Movements of Olive Ridley Turtles (*Lepidochelys olivacea*) in the Bay of Bengal, India, Determined via Satellite Telemetry

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**ABSTRACT.** – The migratory movements of 14 olive ridley turtles (*Lepidochelys olivacea*) in the Bay of Bengal were studied using satellite telemetry during 2009–2010. Tracking data show that olive ridley turtles undertake open-ocean migrations in the bay and exhibit migratory corridor between foraging habitat of Sri Lanka and nesting sites along the Odisha coast of India. Tracking durations ranged 7–331 d (mean = 151 ± 95.9 d). The tracked turtles had a mean traveling speed of 2.49 ± 0.02 km/hr and moved an average of 31.7 km/d, remaining within a mean distance of 163.28 ± 50.9 km (range, 1–535 km) from the east coast of India. Turtles occupied waters with sea surface temperature (SST) ranging from 24°C to 31°C with chlorophyll concentrations of 0 to 3.9 mg/m³. Our study confirms that olive ridley turtles in the Bay of Bengal move within a broad range of SSTs and chlorophyll *a* concentrations; no correlation was found between turtle movements and these 2 oceanographic parameters (*r*² = 0.02, *n* = 77). Our data indicate that many habitats within the Bay of Bengal are important for olive ridley turtles and that the entire bay should be considered a priority conservation region for this vulnerable species.

**KEY WORDS.** – Reptilia; Cheloniidae; sea surface temperature; chlorophyll *a*; Gahirmatha; PTT

Current knowledge of sea turtle life history suggests that individuals occupy a series of different habitats during their life cycles (Musick and Limpus 1997). However, the location and movement patterns of sea turtles are often challenging to study owing to their cryptic nature and the logistical difficulty in accessing turtles far from shore. In recent decades, satellite telemetry has made it possible to monitor the movements of free-ranging sea turtles in the open ocean, and the results of these studies have yielded insights about many aspects of sea turtle ecology and behavior, including the spatiotemporal distribution of transoceanic migrations (Pandav and Choudhury 2000; Godley et al. 2008; Tripathy and Pandav 2008).

In addition to revealing a turtle’s whereabouts, the application of satellite telemetry can also be linked with remotely sensed oceanographic information to identify the environmental factors associated with their movements (Arnold and Dewar 2001; Polovina et al. 2001; Etnoyer et al. 2006; Godley et al. 2008; Swimmer et al. 2009; Hart et al. 2010). For example, olive ridley turtle (*Lepidochelys olivacea*) movements in the central North Pacific are centered in sea surface water temperatures (SSTs) between 24°C and 27°C with a chlorophyll *a* concentration of ~ 0.1 mg/m³ (Polovina et al. 2004). Similarly, postnesting movements of green turtles (*Chelonia mydas*) from the Galápagos Islands (Ecuador) were tracked with satellite telemetry, the results of which showed that turtles’ oceanic movements occurred in waters with a mean SST of 26.5°C and mean surface chlorophyll *a* concentration of 0.18 mg/m³, whereas neritic movements were in waters with a mean SST of 24.3°C and mean surface chlorophyll *a* concentration of 0.47 mg/m³ (Seminoff et al. 2008). Indeed, knowledge about the oceanographic characteristics of areas where sea turtles migrate can help predict where they may be found (Epperly et al. 1995), and this understanding can be useful for conservation (Godley et al. 2008).

The olive ridley turtle is the most abundant of the 5 species of sea turtles found along the Indian coast, and has been studied along the Odisha coast of India for more than three decades (Dash and Kar 1990; Pandav and Choudhury 2000; Tripathy 2002; Shanker et al. 2004). Some information is known about their migrations near India, with postnesting migrations having been recorded extensively (Pandav and Choudhury 1998; Shanker et al. 2002). Further, in the Bay of Bengal migrating olive ridleys are seen prior to October–November and after the April–May nesting season in Odisha (Oliver 1946; Deraniyagala 1953). Satellite tracking of sea turtles was first conducted in India in 2001, with the study of 4 olive ridleys at the Devi rookery of Odisha within the Bay of Bengal (Shanker et al. 2002). Among these turtles, 1 individual reached the Sri Lanka coast within 18 d after departing the Odisha coast (Shanker et al. 2002). However, the correlation...
between the SST and chlorophyll a concentrations associated with olive ridley migration in the Bay of Bengal is poorly understood. Information such as this will be instructive for better understanding the oceanographic conditions in which olive ridley turtles are located; this information will have value for future conservation of olive ridley turtles in the region.

In this study, we used satellite telemetry to track the movements of 14 olive ridley turtles in the Bay of Bengal. To our knowledge this is the first-ever study of postmating movements and migration of male olive ridley turtles (n = 3) in India. In addition to generating information on overall movements, our goal was to better understand the oceanographic conditions (SST and chlorophyll a) in the areas through which olive ridley turtles migrated. We also hope that our data contribute to the overall knowledge of this species near India.

**METHODS**

**Study Site.** — Olive ridley sea turtles congregate en masse along the Odisha coast between November and April for mating and nesting, with nesting occurring primarily on the beaches of Gahirmatha, Devi, and Rushikulya; Gahirmatha is known to be the largest mass nesting rookery for olive ridley sea turtles in the world (Bustard 1976). The coastal waters of Gahirmatha were declared a wildlife sanctuary in September 1997 for protecting the olive ridley sea turtles both on the nesting beaches and in near-shore habitat. The Gahirmatha Marine Wildlife Sanctuary encompasses an area of 1435 km², 1408 km² of which are coastal waters, whereas the rest is made up of mangrove forests, mudflats, and sand spits. The coastline extends for ~35 km from Dhamra to the Barunei River mouth, an area that includes the Gahirmatha Marine Wildlife Sanctuary (between 80°45′E and 20°17′N; Fig. 1). The continental shelf in this region is shallow and does not exceed 20 m depth, even at an offshore distance of 7 km.

**Satellite Tracking.** — Satellite telemetry was used to track the local and long-distance movements of olive ridley turtles from the Gahirmatha offshore waters of Odisha. We attached Kiwisat 101 (Sirtrack Ltd, Havelock North, New Zealand) platform terminal transmitters (PTTs) to 14 olive ridley turtles (3 males and 11 females). The first 7 PTTs were deployed in February 2009 on turtles (3 males and 4 females) that were captured at sea while mating (single male was mating with 2 females). Subsequently, in March 2009, 5 female olive ridleys were restrained after nesting at Gahirmatha and fitted with PTTs, and in April and May 2009 an additional 2 females were equipped with PTTs after nesting (Table 1). All transmitters were programmed with a duty cycle of “24 hrs on” for the first 2 wks of tracking, followed by a cycle of “24 hrs on/48 hrs off” (72 hrs/cycle) until the end of transmissions.

For each tracked turtle we measured curved carapace length (CCL) and curved carapace width (CCW) with a flexible measuring tape and straight carapace length (SCL) and straight carapace width (SCW) using a tree caliper; each turtle was also weighed to the nearest 0.1 kg using a spring scale and netting. Prior to PTT application we removed epibionts (e.g., barnacles, algae), sanded the carapace to remove algae and exfoliating keratin, and then cleaned the carapace with isopropyl alcohol. PTTs were attached to the carapace of each turtle using quick-set epoxy resin adhesive (Sika Anchor Fix 3®, Sika Inc). Additionally, fiberglass tape was placed on the wet epoxy to provide extra reinforcement for the attachments. Photographs to document carapace and skin anomalies were also taken from each PTT-equipped turtle. The entire process of turtle capture, PTT placement, and release back to sea took 4–6 hrs for each turtle. We verified that all PTTs were operational prior to release.

Location of each tagged turtle was collected via the Argos satellite system (Argos 1996). Argos (1996) assigns location classes (LC) to each location as an estimate of accuracy, which includes LC3 (≥ 150 m), LC2 (± 350 m), LC1 (± 1000 m), and LC0 (> 1000 m). Field tests showed that these estimates of accuracy were close to real errors from the known locations (Hays et al. 2001). Additional location classes (LCA and LCB) have an unknown accuracy (Argos 1996). The tracking information was automatically downloaded and sorted into fields from the Argos databank via Satellite Tracking and Analysis Tool (STAT) (Coyne and Godley 2005). Only LC3, LC2, and LC1 positions were used to calculate speed and distance. Erroneous locations were removed by STAT (Coyne and Godley 2005) if it meant swim speeds of over 5 km/hr were required to reach that location (e.g., Luschi et al. 1998). Migration routes were plotted using an additional LC0 with the STAT angle filter set at 70° to ensure that maximum data were used to depict migration routes. Movement data of olive ridley turtles were obtained from STAT for further analysis and mapping. The migration routes of olive ridley turtles in the Bay of Bengal were plotted in Arc GIS 9.0 using all the best-quality locations of olive ridleys. Also, the SST and chlorophyll a data were procured from the STAT Web site and the overall range and mean values for each parameter were calculated for each olive ridley satellite track. Statistical software SPSS 15.0 was used for linear correlation analysis between the SST and chlorophyll a concentration.

**RESULTS**

**Morphometrics of Transmittered Turtles.** — Satellite transmitters were fitted to 3 male and 11 female olive ridley turtles. The transmitter-equipped turtle measurements ranged from 65.0 to 73.0 cm for CCL, 62.5 to 71.0 cm for CCW, 61.4 to 68.8 cm for SCL, and 53.3 to 65.3
cm for SCW (Table 1). Turtle body weights ranged from 28.0 to 43.5 kg (Table 1).

**Tracking Duration and Location Class.** — A total of 6483 locations were received from the 14 PTT-equipped olive ridley turtles. Only 4013 (61.9%) satellite locations were used for analysis, including LC3 \((n = 825)\), LC2 \((n = 1108)\), LC1 \((n = 1147)\), and LC0 \((n = 933)\) positions (Fig. 2).

Olive ridleys were tracked for a mean duration of 151 ± 95.9 d standard error (SE) (range, 7–331 d) and a mean distance of 5184.9 ± 3314 km SE (range, 167–9626 km). Individuals traveled at a mean speed of 2.49 ± 0.02

**Table 1.** Details of deployment of platform terminal transmitters (PTTs) on olive ridley turtles at Gahirmatha, Odisha, India. CCL = curved carapace length; CCW = curved carapace width; SCL = straight carapace length; SCW = straight carapace width.

<table>
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<tr>
<th>Turtle no.</th>
<th>Deployment date</th>
<th>Sex</th>
<th>Capture location</th>
<th>PTT ID</th>
<th>CCL (cm)</th>
<th>CCW (cm)</th>
<th>SCL (cm)</th>
<th>SCW (cm)</th>
<th>Weight (kg)</th>
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<td>9</td>
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<td>F</td>
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<td>69.5</td>
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km/hr SE (range, 1.18–3.19 km/hr) and a mean daily distance of 31.7 ± 0.4 km SE (range, 12.1–47.3 km). All turtles generally remained along the east coast of India within a mean distance from shore of 163.28 ± 50.9 km SE (range, 1–535 km) (Table 2). Most of the turtles moved 30–400 km from the shore of the Indian mainland.

Migration Routes and Movement Patterns. — The migration routes of turtles from their breeding grounds in Gahirmatha (20°N) spanned nearly the entire Bay of Bengal. All turtles migrated through near-shore waters off the Odisha coast, with 4 turtles remaining in shallow coastal waters and 10 turtles moving into deep pelagic waters of the Bay of Bengal. Turtles were wide-ranging and maintained consistent swim speeds, except for occasional brief periods of slower movement that lasted several days to a few weeks. There were no apparent migratory corridors and no common feeding grounds observed, nor any specific feeding grounds identified for

<table>
<thead>
<tr>
<th>Turtle no.</th>
<th>PTT ID</th>
<th>Total distance (km)</th>
<th>Total displacement (km)</th>
<th>Mean travel speed ± SE (km/hr)</th>
<th>Tracking duration (d)</th>
</tr>
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<td>8759</td>
<td>1316</td>
<td>2.89 ± 0.10</td>
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any individual turtle. Most turtles never returned to a location visited previously.

The majority of turtles started their migration toward the Sri Lankan coast between mid-April and late May; a few turtles commenced migration in early June. Four of the 14 turtles were not wide-ranging, whereas the rest moved throughout the Bay of Bengal—4 of which reached the northeastern part of Sri Lanka before moving back offshore to the southeast. Turtles with PTTs 90019, 90030, and 90033 reached 5°N off Sri Lanka and their signals were lost while swimming along the northeastern side of the Yalla coast. Similarly, turtle PTT 90015 reached the Sri Lanka coast (4°N), stayed for 1 mo, and then migrated back to the Tamil Nadu coast (11°N) in August. Six satellite-tagged olive ridleys (PTTs 90013, 90014, 90017, 90018, 90020, and 90031) departed Odisha for eastern and southern waters off Sri Lanka before traveling to the Andaman Islands (Fig. 2). Olive ridleys with PTTs 90019, 90030, 90033, and 90015 moved 50–100 km away from the Odisha coastline and then toward the south of Andhra Pradesh for a period before moving 300–500 km away from coastline of Tamil Nadu before finally reaching eastern Sri Lanka, where they remained from July to October.

Of the 3 male olive ridleys tracked in 2009, 1 turtle (PTT 90011) was only tracked for 19 d. The second male (PTT 90013) was tracked for 331 d, and the third male (PTT 90014) was tracked for 158 d. Transmissions from the latter 2 turtles ceased near the Andhra Pradesh and Tamil Nadu coasts. No apparent gender-specific differences were observed in terms of postnesting migration, as the migratory paths of female and male olive ridleys were similar. However, although not statistically significant, males did show a tendency to remain slightly closer to the Odisha and Andhra Pradesh coasts (Fig. 3).

One turtle (PTT 90015) released in February 2009 took a direct open-oceanic migration southward from Gahirmatha. The animal reached the Andhra Pradesh coast at the end of March and reached the Tamil Nadu coast by early May. The journey performed by the animal was far away from the coastline, about 500 km from the shoreline, before reaching the Tamil Nadu coast. The animal remained along the Tamil Nadu coast for a couple of weeks and again started moving in the southeast direction toward Yala National Park, along the Sri Lankan coast. The turtle passed through southeastern part of the Sri Lanka coast by the end of May and reached 4°N. In early June, the turtle started its return migration toward Andaman and Nicobar islands. However, the animal spent

Figure 3. Movements of male olive ridley turtles in the Bay of Bengal as determined via satellite telemetry.
nearly 2 mo, largely foraging, 300 km southwest of Andaman and Nicobar islands. The animal stopped signalling on August 2009 after 178 d of satellite tracking (Fig. 2).

The movements of 4 olive ridleys turtles in Bay of Bengal that completed postnesting migrations from their breeding sites at Gahirmatha to foraging areas along to the Sri Lanka coast are shown in Fig. 4. One female turtle (PTT 90019) moved south of the Gahirmatha nesting beach, travelling ~ 400 km from the coast and making circular movements in early April. This was followed by open-ocean movements toward Andhra Pradesh in early May. This turtle then reached the Tamil Nadu coast by the end of May, where it again made circular movements before reaching the southeastern part of Yala National Park in Sri Lanka in early July. The animal remained near Sri Lanka for about 3 mo before transmissions ceased September 2009 after 186 d of transmissions. Similarly, the female turtle with PTT 90030 moved toward the Sri Lankan coast, although with more direct movements, where it reached the southeastern area of Yala National Park by late May. This turtle remained there until June and was largely foraging near the shallow coast of south Sri Lanka. The return migration of the animal was recorded in early July prior to transmissions ceasing at ca. 300 km offshore of the Sri Lanka coast; the total transmission duration for this turtle was 106 d. An additional female (PTT 90033) moved north of Gahirmatha; from there it migrated south of the Odisha coast, reaching the Andhra Pradesh coast by late May. The total migration distance of this turtle was greater than 500 km (Fig. 4). The animal directly approached the Sri Lankan coast by mid-June and remained in the deep pelagic waters of Sri Lanka until the end of July. However, at the onset of August, the animal was gradually approaching toward the shallow coast of southeastern part of Sri Lanka and remained there until December 2009, perhaps foraging near the shallow area of the coast. In the early January 2010, the animal was observed moving northwest toward the Tamil Nadu coast and stopped signalling on 7 January 2010 near the Tamil Nadu coast after 239 d of satellite tracking.

**SST and Chlorophyll a Along Tracklines.** — All tracked turtles remained in water temperatures of 24°–31°C (mean, 28°C) and chlorophyll concentrations of 0–3.9 mg/m³ (mean, 0.81 mg/m³) throughout their respective tracking periods. There was no correlation between sea surface temperature and chlorophyll a concentration (linear regression; \( r^2 = 0.02, n = 77 \)). Sea surface temperatures had a latitudinal gradient, with temperatures increasing from 24°C to 31°C as turtles moved from 20°N to 4°N (Fig. 5).

**DISCUSSION**

Sea turtles are one of the marine vertebrate taxa that have been the subject of extensive satellite telemetry research (Godley et al. 2008; Hazen et al. 2012). The ongoing use of satellite tracking techniques, coupled with habitat/environmental modeling of sea turtle movements, has provided insight into their spatial and temporal ecology (Polovina et al. 2000; Seminoff et al. 2008; Shillinger et al. 2008; Hawkes et al. 2011; Silva et al.
and has identified potential hotspots of anthropogenic threats, thus highlighting focal areas for conservation (Peckham et al. 2007; Silva et al. 2011; Witt et al. 2011).

Our data confirm that olive ridley turtles depart their tagging locations near the Odisha coast by May or early June each year. Four turtles remained on or near the continental shelf during tracking efforts, which differs from the idea that olive ridley turtles spend most of their nonbreeding time in oceanic waters, quickly migrating back to oceanic waters once breeding is complete (Byles and Plotkin 1994; Plotkin 2003). The remaining 10 olive ridleys (PTTs 90013, 90014, 90017, 90018, 90020, 90031, 90019, 90030, 90033, and 90015) departed the Odisha coast and moved 300–500 km away from coastline and into oceanic waters.

Of the 14 tracked turtles, 10 traveled more than 5000 km (Table 2). With a maximum travel distance of 9626 km, and 2 additional tracks measuring 9417 and 8759 km, we believe this study documents the longest satellite tracks ever recorded for olive ridleys. To our knowledge, the next longest tracks come from nonnesting olive ridley turtles tagged in the Pacific Ocean (2691 km, Beavers and Cassano 1996; 7282 km, Polovina et al. 2004) as well as nesting olive ridleys in the same ocean basin (3669 and 2379 km, Plotkin 2010). Satellite telemetry studies of other sea turtle species have documented long-distance postnesting movements to foraging habitats that took from a few weeks to several months after departing nesting beaches (Plotkin et al. 1996; Luschi et al. 1998; Godley et al. 2002; Hays et al. 2002; McMahon et al. 2007; Cuevas et al. 2008; Seminoff et al. 2008; Plotkin 2010).

Our tracking efforts indicate that 4 turtles apparently completed their postnesting migrations to foraging habitats in the Bay of Bengal. Three of these turtles (PTT 90019, 90030, 90033) reached northeastern sites along the Sri Lanka coast and subsequently lost their signals after a couple of weeks. One turtle (PTT 90015) was tracked for 25 wks and migrated northward to the Odisha coast after swimming along Sri Lanka and Tamil Nadu coasts, where transmissions ceased.

Many sea turtles undertake migration from their breeding ground to a single foraging area, where they remain more or less resident until the next breeding season comes (Broderick et al. 2007). However, in this study 10 turtles made extensive migrations during which they apparently used multiple foraging areas in the open ocean. Although feeding was not observed directly, turtles stopped briefly on occasion along their migratory routes, which we believe is an indication of foraging. Similar slow swimming speeds, continual movements, and a tendency to spend short periods of time in an area before moving elsewhere were similarly interpreted as reflecting foraging activity for olive ridley turtles (Swimmer et al. 2006; Plotkin 2010). Several other satellite tracking studies, all in the Pacific, also confirmed oceanic foraging behavior for adult and juvenile olive ridley turtles (Plotkin 1994; Plotkin et al. 1996; Beavers and Cassano 1996; Parker et al. 2003; Polovina et al. 2003, 2004).

In the present study, Bay of Bengal olive ridley females and males had mean movement speeds of 2.65 and 1.91 km/hr, respectively. This appears substantially faster than olive ridley movements in other regions. For example, in northern Australia olive ridleys migrated at mean travel speeds of 0.87 to 1.54 km/hr en route to foraging areas that were reached in 5.5 to 34 d (Whiting et al. 2007). In eastern tropical Pacific, female olive ridleys had an average rate of movement of 1.18 km/hr, whereas...
that for males was 0.92 km/hr (Plotkin 2010). It is presumed the influence of eddies and gyres within the Bay of Bengal may have contributed to the relatively faster movements of olive ridleys in this area relative to other regions. Also, although the potential reasons are unclear, it is interesting that males moved at slower speeds than females in both our study as well as that of Plotkin (2010).

The turtles tracked in this study spent most of their time at the sea surface during migrations. Perhaps, the turtles in oceanic waters were not able to feed at the seafloor and needed to rely on pelagic and epi-pelagic food sources, and this kept them near or at the surface; also, oceanic waters may be cooler than coastal waters and turtles may spend more time at the surface to obtain solar radiation and increase body temperature (Plotkin 1998). Previous studies indicated that olive ridley turtles as mostly pelagic with large unidirectional wandering movements (Luschi et al. 2003; Polovina et al. 2003, 2004; Plotkin 2003). Therefore, this study indicated that the turtles we tracked spent most of the time on the water surface during their postnesting migrations.

Olive ridley turtles tracked in this study largely remained in waters of 24°C to 31°C between Gahirmatha and the Sri Lankan coast. This is generally consistent with prior studies of olive ridley movements. For example, in the central North Pacific olive ridleys were found primarily in water with SSTs of 23°–28°C (Polovina et al. 2004). Similarly, off Costa Rica, Swimmer et al. (2009) reported that turtles remained within a SST range between 23.3°C and 30.5°C (mean, 27.1°C). The broader temperature range associated with turtle movements tracked in this study perhaps owes to the wide range of SSTs present in the Bay of Bengal during the periods in which turtles were tracked.

In closing, our results contribute additional knowledge about the migratory movements of olive ridley turtles from Gahirmatha breeding sites northward to foraging grounds off the Sri Lankan coast. Most turtles that were tracked for extended periods undertook large, circular movements to reach their feeding destinations. Indeed, our data indicate that many habitats within the Bay of Bengal are important for olive ridley turtles and that the entire Bay should be considered a priority conservation region for this vulnerable species.

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