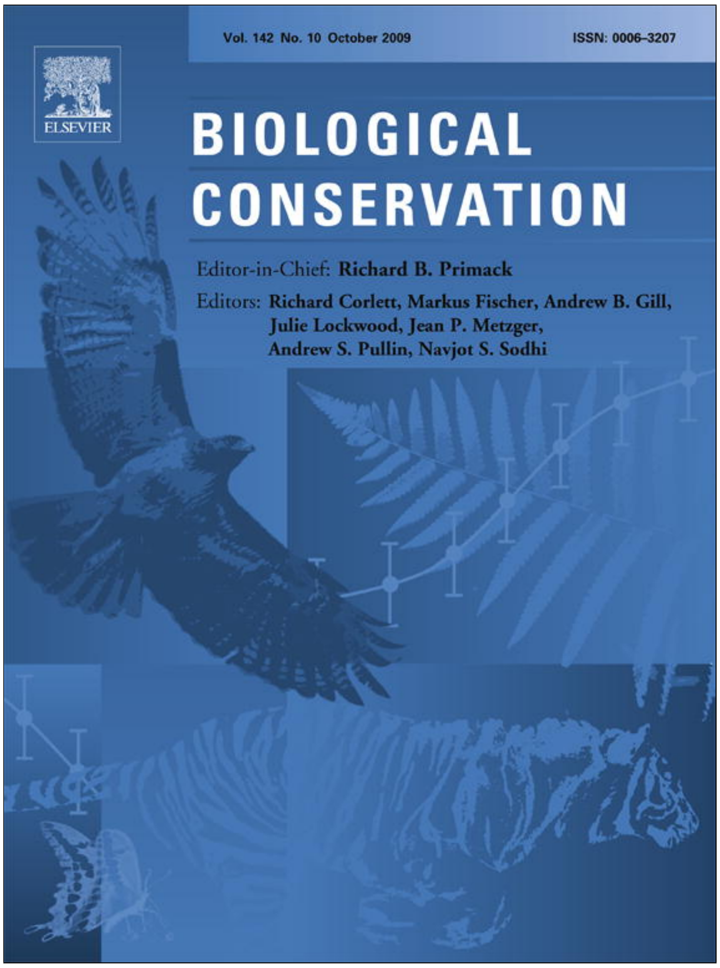
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Lighting the way: Towards reducing misorientation of olive ridley hatchlings due to artificial lighting at Rushikulya, India

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ABSTRACT

Sea-finding behavior in sea turtle hatchlings is modified by the visual cues provided by artificial beach front lighting. The consequent landward movement of hatchlings in response to coastal electric lighting reduces their survival rates. We assessed the potential impact of coastal lighting at Rushikulya, an important mass nesting site of the olive ridley sea turtle (*Lepidochelys olivacea*) in the Indian Ocean region. We examined the response of hatchlings to light characteristics in an experimental setup, as well as to the existing lighting regimes along the beach, using arena trials. Previous studies on other species indicate preferential orientation towards low wavelength and high intensity light. Our study confirms these preferences among hatchlings from the Indian Ocean population of olive ridleys. In addition we also found that wavelength and intensity could have an interactive effect upon hatchling orientation. Hatchlings at the study site respond both to visible point sources of light and to sheer glows of light. Though beach plantations of introduced *Casuarina equisetifolia* are generally considered to have negative impacts on sea turtle nesting beaches, we found that they acted as an effective light barrier when planted about 50 m away from the high tide line. We developed a model of the expected impact of artificial lighting on hatchling orientation during mass hatching events of previous years, and predict as much as 50% misorientation in some years. We also developed a map representing the misorientation of hatchlings due to artificial lighting based on arena trials in different regions of the beach. The results of the study helped identify focal areas for light management on the beach, which could be critical for the survival of this population.

1. Introduction

Sea turtle hatchlings emerge from their nests at night and are thought to be positively phototropotactic, orienting towards the brighter of two horizons (Mrosovsky and Kingsmill, 1985). This positive phototropotaxis plays a critical role in sea-finding (Mrosovsky, 1972; Verheijen, 1985; Witherington, 1990). The naturally brighter horizon is seaward, but in recent decades, increasing beach front lighting has created an artificial light horizon on the landward side along many parts of the coast. Subsequently, hatchlings have been observed to orient away from the sea (Peters and Verhoeven, 1994), resulting in considerable mortality (McFarlane, 1963). Increasing coastal development is likely to amplify hatchling mortality due to light pollution and therefore, finding suitable mitigation measures is vital.

Hatchlings use multiple visual cues during sea-finding, of which intensity, wavelength, background illumination and landward silhouettes are important factors (Witherington and Bjorndal, 1991; Witherington, 1992; Godfrey and Barreto, 1995; Salmon and Witherington, 1995; Tuxbury and Salmon, 2005). Ambient (celestial) illumination and landward silhouettes reduce the relative effects of coastal artificial light, whereas broad-spectrum, short-wavelength, and high intensity light from artificial sources tend to increase a hatchling's probability of disorientation (Lohmann et al., 1997). However response of hatchlings to intensity and wavelength of light show species specific differences (Witherington and Bjorndal, 1991). Variable sensitivity to light characteristics is based on the properties of the environment in which turtles live (Granda, 1979 in Horch et al., 2008). Hence, variation in response to light at the population level may also be possible.

Olive ridleys from the Pacific Ocean preferentially orient towards short wavelength and high intensity light (Witherington, 1992). However no prior research has quantified the wavelength and intensity preferences of hatchlings of the genetically distinct olive ridley (*Lepidochelys olivacea)* population from the Indian

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Ocean, although significant misorientation has been reported at their mass nesting sites (Tripathy, 2005b). In this study, we examined the response of hatchlings from this population to light characteristics, to address the issue of beach front lighting due to coastal development and industrialization at an important nesting site on the east coast of India.

On the mainland of India, olive ridley turtles nest in significant numbers along the east coast, particularly at the three main mass nesting sites of Gahirmatha, Devi and Rushikulya (Bustard, 1976; Kar, 1982; Pandav et al., 1994), although sporadic nesting also occurs along the west coast (Kar and Bhaskar, 1982; Shanker and Choudhury, 2006). Mass nesting events have been erratic at Gahirmatha in the past decade, possibly due to fragmentation of the nesting beaches and offshore fishing impacts (Shanker et al., 2003). Nesting at the Devi river-mouth has also declined over the years, with only the Rushikulya river-mouth showing consistent mass nesting, and perhaps an increase in numbers (Pandav, 2000; Shanker et al., 2003; Tripathy, 2005a; D.K. and K.S., pers obs). Artificial lighting along the beach is potentially the highest anthropogenic cause of hatchling mortality at Rushikulya. The field conditions at this site also form a good representative of the light pollution sources and potentially mitigating barriers that this species encounters along the east coast of India.

We studied the influence of light wavelength and intensity on hatchling orientation, as well as their responses to different types of light available on the beach. We also examined whether *Casuarina equisetifolia* (hereafter casuarina) plantations along the beach acted as light barriers along some stretches in Rushikulya. Based on the responses of hatchlings in the experiments above, we identified the major sources of light pollution and potential barriers to this pollution on hatchling orientation at the Rushikulya mass nesting site. Finally, we used our findings on hatchling response to experimental and coastal light conditions together with spatial information of previous nesting records to develop a model of the expected impact of the light regime at Rushikulya on hatchling orientation and mortality.

2. Methodology

2.1. Study area

The study site is a 5 km stretch of beach encompassing the Rushikulya mass nesting site in Orissa, India (19° 22′ 56.30 N, 85° 5′ 0.23 E–19° 24′ 35.74 N, 85° 05′ 59.48 E). This is the southernmost mass nesting beach in India. Siltation and flooding of the Rushikulya River causes the beach profile to vary both seasonally and annually. The three villages (Purunabandha, Gokharkuda and Kantiagada) (Fig. 1), along the beach have a human population of about 9000 of which around 3000 persons are involved in fishing activity (unpublished data).

Plantations of casuarina flank the northern portion of the study area. These plantations support predators of sea turtles and hatchlings including the golden jackal (*Canis aureus*), striped hyena (*Hyaena hyaena*), jungle cat (*Felis chaus*), jungle crow (*Corvus splendens*) and white-bellied sea eagle (*Haliaeetus leucogaster*). Large sand dunes and disused prawn farms run parallel to the coast close to the river mouth. The main sources of light pollution are the three villages along the beach, the Chennai–Kolkata National Highway (NH5), which cuts across the landscape from south to north and the chemical factory at the southern end of the beach.

2.2. Experiment 1: testing responses to light characteristics

All experiments were conducted between 20:00 h and 02:30 h under a clear sky when the lunar phase was full to waning gibbous. A circular lightproof arena of 1.5 m radius was setup well above the high tide line, and was divided into eight sectors. It had light barriers (walls) along the periphery to prevent external illumination entering the experimental chamber. The experimental light source was inserted through a hole in one of the walls of the arena at a height of 30 cm. The light source was a LED torch, which was held at an angle of 30° from the wall. Lights of two intensities (categories of eight and four LED bulbs of 15,000 mcd) were chosen in four bands of wavelength (Lee polyester filters of specifications; red: 580–800 nm, yellow: 475–600 nm, blue: 375–575 nm, violet: 300–450 nm) using light filters. Ten active hatchlings from a nest were randomly chosen, placed in complete darkness prior to the experiment, and remotely released at the centre of the arena such that they were offered the choice of an experimental light on one side of the head (one eye) and no light on the other. They were allowed to orient to the particular wavelength and intensity of light chosen for the trial, and move to the walls of the arena, which denoted the end of the trial. The hatchlings were re-oriented and released at the end of each trial. Hatchlings from another nest were selected for the next trial. Nine such trials were conducted for each combination of wavelength and intensity as well as control experiments in complete darkness.

Choice experiments involving a T tube setup were also conducted. Here hatchlings were subjected to all pair comparisons ($n = 6$) where they chose between pairs of wavelengths at constant relative intensities. Hatchlings were also made to choose between the two intensities ($n = 4$) for each wavelength to resolve the differences in hatchling response to these aspects of light.

2.3. Experiment 2: impact of photic regions on the beach

By visual classification, the beach was divided into four different photic regions based on the light shading effect of the casuarina plantation as well as intense lighting from surrounding sources of light pollution.

In the photic region one (PR 1) casuarina plantations were 50 m from the high tide line (HTL), which appeared to effectively cut out illumination from the surroundings. The second photic region (PR 2) casuarina plantations were about 500 m away from the HTL, so the region experienced a glow from the surrounding areas. Photic region three (PR 3) had no casuarina barrier and was exposed to well spaced point sources of light from the highway. The fourth photic region (PR 4) also had no light barrier and experienced light of high intensity from the highway as well as the nearby chemical industry.

The movement of hatchlings seawards and landwards was experimentally evaluated at the four different photic regions using circular arenas of 1.5 m radius, well above the high tide line, which were divided into eight sectors. Newly emerged hatchlings were tested for activity and then placed in complete darkness before being released 10 at a time into the centre of the arena. The hatchlings were placed in such a way as to be able to view both the landward light source and the seaward horizon. They were allowed to orient and move to the periphery of the arena from where they were collected, re-oriented and released into the sea. The number of hatchlings in each of eight sectors was counted at the end of every trial. Altogether nine trials were conducted at each of the sites. All experiments were conducted between 22:00 h and 02:30 h under a clear sky when the lunar phase was full to waning gibbous.

2.4. Model of expected orientation

The beach was classified based on the exposure to light in four different photic categories (as above). A model of the orientation profile of hatchlings was developed based on the probability of

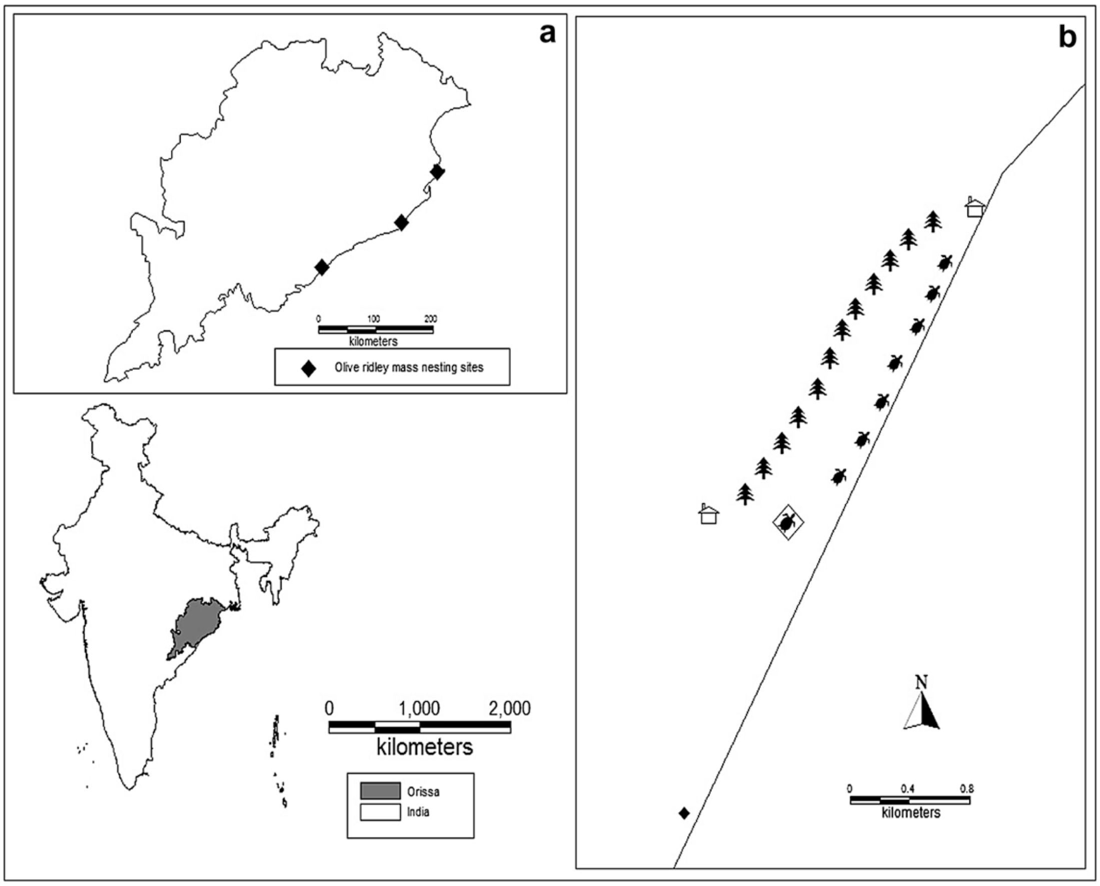

Fig. 1. Map showing (a) olive ridley mass nesting sites: Gahirmatha, Devi and Rushikulya and (b) study area at Rushikulya.

their misorientation (number disoriented in a photic region/total number misoriented in all photic regions) conditional on their emergence from different photic regions of the beach (Table 2).

$$\text{Conditional probability} = \frac{p(\text{misorientation in a given PR})}{p(\text{misorientation in all PR})}$$

The model was extended to include those parts of the beach known to have harbored mass nesting events in the past and those that were likely to do so in the future. Based on this model a map of the site showing photic regions and probability of misorientation was developed. This model was used to predict hatchling response only for that period of the lunar cycle, around the full moon.

2.5. Analysis

Analysis was conducted using the software R version 2.7.0 (R Development Core team 2008), SPSS version 10 (SPSS Inc., Chicago USA) and ORIANA version 2. We used the Exact Binomial Test (S-PLUS, 2000) to test the difference in proportions of hatchlings moving towards two halves of the arena (i.e. towards and away from where light sources were placed during the wavelength and intensity experiments) in complete darkness. In the evaluation of the experiments with wavelength and intensity, number of hatchlings moving towards or away from the light was taken as response with wavelength, intensity and their interaction as predictors in a generalized linear model (GLM) framework with binomial errors. Hatchling response to the choice based trials was recorded as the arm of the tube in which the hatchling was located at the end of each trial. These results were analyzed using non parametric Chi-square analysis. In the experiments evaluating field conditions, movement towards or away from land was taken as the response with photic regions as the predictors in a GLM with binomial errors. Hatchling response, recorded as position of hatchlings in each of eight segments of the arena, was also tested for significance of directionality by finding the mean vector and performing Rayleigh's test of significance of directionality.

3. Results

3.1. Experiment 1

Wavelength and light intensity interacted to influence hatchling orientation towards light (GLM; *Deviance* = 84.603, $df = 3$, residual $df = 69$, $p < 0.0001$), measured in mean number of hatchlings moving towards the light source in the arena trials. Hatchlings in complete darkness moved at a mean angle of 112.5°, and a standard deviation of 129.24° (Table 1), which indicates their wide dispersal through the arena (Rayleigh's $p = 0.94$; values closer to one indicate higher dispersion). In complete darkness, there was no significant difference between the numbers of hatchlings oriented towards and away from that half of the arena where light sources were placed during the wavelength and intensity experiments (Exact Binomial test $p = 0.59$). Hatchlings oriented towards high intensity light more than to low intensity for all wavelengths except violet (Fig. 2). Hatchlings also consistently chose higher intensity light in choice based trials (Chi-square test: $\chi^2 = 4.5988$, $df = 1$, $p = 0.03$). The hatchlings differentiated between long and short wavelengths ($\chi^2 = 15.2191$, $df = 3$, $p < 0.001$) and preferentially moved towards shorter wavelengths (violet and blue) of light in the choice based trials. The response of hatchlings to red light was very similar to their movements in complete darkness, in arena trials.

Table 1
Directional responses (measured in degree angles) of hatchlings to differing wavelengths during arena experiments.

Colour (wavelength band)	Mean vector (°)	Mean vector length (r)	Circular SD (°)	Rayleigh's (p)
Violet	4.16	0.99	2.86	$<1e^{-12}$
Blue	360	0.96	15.05	$<1e^{-12}$
Yellow	11.87	0.85	32.47	$9.97e^{-5}$
Red	345.36	0.57	60.35	0.03
Dark	112.5	0.079	129.24	0.94

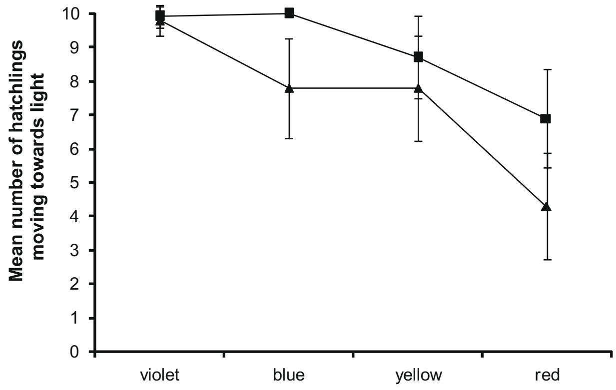

Fig. 2. Hatchling response (measured in mean numbers of hatchlings across trials moving towards that 1/2 of the arena which is illuminated by the light source) to wavelength (violet, blue, yellow, red) and intensity (square – high, triangle – low) in arena experiments.

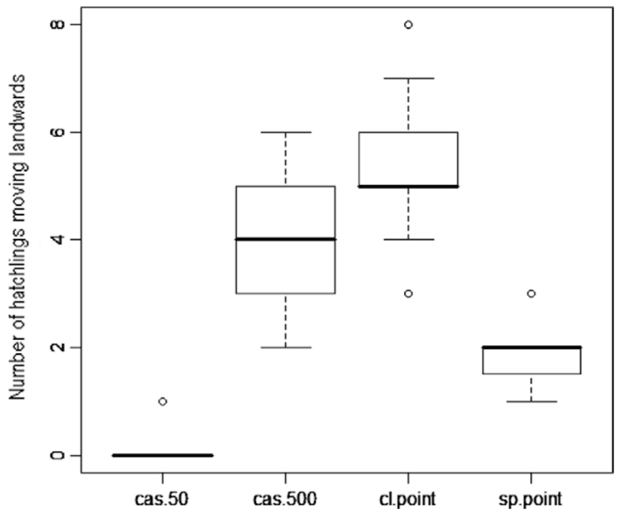

Fig. 3. Response of hatchlings (measured in numbers of hatchlings moving towards the light source – landward) to light in different photic zones along the Rushikulya beach. Cas. 50 denotes experiments conducted where casuarina was 50 m away from the high tide line, cas. 500 denotes experiments conducted where casuarinas was 500 m away from the high tide line, sp. point denotes experiments conducted where spaced light sources from the highway were visible from the beach and cl. point denotes experiments conducted where clustered light sources were visible from the beach (boxes show median and interquartile range).

Orientation towards the source of light was significant at all bands of wavelength except red (Rayleigh's R, $p < 0.01$). The greatest dispersion of hatchlings, as indicated by the mean vector length and circular standard deviation, occurred in response to the red band of wavelength (580–800 nm) followed by that of the yellow band (475–600 nm) (Table 1).

As a constant light source was filtered for different wavelengths in all these experiments, the transmittance differed in intensity at each wavelength. Therefore although absolute intensity was not constant across wavelengths, relative intensities for each wavelength were consistently maintained. The output transmittance curve for the torch, given different filters was examined and deemed not to have affected our interpretations of the results in any way.

3.2. Experiment 2

Both concentrated point sources of light and visible glows from the beach caused more hatchlings to move towards them (greater misorientation of hatchlings) than spaced sources or parts of the beach flanked by casuarina 50 m away (Fig. 3, generalized linear model; *Deviance* = 108.6, residual $df = 70$, $p < 0.001$).

The greatest deviance from the expected seaward orientation (0° or 360°) was seen in photic region four, which had no light barrier and experienced intense light. Rayleigh's test for circular uniformity indicates that the hatchlings showed significant seaward orientation only in photic region one where the casuarina was closest to the high tide line (Table 2).

3.3. Model of expected orientation

The probabilities of hatchling movement towards land were calculated, based on response of hatchlings in different photic regions location at the beach. The map developed based on these probabilities indicated that hatchlings along the northern portion of the beach were less likely to be misoriented due to artificial lighting than those on the southern part of the beach (Fig. 4). Hatchlings were most misoriented in parts of the beach that were close to the current river mouth and in areas where lights from nearby villages illuminated the horizon. As mass nesting took place along these parts of the beach in the years 2005 and 2006, we predict that more 50% of the hatchlings in those years were misoriented. During the years 2004 and 2008, only about 10.13% of hatchlings were likely to be misoriented, if hatching took place around full moon.

4. Discussion

Our study confirms that both wavelength and intensity of light are important orientation cues for hatchlings from the Indian Ocean population of olive ridley turtles. Wavelength and intensity may have an interactive effect on hatchling orientation. Hatchlings of other species are reported to orient towards high intensity light of a particular wavelength even if they do not prefer the same wavelength at lower intensities (Witherington and Bjorndal, 1991). The hatchlings from the Indian Ocean population of olive ridleys turtles show similar patterns of light preference.

Our findings also suggest that casuarina plantations form an effective means of preventing hatchling misorientation on turtle nesting beaches; substantially fewer hatchlings in our study were misoriented near plantations. This is consistent with other studies which have shown that beach vegetation and landward silhouettes that block light are used as orientation cues by sea turtle hatchlings (Salmon et al., 1995; Tuxbury and Salmon, 2005). We also found that a clear distinction could not be made between hatchling responses to point sources and to glows. This suggests that hatchlings make decisions by comparing the gradient between the two horizons, rather than moving towards the brightest point in their visual range. The role of casuarinas plantations as light barriers that help augment sea turtle survival has never been considered until now as they do not naturally occur in the Indian coastal ecosystems, but have been planted there for use by the local people.

Table 2
Directional responses (measured in degree angles) of hatchlings to existing lighting along the beach in the four different photic regions (PR).

Photic region	Mean vector (°)	Mean vector length (r)	Circular SD (°)	Rayleigh's (p)
PR 1	326.19	0.68	46.97	0.01
PR 2	337.5	0.19	104.49	0.71
PR 3	355.94	0.42	75.06	0.17
PR 4	112.5	0.19	104.49	0.71

Using the orientation model, we identified the areas along the study site that need to be targeted for light spillover prevention measures. We also confirmed that artificial light has serious implications for hatchling mortality, if the mass nesting site is in a well–lit part of the beach. Observations of rescue measures by local conservation organizations indicate that the number of misoriented hatchlings overwhelm the manpower involved (K.S., pers obs). Rescuing misoriented hatchlings is a laborious process and large numbers of hatchlings (numbering hundreds of thousands) are lost to predators and dehydration (D.K., pers obs). Even those that are rescued likely have a lower chance of survival due to energy expended misoriented on or behind the beach. Therefore a combination of measures have been employed in the past including the premature collection and release of hatchlings from the nest, as well as the use of mosquito net barriers on the landward side to trap misoriented hatchlings (Tripathy, 2005b). However, such measures are not effective and are often erratically organized. Therefore, the best solution would be to shield and redirect lighting in close to the river mouth and in the villages. Such recommendations would be best implemented through laws and educational programs. Given the propensity of olive ridleys to nest near river mouths and the lack of vegetation in this zone, these areas may have the highest susceptibility to lighting impacts on hatchling mortality.

A confounding factor in this study was that it coincided with the peak phase (full moon) of the lunar cycle. Sea turtle hatchlings response is modulated by the background illumination of the moon (Salmon and Witherington, 1995; Bourgeois et al., 2008). This might explain why previous studies have reported misorientation rates as high as 80% (Tripathy et al., 2003), whereas we recorded lower rates of close to 60%. Another factor that could contribute to this difference is that the mass nesting during our study occurred in the part of the beach shaded by casuarina as compared to the previous study where it occurred in the more exposed parts of the beach.

Casuarina as a light barrier, although effective in lowering misorientation due to lighting, may have other negative impacts. There is an uncertainty associated with measures to reduce hatchling misorientation, which is reflected in the lack of detailed studies on the topic world-wide. The plantation that acted as a light barrier in our study was of mixed age and supported predators of olive ridley turtle eggs and hatchlings. It was possibly more effective than the single age plantation stands that are found along much of the east coast of India. Although planted widely as a shelterbelt and used for its wood (Pinyopusarerk and Williams, 2000), casuarina is an exotic species. Besides disrupting changing erosion patterns,

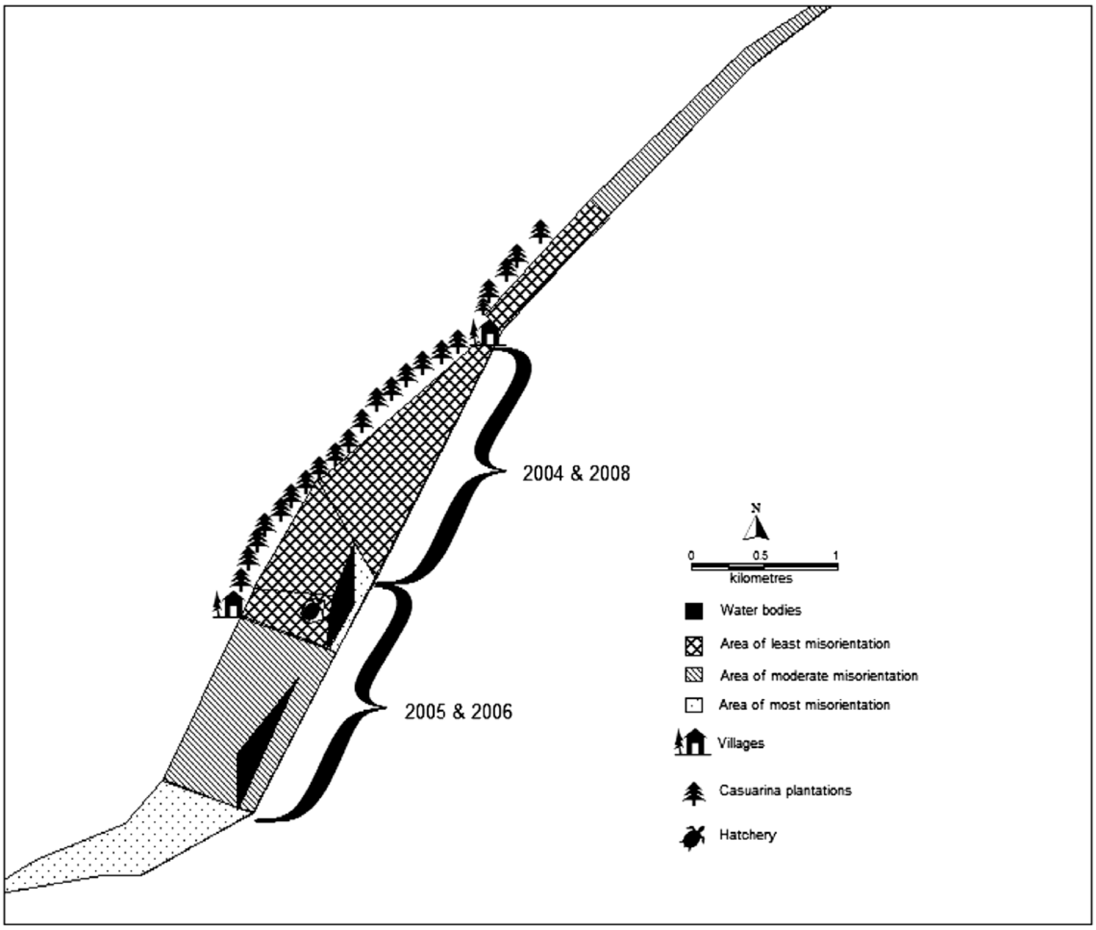

Fig. 4. Map indicating different hatchling misorientation rates (due to artificial lighting) in different parts of the beach. The year and location of different mass nesting events have also been overlaid.

beach slopes and beach dynamics in general, a study suggests that a decline in nesting can be linked to these plantations (Chaudhari, 2008). Elsewhere, it is being actively promoted as a 'bioshield' or coastal protection against storm surges or tsunamis, though there is little evidence to support its role in protecting the coast (Mukherjee et al., in press). Therefore light management mechanisms and appropriate coastal vegetation would be preferred to casuarina plantations as light barriers.

The threat of increasing development in terms of oil pipelines, ports or industries at Rushikulya and other olive ridley turtle nesting sites only increases the probability of misorientation of hatchlings at those sites. Coastal lighting needs to be modified to reduce hatchling misorientation. Although longer wavelength light (red: 630–700 nm) causes least misorientation, such light at high intensities could still have a significant impact on hatchlings. Although some types of modified light do reduce hatchling misorientation (Bertolotti and Salmon, 2005), filtered 'turtle-friendly' streetlights were still found to attract a significant number of hatchlings in Florida (Sella et al., 2006). The preferred solution would be the use of light barriers. However, it may not be possible to install such barriers (plantations or artificial) along all nesting beaches. Finding solutions to the conflict over coastal resources is imperative and requires long term light management planning and the use of a combination of the measures examined in this study.

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