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An Overview of Some Biological Aspects and Status of Sea Turtle Nesting along the Indian Coastline

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Authors' contributions

This work was carried out in collaboration among all authors. Author DJS planned and designed the review, managed a partial literature search, and wrote the first draft of the manuscript. Author SR finalized the entire draft along with rectifications, managed a partial literature search, and performed all sorts of correspondence. Authors VMC, JBS and MNM managed the respective literature searches. All authors read and approved the final manuscript.

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ABSTRACT

India's extensive coastline is a crucial nesting ground for various sea turtle species, including the Olive Ridley, Green, Hawksbill, and Leatherback turtles. Key nesting sites range from Gujarat to Odisha and the Andaman and Nicobar Islands. However, human activities such as coastal development, pollution, and fishing pose significant threats to sea turtle populations. Conservation

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efforts, including beach protection, hatchery programs, and community involvement, are essential for safeguarding these species. This review examines the nesting patterns, reproductive behaviour, and challenges faced by sea turtles along the Indian coastline. It highlights the importance of specific nesting sites in different states for sea turtle conservation. Also discusses the impacts of climate change, human-induced threats, and the importance of genetic diversity and population dynamics. Comparative analyses with global nesting sites provide insights into enhancing sea turtle conservation efforts worldwide. India's diverse and essential nesting habitats are vital for the survival of sea turtles and the health of marine ecosystems. Protecting these nesting sites is crucial for the conservation of sea turtles and the overall well-being of marine biodiversity.

Keywords: India; nesting grounds; management; state-wise; threat.

1. INTRODUCTION

Sea turtles are ancient marine animals that have inhabited the oceans for over 100 million years. The extensive beaches and diverse marine environments along India's coastline serve as significant nesting sites for various sea turtle species, including the Green turtle, *Chelonia mydas* (Linnaeus, 1758), Hawksbill turtle, *Eretmochelys imbricata* Linnaeus, 1766 and Leatherback turtles, *Dermochelys coriacea* (Vandelli, 1761). The Olive Ridley turtle, *Lepidochelys olivacea* Eschscholtz, 1829 famous for their mass nesting events called 'arribadas', are the most prolific nesting species on the Indian coast (Tripathy, 2008). They are predominantly found in the eastern regions, especially at Gahirmatha Beach in Odisha and at the mouth of the Rushikulya River (Pandav et al., 1994). Gahirmatha hosts one of the world's largest nesting grounds for Olive Ridleys, where hundreds of thousands of turtles come to lay their eggs annually. Although green turtles are rare, they inhabit the waters off the Indian coast and have substantial nesting sites in the Andaman and Nicobar Islands (Andrews and Shanker, 2002). The critically endangered hawksbill turtles prefer the rocky areas of Lakshadweep Island for nesting. Leatherback turtles, the largest of all sea turtle species, are mainly found in the Andaman and Nicobar Islands, with Little Andaman and Great Nicobar Islands being their primary nesting locations (Bhaskar, 1993).

Human actions like coastal development, pollution, and fishing present significant dangers to sea turtle populations (Shanker and Pilcher, 2003). Conservation efforts, including beach protection, hatchery programs, and community involvement, are essential for the protection of these species (Namboothri et al., 2012). Organizations like the Madras Crocodile Bank Trust and the TREE Foundation play active roles in sea turtle conservation along the Indian coastline (Shanker, 1996). India's coastline, which stretches over 8,118 km, provides diverse and crucial nesting habitats for sea turtles, making it a key area for their conservation. Protecting and understanding these nesting sites are vital for the survival of sea turtles and the overall health of marine ecosystems worldwide (Shanker, 1996).

2. BIOLOGICAL ASPECTS OF SEA TURTLES ON THE INDIAN COASTLINE

Identification of sea turtles: The identification of adult sea turtles is primarily based on external characteristics such as carapace length, the number of prefrontal scales, and the configuration and count of coastal scutes (Shanker, 2003). Confirming track identification necessitates examining concrete evidence like hatchling remains and the sizes of eggshells (Shanker and Pilcher, 2003). The types of body pits vary among species: loggerheads, hawksbills, and ridleys create shallow body pits, whereas green turtles and leatherbacks produce larger, deeper pits (Andrews and Shanker, 2002).

Track characteristics: The type of tracks also differs; symmetrical tracks are formed when the front flippers move in unison, while asymmetrical tracks occur when the flippers move alternately (Tripathy, 2008). Although other animals, such as crocodiles and monitor lizards, can leave tracks on the beach, these can be easily distinguished by their shape and size (Namboothri et al., 2012).

Reproduction: Both male and female sea turtles initiate their reproductive cycle by migrating from feeding grounds to breeding grounds, which can be several thousand kilometers apart (Shanker and Pilcher, 2003). Mating occurs primarily in the offshore waters of the breeding sites; the male

mounts the female, gripping her with his claws on the front flipper while copulating. Both males and females may mate with multiple partners (Shanker, 2003).

Nesting: A few weeks post-mating, females return to land to nest, typically at night. They crawl above the high tide line, locate a suitable nesting site, clear away the surface sand, and dig a flask-shaped nest using their hind flippers (Tripathy, 2008). This nest may reach depths of two to three feet, depending on the size of the turtle. Once egg-laying begins, the turtle enters a 'nesting trance' that makes her less responsive to disturbances (Andrews and Shanker, 2002). They typically lay around 100–150 eggs in the nest and cover it with sand; some species press down the nest with their bodies to compact it. Afterward, they camouflage the nest by throwing sand around it and return to the ocean. Factors affecting beach selection include accessibility, elevation, and substrate type. Olive Ridleys and leatherbacks prefer broad beaches and sandbars at river mouths, while hawksbills and green turtles are more inclined towards smaller island beaches. Most turtles nest multiple times within a season, typically with about two weeks between each nesting event (Pandav et al., 1994).

Philopatry: It has long been known that adult sea turtles return to their designated nesting grounds to lay their eggs (Bhaskar, 1993). Typically, during the nesting season, most turtles lay all their eggs in a small, localized area (within 0 to 10 km). However, certain species, like the Olive Tortoise in Orissa, are known to travel greater distances to locate suitable nesting sites (Shanker, 1996).

Temperature-dependent sex determination: The temperature during incubation affects the sex of sea turtle hatchlings. Cooler temperatures tend to produce more males, while warmer temperatures result in a higher proportion of females. Each species and population have an optimal temperature range for achieving a balanced sex ratio, usually between 28 to 32 °C (Namboothri et al., 2012). The sex of the hatchlings is determined during the second developmental stage (REF). Changes in nest temperature, especially due to climate change, can lead to imbalanced sex ratios, potentially impacting future reproductive success (Shanker and Pilcher, 2003).

Hatching: During the incubation period, which usually ranges from 45 to 70 days for most sea turtle species, the eggs are exposed to heat and sunlight. The eggs typically hatch around the same time over a span of several days, with the hatchlings emerging from the nest together at night to evade predators (Shanker, 1996). Predators such as crabs, birds, dragons, wild dogs, and various fish pose a threat to the hatchlings until they reach the sea.

Distinguishing hatchlings: Hatchlings can be identified using similar features as adults, such as the number of coastal scutes, though coloration may vary. During the hatching season, tracking hatchling footprints is crucial, as they lead to nests where further examination can determine hatching success (Namboothri et al., 2012).

Development of hatchlings: Once hatched, young turtles undergo a period of vigorous swimming, using their stored energy to travel towards the open ocean. They spend several years in juvenile habitats before moving to their adult feeding areas (Shanker, 1996). During this initial pelagic phase, they are commonly transported by ocean currents and often feed in sargassum beds and fish aggregating devices (FADs) (Pandav et al., 1994).

Adult migration: The maturation process for sea turtles, from hatchlings to adults, typically takes 10 to 15 years for most species, with green turtles sometimes requiring up to 30 years. As they mature, turtles migrate to their breeding grounds (Bhaskar, 1993). After mating, males usually return to their feeding areas, while females head back to their nesting sites. Migration patterns can vary widely among species and populations; some may nest and feed in the same area, while others undertake long migrations (Tripathy, 2008).

Adult identification: In Indian waters, adult sea turtles can be identified by external features such as carapace length, the number of frontal scales, and the pattern and number of coastal stripes. Five species are particularly distinguishable with detailed study (Shanker and Pilcher, 2003).

Identifying tracks and nests: To differentiate sea turtle species based on their tracks, it is important to consider factors such as track width, burrow depth, and track pattern (symmetric or asymmetrical). Identifying tracks can be challenging even for experts due to variations between populations and individuals. Field

workers need to observe nesting turtles directly and analyze track characteristics, confirming identifications with additional evidence like hatchling remains and eggshell size (Tripathy, 2008).

I. Body Pit Types: Loggerheads, hawksbills, and ridleys create shallow body pits, while green turtles and leatherbacks produce larger, deeper pits.
II. Track Types: Symmetrical tracks indicate synchronized development of the front flippers, whereas asymmetrical or erratic tracks suggest alternating development. These tracks can be distinguished from those of other animals based on their pattern and size (Pandav et al., 1994).

3. DISTRIBUTION OF SEA TURTLE NESTING GROUNDS ALONG THE INDIAN COASTAL STATES

Gujarat: Gujarat, which has the longest coastline in India at 1,650 km, has 520 km and the primary nesting species are Olive Ridley and Green turtles. The coastline is divided into Kachchh, Saurashtra, and mainland regions, and is further classified into five sub-regions based on inter-tidal characteristics (Patel, 1997; Sunderraj et al., 2006). The Saurashtra coastal study area, extending from Jamnagar (Okha) to Bhavnagar, covers over 450 km and includes the districts of Junagadh, Amreli, and Porbandar. Surveys have revealed a variety of beach compositions: 62% sandy, 25% a mix of sandy and rocky, and 13% muddy and rocky. Central Saurashtra has the highest concentration of sandy nesting beaches, while the eastern and western areas feature rocky and sandy stretches, and the far east and west ends have muddy and sandy stretches. Twenty-two potential nesting sites have been identified across three main sections: (1) Dwarka to Madhavpur; (2) Madhavpur to Chorwad; and (3) Adri to Santeshwar. The nesting season of sea turtles took place from June to January (Patel, 1997). Key nesting beaches along the 1,600 km coastline include Kantela− Kachha, Mangrol− Bara, and Navadra− Lamba (Sunderraj, 2002).

Maharashtra: Maharashtra, which has the second-longest coastline on India's western side, with nesting records of mainly Olive Ridley turtle habitats that have been monitored by Sahyadri Nisarga Mitra (SNM) since 2002 (Katdare and Mone, 2003). Although green turtles have been occasionally observed (Gole, 1997). SNM has not recorded any nesting by this species since 2002. Comprehensive surveys of Maharashtra's coastline, carried out by the GOI UNDP project between 2000−2001 and the UNEP−CMS IOSEA between 2004−2005, identified 15 significant nesting sites primarily in the Ratnagiri and Sindhudurg districts. These districts, along with Raigad, continue to host the majority of Olive Ridley turtle nesting activities, with occasional sightings reported from 13 key beaches (Giri and Chaturvedi, 2006).

Goa: Goa, located on India's western coast, is a significant nesting area for Olive Ridley turtles. The nesting season in Goa spans from October to February along its 160 km coastline (Giri and Chaturvedi, 2006). Key nesting beaches in Goa include Morjim, Kerim, Galgibaga, and Agonda (Shanker, 2015). Extensive surveys have been conducted along Goa's coastline to monitor sea turtle nesting activities. Initial surveys identified Olive Ridley turtles nesting along both the Maharashtra and Goa coasts (Giri, 2000). Follow-up surveys confirmed ongoing nesting activities and provided detailed information on the distribution and status of sea turtles in the region (Giri, 2001; Bhaskar, 1984).

Karnataka: Karnataka's 260 km coastline is a crucial nesting site for Olive Ridley turtles, with the nesting season occurring from October to February (Sharath, 2006). Important nesting areas are located in the Udupi and Mangalore districts (Madhyastha et al., 1986; McCann, 2007). Early research on marine turtle hatcheries at Bengre Beach in Mangalore highlighted the region's initial conservation efforts (McCann, 2007) which laid the foundation for subsequent conservation projects along the Karnataka coast. Notably, conservation activities have been particularly vigorous in the Udupi district, with many initiatives documented (McCann, 2007). Local communities and researchers have played a significant role in conservation efforts, including monitoring nesting sites, protecting nests, and studying hatchling success rates (Appayya, 1985; Frazier, 1989). Nonetheless, incidental capture of sea turtles in fishing nets remains a significant issue, underscoring the ongoing need for conservation and awareness programs (Rajagopalan et al., 1996).

Kerala: Kerala’s 590 km coastline is a vital nesting ground for Olive Ridley turtles, with the nesting season from October to February (Dileepkumar and Jayakumar, 2006). Prominent nesting beaches include Alungal, Kolavipalam,

and Thaikkadappuram (Shanker, 2015). Initial surveys established the presence and distribution of sea turtles along Kerala's coast, setting the stage for future conservation work (Bhaskar, 1981). Continued monitoring has yielded important insights into nesting patterns and the effectiveness of conservation efforts (Bhupathy, 2007). Various projects have facilitated field studies and promoted networking for turtle conservation in Kerala, emphasizing the need for coordinated protection measures for these endangered species (Dileepkumar and Jayakumar, 2006). Community involvement, particularly in Kolavipalam, has been crucial for conservation efforts, including the release of accidentally captured turtles back into the sea, demonstrating the community's commitment to protecting sea turtles (Kutty, 2001).

Tamil Nadu: Tamil Nadu and Puducherry, with a combined coastline of 1,076 km, provide a significant nesting habitat for Olive Ridley turtles. Nesting occurs from December to April (Bhupathy and Saravanan, 2006). Key nesting sites in the region include Nallavadu, Marina−Neelankarai, Mamallapuram−Puducherry, Nagapattinam, Alikuppam, and Neelankarai−Uthandi (Arun, 2011; Bhupathy et al., 2006). Early studies examined the biology and nesting behaviours of sea turtles in this area, highlighting the need for conservation measures (Agastheesapillai and Thiagarajan, 1979; Banugopan and Davidar, 1998). Ongoing monitoring and conservation efforts are crucial for safeguarding these endangered species (Shanker, 2003). Local community involvement has been key to successful conservation outcomes (Arun, 2011). The support from local groups and international collaborations underscores the importance of coordinated conservation approaches (Bhupathy et al., 2006).

Andhra Pradesh: Andhra Pradesh, with its 980 km coastline, is an important nesting area for Olive Ridley turtles, with nesting occurring from December to April (Tripathy et al., 2006). Key nesting sites in the region include Sacremento Island, Neelarevu, Elichetladibba, and Kapaskudi (Sekhar and Rao, 1993). Early research highlighted the presence of sea turtles in northern Andhra Pradesh and underscored the need for conservation efforts (Bhaskar, 1982; Dutt, 1979). Conservation measures have included on−site protection and the use of turtle excluder devices (Sankar and Pilcher, 2003). However, large-scale mortality events among Olive Ridley turtles have been reported along the Andhra Pradesh coast (Murthy and Murthy, 2011). Ongoing efforts are focused on monitoring nesting activities and implementing effective conservation strategies (Rajasekar and Rao, 1993; Rao et al., 1987).

Odisha: Odisha's 480 km coastline is a crucial nesting site for Olive Ridley turtles, with nesting occurring from December to April (Pandav and Choudhury, 2000). Key nesting locations include Rushikulya, Gahirmatha, and the Devi River mouth (Shanker, 2015). Early research has concentrated on conservation and management efforts for sea turtles in Odisha, focusing on habitat monitoring and conservation strategies (Kar and Bhaskar, 1982; Kar and Dash, 1984; Pandav et al., 1994; Pandav et al., 1995). Efforts have also tackled threats such as accidental capture in fishing nets and employed remote sensing to study nesting patterns (Rout and Behera, 2006). The coastline is known for significant mass nesting events (arribadas), which are a notable natural occurrence.

West Bengal: West Bengal, with its 950 km coastline, is an important nesting area for Olive Ridley turtles from December to April (Chowdhury et al., 2006). Key nesting sites in the region include Dadanpatra, Digha, Junput, and Shankarpur (Chowdhury, 2001). Early research has highlighted the need for conservation and management efforts for sea turtles in West Bengal, focusing on monitoring nesting habitats and implementing effective conservation strategies (Sen, 1978; Raut and Nandi, 1986; Chowdhury et al., 2001). Initiatives also address threats such as accidental capture in fishing nets (Raut and Nandi, 1986) and use remote sensing to study nesting dynamics (Mukherjee, 2006). The coastline is known for mass nesting events (arribadas), which are significant natural occurrences (Biswas, 1981).

Andaman and Nicobar Islands: Andaman and Nicobar Islands, with a coastline of 1,962 km, are vital nesting sites for four sea turtle species: Olive Ridley, Leatherback, Green, and Hawksbill turtles Nesting seasons differ by species: Leatherback and Olive Ridley turtles nest from November to March, while Green and Hawksbill turtles nest from April to September. Key nesting sites include Cuthbert Bay, South Reef Island, Great Nicobar Island, Little Nicobar Island, and Little Andaman Island. Research by Andrews and Shanker (2002), identified a significant Leatherback turtle population in the Indian

Ocean. Conservation genetics studies by Pandav and Choudhury (2000) provided insights into the genetic diversity of marine turtle populations along India's mainland coast and offshore islands, which are essential for effective conservation strategies. Bhaskar's surveys in the late 1970s and early 1980s extensively documented the distribution and status of sea turtles in the region (Bhaskar, 1979; 1981; 1993).

Lakshadweep: Lakshadweep Archipelago is a key nesting area for Hawksbill, Green, and Olive Ridley turtles. Nesting seasons vary: Leatherback and Olive Ridley turtles nest from November to March, while Green and Hawksbill turtles nest from April to September (Tripathy et al., 2006). Important nesting beaches in Lakshadweep include Suheli Island, Agatti Island, Kalpitti Island, and Bitra Island (Tripathy et al., 2006). The early researchers documented marine turtles in the Lakshadweep Islands, offering initial insights into their presence and nesting behaviours. A comprehensive survey provided detailed information on marine turtles and their nesting habitats in Lakshadweep, with findings published as part of the GOI-UNDP sea turtle project (Tripathy et al., 2002).

4. CHALLENGES AND CONSERVATION STRATEGIES FOR SEA TURTLE NESTING ALONG THE INDIAN COASTLINE

Marine Debris: Plastic waste in marine environments is a global issue, significantly impacting sea turtles. high levels of floating plastic in the found plastic as the main litter on seafloors and beaches. Such debris harms sea turtles through ingestion, entanglement, and nesting site degradation. Ingested synthetic particles were observed in 100% of loggerheads, with 35.2% of loggerheads in Adriatic habitats having ingested debris, posing risks to turtle health (Casale et al., 2010). Marine debris also threatens leatherbacks entanglement contributes to Mediterranean turtle mortality leading to injuries, impaired foraging, and risk of starvation or drowning.

Oil Pollution: Though less frequent, oil spills present a hazard by coating turtles in tar, impeding movement and health. Compared to other threats like bycatch and marine debris, oil pollution is less common in the Adriatic and Mediterranean regions (Gvozdenović et al., 2021).

Chemical Pollution: Contaminants like heavy metals and POPs from industrial, agricultural, and urban sources accumulate in marine fauna, affecting turtle health. Studies link these toxins to viral infections, such as fibropapillomatosis, due to immune suppression. Adriatic turtles exhibit higher contamination levels than Atlantic ones, including elevated mercury, likely due to regional human activity, putting these turtles at risk (Bucchia et al., 2015).

Noise Pollution: Underwater detonations cause serious harm to sea turtles, damaging tissues near air-fluid interfaces like lungs and gastrointestinal tracts, potentially causing injuries, unconsciousness, and even death (Piniak et al., 2012).

Light Pollution: Coastal development and tourism lead to light pollution, disrupting turtle nesting. Studies show that artificial lighting disorients hatchlings and deters females from nesting, highlighting the need for mitigation (Salmon, 2006).

Climate Change Impacts: Climate change profoundly affects sea turtles globally, including those nesting along the Indian coast. Key impacts include altered nest sex ratios due to rising temperatures, changes in ocean currents affecting migration and food availability (Poloczanska et al., 2016), and rising sea levels threatening nesting beaches (Hawkes et al., 2009).

Conservation Strategies; Effective strategies are vital for mitigating threats and ensuring sea turtle survival. These include protecting nesting beaches from development and erosion (Wallace et al., 2013), mandating Turtle Excluder Devices (TEDs) in fisheries to reduce bycatch (Hamann et al., 2013), establishing Marine Protected Areas (MPAs) as safe habitats (Tomillo et al., 2021) and engaging local communities in conservation efforts (Mazaris et al., 2017).

Human-Induced Threats: Human activities pose significant risks to Indian coast sea turtles, including habitat loss from coastal development (Hawkes et al., 2009), plastic pollution leading to ingestion and entanglement (Schuyler et al., 2016), bycatch in fishing gear (Wallace et al., 2013), and illegal trade of turtle products (Shanker and Pilcher, 2003).

Genetic Diversity and Population Dynamics: Understanding genetic diversity and population

dynamics is critical for effective conservation. Genetic studies emphasize maintaining genetic diversity for population resilience (Fitzsimmons et al., 2014) population assessments reveal variable trends across nesting sites and species (López-Castro et al., 2014), and studying connectivity aids in understanding migration patterns (Shamblin et al., 2014).

Comparative Analysis with Global Nesting Sites: Comparative studies with global nesting sites provide insights into regional nesting behaviours, threats, and conservation strategies. Comparing nesting sites across regions highlights regional conservation challenges and successes (Troëng and Chaloupka, 2007) while analysing conservation strategies globally identifies best practices for enhancing sea turtle conservation efforts (Wallace et al., 2013).

5. CONCLUSION

India's coastline, extending over 8,118 km, provides vital nesting grounds for several sea turtle species, including the Olive Ridley, Green, Hawksbill, and Leatherback turtle. This extensive and diverse habitat is crucial for the reproductive success and survival of these species. However, significant threats such as climate change, coastal development, pollution, and bycatch jeopardize their populations. Addressing these challenges requires a comprehensive approach, including habitat protection, implementation of Turtle Excluder Devices (TEDs), and the establishment of Marine Protected Areas (MPAs). Engaging local communities in conservation efforts and advancing scientific research on genetic diversity and population dynamics are also vital. Comparative studies with global nesting sites highlight the importance of adopting best practices and enhancing conservation strategies. Ensuring the protection of India's sea turtle nesting sites is not only critical for these species but also for the overall health of marine ecosystems. Collaborative and sustained efforts are essential to secure the future of sea turtles and preserve the ecological balance of our oceans.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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