Herpetology Notes, volume 13: 435-442 (2020) (published online on 30 May 2020)

Threats to the nests of Olive Ridley Turtles (*Lepidochelys olivacea* Eschscholtz, 1829) in the world's largest sea turtle rookery at Gahirmatha, India: need for a solution

Satyaranjan Behera[1,*] and Hinrich Kaiser[2]

Abstract. We report on a preliminary study of threats to olive ridley turtle (*Lepidochelys olivacea*) nesting beaches at their largest rookery in Gahirmatha, Odisha State, India during the 2012 season. We found a total of 1223 olive ridley nests, of which nearly two thirds had been destroyed by inundation and depredation. Likewise, two thirds of turtle landings, as indicated by their tracks, did not lead to nest establishment. The nest encounter rate (nests per km) was highest on beaches of isolated islets in the northern part of the rookery. Nesting frequency was 25.4 ± 6.7 nests/km with 18.5 ± 4.8 destroyed nests/km. The Gahirmatha sea turtle rookery needs continuous monitoring throughout the year to determine levels of nesting activity, non-nesting crawls, and predation threats, and we advocate for the establishment of a fence to minimize the impact of terrestrial predators on the nesting beach.

Keywords. Gahirmatha rookery, Nesting, Inundation, Nest, Olive ridley turtle, *Lepidochelys olivacea*, Predation

Introduction

Nesting beaches of marine turtles are ephemeral and subject to destruction by natural processes (e.g., submersion, erosion), and in addition they can be made inhospitable to turtles' egg-laying needs by the activities of humans and their domestic animals (e.g., Fish et al., 2005; Tripathy and Rajasekhar, 2009; Fuentes et al., 2010; Whytlaw et al., 2013). Furthermore, large numbers of olive ridley nests may be predated upon by native predators (e.g. Silas et al., 1984; Blamires, 1999). This invariably leads to a significant reduction in the numbers of turtle nests, laid eggs, and hatchlings.

Olive ridley turtles are found nearly circumglobally in tropical oceans (Reichart, 1993; Turtle Taxonomy Working Group, 2017). Out of the four sea turtle species reported to occur along the coast of Odisha State, India[3] (*Chelonia mydas*, *Dermochelys coriacea*, *Eretmochelys imbricata*, *Lepidochelys olivacea*), only the latter has been confirmed to nest (Dash and Kar, 1990; Pandav and Choudhury, 2000; Shanker et al., 2004; Tripathy, 2008; Tripathy and Rajasekhar, 2009). *Lepidochelys olivacea* is listed as Vulnerable (VU) by the IUCN (Abreu-Grobois and Plotkin, 2008), and its trade is forbidden by its listing as a CITES Appendix I species (Turtle Taxonomy Working Group, 2017). It is also legally protected throughout India by its inclusion in Schedule I of the Wild Life (Protection) Act, 1972 (Government of India, 1972). As a consequence, the protection and preservation of its nesting habitats must be a priority for wildlife conservation managers.

Lepidochelys olivacea is a vulnerable species throughout most of its range because of habitat loss, incidental capture in gill nets, and illegal local trade in meat (e.g., Pandav and Choudhury, 2000; Behera et al., 2016). In addition, there exists high predation

[1] Odisha Biodiversity Board, Regional Plant Resource Centre Campus, Nayapalli, Bhubaneswar, Odisha 751015, India.
[2] Department of Vertebrate Zoology, Zoologisches Forschungsmuseum Alexander Koenig, Adenauerallee 160, 53113 Bonn, Germany; and Department of Biology, Victor Valley College, 18422 Bear Valley Road, Victorville, California 92395, USA.
[*] Corresponding author. E-mail: behera.satyaranjan@gmail.com

[3] Until the 2011 passage of the *Orissa (Alteration of Name) Bill, 2010* and the *Constitution (113th Amendment) Bill, 2010*, the name of this state was Orissa.

pressure on its eggs from feral pigs, dogs, monitor lizards (*Varanus* spp.), and indigenous harvest at several locations in other parts of the world (e.g., Whiting et al., 2007; Chatto and Baker, 2008). Especially feral dogs (*Canis familiaris*) and wild pigs (*Sus scrofa*) are known to cause considerable damage to nests of leatherback, green, hawksbill, and olive ridley turtles (e.g., Bhaskar, 1993; Whytlaw et al., 2013; Engeman et al., 2019; Nordberg et al. 2019). It has also been determined that the predation risk on solitary nests is higher than for arribada nesters (e.g., Costa Rica: Eckrich and Owens, 1995) and that the position of a nest on a nesting beach influences its survival rate (Whitmore and Dutton, 1985; Eckert, 1987; Behera et al., 2018).

The 480-km-long Odisha coastline harbours three mass nesting beaches (Gahirmatha, Devi, Rushikulya). Each year, olive ridleys arrive in the area during October, followed by mating in shallow coastal waters and nesting from January–May. With an estimated annual nesting of 100,000–500,000 turtles during arribadas, Gahirmatha is the world's largest known nesting aggregation of olive ridleys (Dash and Kar, 1990; Behera, 2012). Moreover, sporadic nesting by olive ridleys has been observed year-round at these and other localities along the Odisha coast (Dash and Kar, 1990; Tripathy, 2008; see also additional references in Tripathy et al. 2008) and these nests are reproductively highly effective and need to be protected in natural condition.

Studies on the population dynamics and reproductive biology of olive ridleys at Gahirmatha have indicated that a large percentage of the eggs laid during each nesting season are destroyed (Dash and Kar, 1990; Behera et al., 2015). Indeed, it has been documented that heavy beach erosion and predation on eggs may lead to high levels of destruction of olive ridley eggs on nesting beaches (Valverde et al., 2012; Behera et al., 2013), but quantitative information on olive ridley nest predation is anecdotal. It has generally been accepted that high predation pressure at accessible mainland sites can play an important role in the adaptive selection of islands and isolated beaches by sea turtles for nesting (e.g., Hendrickson, 1958; Carr et al., 1974). Nests of olive ridleys, in particular, are frequently depredated by dogs (*Canis familiaris*), jackals (*C. aureus*) and hyenas (*Hyaena hyaena*) along the Andhra Pradesh Coast (Tripathy et al., 2003). The aim of this study was to identify and quantify the main threats to solitary nesting of olive ridleys at Gahirmatha and determine possible solutions.

Materials and Methods

Study site.—The study was carried out along the ca. 35 km of coastline known as Gahirmatha, a significant sea turtle rookery on the Odisha coast of India that lies between the mouths of the Dhamra and Barunei Rivers[4] (20.5049°N, 86.7602°E in the south to 20.7233°N, 87.0701°E in the north; Fig. 1). The beach forms the eastern boundary of Bhitarkanika National Park. The coastline is part of the extensive delta system produced by the Brahmani River estuary, and it is locally intercepted by two tributaries, the Maipura and Baunsagada Rivers. In addition to mainland beaches, there is a long sand spit of over 4 km length extending into the mouth of the Maipura and there is some isolated beach area on two small sandy islets, Nasi-I (Segment 2) and Nasi-II[5] (Segment 1; Fig. 1). She-oak (*Casuarina* spp.) has been planted on a massive scale as an erosion control measure along the mainland beach and along the spit. Extensive native mangrove forests are present behind the *Casuarina* (see Reddy et al., 2007; Upadhyay et al., 2008). Thus, the mainland beach is flanked primarily by *Casuarina* trees and mangroves. The lowest elevations of the nesting beach are open and covered in sand. Above this open area, several low, herbaceous, and salt-resistant plants grow, including psammophytes (or sand binders) such as *Ipomea pescaprae, Launea sarmentosa, Gisekia pharnacoides*, and *Spinifex littoreus* (Behera, 2012).

We divided the study area into seven segments of similar length along the shoreline to allow systematic monitoring (Fig. 1). These include opportunities for both island and mainland nesting by olive ridleys. Two of these segments, assigned to cover Nasi-I and Nasi-II to the east of the Maipura, are very short on account of the islets' shortened shoreline (Fig. 1). However, over the past two decades, most nesting has occurred on the islets (Behera et al., 2018), with only sporadic or solitary nesting occurring along the rest of the coastline. The breeding season of olive ridley turtles in Odisha is from

[4] The names of rivers in this area may be confusing because some of the area is a river delta. Names are not correctly presented on Google Maps, were the river in the north is called the Baitarani River and the one in the south the Brahmani River. We list these main geographical features by names used and known locally.

[5] Nasi-II used to be called Wheeler Island but is now known as Abdul Kalam Island, which is the name used on Google Maps.

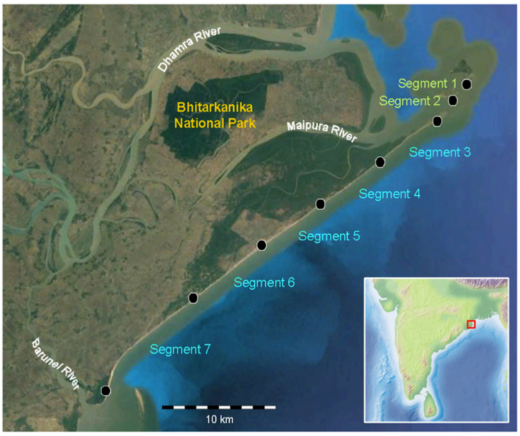

Figure 1. Map of the olive ridley (*Lepidochelys olivacea*) rookery at Gahirmatha Beach on the coast of Odisha State, India, showing its location in India (red square in the inset), as well as its division into seven Segments for the purposes of this study. Segments 1 and 2 are two small islets (Nasi-II and Nasi-I, respectively). Black dots demarcate the northern and southern extent of each Segment, with the exception of the islets, where a single dot denotes the entire beach. Map by Mark O'Shea.

November–May, during which mating, egg-laying, and hatching take place (Behera et al., 2010).

Beach profiling.—To characterize the available area for nesting, beach profiling (to obtain a measurement of available nesting beach width) was executed on a fortnightly basis from January–May following standard procedures (Cooper et al., 2000). Permanent GPS points were marked along the high tide line (HTL) on both the seaward and estuarine sides at 100-m increments. These points were marked with a handheld GPS (Garmin 72, Garmin Ltd., Olathe, Kansas, USA) for subsequent monitoring. Beach width was measured perpendicular from HTL to the permanent landmark. The average nesting beach width was calculated as the arithmetic mean of beach width measurements at each landmark. Following the calculations of average beach width for each of the seven nesting segments, the total available nesting beach area (average beach width x total beach length) could be estimated.

Surveys.—Data were obtained from January–May 2012 with three people surveying the beach every morning to identify nesting crawls and count identifiable nests. Nests were characterized by the presence of a nest pit and could be located by following nesting crawls. In contrast, non-nesting crawls lack a nest pit and the turtle likely returned back to sea without nesting. For nests that were determined to have been predated, the species of predator was identified by direct sighting or indirectly from footprints and faeces near the degraded nests (Menon, 2014). Identified nests were flagged and also monitored at night.

Results

During the olive ridley breeding season in 2012, we identified 1223 solitary nests at Gahirmatha. Tidal inundation and predation destroyed 749 (61%) of these nests. All nests in Segments 2–5 were destroyed or lost during the study period (Table 1). The nest density (nest/km) was highest in Segments 1 and 2 on Nasi-II and Nasi-I, respectively, followed by Segment 7, the southernmost mainland beach segment. The mean ± SD nest encounter rate (a measure of estimated nest density) was 25.4 ± 6.7 nests/km and it was 18.5 ± 4.8 nests/km for destroyed nests. During this survey, the average beach width was 52.3 ± 7.8 m.

A total of 3642 crawls produced 2419 non-nesting crawls (66%), with successful nest establishment resulting from only one third (34%) of turtle landings. Numerous non-nesting crawls were observed in each survey segment, except for Segment 5 where only very few were recorded. The average beach width during the study was 49 ± 7.2 m and 62 ± 11.5 m in Segments 1 and 2 respectively on both islands during the course of study. On the mainland beach the smallest beach widths were 13 ± 3.2 m and 19 ± 5.6 m in Segments 4 and 5, followed by the highest in Segments 6 and 7 (Fig. 2).

A total of 285 nests (mean = 69 ± 21) per segment were destroyed by inundation, 267 (27 ± 8.9) were depredated by feral dogs, 114 (23 ± 7.1) by wild pigs, 53 (15 ± 3.4) by jackals, 17 (3 ± 1.7) by hyenas, and 13 (2 ± 0.8) by water monitors (*Varanus salvator*). Stranded turtles were also scavenged by these animals. Nest predators were directly observed 31 times and indirectly recorded near depredated nesting pits through their footprints 53 times. Predation data were not normally distributed, given that all seven segments had different lengths, dissimilar beach widths, disparate probabilities of nest occupancy, and therefore it was likely that predation pressures would be different. Results of a Kruskal-Wallis test showed that there were highly significant differences in predation pressure among segments (n = 464, mean rate = 14, Kruskal-Wallis $P < 0.001$).

Table 1. Beach parameters for seven demarcated Segments at Gahirmatha, an olive ridley (*Lepidochelys olivacea*) nesting rookery in Odisha State, India. (a) Beach width, (b) nest density, (c) ratio of false crawls to successful nesting attempts, (d) rate of inundation and (e) rate of predation on olive ridley turtles during 2012 breeding season in.

Segment Number	Beach width (m)	Nest density (per km)	Ratio of false crawls to successful nesting attempts (%)	Rate of inundation (per km)	Rate of predation (per km)
1	49	48.1	57	18.3	15.3
2	62	61.8	53	30.6	31.2
3	32	9.0	24	1	8
4	13	3.8	20	0	3.8
5	19	3.7	23	0	2.9
6	84	8.2	21	0.3	4.2
7	107	43.3	42	0	13.2
Overall	52.3	25.4	34	7.1	11.2

Discussion

Erosion and inundation.—The loss of nests by inundation and erosion accounted for 23% of the total nest loss by natural factors at Gahirmatha rookery (Fig. 3). In recent years, significant temporal and spatial geomorphological changes in Gahirmatha have led to considerable changes in the nesting beach profile and an accelerated loss of nesting habitat (Prusty et al., 2007; Wildlife Institute of India, 2012; Behera et al., 2013). In the study area, the Segments used most for nesting, including the sand spit and the islets (Segments 1–3), have undergone conspicuous changes over time due to natural calamities, including cyclones and the interaction of oceanic forces and fluctuating riverine discharge (Prusty et al., 2007). In addition, the construction of Dhamra Port near the Gahirmatha mass nesting site and the concomitant need for the dredging of ship channels are major, permanent intrusions. Plans for the construction of additional ports in the area, including in protected areas, will doubtlessly have further significant and permanent negative impact on the rookery (Senapati, 2013). Furthermore, sea level rise as a consequence of climate change and the resulting dynamic coastal processes pose another threat to these nesting beaches (National Research Council, 1990; Leatherman et al., 2000; Garcia et al., 2015; Grases et al., 2020).

A large sand spit in Segment 1 (Nasi-II islet), where mass nesting occurred at Gahirmatha, was inundated by several high tides during March 2012, which likely affected the incubation success of the nests. Nests deposited on shifting beaches are more susceptible to damage due to erosion, and the natural and human impacts listed above appear to degrade what was for some time a stable nesting habitat. It has been reported that beach erosion caused the loss of 40–60% of leatherback turtle (*Dermochelys coriacea*) nests on beaches in Suriname (Whitmore and Dutton, 1985), and similar losses have been reported for olive ridleys (Mortimer, 1981; Dash and Kar, 1990; Andrews et al., 2003; Behera et al., 2018). Erosion at Gahirmatha began in the 1970s with the planting of *Casuarina equisetifolia* along the Odisha coast, which was planted to avoid land-side erosion but appears to have promoted beach-side erosion. However, coastal industrial developments

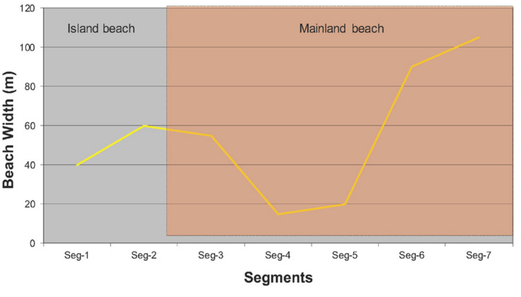

Figure 2. Availability of nesting beach area at the Gahirmatha rookery on the coast of Odisha State, India, during the 2012 nesting season. Segments 1 and 2 are island beaches and Segments 3–7 are on the mainland (Fig. 1). Segments 4 and 5 have less beach area available, which is reflected in the reduced number of nests observed.

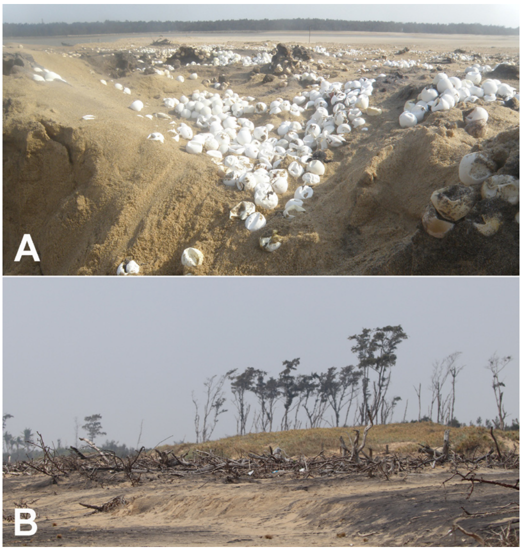

Figure 3. (A) Olive ridley (*Lepidochelys olivacea*) eggs in a destroyed nest, exposed by the combined action of natural erosion and wind, photographed at Segment 1 (Nasi-II) of the Gahirmatha rookery on the coast of Odisha State, India. The photograph is taken in a landwards direction, showing planted *Casuarina* trees in the background. (B) Accumulation of beach debris at Segment 3, with *Casuarina* trees in the background. This obstacle can be found in nearly all mainland Segments at Gahirmatha. Photos by Satyaranjan Behera.

have at least equally affected the nesting turtles along the Odisha coast (Behera and Tripathy, 2014). Due to limited nesting beach availability in Segment 1 of Nasi-II (Abdul Kalam Island), turtles may be shifting their nesting activity to nearby beaches. This is largely because of beach exchange, which is part of a complex phenomenon that olive ridleys use to colonise new areas or move to other beaches altogether (Valverde et al., 1998; Tripathy and Pandav, 2008).

Reduction in nesting beach area.—As observed during earlier studies between 2009 and 2012, the nesting decline at Gahirmatha likely parallels the decline in beach nesting areas availability (Behera et al., 2015). This study showed that there may be insufficient average beach area available for sea turtle nesting, with the exception of the 900-m island beach (Segment 1) connected to Nasi-II (Behera et al., 2015, 2018). Although there was some apparently suitable beach available in the northern mainland part of Gahirmatha, nesting was not found and only few non-nesting crawls were observed. Sand in this area is mixed with clay and a muddier area is present along this stretch. Olive ridleys prefer to nest in medium, coarse, or fine sand (Rubio, 2009) and with regard to the bathymetry profile, sea turtles prefer to congregate in water between 5–30 m in depth prior to approaching a nesting beach (Mishra et al., 2011). Thus, this area may be of only limited use to olive ridleys for nesting. This reflects the reality that while the east coast of Odisha generally has suitable environmental conditions for olive ridley nesting, nesting opportunities may be spotty in parts. Beyond Gahirmatha's famous arribada areas (Segments 1 and 2), olive ridleys apparently prefer to nest in the southern portion of the beach (Segments 5–7), as evidenced by the highest levels of sporadic and solitary nesting there (Fig. 2; Behera et al., 2013). Should a permanent reduction of suitable beach habitat push the beach area below an unknown threshold, olive ridleys may move away from Gahirmatha and seek other suitable beaches.

Storms and tides.—With the breeding season of olive ridleys in Odisha extending from November–May, nest loss is affected by the tropical storm season, which in this area coincides with the sea turtle nesting season (Garcia et al., 2003). In the course of this study, beach availability for nesting was quite low for Segments 1–5, while it was higher for Segments 6 and 7. High tides during this time tended to cover most nesting beaches in Gahirmatha. For example, high tides covered Segment 1 and 2 beaches due to their low elevation and width. Nesting beaches in Segments 3–5 also became inundated during high tides because the beach is low and narrow, and water can reach the tree line or mangrove vegetation. In many places, tidal mud deposited on the surf zone of the beach may prevent turtles to successfully emerge and nest. This appears to push more turtles to nesting in the southern section (Segments 6 and 7), where conditions may be more favourable (Fig. 2). Mrosovsky (1983) found that leatherback turtles tended to nest closer to the high tide line, where nests were easily inundated by seawater, and this was also reported for olive ridleys in Australia by Whiting et al. (2007). At Gahirmatha, we observed some olive ridley nests deposited within 1 m of the high tide line, and these were subsequently destroyed by incoming tidal seawater. In some cases, clutches were laid within 1 m of the spring high-water line.

Predation.—Predation is a major cause of sea turtle nest losses in many beaches of the world (Fowler, 1979; Cornelius, 1986). In addition, Tripathy et al. (2003) reported that almost all solitary turtle nests were destroyed in Andhra Pradesh, and those were destroyed mostly by animals. Our study documents that at Gahirmatha, olive ridleys prefer to position their nests in locations without vegetation cover, a strategy that was previously documented for Green turtles (*Chelonia mydas*) at Tortuguero, Costa Rica (Bjorndal and Bolten, 1992). As a consequence, these nests may be easier to locate by predators. We found that of the destroyed nests not impacted by erosion or inundation, over 80% were predated by feral dogs, wild pigs, jackals, hyenas, and water monitor lizards (Fig. 3A). There were significant differences in predation levels among beach Segments. Feral dogs were found in Segments 1 and 2 (islets) and these dogs have remained on Abdul Kalam Island. Dogs often follow the crawl marks of turtles and spot the actual nesting sites, then sometimes prey on the nests. Additionally, ghost crabs (Decapoda: Ocypodinae) burrow into turtle nests and consume a few eggs, with the crab's burrow becoming a conduit for bacteria that grow on the eggs and can destroy embryos (Eckrich and Owens, 1995). Crab burrows may also release a turtle egg scent, which can lead to secondary predation by mammals. We observed ghost crabs near olive ridley nests at Gahirmatha but did not attempt to quantified crab predation due to its small scale and the fact that nests reached by crabs were almost always secondarily depredated by larger predators; opened and destroyed nests, of course, attract all manner of scavengers, including ghost crabs. The many tracks of non-nesting crawls we observed, when turtles returned to the water without nesting, might be a response to predator avoidance, with the presence of predators on nesting beaches altering the behaviour of females planning to nest (Santos et al., 2016).

Human activities and pollution.—In addition to the factors listed above, human activities have also dramatically increased the pressure on these sea turtles. This includes rendering the habitat unsuitable for nesting turtles, such as by the establishment of *Casuarina* trees close to the beach, by port construction, through the increase of predatory human commensals (feral mammals), or by agents of pollution (e.g., chemicals, discarded fishing gear). Construction and the resulting alteration of local currents, along with natural storm events, now lead to the establishment of debris piles (Fig. 3B), some of which are difficult for turtles to surmount of circumvent. Some turtles hurt by human activities float and are deposited onto the beach or die from injury after leaving the water, which may bring additional land-based predators to the beach.

Management proposal.—The present study indicates that many factors, both natural and human-caused, impact the ability of turtles to nest at Gahirmatha. Whereas beach indundation and erosion are the leading natural causes of severe nest loss at Gahirmatha, predation by human commensal species is the most significant other problem. Large scale environmental impacts by the human population, including port construction and the establishment of *Casuarina* trees, promote the impact of the former, and the encroachment of human habitations promotes the latter. We propose to limit predator intrusion into the nesting beach by the establishment of wire fencing along the vegetation line. This would not only protect the more isolated arribada sites but would also help maintain sporadic or solitary nests along the Gahirmatha coast. In addition, turtle carcasses and excessive accumulations of debris should be eliminated from the beaches to facilitate turtle movement and to reduce predator attraction and predation risk on nests and live individuals. The Gahirmatha sea turtle rookery should be continuously monitored to determine nesting activity, non-nesting crawls, and predation stress, and these data should be provided to and used by wildlife managers in real time to implement proper management strategies and mitigate the nest loss by olive ridley sea turtles.

Acknowledgements. This research was carried out as part of the Wildlife Institute of India's DGH-Satellite Sea Turtle Telemetry Programme in Odisha. We thank the Principal Chief Conservator of Forests and Chief Wildlife Warden of Odisha for granting permission to carry out this study. We are also very grateful to Kalakar Behera, Sridhara Pradhan, Mahadev Mandal, and Shankar Pradhan, who assisted with the fieldwork, and to Mark O'Shea for assisting us with his excellent map-making skills to produce Fig. 1.

References

Abreu-Grobois, A., Plotkin, P. [IUCN SSC Marine Turtle Specialist Group] (2008): *Lepidochelys olivacea*. The IUCN Red List of Threatened Species 2008: e.T11534A3292503. Available from: www.iucnredlist.org. Accessed on 23 April 2020.

Andrews, H., Choudhury, B.C., Pandav, B., Tripathy, B. (2003): Sea Turtle Conservation: Eco (Turtle) Friendly Coastal Development. Mammalapuram, Tamil Nadu, India Centre for Herpetology, Madras Crocodile Bank Trust. 45 pp.

Behera, S. (2012): Ecology and distribution patterns of olive ridley sea turtles *Lepidochelys olivacea* at Gahirmatha rookery of Orissa Coast, India. Unpublished PhD dissertation, North Orissa University, Odisha, India.

Behera, S., Tripathy, B. (2014): Review of current developmental activities and their possible impact on olive ridley sea turtles along the Odisha coast of India. Testudo **8**: 38–55.

Behera, S., Tripathy, B., Choudhury, B.C., Sivakumar, K. (2010): Behaviour of Olive Ridley Turtles (*Lepidochelys olivacea*) prior to arribada at Gahirmatha, Orissa, India. Herpetology Notes **3**: 273–274.

Behera, S., Tripathy, B., Sivakumar, K., Choudhury, B.C. (2013): A case study on olive ridley (*Lepidochelys olivacea*) solitary nests in Gahirmatha rookery, Odisha, India. Testudo **7**: 49–60.

Behera, S., Tripathy, B., Choudhury, B.C. (2015): World's largest olive ridley turtles *Lepidochelys olivacea* nesting grounds: Gahirmatha rookery now un-certain for arribada in future, East-Coast of India. Herpetological Bulletin **130**: 18–20.

Behera, S., Tripathy, B., Sivakumar, K., Choudhury, B.C., Pandav, B. (2016): Fisheries impact on breeding of olive ridley turtles (*Lepidochelys olivacea*) along the Gahirmatha coast, Bay of Bengal, Odisha, India. Herpetological Journal **26**: 93–98.

Behera, S., Tripathy, B., Sivakumar, K., Choudhury, B.C., Dutta, S.K., Pandav, B. (2018): Nesting space dynamics and its relationship with the arribada of olive ridley turtles at Gahirmatha rookery, East Coast of India. Journal of Herpetology **52**: 381–386.

Bhaskar, S. (1993): The status and ecology of sea turtle in the Andaman and Nicobar Islands. Centre for Herpetology Publication ST 1/93. Mamallapuram, Tamil Nadu, India, Centre for Herpetology, Madras Crocodile Bank Trust. 37 pp.

Bjorndal, K.A., Bolten, A.B. (1992): Spatial distribution of Green Turtle (*Chelonia mydas*) nests at Tortuguero, Costa Rica. Copeia **1992**: 45–53.

Blamires, S.J. (1999): Quantifying the impact of predation on sea turtle nests by varanids at Fog Bay. Unpublished MSc Thesis, Northern Territory University, Darwin, Northern Territory, Australia. 148 pp.

Carr, A.F., Ross, P., Carr, S. (1974): Internesting behavior of the green turtle, *Chelonia mydas* at a mid-ocean island breeding ground. Copeia **1974**: 703–706.

Chatto, R., Baker, B. (2008): The Distribution and Status of Marine Turtle Nesting in the Northern Territory. Palmerston, Northern Territory, Australia, Parks and Wildlife Service of the Northern Territory. 309 pp.

Cooper, N.J., Leggett, D.J., Lowe, J.P. (2000): Beach-profile measurement, theory and analysis: practical guidance and applied case studies. Water and Environment Journal **14**: 79–88.

Cornelius, S.E. (1986): The Sea turtles of Santa Rosa National Park. San José, Costa Rica, Fundación de Parques Nacionales. 64 pp.

Dash, M.C., Kar, C.S. (1990): The Turtle Paradise Gahirmatha: an Ecological Analysis and Conservation Strategy. New Delhi, India, Interprint Press. 295 pp.

Eckert, K.L. (1987): Environmental unpredictability and leatherback sea turtle (*Dermochelys coriacea*) nest loss. Herpetologica **43**: 315–323.

Eckrich, C.E., Owens, D.W. (1995): Solitary versus arribada nesting in olive ridley sea turtles (*Lepidochelys olivacea*): a test of the predator-satiation hypothesis. Herpetologica **51**: 349–354.

Engeman, R.M., Byrd, R.W., Dozier, J., McAlister, M.A., Edens, J.O., Kierepka, E.M., Smyser, T.J., Myers, N. (2019): Feral swine harming insular sea turtle reproduction: the origin, impacts, behavior and elimination of an invasive species. Acta Oecologica **99**(103442): 1–8.

Fish, M.R., Cote, I.M., Gill, J.A., Jones, A.P., Renshoff, S., Watkinson, A.R. (2005): Predicting the impact of sea-level rise on Caribbean sea turtle nesting habitat. Conservation Biology **19**: 482–491.

Fowler, L. (1979): Hatching success and nest predation in the green sea turtle *Chelonia mydas* at Tortuguero Costa Rica. Ecology **60**: 946–955.

Fuentes, M., Limpus, C.J., Hamann, M., Dawson, J. (2010): Potential impacts of projected sea level rise on sea turtle rookeries. Aquatic Conservation Marine and Freshwater Ecosystems **20**: 132–139.

Garcia, A., Ceballos, G., Adaya, R. (2003): Intensive beach management as an improved sea turtle conservation strategy in Mexico. Biological Conservation **111**: 253–261.

García, Y.C., Ramírez-Herrera, M.T., Delgado-Trejo, C., Legorreta-Paulin, G., Corona, N. (2015): Modeling sea-level change, inundation scenarios, and their effect on the Colola Beach Reserve – a nesting-habitat of the black sea turtle, Michoacán, Mexico. Geofísica Internacional **54**(1): 179–190.

Government of India (1972): Wild Life (Protection) Act, 1972. In: India Code, unpaginated. Government of India, Delhi, India. Available at https://indiacode.nic.in/handle/123456789/1726?view_type=browse&sam_handle=123456789/1362. Accessed on 25 April 2020.

Grases, A., Gracia, V., García-León, M., Jue, L.-Y., Sierra, J.P. (2020) Coastal flooding and erosion under a changing climate: implications at a low-lying coast (Ebro Delta). Water **12**(346): 1–26.

Hendrickson, J.R. (1958): The green sea turtle, *Chelonia mydas* (Linn.) in Malaya and Sarawak. Proceedings of Zoological Society of London **130**: 455–535.

Leatherman, S.P., Zhang, K., Douglas, B.C. (2000): Sea level rise shown to drive coastal erosion. Eos **81**(6): 55–57.

Menon, V. (2014): Indian Mammals: a Field Guide. Gurugram, Haryana, India, Hachette India Publishing. 528 pp.

Mishra, R.K., Marale, S.M., Mishra, S., Naik, S. (2011): Olive ridley sea turtle movement in relation to oceanographic parameters in India. International Journal of Environmental Protection **1**: 49–54.

Mortimer, J.A. (1981): Reproductive ecology of the green turtle, *Chelonia mydas* at Ascension Island. Unpublished PhD Thesis, University of Florida, Gainesville, Florida, USA.

Mrosovsky, N. (1983): Ecology and nest-site selection of leatherback turtles *Dermochelys coriacea*. Biological Conservation **26**: 47–56.

National Research Council (1990): Decline of Sea Turtles: Cause and Prevention. Washington, D.C., USA, National Academy Press. 259 pp.

Nordberg, E.J., Macdonald, S., Zimny, G., Hoskins, A., Zimny, A., Somaweera, R., Ferguson, J., Perry, J. (2019): An evaluation of nest predator impacts and the efficacy of plastic meshing on marine turtle nests on the western Cape York Peninsula, Australia. Biological Conservation **238**(108201): 1–8.

Pandav, B., Choudhury, B.C. (2000): Conservation and management of olive ridley sea turtle (*Lepidochelys olivacea*) in Orissa. Project Final Report, Wildlife Institute of India, Dehradun.

Prusty, G., Dash, S., Singh, M.P. (2007): Spatio-temporal analysis of multi-date IRS imageries for sea turtle habitat dynamics characterisation at Gahirmatha coast, India. International Journal of Remote Sensing **28**: 871–883.

Reddy, C.S., Pattanaik, C., Murthy, M.S.R. (2007): Assessment and monitoring of mangroves of Bhitarkanika Wildlife Sanctuary, Orissa, India using remote sensing and GIS. Current Science **92**: 1409–1415.

Reichart, H.A. (1993): Synopsis of biological data on the olive ridley sea turtle *Lepidochelys olivacea* (Eschscholtz, 1829) in the western Atlantic. NOAA Technical Memorandum NMFS-SEFSC-336. 76 pp.

Rubio, M. (2009): Nesting beach characteristics of endangered sea turtles in Las Perlas Archipelago, Panama. Unpublished MSc Thesis, Heriot-Watt University, Edinburgh, Scotland.

Santos, R.G., Pinheiro, H.T., Martins, A.S., Riul, P., Bruno, S.C., Janzen, F.J., Ioannou, C.C. (2016): The anti-predator role of within-nest emergence synchrony in sea turtle hatchlings. Proceedings of Royal Society B **283**: 20160697.

Senapati, A. (2013): Olive ridley sea turtles may be extinct in ten years in Orissa. In: Proceedings of the Thirtieth Annual Symposium on Sea Turtle Biology and Conservation, NOAA Technical Memorandum NMFS-SEFSC-640, p. 72–73. Blumenthal, J., Panagopolou, A., Rees, A.F., Eds., Miami, Florida, USA, National Marine Fisheries Service.

Shanker, K., Pandav, B., Choudhury, B.C. (2004): An assessment of the olive ridley turtle (*Lepidochelys olivacea*) nesting population in Orissa, India. Biological Conservation **115**(1):149–160.

Silas, E.G., Rajagopalan, M., Dan, S.S., Fernando, A.B. (1984): Obervations on the mass nesting and immediate postmass nesting influxes of the olive ridley *Lepidochelys olivacea* at Gahirmatha, Orissa –1984 season. CMFRI Bulletin **35**: 76–82.

Tripathy, B. (2008): An assessment of solitary and arribada nesting of olive ridley sea turtles (*Lepidochelys olivacea*) at the Rushikulya rookery of Orissa, India. Asiatic Herpetological Research **11**: 134–140.

Tripathy, B., Pandav, B. (2008): Beach fidelity and internesting movements of olive ridley turtles (*Lepidochelys olivacea*) at Rushikulya, India. Herpetological Conservation and Biology **3**: 40–45.

Tripathy, B., Rajasekhar, P.S. (2009): Natural and anthropogenic threats to olive ridley sea turtles (*Lepidochelys olivacea*) at the Rushikulya rookery of Orissa coast, India. Indian Journal of Marine Sciences **38**: 439–443.

Tripathy, B., Shankar, K., Choudhury, B.C. (2003): Important nesting habitats of olive ridley turtles *Lepidochelys olivacea* along the Andhra Pradesh coast of eastern India. Oryx **37**: 454–463.

Tripathy, B., Kumar, R.S., Choudhury, B.C., Sivakumar, K., Nayak, A.K. (2008): Compilation of Research Information on Biological and Behavioural Aspects of Olive Ridley Turtles along the Orissa Coast of India – a Bibliographical Review for Identifying Gap Areas of Research. Dehra Dun, Uttarakhand, India, Wildlife Institute of India.

Turtle Taxonomy Working Group [Rhodin, A.G.J., Iverson, J.B., Bour, R. Fritz, U., Georges, A., Shaffer, H.B., van Dijk, P.P.] (2017): Turtles of the world: annotated checklist and atlas of taxonomy, synonymy, distribution, and conservation status. Chelonian Research Monographs **7**: 1–292.

Upadhyay, V.P., Mishra, P.K., Sahu, J.R. (2008): Distribution of mangrove species within Bhitarkanika National Park in Orissa, India. Trees for Life Journal **3**: 1–5.

Valverde, R.A., Cornelius, S.E., Mo, C.L. (1998): Decline of the olive ridley sea turtle (*Lepidochelys olivacea*) nesting assemblage at Nancite beach, Santa Rosa National Park, Costa Rica. Chelonian Conservation and Biology **3**: 58–63.

Valverde, R.A., Orrego, C.M., Tordoir, M.T., Gómez, F.M., Solís, D.S., Hernández, R.A., et al. (2012): Olive ridley mass nesting ecology and egg harvest at Ostional Beach, Costa Rica. Chelonian Conservation and Biology **11**: 1–11.

Whitmore, C.P., Dutton, P.H. (1985): Infertility, embryonic mortality and nest-site selection in leatherback and green sea turtles in Suriname. Biological Conservation **34**: 251–272.

Whiting, S.D., Long, J.L., Hadden, K.M., Lauder, A.D.K., Koch, A.U. (2007): Insights into size, seasonality and biology of a nesting population of the Olive Ridley turtle in northern Australia. Wildlife Research **34**: 200–210.

Wildlife Institute of India (2012): Determining the Offshore Distribution and Migration Pattern of Olive Ridley Sea Turtle (*Lepidochelys olivacea*) along the East-Coast of India. Dehradun, Uttarakhand, India, Wildlife Institute of India. 197 pp.

Whytlaw, P.A., Edwards, W., Congdon, B.C. (2013): Marine turtle nest depredation by feral pigs (*Sus scrofa*) on the Western Cape York Peninsula, Australia: implications for management. Wildlife Research **40**: 377–384.

Accepted by Eric Munscher