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The Effect of Rookery Geomorphology on Olive Ridley Nesting in Gahirmatha, Orissa

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The Nasi barrier bar of the Gahirmatha coast witnesses the mass nesting of thousands of migrant olive ridley turtles every year during winter (Dash and Kar 1990, Pandav et al 1998). The widespread destruction of their habitat due to natural processes like erosion is a cause for concern (Prusty et al 2000). Rookery dynamics have attracted less attention than human-related threats. Throughout the world, most nesting beaches of marine turtles are ephemeral in nature—they are either submerged or destroyed by natural processes, or decimated by human activities. Although natal homing and site fidelity are characteristic of sea turtles, the mass-nesting record of Gahirmatha indicates their quick response to change in any geo-environmental rookery. With the change in geo-environmental parameters of the site, the turtles shifted nesting activities to a nearby site within the natal region. Although there are eight other coastal depositional features present in Gahirmatha, the Ekakula spit at the Maipura river mouth was the only site for mass nesting till the cyclone in 1989, after which only the Nasi barrier bars have been used.

Study Area

The Gahirmatha estuary is located at the mouths of the Maipura and Dhamra rivers—the distributary channels of the Brahmani and Baitarani river systems, belonging to the Mahanadi composite delta in Kendrapada district, northern Orissa (Figure 1). The geomorphology of the Gahirmatha ecosystem is the result of complex interactions between the fluvial flows of inland rivers and coastal wave action (Chakraborty 1991, Bharali et al 1991). Apart from the mainland shore zone coastal plains, a number of significant geomorphic landforms are present in the Gahirmatha estuary. They are:

(i) A channel bar in the Dhamra river namely Kalibhanja Dian,
(ii) Two near shore sandbars: Musachoti and Udabali,
(iii) Three far shore sandbars: Tentulia, Babubali and Sakarabali,
(iv) Two barrier bars: Nasi I and Nasi II,
(v) An elongated spit on the mouth of River Maipura: Ekakula spit.

The Nasi barrier bars originated due to the breaching of the Ekakula spit during the 1989 cyclonic storm, which were followed by high floods in the Maipura River. The hydrodynamic coastal environment resulted in an increase in its length each year. The bar attained its maximum length in 1997, and then disintegrated after the impact of another cyclone in May 1997 (the bars were later named Nasi I and Nasi II).

The average air temperature during the nesting season ranges from 18.9–28.7^{0}C. However, the average sea surface temperature (SST) during the nesting period is 27^{0}C. The maximum water depth in the estuary is less than four metres at low tide, except for the underwater channels that attain a depth of 10 m. The region experiences monsoon storms with moderate but marked seasonal variation in wave energy levels. Wave heights are greater during the southwest monsoon, about two metres high (reaching a maximum of 2.5 m). During September–October, the swell waves attain a height of 1 m and the current is mostly tidal. The highest tidal current recorded during March 2000 was 1.2 m/s. During the southwest monsoon, the wave approach is from the southeast and littoral drift is upcoast whereas the remaining period experiences down-coast drift. As a result, the delta is actively building in a northerly direction (Meijerink 1983, Sastri et al 1991). The long-shore current varies between 16–48 cm/s in a northeasterly direction and plume movement is northern. The maximum wind speed in the month of July is recorded to be 8.5 m/s.

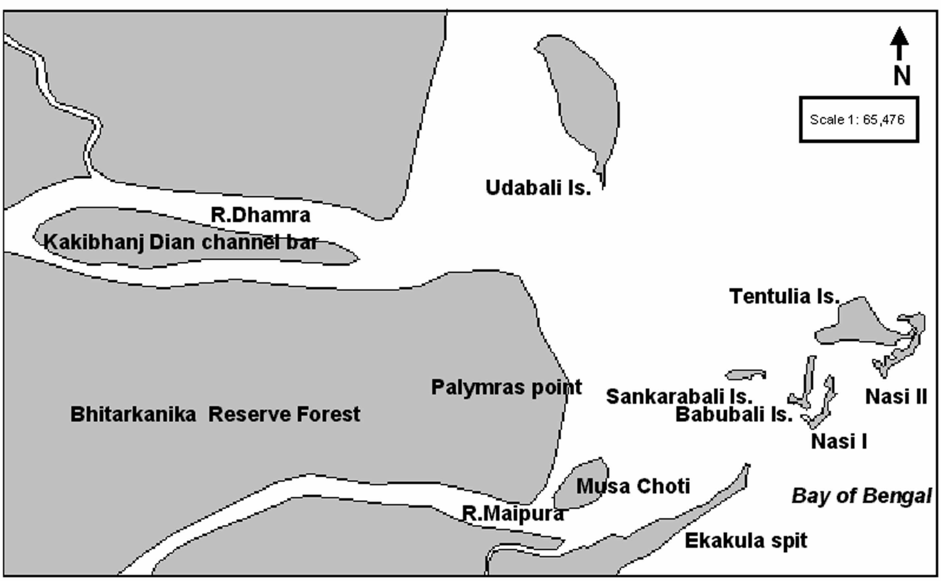

Figure 1. Overview of the Gahirmatha estuary and distribution of depositional landforms.

Methods

The nesting site at Gahirmatha was characterised using multi-temporal satellite images from the Indian Remote Sensing Satellite , IRS-1D, sampled during the nesting seasons of 1999, 2000 and 2001. In addition, field studies were carried out coinciding with the nesting event (Prusty 2003). Considering the urgent need for preservation of these rookeries, ecological/geo-environmental parameters critical to mass-nesting were identified using data from Gahirmatha. Secondly, the spatio-temporal change in position of the Nasi barrier bar in the last 14 years, and the dynamic change of effective nesting surface area has thrown light on the failure of the arribada for two consecutive years (1997–98). The centre of the landform area, i.e. centroid position, is used as the mapping parameter to determine the migrational behavior of the rookery. Twenty-two IRS-1B/1C/1D images were used to depict the migration pattern of the Nasi barrier bar (Figure 2). Finally, selection of barrier bars for mass-nesting between 1999–2001 could be understood from 3-D terrain analysis, utilising elevation data of field measurements, integrated with remote-sensing observations in a Geographic Information System (GIS) environment (Plate 20).

Results

FAVORABLE GEO-ENVIRONMENTAL PARAMETERS OF THE NASI ROOKERY OF GAHIRMATHA

Gahirmatha possesses nine coastal landforms, which are depositional in nature (Figure 1). The turtles are selective in nature and mass nesting is restricted to Nasi I and Nasi II barrier bars only. Geomorphological characterisation of all the Gahirmatha landforms identified the following characteristics of the Nasi barrier bars, which can be considered favourable for the nesting of turtles (Prusty 2003).

(i) Surrounding bathymetry: deeper depth on the seaward side,
(ii) Nesting site proximity to surf zone/ wave breaking zone: very close, only a few metres away,
(iii) Sea facing beach slope: steep,
(iv) Vegetation cover: barren,
(v) Compactness and period of deposition: freshly deposited outer surface cover of soil with loose sand,
(vi) Hydrodynamic environment: high-energy level of depositional environment, where actions of wave-current-tide is relatively more,
(vii) Sediment texture of surface soil: sediment texture characterised by more than 60 per cent of medium grained sand in the range of 125–250 m sizes is ideal, less clay or silt size particles,
(viii) Presence of black-coloured placer mineral: patches of placer deposits significantly present all over the site (Acharya et al 1998),
(ix) Landform morphometry: elongated, can provide greater exposure to sea for mass migration,

(x) Length to width ratio: more than 9,

(xi) Surface area above highest high tide: more than 0.25 sq km (Prusty et al 2000),

(xii) Proximity to mainland coastline: the further the distance of landform from the mainland, the less the effect of artificial illumination, influence of land predators and the disturbances caused by mechanised boats (Witherington et al 1997).

The high energy level of hydrodynamic forces (wave-current-tide) in the vicinity of the Nasi barrier bars provides an environment that supports deposition of frequently reworked medium- to coarse-grained sediments with placer mineral concentration in abundance. Its barren topography with no trace of vegetation is also ideal for nest digging. The relatively deeper surrounding water of the Nasi barriers, with a sharp break in sea facing beach and proximity to the wave breaking zone, reduces the unsafe littoral zone between the point of emergence, i.e. surf zone and the nesting site. Additionally, the Nasi barrier bars are characterised by larger length to width ratio, coupled with an exposed surface area of more than 0.25 sq km above the highest high tide line. Such geo-environmental factors can be considered as ideal conditions for turtle nesting.

The supercyclone of October 1999 uprooted a large number of *Casuarina* trees from the eastern part of Babubali Island and concurrently Nasi I barrier bar moved a few hundred metres away from its original position in a southwest direction exposing the eastern face to sea-wave action. Consequently, mass nesting occurred on the Babubali sandbar in March 2000, for the first time. This may indicate the influence of vegetation and a hydrodynamic environment on mass nesting.

The large-scale erosion and ephemeral nature of the current nesting site due to frequent occurrence of cyclonic storms suggests that potential alternate sites along the coast should be identified. A critical analysis of all the depositional features at the mouths of Brahmani–Baitarani, Devi, Mahanadi and Rushikulya rivers revealed that the Sahana spit of the Devi river mouth and the north spit of Rushikulya possess more than 9 conducive geo-environmental parameters akin to the Nasi barrier bar (Table 1). Since olive ridleys are known to mass-nest at both these sites, these landforms may serve as major nesting sites in the future, and need suitable conservation measures. The Jatadhar sandbar of the Devi river mouth, and Ekakula spit and Babubali Island of Gahirmatha with seven favorable parameters can also be considered as prospective nesting sites in the near future.

SPATIO-TEMPORAL CHANGE PATTERN OF NASI BARRIER BAR

The spatio-temporal change pattern of Nasi was determined by evaluating the progressive change in the location of the landform's centroid position and computation of normalised surface area in time. Here, the centre of the area of the bar is considered as centroid. The Nasi barrier bar originated due to breaching of the spit after the 1989 cyclonic storm which was followed by high floods in the Maipura River. Subsequently, the landform underwent conspicuous temporal changes with the interaction of oceanic forces coupled with riverine discharges. Analysis of 14 years of historic satellite images of the Nasi barrier bar from 1988–2001 revealed the change in location of the centroid position of the bar and clearly depicted the extent of migration in the northeast direction due to the long-shore transport of sediments (Figure 2).

Table 1. Analysis of favourable geo-environmental characteristics possessed by deltaic landforms on the Orissa coast, based on the Gahirmatha experience. (Data source: Image analysis of March 1999, March 2000 and April 2001 satellite data and selective field measurements)

Geo-environmental favorable factors	**Nasi barrier bars**	**Ekakula spit**	**Wheeler islands**	**Sahana spit**	**Jatadhar bar**	**Robert and Akashdia**	**False Point**	**Rushikulya Channel bar**	**North spit**	**South spit**
River mouth / delta	*Dhamra–Maipura*	*Maipura*	*Dhamra–Maipura*	*Devi*	*Devi*	*Devi*	*Mahanadi*	*Rushikulya*	*Rushikulya*	*Rushikulya*
Landform Type	barrier bar	spit	sand bar	spit	sand bar	channel bar	spit	channel bar	spit	spit
1. Surrounding bathymetry: deep	yes	Yes	No	Yes	No	No	No	No	Yes	Yes
2. Proximity to surf zone: close	Yes	Yes	No	Yes	No	No	No	No	Yes	Yes
3.Barren topography: no vegetation cover	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes	Yes
4. High energy hydrodynamics	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
5. Depositional environment: not stable	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	
6. Sediment size variation: medium sand and no clay/silt	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
7. Presence of patches of placer deposits	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes
8. Large effective surface area:>0.25 sq km	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No
9. Length to width ratio: higher than 9	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
10. Sea ward slope: steeper	Yes	Yes	No	Yes	Yes	No	No	Yes	Yes	No
11. Distance from mainland: far	Yes	No	Yes	No	Yes	No	No	No	No	No
12. Light illumination: minimum	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No
No. of favourable factors possessed	**12**	**9**	**6**	**10**	**8**	**6**	**5**	**8**	**10**	**8**

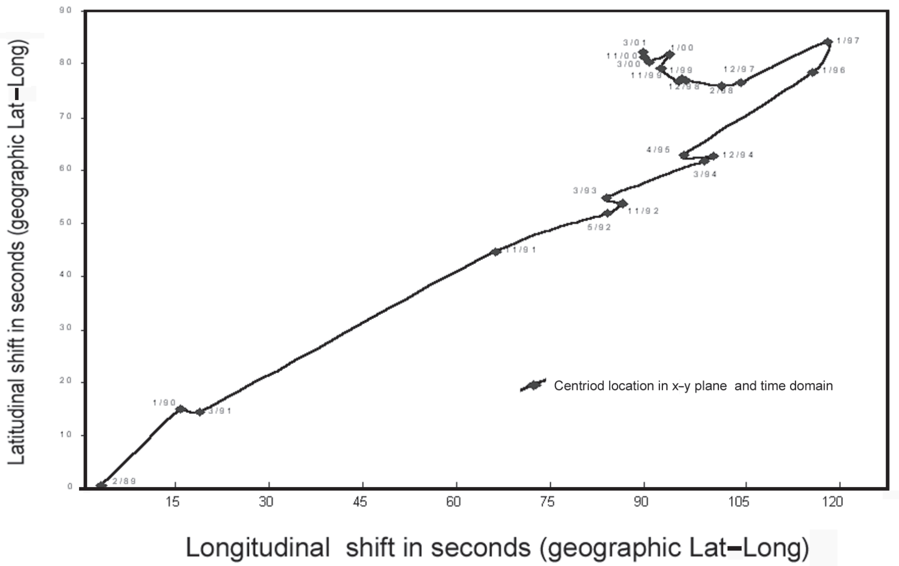

Figure 2. Spatio-temporal migration pattern of the Nasi barrier bar. (Based on centroid position of the landform as interpreted from Indian Remote Sensing multi-temporal satellite image analysis. 22 images were sampled between the period November 1988-March 2001, the co-ordinate position 0,0 in the figure is the centroid location of November 1988).

Another significant observation is that major disintegration of the nesting site was preceded by the failure of arribadas. The nesting site was breached or disintegrated once in 1989; no arribada occurred in 1988. The second time was May 1997, when no mass nesting occurred in 1997–98.

The tide normalised change detection analysis of the Nasi barrier bars revealed that within a period of five years since its origin, a considerable amount of sand particles were added to the bar by natural processes. The bar area of 0.79 sq km in January 1990 (at 1.88 m tide level) was enhanced to 0.99 sq km in late 1994, a 45 per cent increase in surface area. Such an increase in surface area could be attributed to the long-shore drift of sediments in the estuary during 1990–94. As the barrier bar could not migrate further into the deep sea along the northeast direction due to the hydrodynamic environment of the estuary, the path of migration shifted towards the NNE direction. Hence its length increased almost two-fold by 1997 and the effective surface area above the highest high tide decreased to a great extent. By this time, the Nasi bar was placed opposite to the strait between Tentulia–Babubali, the major opening of the estuary into the sea where the tidal current is very strong. High accumulation of water in the estuary during the May 1997 cyclone breached the Nasi barrier into two distinct units, Nasi I and Nasi II. After this event, the estuary opening was re-established between the two Nasi barrier bars and the reversal tidal current widened the gap, pushing Nasi I and Nasi II towards the nearby stable islands of Babubali and Tentulia respectively. The normalised surface area statistics indicates that both the Nasi bars are now showing a positive trend of accretion due to redistribution of transported sediments under the influence of the long-shore current.

ABANDONMENT OF NESTING DURING 1997–98

Arribadas failed to occur in 1997–98 for two consecutive nesting seasons. The habitat geomorphologic characterisation study revealed the major reason behind this phenomenon the migrational barrier bar encountered a deeper water regime during this period and thereby lost a significant amount of sediments, and the prevalent longshore current stretched its length considerably. Hence, the effective nesting area of the habitat decreased gradually until a breach took place after the May 1997 cyclonic event, followed by large accumulation of water in the estuary. However, the reversal tidal current at the estuary opening of Tentulia–Babubali strait rebuilt the fragmented Nasi barrier bars considerably, providing a conducive environment for nesting in early 1999. The spatio-temporal change location analysis also indicated that the positional shift of landform centroid was minimum in 1997–98.

MORPHO-DYNAMICS LEAD TO SHIFT IN NESTING WITHIN NASI BARS

The fragmentation of the elongated Nasi barrier bar in 1997 and recouping of lost volume of sediments in the subsequent period due to reversal tidal current, increased the surface area of both the Nasi barriers considerably. The changed geo-environment resulted in mass nesting in March 1999 on both Nasi I and Nasi II. However, olive ridley mass nesting was restricted to the Nasi I barrier bar in 2000 and did not extend to Nasi II. Conversely, in 2001, mass-nesting took place at Nasi II only (S K Patnaik and C S Kar, pers. comm.).

To evaluate the extent of erosion/accretion processes that caused the shifting of nesting activities, 25 beach profile transects measured systematically from 1999–2001 by DTRL were analysed to construct the 3D surface of both landforms during these nesting seasons. About 2,350 point measurements were undertaken for height estimation during each season with the help of a total station (*Sokkia*) and global positioning system (*Leica*). Multi-temporal satellite image analyses, sampled at varied tidal levels in conjunction with point observations, were compiled to generate a 3D surface of a digital elevation model (DEM) for the years 1999, 2000 and 2001 for Nasi I and Nasi II barrier bars (see Plate 20).

Although the surface area change analysis of satellite images did not reveal any conspicuous change in the area of the barrier bars, the 3D analysis of the DEM revealed the reason for the shift in mass nesting from one island to other. The effective nesting area above highest high tide was significantly less on Nasi II in 2000 and Nasi I in 2001 (Table 2). Hence, the turtles were forced to adopt the bigger nesting site abandoning the geomorphologically unfit one. Moreover, a close inspection of DEM maps also revealed that the elongated strip of the Nasi II rookery preferred for mass nesting was fragmented or inundated during high tide and the surface was uneven. This terrain condition of Nasi II might have been caused in 2000 by the impact of the 1999 supercyclone. However, it was rebuilt prior to the nesting season of 2001. On the contrary, the cyclone had little impact on the inverse L-shaped configuration of Nasi I and the terrain condition was favourable for nesting in 2000. With the changed geo-environmental condition, the Nasi I barrier migrated westward and the area above highest high tide zone reduced considerably in 2001.

Table 2. Exposed surface area of Nasi bars above highest high tide level during the nesting seasons of 1999 to 2001(results of DEM analysis*).

Nesting site	March–May 1999	March–May 2000	March–May 2001
Nasi I	0.325 sq km	0.486 sq km	0.224 sq km
Nasi II	0.272 sq km	0.145 sq km	0.296 sq km
Highest high tide level of the season**	3.53 m	3.57 m	3.56 m

* Inputs for construction of DEM: 4 IRS LISS III images at varied tide levels sampled during the period January–April, and about 1,100 measured elevation point data from each barrier bar during the nesting season. Point measurements are through total station and differential GPS.
** Source: Indian tide tables published by Survey of India.

Conclusion

Presently, the Nasi barrier bars situated in the Gahirmatha estuary possess ten typical favourable geo-environmental parameters conducive for mass nesting. Since the Nasi bars are under the threat of natural processes of erosion and frequently occurring cyclonic events, a need arises to identify alternate sites based on the Nasi rookery's geo-environmental features. The sparingly used Sahana spit and north spits of the Devi and Rushikulya rivers are potential sites for mass nesting. Ekakula spit, on the mouth of the Maipura River, and Babubali Island are the other prospective sites.

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