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# Environmental cues for mass nesting of sea turtles

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ABSTRACT

Mass nesting of Olive Ridley sea turtles at Rushikulya rookery exhibit interannaul variability in population size as well as location of nesting site. This year mass nesting was observed over sand spit (0.25 million) and sporadic nesting (0.05 million) at the rookery and the nesting population surpassed all previous records. The present study examines multiple environmental cues (beach width, volume, shoreline change, foreshore slope, sediment grain size, littoral environmental observation, wind speed and direction) during mass nesting events to assess the factor(s) which favour mass nesting and also the reasons for the record mass nesting over a new site (sand spit). Analysis of results indicates that beach/spit to the north of the river mouth with medium width, mild slope and medium sand grain is a favoured location for mass nesting. Near shore oceanographic conditions conducive for mass nesting are low saline near shore surface water, low energy and relatively longer period south southeasterly waves. Local wind burst with a few days lag/lead of the new/full moon appears as one of the most important factors which trigger mass nesting. Environmental cues for selection of mass nesting site and the factor triggering the mass nesting revealed in the present study are of paramount importance for rookery management and conservation of the vulnerable sea turtles.



## 1. Introduction

Olive Ridley (*Lepidochelys olivacea*) sea turtles inhabit tropical and subtropical sea throughout the world. They travel through the world's ocean and return to the natal beach for nesting which occurs at different times around the world. In spite of the Olive Ridley being the most abundant sea turtles, information on its population size is extremely scarce and uneven across the regions. As per the estimate of the Marine Turtle Specialist Group (MTSG) of the International Union for the Conservation of Nature (IUCN) (http://www.nmfs.noaa.gov/disclaimer.htm), there has been a 50% reduction in population size of Olive Ridley since 1960s. In the Western Atlantic Ocean (Surinam, French Guiana, and Guyana), there has been an 80% reduction in certain nesting populations (USFWS, 2005) since 1967. Rough estimates put the worldwide population of nesting females at about 800,000 (http://animals.nationalgeographic.co.in/animals/reptiles/olive-ridley-sea-turtle/). The United States lists the western Atlantic population of Olive Ridleys as endangered and all other populations as threatened (http://www.nmfs.noaa.gov/pr/species/turtles/oliveridley.htm). However, at present the Red List category of Olive Ridley is put as Vulnerable A2bd ver 3.1 and has been downlisted one step from endangered (Abreu-Grobois and Plotkin, 2008; IUCN, 2012). A2 bd category mentioned above refers to an observed, estimated, inferred or suspected population size reduction of $\geq$30% over the last 10 years or three generations, whichever is the longer, where the reduction or its causes may not have ceased or may not be understood or may not be reversible, based on an index of abundance appropriate to the taxon (b) and actual or potential levels of exploitation (d). Sea turtles have significant ecological and economic importance. Green sea turtles help in maintaining healthy seagrass beds (Bjorndal, 1980; Thayer et al., 1984), Hawksbill sea turtles help colonization of coral reefs (Leon and Bjorndal, 2002), the loggerheads trails affect the compaction, aeration and nutrient distribution of the sediment (Bjorndal and Jackson, 2003) as well as the species diversity and dynamics of the benthic ecosystem (Preen, 1996), sea turtles improve their nesting beaches through supply of a concentrated source of high quality nutrients which in turn aid in the growth of vegetation and stabilization of dunes (Bouchard and Bjorndal, 2000) and sea turtles help maintain a balanced food web (Gibbons and Richardson, 2009; Purcell et al., 2007). Sea turtles provide increased survival rates (Dellinger et al., 1997) and enhanced foraging (Frick et al., 2004). Olive

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Ridleys provide perching grounds for seabirds and also offer location to roost, feast and hide for birds and fish at sea (Pitman, 1993). Historically, Olive Ridley has been exploited for food, bait, oil, leather, and fertilizer. Harvesting eggs has the potential to contribute to local economies, and the practice has been attempted in several localities (Plotkin, 2007). Olive Ridleys display a complex life cycle and have three modes of reproduction: mass nesting, dispersed nesting, and mixed strategy (Bernardo and Plotkin, 2007). Mass nesting or "arribada" represents the synchronous behavior of the turtles which occurs over a period of days when hundreds to thousands of female turtles come to the beach and lay eggs.

There are three important mass nesting sites (rookeries) of the Olive Ridley along east coast of India. All of them are in Odisha; namely Gahirmatha, Devi and Rushikulya (Pandav et al., 1998; Shanker et al., 2004). Out of the three rookeries in Odisha, Rushikulya is the latest and was discovered in 1994 (Pandav et al., 1994). Since its discovery, turtles are nesting en masse at this rookery but with fluctuations from year to year (Table 1). Turtles inhabit the coastal waters of Odisha from November to May while "arribada" occurs during January to March. Arribada is the event which occurs most often at night when female turtles crawl to a dry and secure/solitary part of the beach and begin preparing their nest for laying eggs. The arribada event continues for 2–10 days. However, the period of arribada in the three rookeries along Odisha coast have lag/lead relationship and are not synchronous (Shanker et al., 2004). Very little is known about why sea turtles nest on some beaches and not on others. Theories on what triggers an arribada, including offshore winds, lunar cycles, and the release of pheromones by females exist. However, actual cues for ridley arribadas are yet to be determined. In the present study, it is aimed to reveal the possible conditions/environment to which the sea turtles prefer while selecting the particular beach as their nesting habitat as well as the condition(s) which triggers the mass nesting event.

Factors driving the selection of a nest site on a specific beach are not well understood for sea turtles (Miller et al., 2003; Kamel and Mrosovsky, 2005) and was suggested as one of the important areas for future research (Hawkes et al., 2009). Wood et al. (2000) examined the relation of temperature, moisture and salinity of the beach sand along with the slope of the beach to nest site selection in loggerhead sea turtles and concluded that slope has greater influence on nest site selection. Several other factors (infrequent inundation, well ventilated beach and near shore oceanographic conditions) also influence in the choice of an optimal nesting site (Miller, 1997; Foley et al., 2006). Many factors are also responsible for the success/failure of mass nesting. Nesting sites near to the water are at primary risk of inundation leading to erosion of beach while increase in distance from water may have the adverse impact on hatchling like disorientation (Kamel and Mrosovsky, 2005). Distance between the nest site and highest spring tide line (HSTL) or vegetation line is also significant during the nesting time (Kamel and Mrosovsky, 2004). Prusty et al. (2005) suggested that depositional environment along with other twelve geomorphologic characteristics favour mass nesting at Gahirmatha rookery in Odisha. Besides coastal development (Pandav et al., 1998), the factors for failure of mass nesting in some of the rookeries in Odisha are nesting habitat loss due to wave induced erosion and cyclonic events (Prusty et al., 2000). Pethick and Crooks (2000) emphasized the need to monitor the coastal geomorphological changes for sustainable coastal resource management and to maximize their yield of economic and environmental services. Effective implementation and enforcement of coastal regulation zone (CRZ) laws was suggested to prohibit unplanned coastal development for coastal zone management (Panigrahi and Mohanty, 2012) including construction setback regulations for mitigating sea turtle nesting beach loss (Fish et al., 2008). Geo-environmental conditions of a nesting beach during and prior to the nesting event are important cues for selection of a particular beach by the Olive Ridley sea turtles as their nesting habitat while the conditions after the nesting are important for hatching success leading to increase in hatchling population. Mazaris et al. (2009) evaluated the impact of coastal squeeze in sea turtle nesting and suggested that understanding the effect of nesting habitat loss as a factor leading to hatchling reduction is essential to establish conservation plans for the recovery of sea turtle population. Yet the information for Rushikulya rookery is not available. Therefore, the present study which examines the environmental cues responsible for mass nesting including the geo-environment assumes importance.

**Table 1**
Estimated nesting population of olive ridley sea turtles and the period of arribada.

| Year | Nesting estimated (million) | Period of arribada/mass nesting | Source of data |
|---|---|---|---|
| 1994 | 0.200 | 1–8 March | Pandav et al., 1994 |
| 1995 | 0.050 | 14–16 March | Pandav, 2001 |
| 1996 | 0.055 | 06–08 March | Pandav, 2001 |
| 1997 | 0.035 | 31 Jan. and 3 Feb. | Pandav, 2001 |
| 1998 | 0.025 | 20–23 March | Pandav, 2001 |
| 1999 | Not available | Sporadic nesting (no arribada) | Shanker et al., 2004 |
| 2000 | Not available | Sporadic nesting (no arribada) | Shanker et al., 2004 |
| 2001 | 0.159 | 26 Feb.–04 March | Shanker et al., 2004 |
| 2002 | Not available | Sporadic nesting (no arribada) | Orissa State Forest Dept. |
| 2003 | 0.208 | 09–14 March | Orissa State Forest Dept. |
| 2004 | 0.203 | 20–21 Feb. & 10–15 March | Orissa State Forest Dept. |
| 2005 | 0.089 | 15–18 Feb. & 14–17 March | Orissa State Forest Dept. |
| 2006 | 0.198 | 04 & 26 March | Orissa State Forest Dept. |
| 2007 | Not available | Sporadic nesting (no arribada) | Orissa State Forest Dept. |
| 2008 | 0.180 | 04–10 March | Orissa State Forest Dept. |
| 2009 | 0.261 | 10–19 Feb. | Orissa State Forest Dept. |
| 2010 | 0.156 | 14–16 March | Orissa State Forest Dept. |
| 2011 | 0.252 | 3–10 March | Orissa State Forest Dept. |
| 2012 | 0.101 | 29 Feb.- 4 March | Orissa State Forest Dept. |
| 2013 | 0.300 | 13–20 February. | Orissa State Forest Dept. |

## 2. Materials and methods

### 2.1. Study area

Fig. 1 depicts the study area which encompasses the Rushikulya river mouth(s), the conventional mass nesting beach from village Purunabandha to village Podampeta (Rushikulya rookery) and the record mass nesting site of 2013 (sand spit). The study area is part of south Odisha coast, east coast of India. Rushikulya River has now two mouths; an old mouth and a new mouth which was cut open by the villagers on 4th November, 2012 to avoid water logging and flood due to heavy rainfall (116–140 mm) on 3rd November, 2012 in the locality. Prior to the opening of the new mouth, the river was running parallel to the shoreline with the sand spit to its right and the Rushikulya rookery to its left and was opening to the Bay of Bengal at the old mouth (Fig. 1). Northward growth of sand spit is a common phenomenon along Odisha coast due to round the year longshore transport from south to north (Mohanty et al., 2012). The river had also two mouths during the nesting season (January–March) of 2012; the old mouth and another mouth to the north of old mouth which is now closed. Since the discovery of the rookery in 1994, mass nesting of Olive Ridley mostly occurred at the Rushikulya rookery (Fig. 1) but with fluctuations in nesting population from year to year (Table 1).

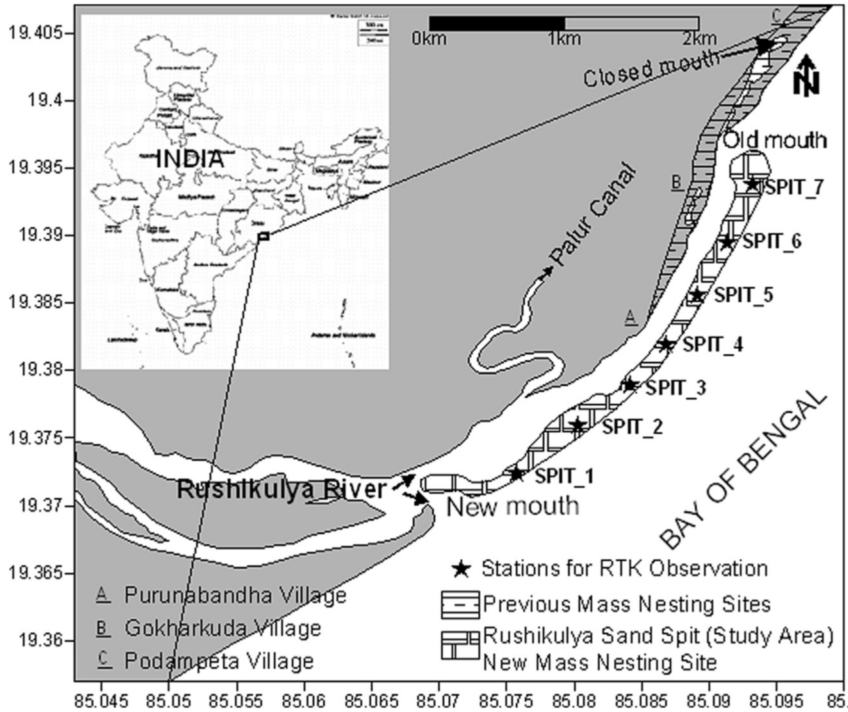


**Fig. 1.** Study area and station locations.

### *2.2. Beach profile, shoreline change and sediment grain size analysis*

Beach profile, shoreline change (foreshore berm position), sediment characteristics and the associated atmospheric and oceanographic conditions near the record mass nesting site (sand spit) and Rushikulya rookery were monitored. Leica SR 1200 model Real Time Kinematic (RTK) Global Positioning System (GPS) with position accuracy $\pm1$ cm and elevation accuracy $\pm2$ cm is used for beach profile monitoring. Beach Morphology Analysis Package (BMAP) version 2.0 of U.S. Army Corps of Engineers is used for computation of beach width and volume. Leica Differential Global Positioning System (DGPS) Arc Pad is used for mapping shoreline or berm position and the shoreline change (change in area due to oscillation of foreshore berm in the landward/seaward) was analysed in a Geographical Information System (GIS) environment using Arc View 3.2a software. Retsch AS 200 Automatic Sieve Shaker is used for the grain size analysis and the grain size statistics are generated using GRADISTAT software (Blott and Pye, 2001). Details of the methodology adopted are same as in Mohanty et al. (2012). Wind speed and direction at an interval of 3 h collected from the nearest meteorological station at Gopalpur of the India Meteorological Department (IMD) are analysed using WRPLOT software of Lakes Environmental software. Littoral Environmental Observations (LEO) are taken following Schneider (1981) to measure the wave direction, wave period, breaker type, breaker height, breaker angle, and swash/backwash velocities.

### *2.3. Data*

Data on beach profile, shoreline change, sediment grain size and LEO observed during the record mass nesting event of 2013 are used for the present study along with the data on shoreline change and sediment grain size of the sand spit for 2011 and 2012. Information on nesting population and periods of mass nesting from 1994 to 2013 has been used from various sources as detailed in Table 1. Wind speed and direction of the nearest meteorological station at Gopalpur for the nesting period from 1994 to 2013 were collected from the Indian Meteorological Department.

## 3. Results

Mass nesting occurs at the Rushikulya Rookery every year since its discovery in 1994 except for the failures during four years (Table 1). In 2012, mass nesting occurred on the sand spit between old mouth and closed mouth (Fig. 1) and also on the beach to the north of closed mouth (near Podampeta village). It was reported (Forest and Environment Department, Govt. of Odisha) that the nests/eggs laid on the sand spit as well as on the beach north of the closed mouth were washed away due to high waves and erosion of the north beach. Following the mass nesting event from 10 to 19 February, 2009 (Table 1), the nesting beach was eroded due to waves of 2.3 m height recorded on 13th March, 2009 (Mohanty et al., 2012) and the turtle eggs were washed out (Fig. 2a and b). Occasional failure of the mass nesting and hatching at Rushikulya rookery is attributed to the erosion of the nesting beach due to high energy wave. Also, coastal development (Pandav et al., 1998), predation by wild animals and birds (Mohanty et al., 2008; Tripathy and Rajashekhar, 2009), plantations of casuarinas (Chaudhari et al., 2009) and misorientation due to artificial lighting (Karnad et al., 2009) are considered as threats to the nesting population and hatchlings at the Rushikulya rookery.

The major geo-environmental conditions which prevailed at the record mass nesting site (Fig. 1) in 2013 are presented here. In 2013, mass nesting on the sand spit started on the night of 12th February and continued till 20th February, 2013 (Forest and Environment Department, Govt. of Odisha). For the first time record mass nesting was observed over the sand spit (0.250 million) and sporadic nesting at the Rushikulya Rookery (0.050 million). Interestingly the total nesting population (0.300 million) surpassed all previous records. Fig. 2c depicts the moderate slope of the record mass nesting site (sand spit) during February, 2013 while Fig. 2d depicts the

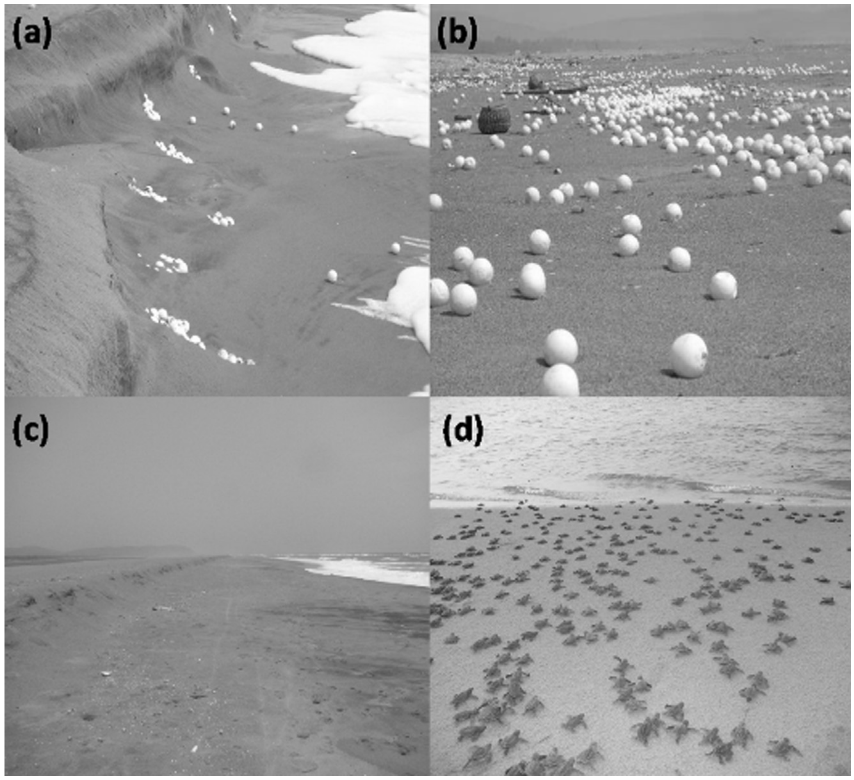


**Fig. 2.** (a) erosion of the turtle nesting beach due to high waves (b) washed away and exposed sea turtle eggs predated by birds, dogs and other wild animals during March, 2009 (c) moderate foreshore slope during February, 2013 and (d) successful turtle hatching during April, 2013.

successful hatching and release of hatchlings at the sand spit during April, 2013. Fig. 3 depicts the beach profiles taken over seven transects (distance maintained between two consecutive transect is 500 m) on the sand spit during February and March, 2013. Beach width (the distance along $x$-axis of Fig. 3 increases from river-side to sea-side) in all transects (SPIT-1 to SPIT-7) increased while foreshore slope decreased (except at SPIT-5 and SPIT-7) from February, 2013 to March, 2013. Table 2 presents a detailed statistics on beach width, volume, foreshore slope of the sand spit during February and March, 2013, and sediment characteristics of the sand spit during record mass nesting time (February, 2013). Mass nesting population was very high between SPIT-3 and SPIT-6 while it was relatively low at Spit-1, Spit-2 and Spit-7. During record mass nesting period (February, 2013), the beach between Spit-3 to Spit-6, recorded high nesting population and had width relatively less as compared to the width of the adjacent beach (Spit-2 and 7). The foreshore slope of the beach between Spit-3 to Spit-6 was also less than that of the Spit-1 and Spit-2 and more than that of Spit-7. Beach at Spit-7 was extremely flat (more width, less volume and foreshore slope) and was prone to inundation during high wave and recorded low mass nesting population. The percentage distribution of sediment grain size (Table 2) shows that during the record nesting season in 2013, medium sand was highest followed by the coarse sand at the high mass nesting population site (SPIT-4 to SPIT-6), while medium sand followed by fine sand were present at the relatively low mass nesting population site (SPIT-1 to SPIT-2). Statistical properties of the grain-size distribution at the high mass nesting population site reveals moderately sorted to moderately well sorted, symmetrical (mostly negatively skewed) and either platikurtic or leptokurtic sediments (Table 2). Although, sediment grain size at Spit-7 was of similar nature as in Spit-4 to Spit-6, it was not preferred as a high mass nesting site due to its flatness and danger of inundation. In 2012, percentage distribution

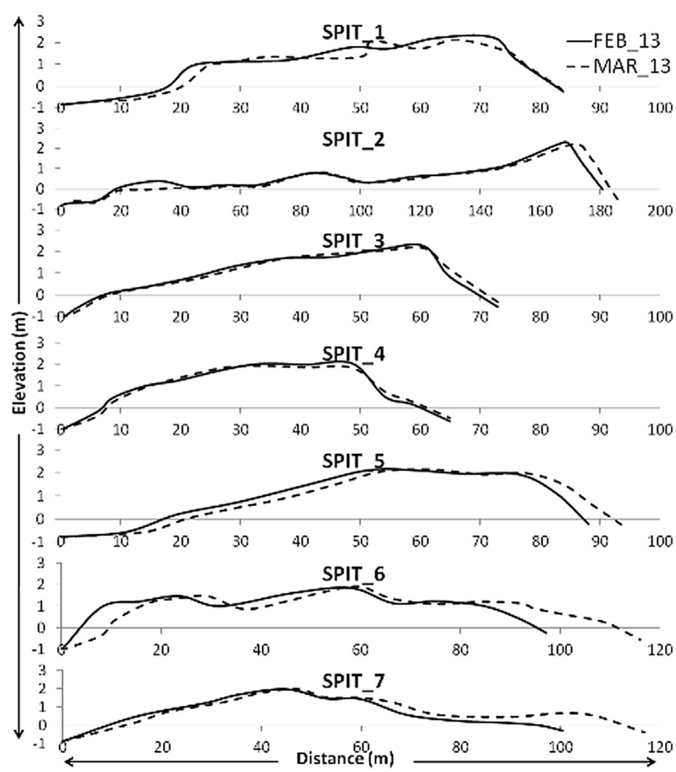


**Fig. 3.** Beach Profiles at Rushikulya sand spit during February and March, 2013.

**Table 2**
Beach width, volume, foreshore slope and sediment characteristics of Rushikulya sand spit.

| | | SPIT_1 | SPIT_2 | SPIT_3 | SPIT_4 | SPIT_5 | SPIT_6 | SPIT_7 |
|---|---|---|---|---|---|---|---|---|
| Beach Width(m) | FEB_13 | 82.5 | 180.62 | 69.76 | 59.95 | 87.29 | 95.37 | 96.15 |
| | MAR_13 | 82.89 | 183.46 | 71.22 | 61 | 92.32 | 111.29 | 112.83 |
| Volume (cu. m/m) | FEB_13 | 93.54 | 109.19 | 79.42 | 73.1 | 100.17 | 110.66 | 81.71 |
| | MAR_13 | 87.26 | 103.45 | 79.67 | 71.5 | 98.06 | 114.73 | 96.36 |
| Foreshore Slope (Degree) | FEB_13 | 10.75 | 11.30 | 10.20 | 7.40 | 6.27 | 4.57 | 2.29 |
| | MAR_13 | 10.20 | 11.30 | 9.64 | 6.27 | 6.84 | 3.43 | 2.86 |
| Sediment Characteristics Feb., 2013 | Coarse sand (%) | 6.5 | 6.5 | 6.5 | 25.5 | 40.5 | 26.5 | 33.0 |
| | Medium sand (%) | 52.5 | 61.0 | 25.5 | 58.5 | 51.5 | 65.5 | 56.0 |
| | Fine sand (%) | 36.5 | 26.0 | 25.5 | 15.0 | 8.0 | 8.0 | 10.5 |
| | Very fine sand (%) | 4.5 | 6.5 | 38.5 | 1.0 | 0.0 | 0.0 | 0.5 |
| | Mean | M | M | F | M | M | M | M |
| | Sorting | MWSt | MSt | PSt | MWSt | MSt | MWSt | MSt |
| | Skewness | Sym | FSk | CSk | Sym | Sym | Sym | Sym |
| | Kurtosis | MKt | MKt | PKt | LKt | PKt | LKt | MKt |
| Legends | M = Medium Sand, F = Fine Sand | | | | | | | |
| | MSt = Moderately Sorted, MWSt = Moderately Well Sorted, PSt = Poorly Sorted | | | | | | | |
| | FSk = Fine Skewed, CSk = Coarse Skewed, Sym = Symmetrical | | | | | | | |
| | PKt = Platykurtic, MKt = Mesokurtic, LKt = Leptokurtic | | | | | | | |

of fine sand was highest (67.5%) followed by very fine sand (25.5%) in the mass nesting sand spit which was inundated and there was failure in hatching. On the other hand, in 2011, the percentage distribution of coarse sand was highest (42.5%) followed by medium sand (35%) and fine sand (20.5%) in the sand spit which was a sporadic nesting site.

Compared to the length, perimeter and area of the sporadic nesting sand spit in 2011 (4.16 km, 8.72 km and 0.51 $km^2$), the mass nesting sand spit of 2012 (between old mouth and closed mouth) had smaller length, perimeter and area (2.01 km, 4.64 km and 0.20 $km^2$). However, the length, perimeter and area of the sand spit during the record mass nesting period in February, 2013 increased to 4.04 km, 8.55 km and 0.40 $km^2$ respectively which subsequently increased to 4.20 km, 8.66 km and 0.42 $km^2$ during March, 2013.

Fig. 4 depicts the position of the Rushikulya river mouth(s) and the sand spit from March 2011 to March 2013. It is clearly evident that the sand spit undergoes frequent transformation with time which results in either shifting of the old mouth to a new position towards north or opening of a new mouth. These frequent transformation of the sand spit also results in bringing geomorphological changes in Rushikulya rookery (Fig. 1) and consequently on the nesting population. More evidently, it has been observed that with the northward growth of the sand spit, the mass nesting site has sifted northward from A to C (Fig. 1). One of the reasons for selection of sand spit (between mouth G and F, Fig. 4) as the record mass nesting site in 2013 is the opening of a new mouth (E) during November, 2012.

Littoral Environmental Observation near the sand spit during February and March, 2013 reveals spilling breakers of height 1.28–1.40 m predominantly from SE/SSE with wave period ranging from 11.37 to 11.82 s. The swash/uprush (1.08 m/s) was less than backwash (1.15 m/s).

Table 3 depicts the wind speed on the day of nesting as well as before 1, 2 and 3 days of the nesting event from 1994 to 2013.

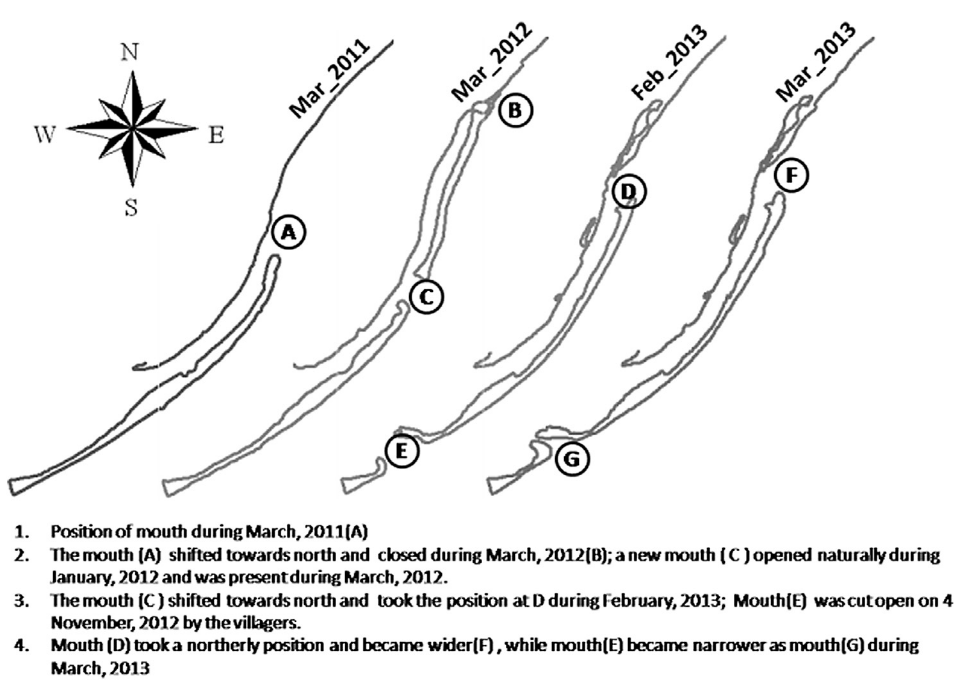


**Fig. 4.** Transformation of sand spit and shifting of mouth from March, 2011 to March, 2013.

**Table 3**
Wind speed (m/s) during the nesting events between 1994 and 2013. D represents the starting date of nesting event and C, B and A are the days before 1, 2 and 3 days respectively. Wind Direction represents the dominant/mean direction and their magnitudes (within bracket) during the nesting dates.

| Year | Maximum wind speed during a day | | | | Lead/lag of nesting event in day(s) from | | Wind direction (Deg) and magnitude (%) |
|---|---|---|---|---|---|---|---|
| | A | B | C | D | Full moon/new moon | Wind burst | |
| 1994 | 2.77 | 3.33 | 3.88 | (7.22) | −2 | 0 | 206 (59%) |
| 1995 | 3.88 | 5.00 | (5.27) | 3.33 | 3 | −1 | 199 (36%) |
| 1996 | 5.00 | 2.22 | 2.22 | 3.33 | −1 | | 231 (51%) |
| 1997 | 2.22 | 1.66 | 3.33 | (6.11) | −8 | 0 | 203 (41%) |
| 1998 | 2.22 | 2.77 | 1.66 | (3.88) | −7 | 0 | 199 (56%) |
| 2001 | 3.33 | 7.22 | (7.77) | 7.22 | −3 | −1 | 175 (50%) |
| 2003 | 3.33 | 3.88 | 3.88 | (5.00) | −6 | 0 | 182 (70%) |
| 2004 | 3.33 | 3.89 | (5.00) | 5.00 | 0 | −1 | 163 (11%) |
| | 5.00 | 3.33 | 3.89 | 3.89 | −4 | | 178 (34%) |
| 2005 | 2.77 | 6.11 | 3.33 | (6.11) | −7 | 0 | 185 (59%) |
| | 5.00 | 3.88 | 3.33 | 3.33 | −4 | | 182 (56%) |
| 2006 | 6.11 | 5.00 | 5.00 | (6.66) | −5 | 0 | 191 (92%) |
| | 3.88 | 3.33 | (5.00) | 5.00 | 3 | −1 | 192 (66%) |
| 2008 | 5.00 | 5.00 | 5.00 | (7.22) | 3 | 0 | 194 (44%) |
| 2009 | 3.89 | 2.77 | 4.16 | (6.11) | −1 | 0 | 204 (30%) |
| 2010 | 2.22 | 3.89 | 2.22 | 2.22 | 1 | | 188 (44%) |
| 2011 | 2.22 | 2.22 | 2.22 | 2.22 | 1 | | 174 (21%) |
| 2012 | 2.22 | 3.33 | 6.11 | (8.33) | −8 | 0 | 201 (61%) |
| 2013 | | 3.88 | (5.00) | 3.33 | −2 | −1 | 16 (42%) |

Besides, lead/lag relationship of nesting event with that of wind burst and full moon/new moon and percentage of occurrence of wind from specific direction are also presented. The results show that mass nesting occurs concomitantly with wind burst (increase of wind speed with time from A to D in Table 3) on 48% occasion while mass nesting with one day lag of the wind burst and with no wind burst occur on 26% occasion each. Examination of wind speed from 1994 to 2013 during nesting period revealed that wind bursts with a few days lag/lead of the full moon/new moon only are favourable for triggering the mass nesting event. In the record mass nesting event of 2013, mass nesting occurred with one day lag of the wind burst while wind burst had 1 day lag of the new moon (Table 3). It is observed that winds are predominantly between S-SW during nesting on most of the years except in 2013, when the wind was northerly.

## 4. Discussion

Out of the three rookeries, mass nesting over the years (Table 1) at Rushikulya rookery has been consistent. The mean annual population at Rushikulya Rookery is 0.1236 million which is 15.45% of global population. The trend analysis of the mass nesting population indicates an increasing trend and is in contrast to the declining regional and global population levels characterizing the IUCN Red List criteria. The information as regards to the mass nesting habitat and their transformation both due to natural and manmade forces, which is critical for formulation of an appropriate conservation strategy and coastal resource management, are either absent or sporadic. Therefore, the present study which examines the geo-environmental conditions of a record mass nesting site near Rushikulya rookery and reveals the conditions which triggers mass nesting assumes importance.

After careful analysis of results it is apparent that Olive Ridley, the solitary and vulnerable sea turtles, prefers a site as their nesting habitat which is relatively undisturbed and away from human intervention. Mass nesting on the sand spit between C and B in 2012 (Fig. 4), record mass nesting on the sand spit between mouth E and D in February, 2013 (Fig. 4) and mass nesting at Gahirmatha rookery (Prusty et al., 2005) are testimony to the above view. Although the reasons for selecting the mass nesting site to the north of the river mouth cannot be confirmed at this stage, it is however certain that greater food/nutrient availability through the riverine system could be one of the reasons. Besides, the stable stratified water with low saline water at the surface and high saline water below probably provides favourable conditions of buoyancy for the Olive Ridley during their coupling phase, the event preceding the mass nesting. Earlier studies (Johannes and Rimmer, 1984; Miller, 1997; Hawkes et al., 2009) indicate low salinity of the beach sand as one of the environmental cues for selection of nest site. In the present study, beach to the north of the river mouth is inundated with low saline surface water and hence has lower salt content in the surface sand than the beach to the south of the river mouth. Therefore, salinity of the near shore water, which influences salt content of the beach sand, could be considered as one of the important cues for selection of nesting site by sea turtles. Wider beach is not a preferred location of nesting because of greater probability of disorientation of hatchling due to increase in distance between the nesting site and low water line (LWL). Beach with steep slope is prone to erosion while flat beach are prone to inundation and pose threat for nesting activities. Therefore, turtles prefer to nest on a beach with mild slope (Spit-3 to Spit-6) than on beach with steep slope (Spit-1 and Spit-2) and flat beach (Spit-7).

Besides beach width and slope, the results distinctly points to the importance of sediment grain size distribution to the success/failure of mass nesting followed by hatching activities. It is however confirmed that the beach consisting of greater percentage of medium sand than fine/coarse sand facilitate the mass nesting in two ways; (i) provide a relatively dry beach and (ii) easy digging condition. Because, while constructing the nest, female turtle usually crawls to a dry part of the beach (beach with medium sand is drier than that with fine sand), flings away loose sand with her flippers, construct a body pit and an egg cavity by digging out the loose sand with her flippers easily. Skewness is an indicator of transport direction and supply sources of sediment while kurtosis indicates the sorting behavior, turbulence and velocity ranges and maturity of the sediments. It is evident that the sediments of the high mass nesting sites are symmetrical (but negative), moderately sorted to moderately well sorted, and hence the high mass nesting site is neither intertidal environment (normally with a very negative skewness) nor a very stable beach with mature sands, highly sorted or fine skewed or very positively skewed sediments.

Period of nesting mostly coincides with low energy but relatively higher period waves. For the first time, the study revealed that local wind burst with one or two days lag/lead of the new moon/full moon event triggers the mass nesting during night as the conditions provide the higher water level due to wave–tide interaction and facilitate the movement of the turtles to the beach easily.

The environmental cues for mass nesting of sea turtles and the factor triggering the mass nesting revealed through the present study for Rushikulya rookery, one of the world's largest Olive Ridley rookeries, would not only help in planning appropriate management strategy for conserving the nest and the hatchlings but also in predicting the nesting event. The information, if integrated properly, may be useful for conservation of vulnerable sea turtles. However, conservation efforts for Olive Ridley population in one country may be jeopardized by activities in another due to their migratory behavior. Olive Ridley turtles are protected by various international treaties and agreements as well as national laws; international trade of this species is prohibited under the Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES). The species is protected under the auspices of the Convention on Migratory Species (CMS) through Memorandum of Understanding on the Conservation and Management of Marine Turtles and their habitats of the Indian Ocean and South-East Asia (IOSEA) and also under Annex II of the Specially Protected Areas and Wildlife (SPAW) Protocol of the Cartagena Convention (http://www.nmfs.noaa.gov/disclaimer.htm). Besides international and national conservation measures, various measures are at place for the specific rookery in the state of Odisha and has been discussed by Mohanty et al. (2008).

## 5. Conclusion

Although Olive Ridley sea turtles are now in the vulnerable category of the IUCN Red List, the regional population shows an increasing trend. Olive Ridleys prefer a site as their nesting habitat which is relatively undisturbed and away from human intervention. Mass nesting mostly occurs to the north of river mouth as the conditions in the near shore water and beach sand are favourable preceding the nesting event and during nesting respectively. The study reveals that turtles prefer to nest on a beach with mild slope, medium width and greater percentage of medium sand with low salinity which are considered as important environmental cues for mass nesting of Olive Ridley sea turtles. Grain-size distribution and their statistical properties indicate mass nesting site with moderately sorted to moderately well sorted, symmetrical and either platikurtic or leptokurtic sediments. Near shore oceanographic conditions conducive for mass nesting are low saline near shore surface water, low energy and relatively longer period south southeasterly waves. For the first time the study provides clues for prediction of mass nesting event with local wind burst having one or two day lag/lead of the new moon/full moon event as the predictor and work in this direction is in progress and shall be reported in future. As the nesting ground is often to the north of the river mouth (estuary), shifting of the estuary to the north due to formation of sand spit associated with the round the year longshore transport from south to north (Mohanty et al., 2012) and/or due to transformation of the spit associated with stochastic events (cyclones/floods) significantly influence the location of the mass nesting site. Therefore, stability of the estuary and sand spit may be considered as an integral part of sustainable Environmental Management Plan of turtle nesting habitat. Environmental cues and the factors triggering the mass nesting would serve as important tools in planning appropriate management strategy for conserving the nests and the hatchling population which in turn would help conserve the vulnerable sea turtles.

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