwar	0.99
North-Sandbar	0
South-Sandbar	0
South-North	0.6349

Table 6.2: Adjusted P-values of Pairwise comparison of beach slope between stretches using Tukey's test

6.1.3 Salinity

The salinity near the high tide line of different stretches was estimated as 198.03 ppm ±22.66 (SE), 319.57 ppm ±14.61 (SE), 57.843 ppm ±19.85 (SE) and 220.86 ppm ±21.07 (SE) at the stretch of South, Sandbar, North and Bateshwar, respectively. The salinity at the turtle nesting area of different stretches was estimated as 10.23 ppm ±1.565 (SE), 207.6 ppm ±47.38 (SE), 22.59 ppm ±6.85 (SE) and 64.3 ppm ±21.24 (SE) at the South, Sandbar, North and Bateshwar, respectively.

The salinity at high tide line was significantly different between the study stretches of nesting beach (ANOVA, $P<0.05$). Similarly, salinity at the nesting line of different stretches of beaches was also varied significantly (ANOVA, $P<0.05$).

6.1.4 Moisture

Moisture contents at different stretches of nesting beaches were measured in weight percentage as 3.278±0.339%, 5.5942±0.43%, 2.788±0.183% and 2.765±0.52% for the south, sandbar, North and Bateshwar, respectively at the high-tide lines (points A). Moist contents at nesting line (point B) was calculated as 2.042±0.155%, 5.45±0.626%, 2.817±0.183% and 2.622% at the south, sandbar, North and Bateshwar, respectively.

Moisture contents at nesting depth at the high-tide line (point A) and nesting line (point B) was more or less same (ANOVA, $P=0.273$). However, the moisture contents at nesting depth were significantly different between four stretches (ANOVA, $P<0.05$).

Island sandbar was found to be different from all the other stretches except the south by post-hoc pairwise comparison (table 6.3).

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	102.8538	3	34.28461	24.89497	6.17E-11	2.741574
Within Groups	92.27041	67	1.37717			
Total	195.1242	70				

ANOVA table for sand moisture

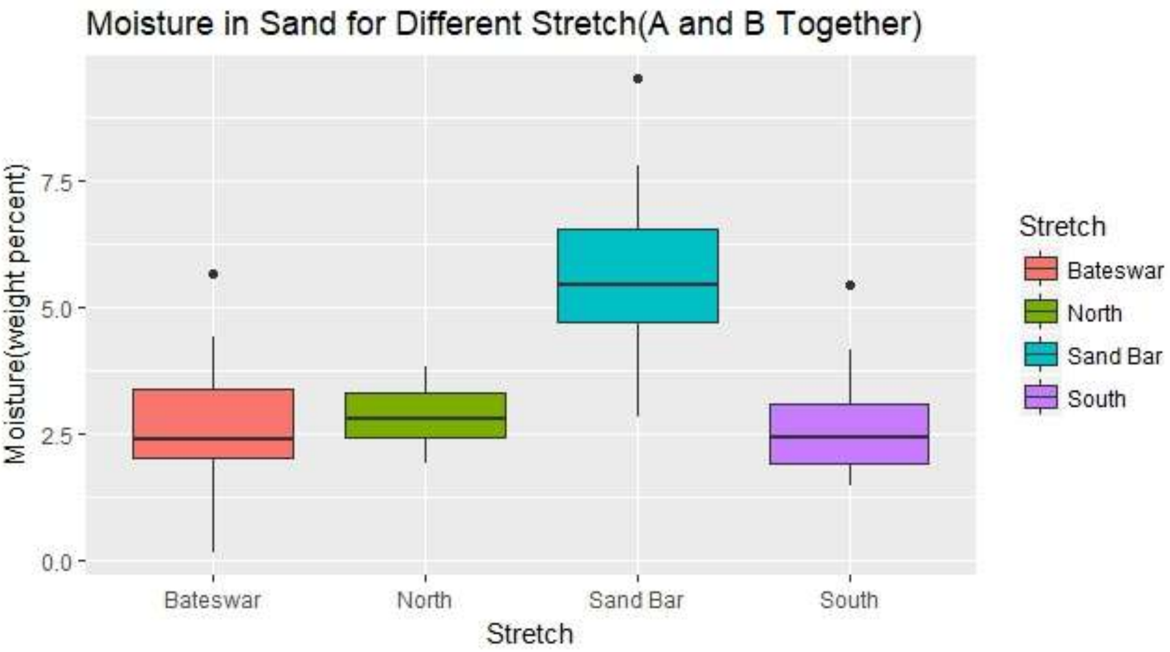

Figure 6.6: Moisture in the samples collected from points A and B of four study stretch.

Between	Adjusted P-Value
Sandbar-Bateshwar	0.00032
North-Bateshwar	0.8364
South-Bateshwar	0.089
North-Sandbar	0.00307
South-Sandbar	0.1791
South-North	0.37872

Table 6.3: Adjusted P-values of Pairwise comparison of sand moisture between stretches using Tukey's test

6.1.5 Sand particle size

The mean size of the sand particles was measured as 483.75 µm ±23.36, 547.8 µm ± 34.5, 399.47 µm ±16.13 and 453.41 µm ±42.78 at high-tide lines of South, sandbar, north and Bateshwar beaches respectively. The mean size of the sand particles at nesting area was measured as 462.05 µm ±32.29, 523.19 µm ±35.05, 435.43 µm ±32.43 and 329.82 µm ±16.12 South, sandbar, north and Bateshwar, respectively.

The mean size of sand particles did not vary significantly between the high tide line and nesting lines of the beaches (ANOVA, P=0.215). However, the mean size of sand particles was significantly different between the studied stretches (ANOVA, P<0.05). Post-hoc pairwise comparison showed that North and sandbar were significantly different from each other and the same was true for the comparison between sandbar and Bateshwar (Table 6.4).

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	208523.4	3	69507.78	7.539524	0.000206	2.743711
Within Groups	608462	66	9219.121			
Total	816985.3	69				

ANOVA table for beach slope

Between	**Adjusted P-Value**
Sandbar-Bateshwar	0.0003
North-Bateshwar	0.836
South-Bateshwar	0.0896
North-Sandbar	0.0030
South-Sandbar	0.1791
South-North	0.3787

Table 6.4: Adjusted P-values of Pairwise comparison of sand size between stretches using Tukey's test

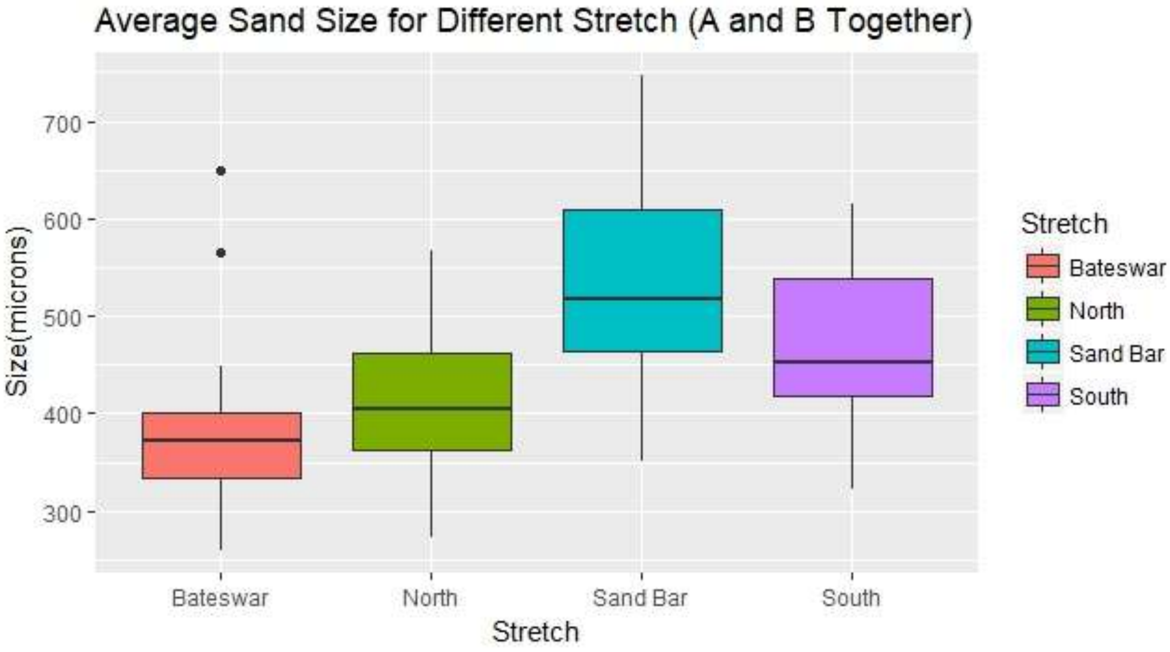

Figure 6.7: Mean sand particle size of the samples collected from the four study stretches.

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6.2 Microplastic Assessment

Microplastic was found in all samples that were collected from different parts of different nesting beaches along Odisha coasts. The observed number and type of microplastic observed varied between different sampling points and are given in Table 6.7, where SL is the samples collected from strand line and the TNL are from the turtle nesting line.

The abundances of microplastic were estimated more at the strandline (1200±162 (SE) per kg) than the nesting lines (960±50 (SE) per kg). Line/ fibre was the most abundant type of microplastic found in all the samples whereas the foam was the least abundant type. Microplastic pollution in Rushikulya was observed to be alarmingly at a higher rate when compared to other parts of the world. The low proportion of pellet and foam in the samples can be due to their poor detection or due to the absence of any major city on the banks of Rushikulya River.

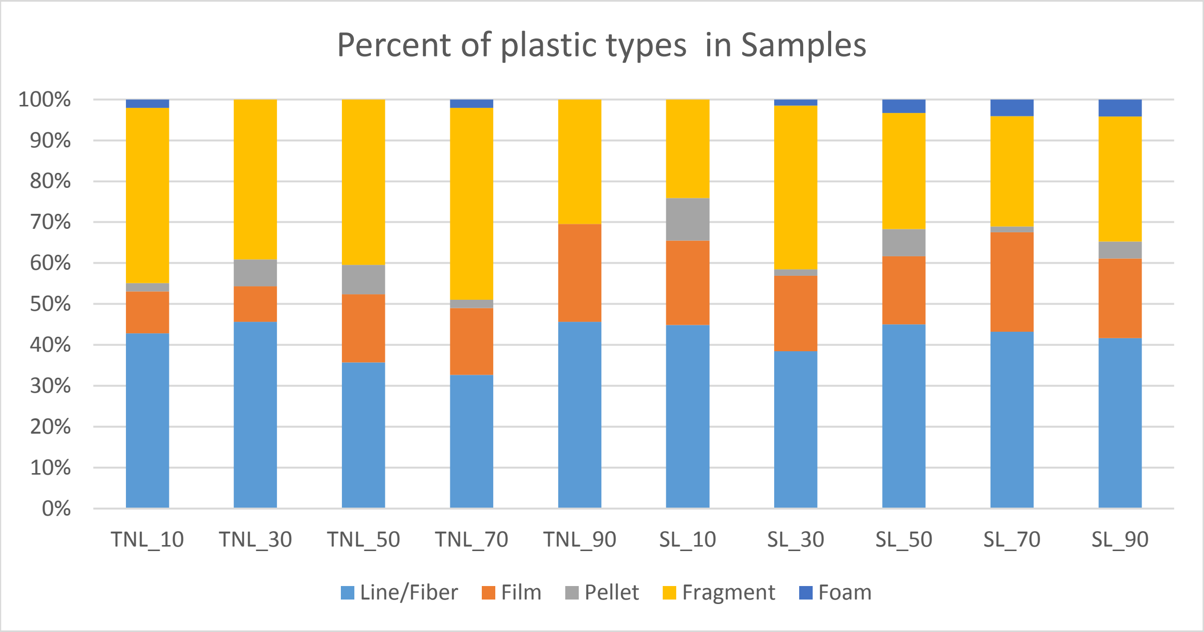

Figure 6.8: Percent of microplastic belonging to different categories in the given samples

For Turtle nesting Line

	Line/Fiber	*Film*	*Pellet*	*Fragment*	*Foam*	*Total*
Mean	18.8	7	1.6	18.6	0.4	48
Standard Error	1.356466	1.224745	0.6	1.568439	0.244949	2.50998
Median	21	7	1	18	0	46
Standard Deviation	3.03315	2.738613	1.341641	3.507136	0.547723	5.612486
Sample Variance	9.2	7.5	1.8	12.3	0.3	31.5
Minimum	15	4	0	14	0	42
Maximum	21	11	3	23	1	57
Sum	94	35	8	93	2	240
Count	5	5	5	5	5	5

For strand line

	Line/Fiber	*Film*	*Pellet*	*Fragment*	*Foam*	*Total*
Mean	25.4	12	2.4	18.4	1.8	60
Standard Error	3.325658	2	0.6	3.203123	0.583095	8.142481
Median	27	12	3	20	2	65
Standard Deviation	7.436397	4.472136	1.341641	7.162402	1.30384	18.20714
Sample Variance	55.3	20	1.8	51.3	1.7	331.5
Minimum	13	6	1	7	0	29
Maximum	32	18	4	26	3	74
Sum	127	60	12	92	9	300
Count	5	5	5	5	5	5

Table 6.5: Number of microplastics of different type found per 50g of samples.

	Line/Fiber	*Film*	*Pellet*	*Fragment*	*Foam*
TNL_10	36.84211	8.77193	1.754386	36.84211	1.754386
TNL_30	45.65217	8.695652	6.521739	39.13043	0
TNL_50	35.71429	16.66667	7.142857	40.47619	0
TNL_70	32.65306	16.32653	2.040816	46.93878	2.040816
TNL_90	45.65217	23.91304	0	30.43478	0
Average	39.30276	14.87476	3.49196	38.76446	0.75904
SL_10	44.82759	20.68966	10.34483	24.13793	0
SL_30	38.46154	18.46154	1.538462	40	1.538462
SL_50	45	16.66667	6.666667	28.33333	3.333333
SL_70	43.24324	24.32432	1.351351	27.02703	4.054054
SL_90	41.66667	19.44444	4.166667	30.55556	4.166667
Average	42.63981	19.91733	4.813595	30.01077	2.618503

Table 6.6: Percent of microplastic belonging to different categories in the given samples.

6.3 Stable isotope analysis

The mean value for $\delta^{13}C$ for the bone tissue of Chennai turtles was found to be -9.58±0.244 (SE) and for Rushikulya, it was 10.5±0.24 (SE) (Table 6.8). The $\delta^{13}C$ value for Odisha turtles stranded between December 2018- February 2019 was -9.91±0.27 (SE).

	Mean	SE	Median	SD	SV	Range	Min	Max	n
Chennai	-9.58	0.244	-9.617	1.584	2.509	6.964	-12.77	-5.806	42
Odisha_All	-10.5	0.246	-10.22	1.871	3.502	8.341	-14.219	-5.879	58
Odisha_Dec-Feb19	-9.91	0.271	-9.74	1.559	2.431	6.394	-13.066	-6.672	33

Table 6.7: $\delta^{13}C$ values for samples from different areas

Carbon isotope ratio between the Rushikulya and the Chennai turtles varied significantly ($P<0.05$) when all turtle samples that were collected throughout the year were pooled together. However, there were no significant differences in the isotope $\delta^{13}C$ values between samples of these two sites concerning turtles that stranded during the peak nesting period i.e. December to February ($P=0.366$).

Sea turtles those stranded from December to February at Chennai as well as Rushikulya seems to be from a similar type of foraging areas as their carbon isotope $\delta^{13}C$ ratio was not much different. However, there was a temporal difference in carbon isotope $\delta^{13}C$ ratio values between turtles those stranded during December-February and the rest of the year (Two Sample t-test, P=.0.0115). Further, the $\delta^{13}C$ values were neither correlated to CCL ($R=0.204$) nor the maximal length of the humerus ($R=0.102$) of samples.

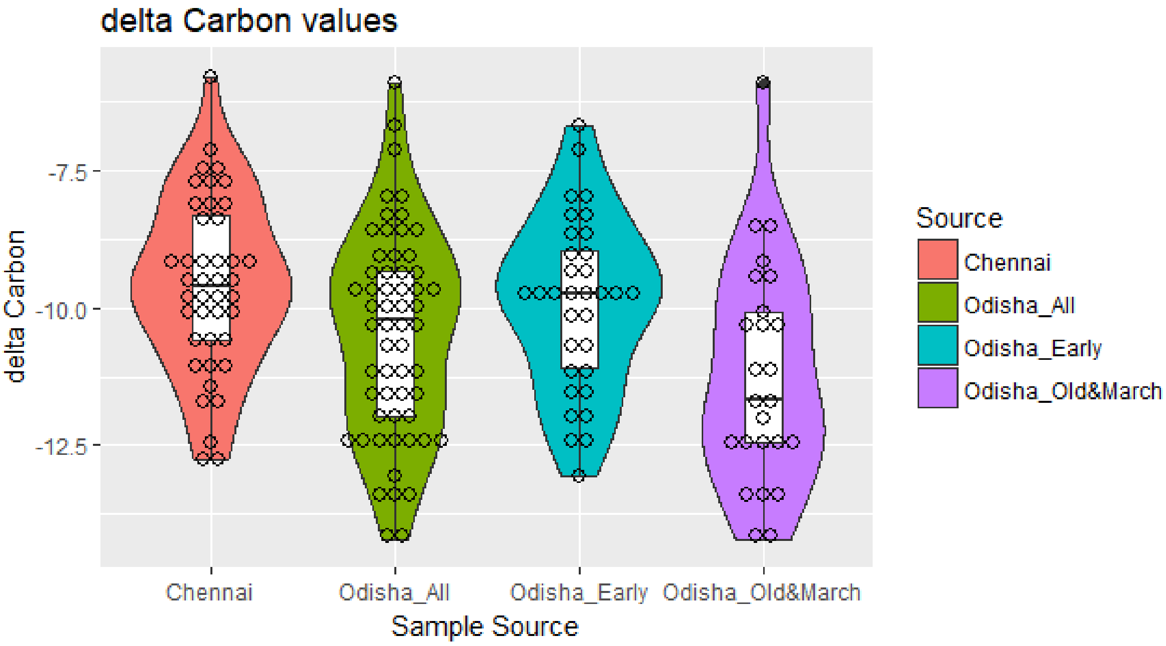

Figure 6.9: Violin plot showing values of $\delta^{13}C$ of the samples collected from humerus of turtles from Chennai (Dec18-Feb19), Odisha_All (Dec18-March19 and previous year samples), Odisha_Early (Dec18-Feb19) and Odisha_Old&March(previous years+March2019). Circles representing individual $\delta^{13}C$ values

7. Discussion

7.1 Nesting habitat characteristics pertinent to sea turtle

Studies on nesting site selection for sea turtles usually focuses upon the characteristics of the beach only at the surface level as female turtles can interact only with these characteristics for cues for nesting. The characteristics at the nesting depth are usually examined in studies focusing on the effect of these characteristics on hatching success and hatchling fitness. Studies on the nesting site selection of loggerhead and olive ridley sea turtles have shown patterns of changes in surface characteristics from high tide line till the vegetation (Muralidharan *et al.*, 2009; Wood & Bjorndal, 2009). For the three sand characteristics of the nesting beaches observed in this study, only salinity was found to be significantly different for the points near the high tide line and on average nesting line. This might show some important characteristics such as moisture and sand sizes are homogenous in a beach if looking for the nesting depth in comparison to characteristics on the surface.

The development of the sea turtle embryo is affected by many sand characteristics (Ackerman, 2017) and in an event such as an arribada where lakhs of eggs are present in beaches, these characteristics might play an important role in their development. Moisture is needed for the proper development of the eggs to facilitate gas exchange (Ackerman, 2017). The particle size of sand affects the moisture retention of the sand as well as the exchange of gases (Ackerman, 1997). In our study, we found that the stretch south of the river mouth had high moisture at nesting distance but smaller particle size. On the sandbar, the sand had larger particles, as well as higher moisture, increasing the porosity and gas exchange, which might make this region capable of supporting more nests than the mainland beaches. Salinity in the sandbar is higher than the rest of the stretches which might be due to the salt water surrounding it, but for mainland beaches, the observed lower salinity might have been due to dilution by ground water or absence of sea water or both. For the sandbar, the average slope was negative, showing a decrease in the beach height at nesting line while the opposite was true for the mainland beaches. The extreme values of moisture and salinity for the sand bar could be the effect of beach height.

My study found that there were no differences in the sand moisture contents and soil particle sizes between the high-tide line and nesting line of nesting beaches. Female turtles might be nesting well above the high tide line due to the less salinity in the sand and to prevent nest loss due to erosion that is very common in these areas. The sandbar that had more moisture, bigger soil particles with high salinity and more chances of erosion had more sporadic nests. This could be due to its higher sand moisture and larger sand particle size in the nesting area as well as isolation from the mainland. It was also observed that the beaches that underwent more geo-morphological changes during the study period (Sandbar and North) had relatively more nests, which is similar to the observation that was made earlier (Behera, Tripathy, & Choudhury, 2015).

Arribadas in Gahirmatha rookery usually takes place on sand bars and adjacent islands (Shanker *et al*., 2006). When the sandbar is present in Rushikulya, mass nesting may occur on sandbar and adjacent northern beach. No mass nesting occurred in

Rushikulya during the study period, but there were three events when more than 150 turtles nested in one night. In these events, most of the nesting happened on the sandbar. Also, the false crawl by females, which is the behaviour where they arrive on the beach and return to the water without nesting even without the presence of any disturbance, was only observed on the sandbar. In terms of nesting habitat characteristics, the study stretch on this sandbar was significantly different from all the other mainland stretches. This unique characteristic of sandbar could be due to its geomorphological placement and it cannot be inferred that the turtles have selected the sandbars for arribada nesting. In the years when no sandbar is present on the river mouth and mass nesting happens on the mainland beaches, it is not known if the characteristics of mainland beach with mass nesting will have similar characteristics as observed for sandbar or will be significantly different from other mainland beaches of this study.

7.2 Microplastic Assessment in the nesting beaches

Rushikulya is one of the only two sites in India that have large active *arribadas*. Gahirmatha being the other site already have a decreasing trend in the arribada nesting due to unsuitable nesting area (Behera *et al.*, 2015). Nesting Olive ridleys are now threatened by another factor that is microplastic. I found the high level of microplasitc contents in the sand of nesting beaches at Rushikulya. Ingesting of plastic is an obvious threat to the nesting turtles and their hatchlings. The presence of the plastic can also raise the temperature of the sand, imperilling the outcome of the hatching.

Fibrous particles were the most abundant category of microplastic in all the samples. These are the most easily detected particles and mainly come from the clothing and fishing gears. Foam and pellet were the least abundant particle categories and were most difficult to identify. This was due to the presence of shells which appeared similar to foam and remnant sand particles and organic materials which looked similar to the pellet. The low number of pellets could be because Rushikulya River does not have many major cities that can act as the source of these particles or due to poor detection of these particles.

Between the two types of sampling locations, microplastic was found to be more on strandline sediments. Both the higher and lower extremes of microplastic abundance were observed on samples from the strand line. A large amount of organic matter was present in the nesting beach, making the identification of microplastics difficult. In cases of doubt, the particles were double checked with the hot needle test. The observed data (in numbers/50grams) was extrapolated to numbers/kg to compare our results with other studies and the number of microplastics ranged from 580 /kg to 1480 /kg with a mean of 1097.77±98 (SE).

Using the standard protocol for assessment of microplastic in beaches, studies have found microplastics in a range of few hundred particles per kilogram to Two thousand particles per kilogram (Karthik *et al*., 2018; Lots, Behrens, Vijver, Horton, & Bosker, 2017; Hamid *et al*., 2018). Because the number of extractions done by the studies is not always available, chances of underestimation are possible in many studies. For our study, the observed value of microplastic for Rushikulya falls in the higher range of microplastic pollution, and there is the possibility of even more microplastic present if it is considered that the pellets and foam particles were detected poorly.

Microplastic pollution in Rushikulya is observed to be very high when compared to other parts of the world. The reason for such a high accumulation of microplastics on Rushikulya beaches can be due to its location. River mouth areas in Tamil Nadu coast have a significantly higher abundance of microplastic (Karthik *et al*., 2018) due to the discharge by the river. In the presence of river outlet and oceanic tides, the river mouth areas, which are the prime nesting areas of olive ridley becomes more vulnerable to microplastic pollution. A high concentration of microplastics in turtle nesting sites could pose a significant threat to turtle hatching success and hatchling sex ratios by raising the temperature of the nesting site. The microplastics in the sand can heat it when exposed to high temperatures, and in places such as Rushikulya where the temperatures can be very high during the nesting period, it can change the overall temperature of the nest. Sex in turtles is determined by temperature during egg development, and higher nest temperature leads to a higher number of females being born. The skewed sex ratio has already been observed as a result of rising temperature due to climate change, many places in the world and microplastic should not further enhance this phenomenon of skewed sex ratio. Therefore, it is high time to device technology to clean-up micro plastic at least from the mass nesting beaches.

7.3 Differences in foraging habitats

Little is known about the non-breeding areas of the olive ridley nesting along the Odisha coast. The few flipper tag recoveries of turtles tagged in Odisha (Behera, Tripathy, Sivakumar, & Choudhury, 2015; Dash & Kar, 1990; Tripathy & Pandav, 2008) and a satellite tracking study in 2001 (Shanker *et al*. 2003) reported turtles to move to the Sri Lankan waters. The information gathered on the offshore movement of the turtles from the telemetry study of Wildlife Institute of India has revealed that minimum three different populations of Olive Ridley turtles that occur in the Bay of Bengal (Behera *et al*., 2018; S. Kumar, 2015) based on their non-breeding habitat locations. They are a) turtles that use nearby off-shore areas as foraging habitat (resident population), or use far away deep-sea areas near Sri Lanka (migratory population) and c) turtles that move to deeper areas of Bay of Bengal for foraging.

In this context, I hypothesised that turtles nesting in mass nesting grounds and sporadic nesting grounds might be using two different foraging areas. To test my hypothesis, I collected samples for stable isotope analysis from multiple growth rings of the humerus for turtle stranded in the study area. Thus, the $\delta^{13}C$ values for the samples represented long-term foraging carbon isotope ratio related to foraging. If the turtles have shifted between various habitats during these last few areas, the observed $\delta^{13}C$ values represented average values from these multiple habitats. Size related variation in foraging habitats for the females of different sizes has been observed for loggerhead sea turtles. We checked if the $\delta^{13}C$ values were related to CCL of turtles or any of the bone morphometric measurements for the samples and found no pattern of size related variations as seen in loggerhead sea turtles. Similarly, Kumar (2015) found that the satellite tagged olive ridley turtles did not show size related differences in post nesting movement.

Chennai and Rushikulya turtles were significantly different in terms of their carbon isotope ratios. The same was true when the analysis was carried out with only the turtles that were stranded in the year 2019. Since the samples for Chennai were presented only for the turtles that got stranded between December and February, a separate analysis was done taking only those Rushikulya turtles which got stranded between December and February. This analysis did not find any significant differences between the turtles from the two areas. The $\delta^{13}C$ values for the old Odisha samples and from March were not significantly different from each other and had lower average values than other samples. These two groups of samples were pooled together and were found to be different from the Chennai as well as early season samples of Rushikulya.

In North America, studies have found organisms near the coast, having higher values of $\delta^{13}C$ than those from deep oceans (Snover *et al*., 2010). If the same is true for the Bay of Bengal, samples with higher $\delta^{13}C$ values might have fed in neritic habitat and the ones with lower $\delta^{13}C$ values in deeper parts of the ocean. Based on this, one may infer more turtles in Rushikulya might have been feeding in open ocean habitat than the ones from Chennai. Temporal variation in the arrival of turtles from different foraging areas to Rushikulya might be the reason for variation in $\delta^{13}C$ values for different months and years. Also, the samples of previous year turtles show lower carbon ratios, which might suggest that during arribada years, more turtles from some specific foraging area arrive in Odisha for nesting.

Satellite tagged olive ridley on the western coast of Africa were seen to have a similar movement pattern but differed in the isotopic ratios showing multiple foraging habitats within a given area (Dawson, 2017). If this is true there can be three or more foraging areas for the olive ridley sea turtles of the eastern coast of India as three different patterns of post nesting migrations have been observed (Kumar, 2015). The spatial and temporal difference in the carbon isotope values in this study can be due to various reasons and if there are different foraging areas in deeper parts of the ocean or neritic areas, carbon isotopes alone may fail to detect the differences. Analysis of nitrogen isotope along with the carbon isotopes is required to detect a difference in foraging areas. The pattern of isotopic ratios for Rushikulya turtles of 2019 might differ from other years as no large arribada was seen this year and what will be the effect of arribada turtles on the overall isotopic ratio for a nesting area is not known. For now, it can be presumed that turtles nesting solitarily, especially from December to February along the east coast of India might have used a similar foraging area.

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