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ARTICLE

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ARTICLE

Nesting and hatching behaviour of Olive Ridley Turtles *Lepidochelys olivacea* (Eschscholtz, 1829) (Reptilia: Cryptodira: Cheloniidae) on Dr. Abdul Kalam Island, Odisha, India

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Abstract: This paper reports the nesting, impact of lunar phase and rainfall on mass nesting, hatching, and hatchling behaviour of *L. olivacea* in Dr. Abdul Kalam Island, Bhadrak District, Odisha. The study site is a well-known rookery for this species. A study of 15 mass nesting events between 2003 and 2020 using Rayleigh's test indicated that the onset of mass nesting was not uniform across a lunar month, but was most intense towards the beginning of the fourth quarter moon (mean lunar day = 22.44). Also, rainfall and mass-nesting data from 2015 to 2020 revealed that ≥3.2 mm rainfall in February delayed mass nesting from the second fortnight of February to the end of the first fortnight of March. Sporadic nesting continued after hatching commenced in May, and continued until the end of May 2020, with an average of three turtles nesting each day. At night, a cohort of hatchlings from individual nests emerged synchronously. Before emergence they remained a little beneath the sand surface in airy-shallow pits. During hatchling emergence these pits fill with sand, leaving depressions described as "emergence craters" in recent literature on *L. olivacea*. To study hatchling emergence 30 such craters were examined in May 2020, and the numbers of emerged hatchlings per cohort varied from 28 to 182. Of 30 craters examined, 28 were circular and two were elliptical, with diameters varying between 10 and 26 cm. Pearson's correlation coefficient between the numbers of emerged hatchlings and crater diameter was 0.38. Hatchlings took 17 min 22 sec (SD= ±5min 30 sec) on average to reach the sea from a mean distance of 34.6m.

Keywords: Arribada, Bhadrak District, cohorts, emergence crater, hatchling emergence, moon phase, sporadic nesting.

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INTRODUCTION

The Olive Ridley Sea Turtles *Lepidochelys olivacea* are the second smallest sea turtles in the world next to the Kemp Ridley *Lepidochelys kempii* (Van Buskirk & Crowder 1994). *Lepidochelys olivacea* have a circumtropical distribution and occur in India, Mexico, Costa Rica, and the Arab Peninsula, further to coastal Africa along the warm tropical and subtropical waters of the Indian and Pacific Oceans (Pritchard 1997; Pritchard & Mortimer 1999). They do not migrate from one ocean to another but move between the oceanic and neritic zones within the same ocean (Plotkin et al. 1995).

Lepidochelys olivacea populations are well known for 'arribada' (a Spanish term, meaning 'arrival by sea') wherein 1000s of pregnant turtles arrive at the same beach site to lay their eggs and nest for the next few days. The mass nesting sites for *L. olivacea* include Costa Rican and Mexican beaches (Pritchard 1997) and the Odisha coast (Bustard 1976) along the Pacific and Indian Ocean, respectively. In Odisha, Gahirmatha Wildlife Sanctuary in Kendrapada District (Bustard 1976), the Devi River mouth in Puri District (Kar 1982) and Rushikulya in Ganjam District (Pandav et al. 1994) are the three principal nesting sites for *L. olivacea*. Among these, Gahirmatha Wildlife Sanctuary is the largest known nesting centre for *L. olivacea* (Bustard 1976) with 1–8 lakh turtles nesting per year (Pattnaik et al. 2001).

Breeding and nesting of *L. olivacea* occur through the year in Costa Rican and Mexican coasts, with mass nesting in the rainy months of July–December (Hart et al. 2014), mostly during the third quarter moon (Plotkin 1994). In the Odisha coast mass nesting occurs in the dry months of January–March (Dash & Kar 1990). In Gahirmatha Wildlife Sanctuary in particular, breeding of *L. olivacea* starts in November and mass nesting occurs in January–March (Behera et al. 2010). *Lepidochelys olivacea* have the ability to delay nesting in response to heavy rainfall, because high moisture level in the beach sand reduces hatching success in the nest (Plotkin et al. 1997). The numbers of turtles participating in mass nesting are variable (Pattnaik et al. 2001). Sporadic nesting by a few individuals of *L. olivacea* along the eastern coast of India from North 24 Parganas District to Kanyakumari (21.638^{0}N, 89.075^{0}E) between December and April are common (Pandav & Choudhury 2000; Tripathy et al. 2008). After 45–50 days of incubation, the hatchlings return to the sea in April.

Hatching within a nest is synchronous (Spencer et al. 2001) and emergence occurs through group-digging behaviour customarily described as 'social facilitation' (Carr & Hirth 1961). The emergence of hatchlings from a single nest occurs in 1–4 cohorts over a few days, with the first cohort having the largest number of hatchlings (Rusli et al. 2016). Before emergence, hatchlings rest in an air-filled pit in sandy soil and during emergence, the surface sand sags into the pit (Salmon & Reising 2014), leaving a depression described as 'emergence crater' (Bishop et al. 2011). Hatchling emergence in *L. olivacea* has been studied using various methods. Among them, the numbers of hatchlings leaving the emergence crater (Burney & Margolis 1998) is considered a reliable index of hatchling emergence. After emergence, the hatchlings crawl radially out of the crater and the crawl marks are used in describing hatchling emergence (Bishop et al. 2011).

Hatchlings emerge nocturnally (Mrosovsky 1968) and move towards negative surface gradient (Salmon et al. 1992). Also, hatchlings exhibit positive phototaxy. Since the sea surface reflects moon light better than the land surface, they move seawards (Mrosovsky & Shettleworth 1968). Artificial illuminations placed on the land distract the seaward movement of hatchlings (Tuxbury & Salmon 2005). In the absence of artificial illumination, disorientation in hatchling movement is high on new moon days (Salmon & Witherington 1995).

Lepidochelys olivacea populations have declined in many countries due to various reasons: collection of eggs (Arauz 2000), destruction of nesting beaches (Pandav & Choudhury 1999), trapping of adults (Fretey 2001), intensive fishing practice using trawlers and banned nets (Pandav 2000), diseases (Herbst 1994), and global warming (Hays et al. 2003) are a few significant ones. The IUCN Red List of Threatened Species has evaluated *L. olivacea* under 'Vulnerable' category (Abreu-Grobois & Plotkin 2008).

In Gahirmatha Wildlife Sanctuary, mass nesting was delayed between February and March 2020 probably because of sporadic rainfall in February (3.2mm). Also, the nesting period (14–20 March 2020) coincided with waning phase of the moon. These observations prompted further study exploring the effect of certain environmental variables, viz., lunar phase and rainfall on mass nesting and hatching behaviour of *L. olivacea*. Although the nesting and hatching behaviour of *L. olivacea* have been reasonably well explored in Gahirmatha (Dash & Kar 1990; Silas et al. 1985; Pandav 2000; Behera et al. 2010), little information exists pertaining the influence of lunar phase and rainfall on mass nesting, and behaviour of hatchlings post emergence.

Therefore, I proceeded with this study keeping the following objectives in focus: (1) mass nesting and its relation with lunar phase, (2) effect of rainfall on mass nesting, (3) the duration of sporadic nesting, (4) the patterns in hatchling emergence and emergence craters, and (5) behaviour of hatchlings post emergence.

MATERIALS AND METHODS

Study Area

Dr. Abdul Kalam Island (previously Wheeler Island, 20.753^{0}N, 87.072^{0}E) falls under the Gahirmatha Wildlife Sanctuary, managed by the forest department of the state of Odisha (Figure 1). The Gahirmatha Beach is 2.4 km long with varying widths. The average annual temperature is 27^{o}C and the average annual rainfall is 1,530mm. *Ipomoea pescaprae* (Convolvulaceae) and *Suaeda maritima* (Amaranthaceae) usually occur abundantly on the sandy shoreline.

Methods

Hatchlings from each nest dig synchronously upwards in cohorts, forming emergence craters on the sand surface. The hatchlings gradually leave the craters and reach the surface, beginning their movement towards the sea. The number of emerged hatchlings per cohort was determined through visual observation of emergence from such craters. During the hatching period, 2–7 May 2020, 30 craters were sampled randomly and each crater was observed from 20.00h to 06.00h, and the numbers of hatchlings emerging from each crater were counted. From each crater, the movements of the first 5–10 hatchlings to the sea were observed individually and the time taken by each of them was measured using a stopwatch. The overall shape of each crater was measured for the diameter using measuring tapes. The

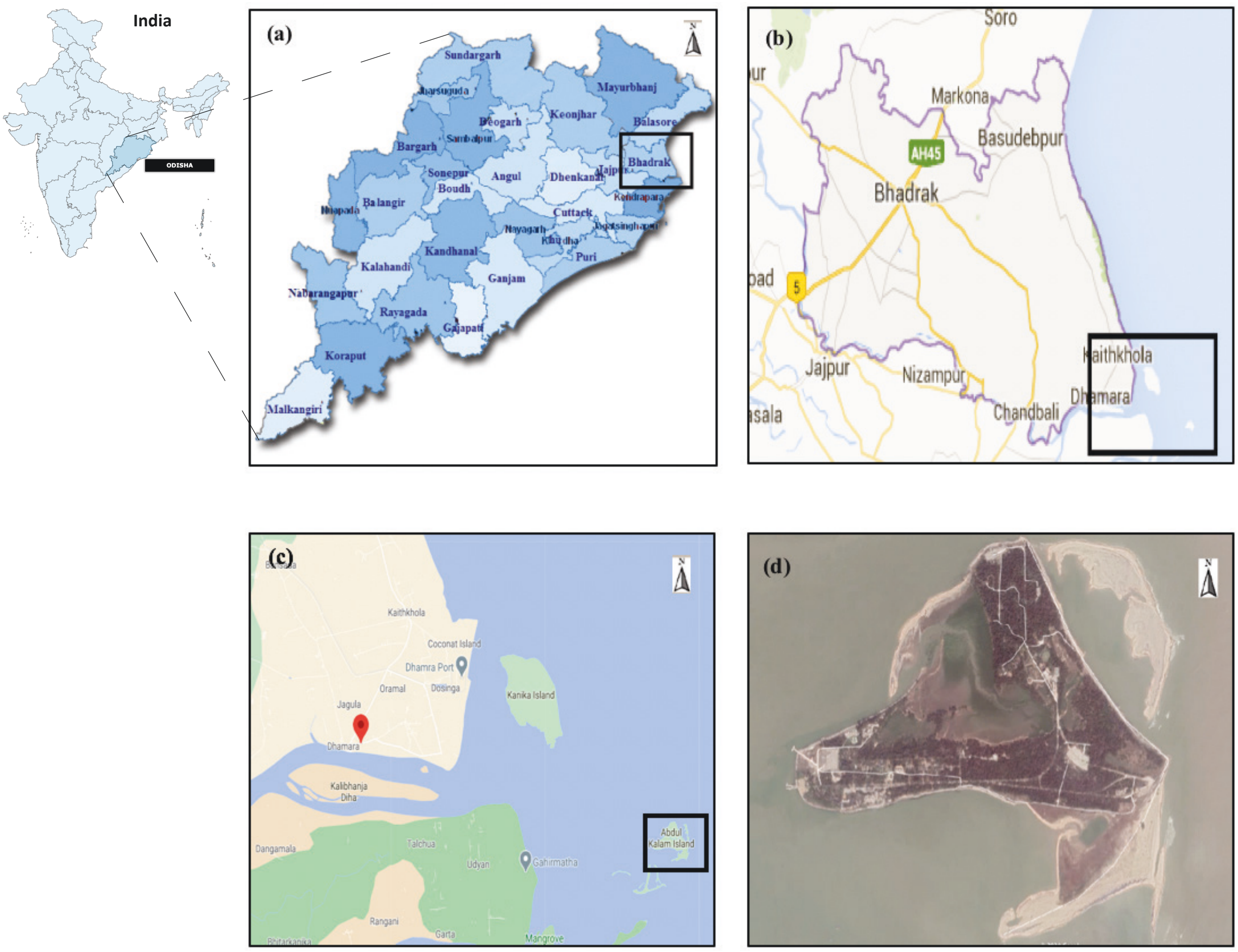

Figure 1 . Study area: a—Bhadrak District (marked) in Odisha map | b—Bhadrak coast (marked area in 'a') | c—Bhadrak coast showing the Dr. Abdul Kalam Island (marked area in 'b') | d—Gahirmatha beach in Dr. Adbul Kalam Island (marked area in 'c'). Source: odishaassembly.nic.in, censusindia.co.in and earth.google.com.

nesting data of *L. olivacea* for 2003–2020 were obtained from the archives of the Rajnagar Wildlife Division Office, Kendrapada. The rainfall data of Dr. Abdul Kalam Island for 2015–2020 were obtained from the nearest meteorological office of Dhamra Port Company Limited, Dhamra, Bhadrak District, Odisha.

The lunar days corresponding to the starting of each mass nesting were obtained from keisan.casio.com (CASIO Computer Co Ltd, 2020, Tokyo, Japan). The lunar days were then converted into angular data for using Rayleigh's test, which was done using MS Excel 2019 to verify uniformity in the occurrence of onset of mass nesting across a lunar month. The correlation between variables in the scatter plot was calculated using Pearson's correlation. Photographs of nesting and hatching were made using a COOLPIX P1000 (125X Optical Zoom Camera, Nikon Corporation, Tokyo, Japan).

RESULTS

Mass nesting (Arribada) and Lunar phase

Mass nesting of *L. olivacea* revealed that 407,204 individuals laid eggs between 14 and 20 March 2020 (Table 1). Maximum numbers (n= 98,700) nested on 17 March (fourth day) and the minimum (n= 3,600) on 20 March (seventh day) (Table 1). Mass-nesting data obtained from Rajnagar Wildlife Division for 2015–2020 revealed that a maximum of 664,897 individuals nested in 2018 and a minimum of 51,995 in 2016 (Table 2)

Rayleigh's test was done to determine if the onset (in lunar days) of 15 mass nesting events between 2003 and 2020 (Table 3) was non-uniformly distributed across a lunar month. Results indicated a highly non-uniform distribution (n= 15, r= 0.504, z= 3.81, $z_{critical}$= 2.945, α= 0.05) with a mean lunar day of 22.44 (i.e., the onset of mass nesting is at the beginning of fourth quarter moon).

Nesting period and rainfall

Mass nesting and the rainfall data for 2015–2020 (Table 4) were analysed in conjunction to study the impact of rainfall on nesting. When the rainfall in February was less than 3.2mm, mass nesting occurred in the last fortnight of February or in the first week of March. When the rainfall increased ≥3.2mm in February, mass nesting was delayed to the end of the first fortnight of March; however, rainfall in the first week of March did not delay mass nesting further, since the nesting season for *L. olivacea* ended in March.

Table 1. Mass nesting data of *L. olivacea* in 2020.

Day	Population numbers
14 March	10,076
15 March	68,311
16 March	98,135
17 March	98,700
18 March	95,541
19 March	32,841
20 March	3,600
Total	407,204

Table 2. Mass-nesting of *L. olivacea* turtles, 2015–2020.

Year	Population numbers
2015	413,334
2016	51,995
2017	603,962
2018	664,897
2019	450,949
2020	407,204

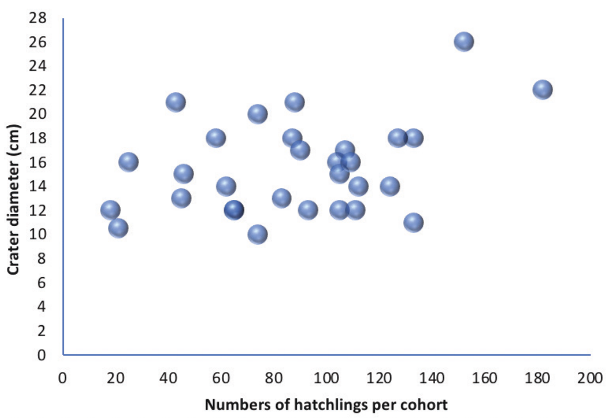

Figure 2. Scatter plot of numbers of hatchlings and crater diameter

Sporadic nesting

Sporadic nesting of *L. olivacea* at Gahirmatha started from the second fortnight of December 2019 and continued after mass nesting from 14–20 March to 1–10 May 2020. Between December and February, an average of 15 individual females of *L. olivacea* nested per day. The numbers increased to 40 per day for a week prior to and after mass nesting. During hatching (2–7 May), an average of three turtles nested on the beach every day.

Table 3. Date of initiation of 15 arribada events and corresponding lunar days, 2003–2020.

Sno	Year	Date of initiation of arribada	Lunar days (out of 29.53 days in a lunar month)	Sno	Year	Date of initiation of arribada	Lunar days (out of 29.53 days in a lunar month)
1	2003	28Feb	26.8	9	2013	17 March	5.4
2	2007	11Feb	23.1	10	2015	12 March	21.3
3	2009	20Mar	23.2	11	2016	03 March	23.7
4	2010 *	24Feb	10.2	12	2017	22 Feb	25.3
5	2010**	19Mar	2.4	13	2018	04 March	16.4
6	2011*	26Feb	23.2	14	2019	26 Feb	21.4
7	2011**	20Apr	16.7	15	2020	14 March	19.6
8	2012	15Mar	22.3	-	-	-	-

Source of mass nesting data: Archives of Rajnagar Wildlife Division, Kendrapada, Odisha Forest Department.
*—First mass nesting | **—Second mass nesting.

Table 4. Yearly rainfall and mass nesting data for Gahirmatha Beach, Dr Abdul Kalam Island, 2015–2020.

Year	Rainfall in 1–15 February (in mm)	Rainfall in 16–28 (29) February (in mm)	Rainfall in 1–15 March (in mm)	Rainfall in 16–31 March (in mm)	Period of mass nesting
2015	0	3.2	0	10.8 (29th)	12–19 March
2016	20.4	5.5	3.7	1	3, 12–20 March (48 turtles on March 3rd)
2017	0	0	0	18.2	22 Feb–1 March
2018	0	0	0	0	4–13 March
2019	0	1	1	1.8	26 Feb–5 March
2020	6.4	6.0	7.8	10 (20th, 22nd, 23rd)	14–20 March

Hatchling emergence

The hatchlings dug through the sand above synchronously to emerge from their sandy nests. At the time of emergence, usually after sunset, an emergence crater formed on the sand surface due to synchronous, collective, digging effort by a single cohort of *L. olivacea* from a nest. These craters lasted for 7–10 days and eventually were either eroded or filled up with sand spread by wind. The hatchlings reached the surface gradually with the hatchlings present near the surface pushed by emerging hatchlings below in the crater. On reaching the surface they spread themselves radially in different directions, but moved towards the sea.

The numbers of hatchlings emerging from the 30 observed individual craters were 2,763. The maximum and minimum numbers of emerged hatchlings per cohort were 182 and 18 with an average of 92.1 hatchlings per cohort. The craters were mostly circular (93.3%) and occasionally elliptical (6.7%). The crater diameter varied between 10 and 26 cm (n= 30). Pearson's correlation indicated a low but positive correlation (0.38) between the numbers of emerged hatchlings per crater and crater diameter. Therefore, when the number of emerging hatchlings per cohort increases, the crater diameter also tends to increase.

Movement of hatchlings towards sea

As soon as the hatchlings emerged, they moved towards the sea. The pace and direction of movement varied among individuals. Time taken by 280 hatchlings from 30 emergence craters to reach the sea indicated that the minimum time taken was 6 min 12 sec and the maximum was 35 min 9 sec. The average time taken by hatchlings to reach the sea from a mean distance of 34.55m was 17 min 22 sec. (SD= ± 5 min 30 sec).

DISCUSSION

Mass nesting and lunar phase

Previous reports on the numbers of mass nesting *L. olivacea* individuals at Gahirmatha Wildlife Sanctuary

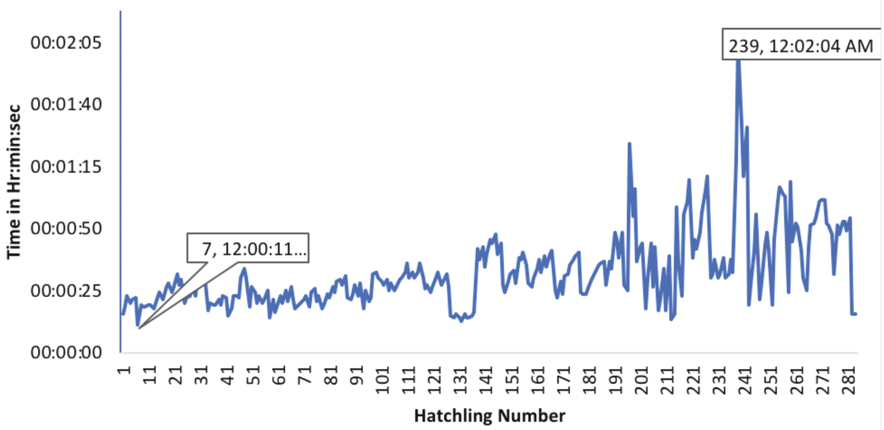

Figure 3. Time taken by individual hatchlings to move 1m

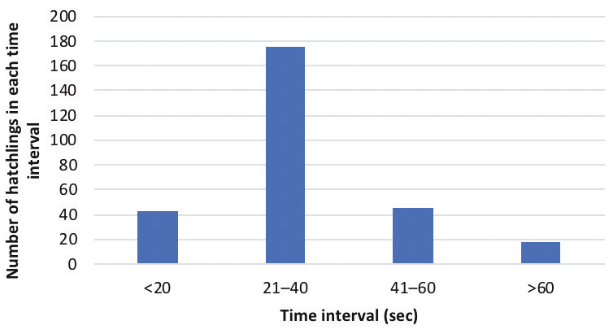

Figure 4. Numbers of hatchlings in various time intervals.

indicate varying annual numbers (Bustard 1976; Kar & Bhaskar 1982; Silas et al. 1985). The data for 2015–2020 also revealed that numbers of turtles differed every year with 51,995 turtles in 2016 and 6,64,897 in 2018. It is possible that the variation was due to changes in productivity in their foraging areas, because females needed sufficient nutrients to support their migratory and reproductive activities (Valverde et al. 2012). Also, an increase or decrease in hatching rates over many years may result in varying adult population participating in arribada (Cornelius et al. 1991). Beach exchange, where Olive Ridleys move to another beach for nesting, mortality in nets (Valverde et al. 1998) also affects the nesting population numbers. The exact reason for variation in the number of individuals in mass nesting, however, requires further study.

At Gahirmatha, the onset of mass nesting occurred at the beginning of the fourth quarter moon. Rayleigh's test showed a highly non-uniform distribution of onset of mass nesting across the lunar month with a mean lunar day of 22.44 days. According to Silas et al. 1985, mass nesting occurred on 7th day after the full moon in Gahirmatha, i.e., after 20.77 days. In Ostional Beach, Costa Rica, mass nesting usually began in the fourth quarter moon with mean lunar days of 23 (Bezy et al. 2020). In Mexico, mass nesting coincided with the third quarter moon (Plotkin 1994). In Ghana, a majority of *L. olivacea* nesting occurred in third quarter, which could be due to less light because of waning moon, and thus to avoid predators (Witt 2013). Another possible advantage of nesting during waning moon was greater prey availability post-nesting (Pinou et al. 2009) because *L. olivacea* feed primarily on crabs, which are nocturnal (Shaver & Wibbels 2007).

Nesting period and rainfall

In Gahirmatha, rainfall (≥3.2mm) in February 2020 delayed mass nesting of *L. olivacea* from February to first week of March 2020. High sand moisture content due to rainfall is indicated as a reason for reduced hatching success in the nest chamber (Packard et al. 1977). In the eastern Pacific Coast, *L. olivacea* individuals delayed nesting during extreme rainfall (>50 cm) (Plotkin et al. 1997), but not during normal precipitation levels (9cm) (Coria-Monter & Duran-Campos 2017) because arribadas coincided with rainy seasons in the eastern Pacific (Cornelius 1986). Whereas in Gahirmatha, even modest rainfall (3.2mm) delayed the mass nesting, because nesting occurred in dry periods in Odisha (Dash & Kar 1990). Since the nesting season of *L. olivacea* ended in March (Behera et al. 2010), there was no further delay in nesting beyond second week of March 2020 despite rainfall in the first week.

Sporadic nesting

Sporadic nesting of *L. olivacea* occurred almost every month along the Odisha coast, but more frequently between February and April (Dash & Kar 1990). Sporadic nesting occurred mainly between December and May

Image 1. Nesting ground for arribada of Olive Ridley turtles: a—arribada in the early morning (05.00h) | b—a female clearing the surface sand for nesting | c—a female turtle in oviposition (laying eggs) | d—hatchlings emerging from the emergence crater | e—emergence craters on the sand surface | f—an individual *L. olivacea* hatchling | g—hatchlings moving towards the sea | h—hatchlings entering the sea. © Poornima P.

along the eastern coast of India (Pandav & Choudhary 2000). During the study period in Gahirmatha, sporadic nesting was noted mainly between December and May. Between December and February, an average of 15 *L. olivacea* individuals nested sporadically. The numbers increased to 40 per day for a week prior to and after mass nesting (14–20 March). In Gahirmatha, more than 10 turtles arrived for sporadic nesting per night (Tripathy 2008). Our observations in Gahirmatha match with those of Tripathy (2008) till April 2020 but the numbers of turtles nesting sporadically in May 2020 was, on an average, only three per night.

Hatchling emergence

Mrosovsky (1968) and Witherington et al. (1990) observed that the emergence of *L. olivacea* hatchlings onto the sand surface was predominantly nocturnal. The hatchlings emerged only after sunset and before sunrise, in Gahirmatha as well. After synchronous hatching from the nests, hatchlings exhibited group-digging behaviour to reach the sand surface (Hendrickson 1958; Carr & Hirth 1961). At Gahirmatha, this behaviour was prevalent in all the nests observed. Final emergence by hatchlings on to the sand surface created emergence craters (Bishop et al. 2011) due to collapse of the cavity in which hatchlings were present (Salmon & Reising 2014). Also, the hatchlings emerged in cohorts of 1–4 from a single nest, over a period of 4–8 days, with the first cohort having maximum number of hatchlings (Rusli et al. 2016). At Gahirmatha, every time a cohort of hatchlings from a nest emerged, an emergence crater formed on the surface, which lasted 7–10 days before being either eroded or filled up with sand by wind.

The minimum and maximum number of hatchlings from individual craters (per cohort) were 18 and 182, respectively, with an average of 92.1 hatchlings. These numbers represent the emergence per cohort. Therefore, the maximum egg count per nest (clutch size) found in Gahirmatha was ≥182 considering the mortality in the nest and mortality during emergence. Whereas, Kumar et al. (2013) observed maximum egg counts of 168. The craters were mostly circular (93.3%) and occasionally elliptical (6.7%). Their diameters varied between 10cm and 26cm. There was a low but positive correlation (0.38) between numbers of hatchlings per crater and respective crater diameter, as per Pearson's correlation.

Movement of hatchlings towards sea

After emergence hatchlings typically move towards negative slope gradient (Limpus 1971), which was observed in Gahirmatha. Hatchlings also typically exhibit positive phototaxy, leading them to move towards the sea since moon light is reflected more by water than land (Carr & Ogren 1960; Mrosovsky & Shettleworth 1968). These findings also match with observations in Gahirmatha. The minimum time taken by hatchlings to move one metre was 11 sec, whereas the maximum time was 2 min 4 sec. The average time taken by hatchlings to move one metre was 33 sec (SD= ±15 sec). This is less than the time taken by *L. olivacea* in Costa Rica, 52.4 sec (Burger & Gochfield 2014) and Indonesia, 36–48 sec (Maulaney et al. 2012). Of 280 hatchlings, 62.5 % took 20–40 sec to move one metre. Considering the total time taken to reach the sea, minimum and maximum time taken was 6 min 12 sec and 35 min 9 sec, respectively. The average time taken by hatchlings in Gahirmatha to reach the sea was 17 min 22 sec (SD= ± 5 min 30 sec) for a mean distance of 34.55m, whereas it was 19 min 12 sec for a mean distance of 27.7m in Ostional Beach, Costa Rica (Burger & Gochfield 2014).

CONCLUSION

The sandy beaches of Dr. Abdul Kalam Island in Gahirmatha Wildlife Sanctuary, even though geographically small in area, continue to be one of the most important nesting site for *L. olivacea* population in the world. Adequate measures are undertaken every year by Odisha Forest and Wildlife Department to ensure protection of *L. olivacea* along the Odisha coast. Further, study of environmental factors such as rainfall, lunar phase, temperature and winds on mass nesting in Odisha in general and Gahirmatha in particular, would further enhance our understanding of *L. olivacea*'s intricate nesting and hatching behaviour.

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