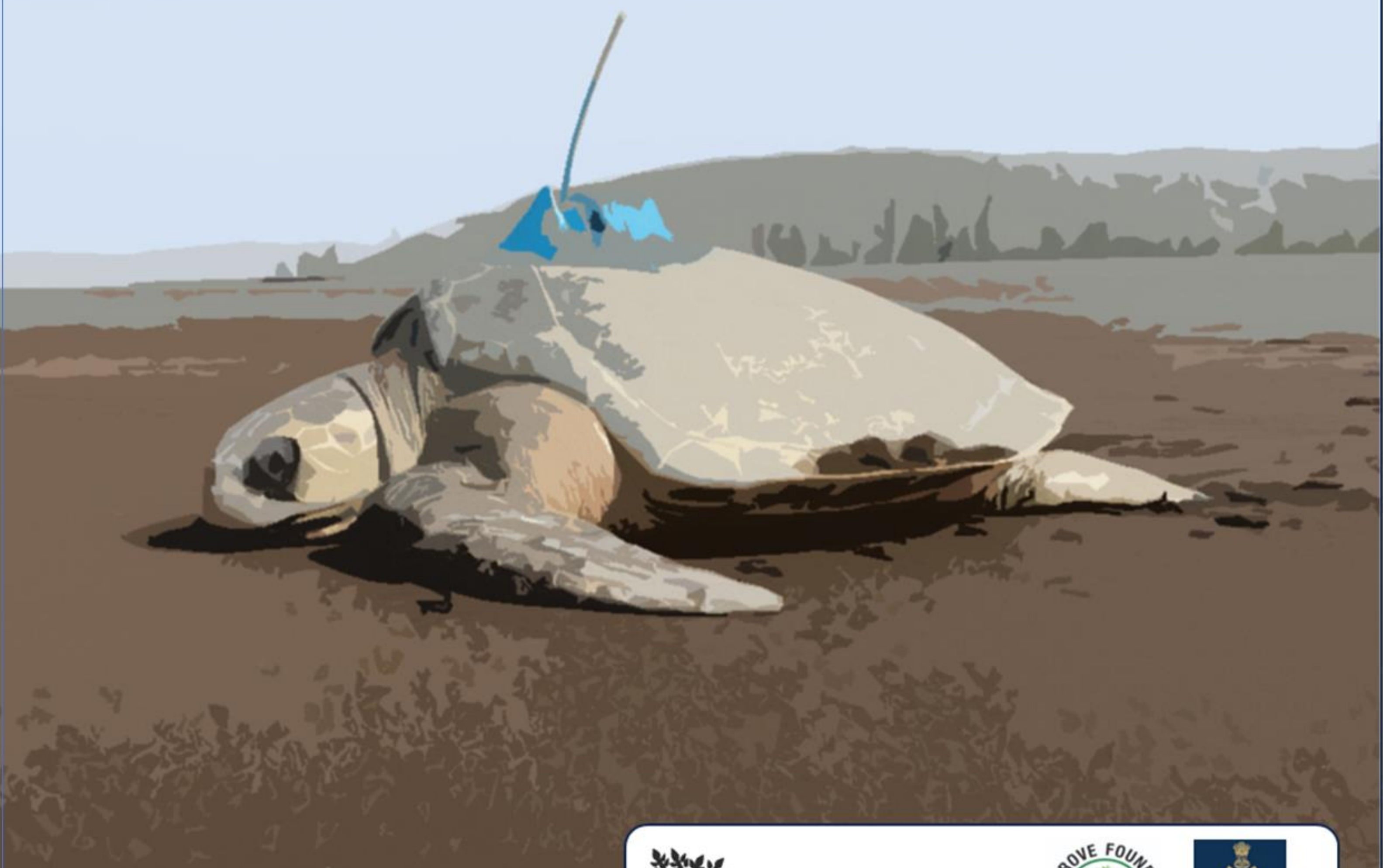
Technical Report

TRACKING THE NEARSHORE AND MIGRATORY MOVEMENT OF OLIVE RIDLEY SEA TURTLES OCCURRING IN THE COASTAL WATERS OF MAHARASHTRA

Mohit M. Mudliar | R. Suresh Kumar



भारतीय वन्यजीव संस्थान
Wildlife Institute of India
MANGROVE FOUNDATION

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Summary

In a first, a satellite tracking study of solitary nesting olive ridley sea turtles was taken up on the west coast of India during 2022-2023 along the Maharashtra coast. Seven olive ridley sea turtles were captured (five in 2022 and two in 2023) and were tagged with Argos satellite transmitters (model-K2G 576E) manufactured by Lotek Wireless Inc. (New Zealand). The tags were attached to the turtle's carapace using a 2-part epoxy-resin adhesive and further secured using fiberglass tape. The tags were programmed to remain on for 24 hours and a transmission limit of 577 messages per day was fixed for each tag. Five turtles tagged in 2022 were tracked for an average duration of 138 days (3 to 173 days), while the two turtles tagged in February 2023 were tracked for 212 and 213 days.

The turtle locations received from the tags were checked for erroneous data and filtered accordingly. Following this, a continuous-time State-Space Model (SSM) was used for track correction and modelling. For every 6–hour interval, a location from the modelled track was extracted for the separate analysis of breeding period and for the post-nesting period, the location was extracted for every 24-hour interval. A movement persistence model was then used to determine the behavioural state of the turtles based on changes in speed and direction of travel between subsequent time steps. This resulted in a Movement Persistence Index (MPI) for every time step that ranged between 0 and 1, where higher values indicated directed movements associated with migration and lower values indicated a slow-moving phase associated with stop-over. The high-use areas of tagged turtles during the nesting period were determined using Kernel Density Estimates (KDE). Further, the diving data obtained for each tagged turtle was summarised for dive depth and duration, and daily time spent on the surface. The diving behaviour was also compared for the turtles in the continental shelf waters and in the open ocean.

During the nesting period, the tagged turtles resided in the nearshore waters for a period ranging from 22 to 41 days and, on average, remained 10 km from the coast. During this period, the high-use area (50% KDE) determined for the tagged turtles ranged from 142 sq. km to 735 sq. km and fell within the 30 m depth contour. The high-use areas were primarily associated with turtle-nesting beaches adjoining river mouths in the region. Two of the tagged turtles of the 2022 season, *Prathama* and *Saavni,* were observed to nest again after 34 and 31 days, respectively, suggesting that the solitary nesting turtles lay multiple clutches in a season. The average time spent at the surface per day (time the tags remained dry) during this period was 50 minutes. This suggests that turtles possibly spent most of their time resting underwater which was also evident from the long U-shaped dives recorded during this phase.

The tagged turtles started on their post-nesting movements from late February to mid-March, and in the case of three turtles, their initial movements were oriented to the North while the others

headed South. The northernmost location of the tagged turtles came 95 km off the coast of Gujarat, where the turtle named Prathama remaining for 31 days, and then began moving South. The post-nesting movements of the tagged turtles in the following months had clear directionality and were not nomadic. The tagged turtles were observed to have a median speed of 1.1 km/h, and the speed increased from 0.6 km/h (range: 0.3-0.9 km/hr) to 1.32 km/h (range: 0.6 -1.79 km/h) when they moved from the continental shelf to open waters. The turtles were observed to have stop-overs in areas off the Gujarat coast, the Karnataka coast, the waters off northeastern Sri Lanka, and the open waters of the Bay of Bengal. At the time of the last tracking location, the displacement distance of the tagged turtles was 190 - 2338 km from their nesting beach and they had travelled 1015-5267 km in 80-213 days.

The turtles were observed to dive to an average depth of 15.7 ± 8.2m during the breeding phase and 61.43 ± 36 m during the post-breeding phase. During these dives, the turtles stayed underwater for an average duration of 27.2±15 and 31.9 ±18 minutes in the breeding and post-breeding phase, respectively. An increase in V-shaped dives (exploration dives) was observed when turtles moved into deeper waters. The turtles performed shallower dives at night in open waters, while no such difference was observed when the turtles were on the continental shelf. A gradual increase in daily surface duration was observed during the post-breeding phase for turtles. At the same time, it was observed that the deepest dive performed in a given day gradually increased, and turtles that moved into the shelf break and open ocean habitat performed exceptionally deeper dives sometimes more than 400 meters. A general southward movement and reduction in MPI in the continental shelf break off the Karnataka coast was observed for most turtles starting from the month of May. This area falls in the well-known Malabar upwelling zone and appears to be an important foraging area for the west coast olive ridley population.

Being first of its kind for west coast of India, this tracking study has been successful in creating awareness about olive ridley sea turtles through extensive media coverage on tagging and movement updates. Even with a small number of tagged turtles, it also provided crucial information on the movement and diving ecology of this lesser-studied population. Most importantly, the patterns of movement from this study suggests that turtles nesting on the Maharashtra coast comprise two foraging populations. Firstly, those that are resident to the Arabian Sea and the others from the Sri Lankan waters or from the Bay of Bengal. Further tracking efforts are recommended where the turtles are tagged early in the nesting season to understand their inter-rookery movements and find nesting frequencies per season. More tracking efforts from Maharashtra and elsewhere along the West coast of India are suggested to be taken up. This will help understand how the turtles from different nesting areas move and forage. Moreover, this will help identify the overlap between fishing zones and critical breeding and foraging areas along the West Coast to better manage and conserve the species through appropriate interventions.

Introduction

Synchronised breeding, a widespread phenomenon observed in various taxa, confers survival advantages for organisms (Riehl, 2017). This behaviour enhances the likelihood of offspring survival and aids in evading predators during vulnerable life stages (Ims and Andreassen, 2000). It is more common in r-selected species with shorter life spans but is also seen in larger, long-living vertebrates. The Olive ridley sea turtle is one such species that performs mass nesting events called arribada.

During an arribada, hundreds of thousands of turtle nests synchronously within 4-5 days in a relatively small stretch of beach. Though olive ridley turtles have a circumtropical distribution, mass nesting is observed only in select beaches of Mexico and Costa Rica in the Eastern Tropical Pacific, and the east coast of India (Pritchard, 2007). These turtles show behavioural polymorphism in nesting and this species nest solitarily (a common strategy for all sea turtles) all along its distribution range. In India, these turtles nest solitarily in all the coastal states and island union territories (Shanker and Choudhury, 2006).

Sea turtle populations around the globe are being threatened due to anthropogenic activities. Along the east coast, mass mortality of turtles due to fishing-related activities was reported from arribada nesting areas in the late 90s (Pandav et al., 1998). Due to this, huge conservation efforts were brought in place for these turtles and extensive studies have been taken up for this population as well. As part of these studies, turtles from Arribada nesting areas were satellite tagged and were found to use waters off Sri Lanka and open waters of the Bay of Bengal (Sivakumar et al., 2010; Kumar, 2015).

Wallace et al. (2010) identified three different Regional Management Units (RMU) for olive ridley turtles in India namely from the Arabian Sea, Bay of Bengal and Andaman Sea. Given that the sea turtles can have their nesting and foraging grounds thousands of kilometres apart, it is interesting to know where the solitary nesting turtles come from. It is further interesting to know where the turtles from populations other than the Bay of Bengal move into and what are their migration strategies.

Around the Indian subcontinent, there have been limited efforts to track the solitary nesting turtles. In the Bay of Bengal region, solitary nesting turtles have been tracked from Bangladesh (Islam et al., 2016); in the Northern Indian Ocean, four turtles were tracked from Sri Lanka (Sivakumar et al, 2010); and in the Arabian Sea, tracking study is primarily from Oman (Rees et al., 2012). The movement patterns and migration strategy of olive ridley turtles nesting along the west coast of India still remain unknown.

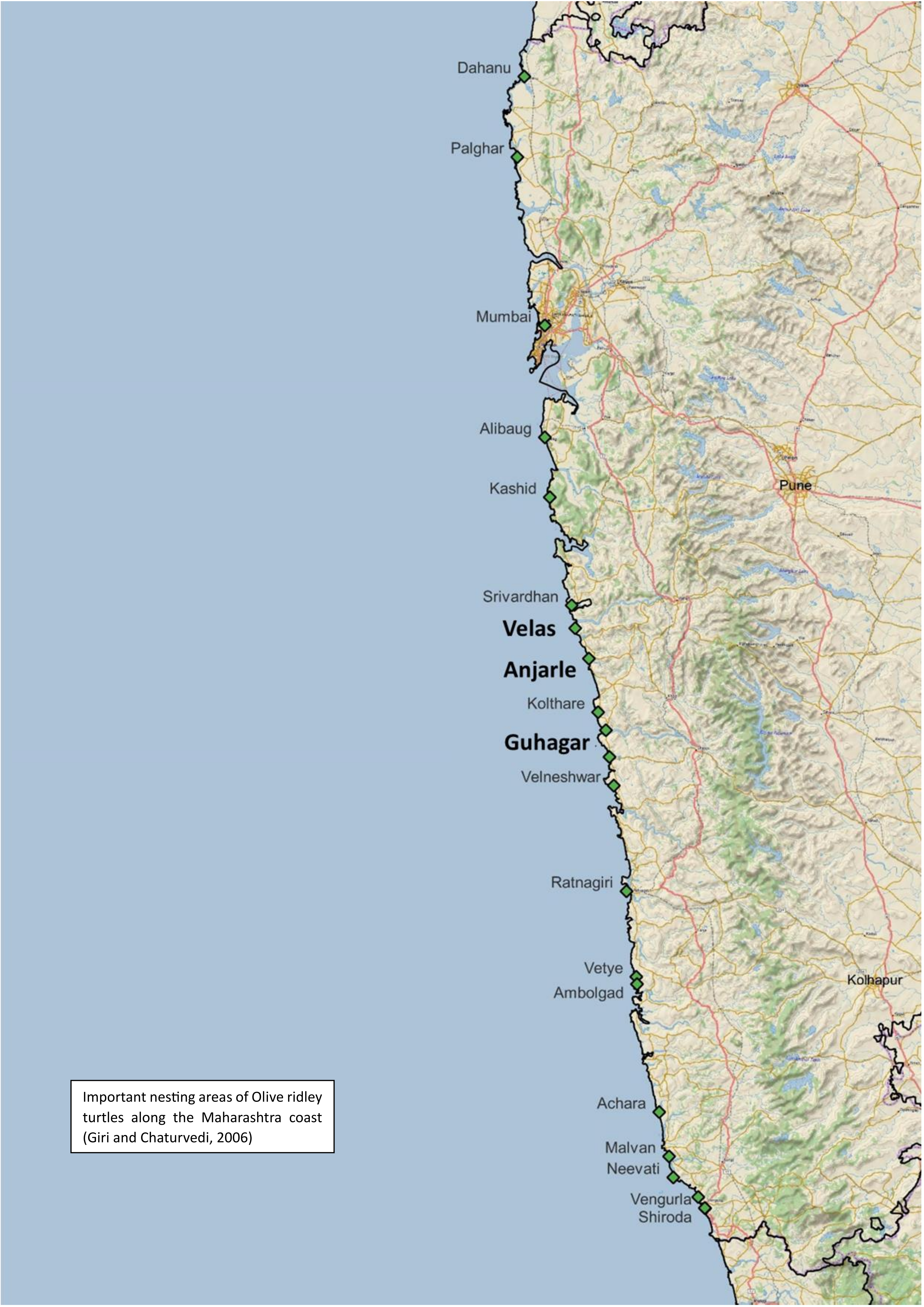
The Maharashtra Forest Department along with the Mangrove Foundation has been taking up proactive measures to conserve and protect olive ridley turtles along the Maharashtra coast. These measures include hatchery management practices, outreach programs and compensating fishermen for releasing accidentally captured turtles. In order to strengthen the management of these turtles, it is critical to identify the areas used by turtles in the nearshore waters. Additionally, this will help in understanding the ecology of this species and add up as critical information for outreach activities.

Considering the above, Mangrove Foundation of the Maharashtra State Forest Department sanctioned a study to the Wildlife Institute of India for undertaking satellite tagging of nesting olive ridley turtles. The tagging activity was taken up with a focus on understanding fine-scale nearshore movements and post-breeding migrations of turtles nesting along the Maharashtra coast. This report details the findings of the study that involved tagging and tracking of seven olive ridley turtles from January 2022 to September 2023.

Maharashtra coast

The Maharashtra state has the fourth-longest coast on the Indian mainland, yet only 17% of this 720-kilometer-long coast consists of sandy beaches (Rajawat et al., 2015). Despite the predominantly rocky coastline, two sea turtle species are known to nest along this coast. The sandy beaches of Maharashtra are comparatively smaller in length when compared to those on the east coast, and they are primarily found in the river mouth areas. The entire Maharashtra coast falls under the Konkan region, which represents the lowland areas located between the Western Ghats and the Arabian Sea, extending from the Damanganga River in Daman to the Gangavali River in Karwar, Karnataka. The Konkan region is predominantly developed on a basement of basalt flows from the Deccan volcanic province (Kumaran et al., 2004) and is intersected by 22 west-flowing rivers originating from the Western Ghats. Olive ridley turtles nest along the sandy beaches of all five coastal districts of Maharashtra (Giri and Chaturvedi, 2006).

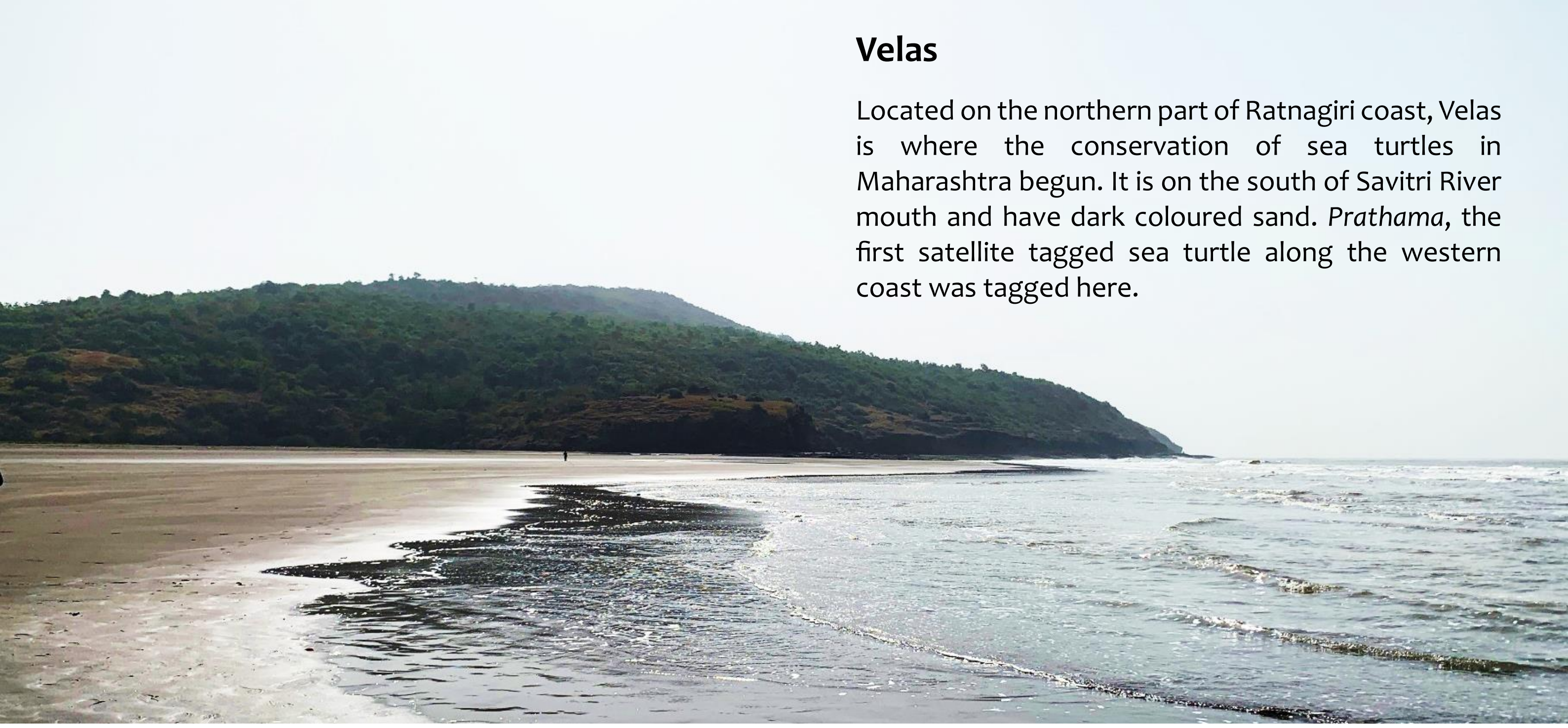
Sea turtle nest protection is carried out by the Maharashtra Forest Department and its Mangrove Foundation along the entire coast. In the northern region, ex-situ hatcheries have been established on nesting beaches, where turtle nests are translocated to safeguard them from introduced predators, such as feral dogs, and from coastal erosion. In the southern district of Sindhudurg, most nests are protected in-situ by constructing mesh around the nest to prevent egg predation. Based on nesting patterns from previous years, three nesting beaches- Velas, Anjarle and Guhagar were selected for the deployment of satellite tags.



Important nesting areas of Olive ridley turtles along the Maharashtra coast (Giri and Chaturvedi, 2006)

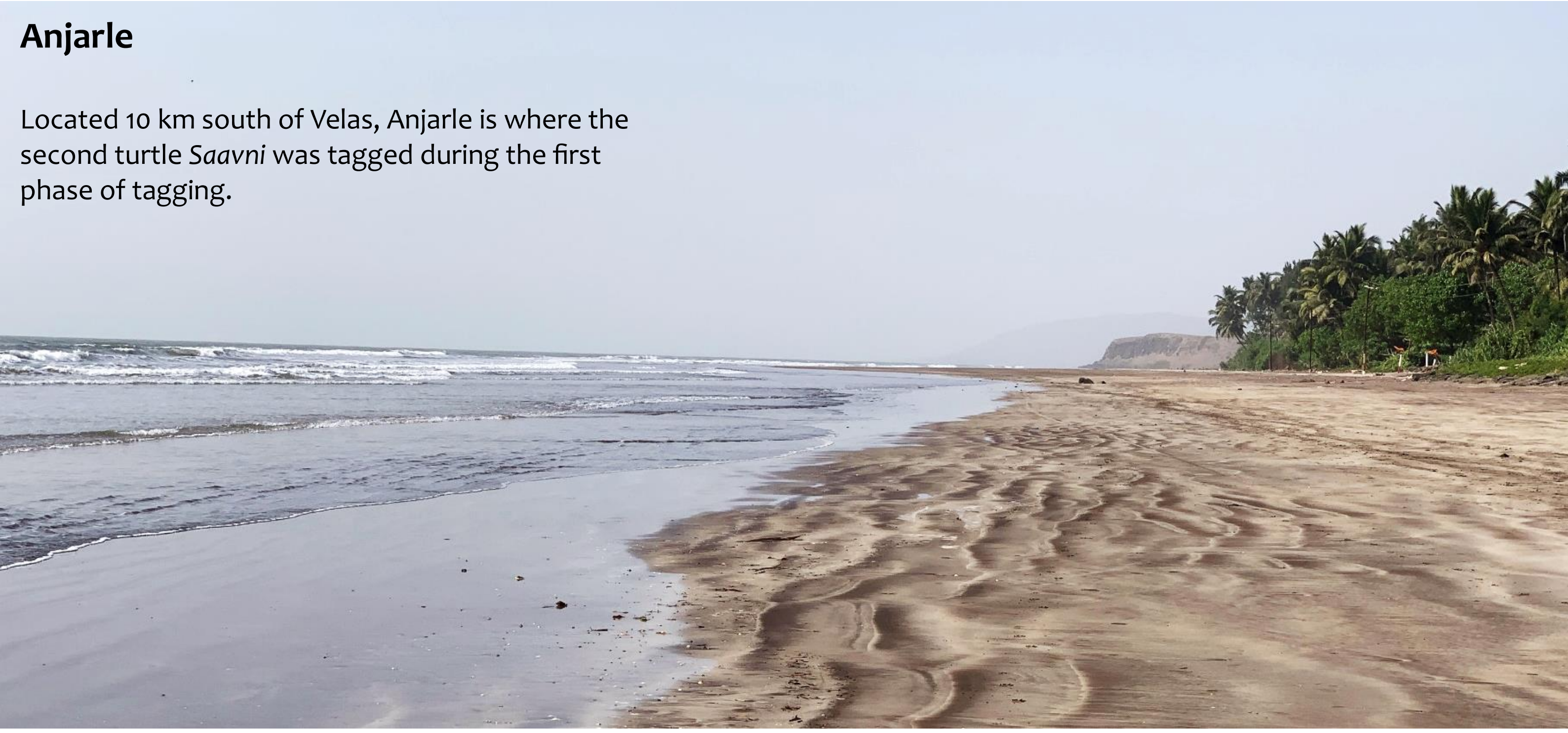
Velas

Located on the northern part of Ratnagiri coast, Velas is where the conservation of sea turtles in Maharashtra begun. It is on the south of Savitri River mouth and have dark coloured sand. *Prathama*, the first satellite tagged sea turtle along the western coast was tagged here.



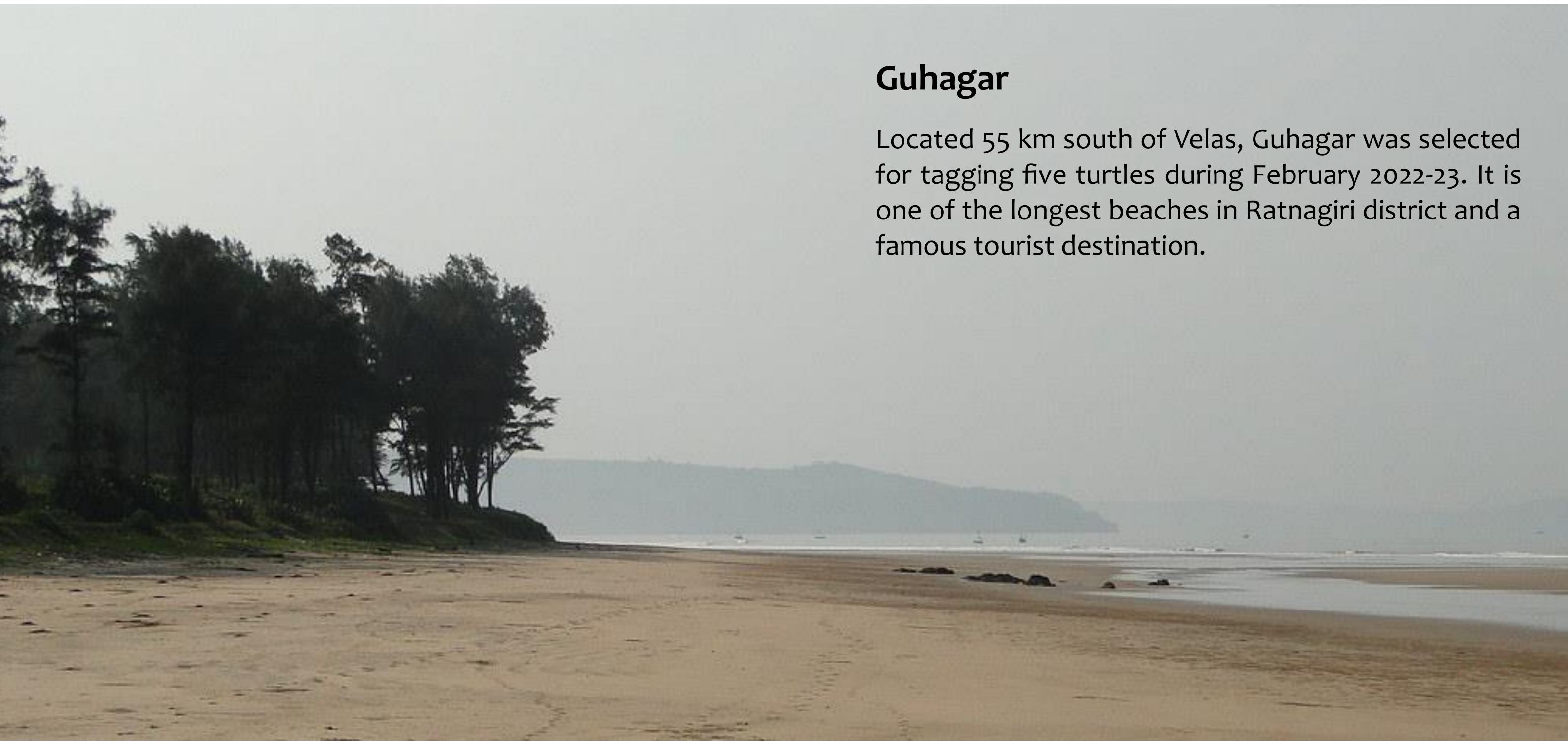
Anjarle

Located 10 km south of Velas, Anjarle is where the second turtle *Saavni* was tagged during the first phase of tagging.



Guhagar

Located 55 km south of Velas, Guhagar was selected for tagging five turtles during February 2022-23. It is one of the longest beaches in Ratnagiri district and a famous tourist destination.



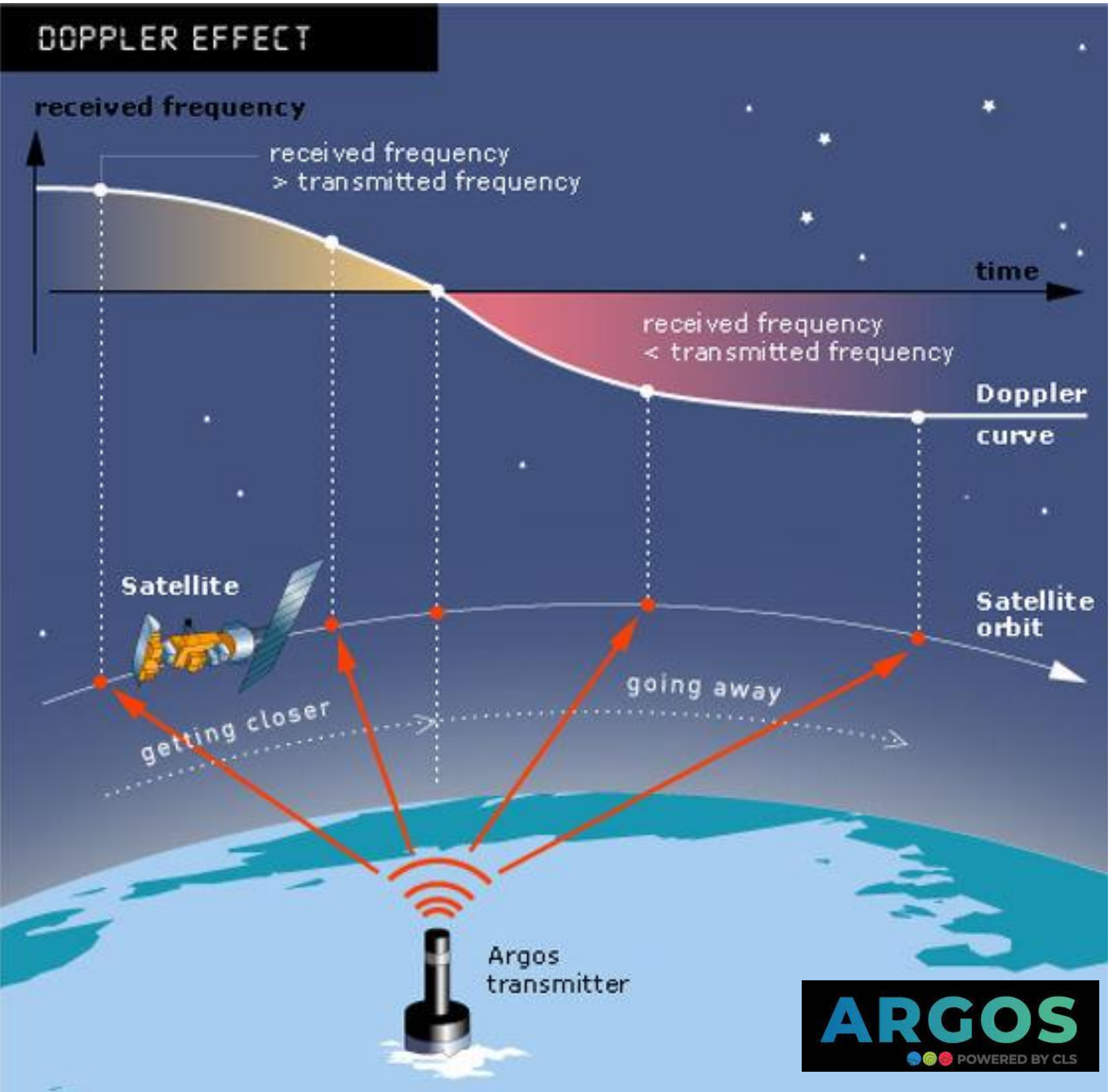
Satellite Telemetry using Argos Systems

Sea turtles spend the majority of their lives in the marine environment, making traditional tracking methods challenging. For species like the olive ridley turtle, their foraging and migration can occur in areas that are hundreds and even thousands of kilometres away from the coast. To track such marine vertebrates, satellite tracking has become a crucial tool, and the Argos satellite system is the most commonly used service provider for such studies. Argos is a dedicated satellite system designed to collect environmental data from fixed and mobile platforms globally. Additionally, this system allows for the tracking of animals through Platform Transmitter Terminals (PTT).

The Argos system operates using eight satellites, ground stations, and transmitter terminals. To track animals, PTTs are attached to them using various methods depending on the species of interest. The PTT is programmed to send signals at predetermined intervals. These signals are received by polar-orbiting Argos satellites, and the tag's location is determined using doppler shifts in the signal frequency. These satellites orbit at an altitude of 850 km and can pick up signals from transmitters in a visibility area of 5000 km^2. During a 10-minute pass at a specific time, the satellites can detect transmitters in the visible region. The data collected from these transmitters is then sent to ground stations for further processing. The location quality of the tags depends on the

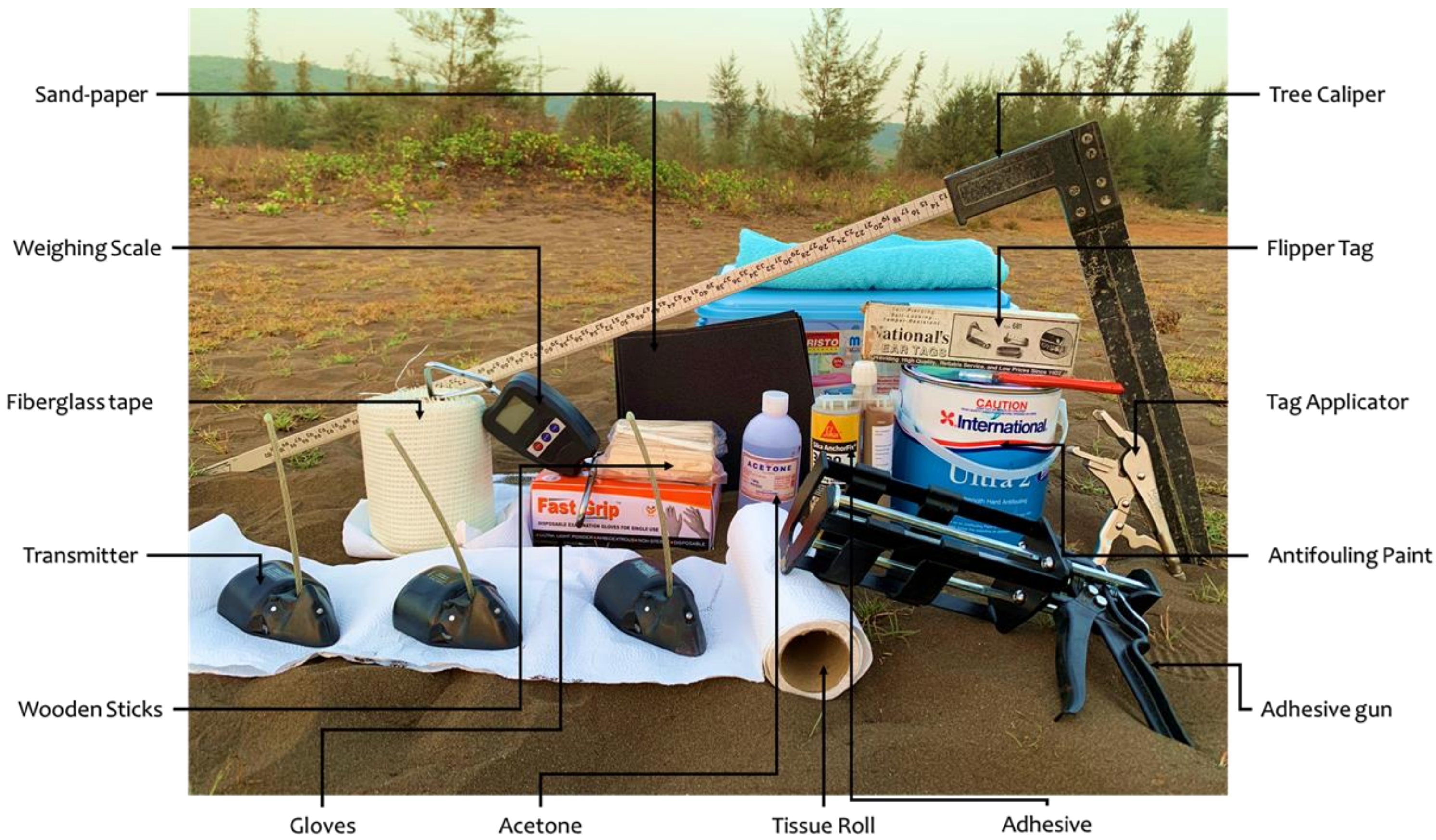
number of signals received by the satellite during the pass, with location categories ranging from 3 (highly accurate) to 0 (least accurate) in decreasing order of location estimate error.

The Argos system also has the capability to receive data collected by sensors embedded in satellite tags. These tags can be manufactured to include sensors for detecting parameters such as temperature, dive parameters, and salinity. The tags used in this study included dive sensors that measured dive depth, dive duration, and the Time Allocation at Depth (TAD) index of dives performed by the turtles.



Methodology

Satellite transmitters (model: K2G 576E) manufactured by Lotek Wireless Inc. (New Zealand) were deployed in this study. The tags were programmed to remain switched on for the entire tracking period, without any duty cycle. These transmitters were equipped with a Wet/Dry switch on the front and back to detect surfacing events, and signals were transmitted only when the turtle surfaced. The tags were equipped with depth sensors that collected depth data every 3 seconds during a dive. In addition to location data, the tags provided daily dive ratio (percentage of time spent underwater), the maximum depth the turtle reached on a given day, the proportion of time spent by turtles at different depth ranges, and individual dive parameters. The tags transmitted data from the most recently completed dive, and a typical dive dataset included the dive duration, maximum depth reached during the dive, the TAD index of the dive, and surface duration since the last dive.



All the PTTs were deployed on female turtles arriving on the beach for nesting. The selected beaches were closely monitored to locate nesting females and were only captured once the nesting process was completed. After capture, the turtles were cleaned of sand and brought to the wooden tagging box. The PTTs were attached to the carapace's second and third dorsal scutes to increase the probability of the transmitters and antenna being exposed when the turtle surfaced for breathing. Before tagging, the turtles were weighed using a digital balance, and morphometric measurements of the carapace were recorded.

The tagging area of the carapace was cleaned with water to remove any debris, algal growth, or epibionts. The area was further cleaned with Isopropyl alcohol and acetone. To attach the PTT, a layer of two-part epoxy glue (Sika AnchorFix 3030) was applied to the bottom of the tag, and a layer of fibreglass tape was applied between the epoxy layers to provide structural strength. For one turtle tagged in 2023 (*Guha*), a different epoxy (Dewalt Pure 150-pro) was used. Once the epoxy hardened, a layer of antifouling paint (International Paints - Ultra 2) was applied. Monel metal tags were also attached to the front flippers of the turtles (except *Prathama* and *Saavni*) for individual marking.

Analytical methods

Sea turtle location and dive data were retrieved from the Lotek data management website and analysed using MS-Excel, QGIS, and R Software. A continuous-time state space model was used for the track correction and modelling of the movement persistence of the turtles. The locations from the modelled track for every 6-hour interval were then extracted for kernel density estimation, and the same for 24-hour intervals were extracted for mapping. The speed of turtles was calculated using distance and time difference between consecutive good-quality locations. The dive parameters were checked for normality, and parametric and non-parametric tests were performed to check the differences between the dives performed in different habitats and the time of the day. Dive shape was determined through TAD index, where values between 50-75 were considered V-shaped or exploratory dives and values above 75 were considered U-shaped or resting dives.

Holding box

Weighing Turtle

Recording morphometrics

Cleaning Carapace

Application of Adhesive

Fiberglass layering

Antifouling paint coating

Results

Seven turtles were deployed with PTTs along the Maharashtra coast during this study, of which five were tagged in January-February 2022 and two in February 2023. Four of the five turtles tagged in 2022, and the two from 2023 provided location data for over three months. One turtle tagged in February 2022 possibly had fishing-related mortality just three days after tagging. The average tracking duration for turtles tagged in 2022 was 138 days (range: 121-173 days), and for turtles tagged in 2023 tracking duration was 212 and 213 days. We received 9671 locations during the tracking period, of which 2686 belonged to good quality (location Quality 1, 2, & 3).

Table 1: Summary of location data received for the seven tagged turtles. The location quality "0, A, B" represents locations with low accuracy while "3" represents the highest accuracy of 150 to 200 m.

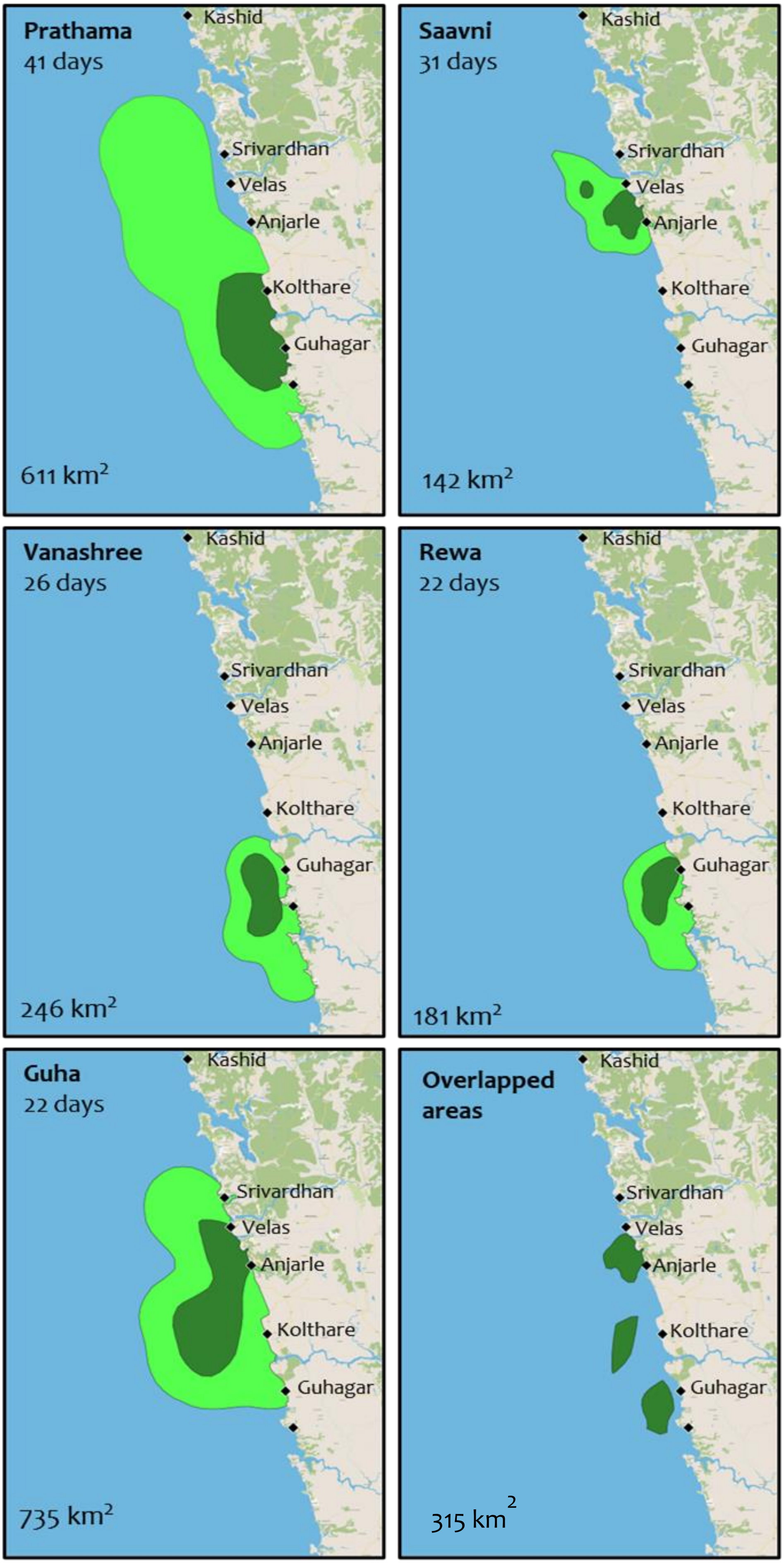
Turtle	Tracking Days	Locations belonging to different Quality class						
		0	A	B	1	2	3	Grand Total
Prathama	119	188	121	226	78	40	18	671
Saavni	131	288	155	264	139	53	23	922
Vanashree	172	476	242	482	146	49	9	1404
Laxmi	3	3	1	4	0	1	1	10
Rewa	128	365	141	346	176	72	22	1122
Bageshree	213	726	425	791	519	316	180	2957
Guha	212	503	392	857	409	210	225	2596

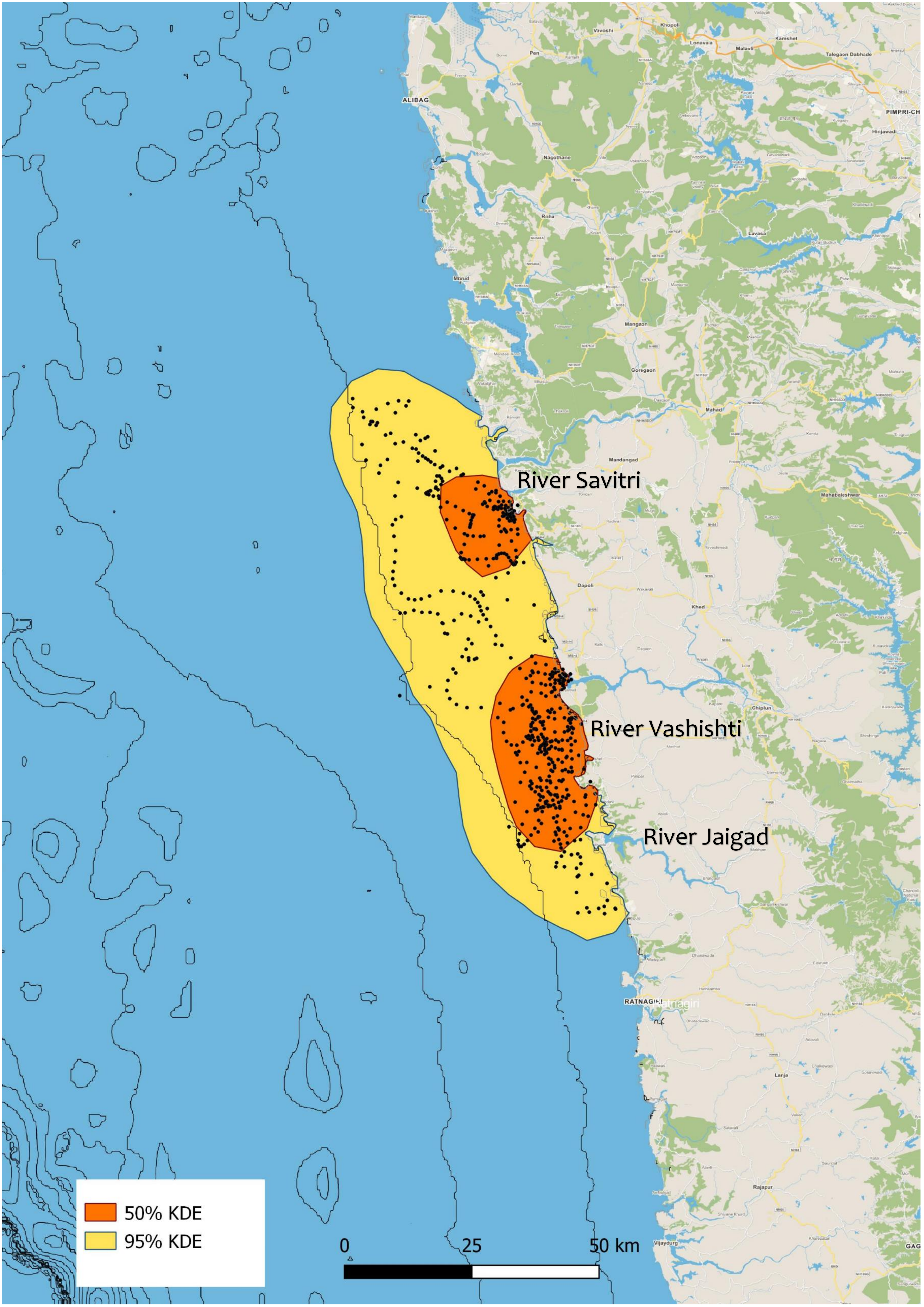
Nearshore Movements

After release, all turtles except *Bageshree* remained in the breeding area for an average duration of 30 days (range: 20-41). Post-tagging, the turtles stayed at an average distance of 9.4 ±8.7 km from the coast during the breeding phase. The core use area (50% KDE) derived from the modelled location of five turtles was 869 km^2, while 95% KDE was 4413 km^2. The individual turtle ranged (MCP) in breeding phase ranged between 255 to 1526 km^2. The turtles remained in areas shallower than 30m depth during the breeding season. Notably, *Prathama* and *Saavni,* from the January 2022 tagging, were observed to renest after 34 and 31 days of release, respectively. *Prathama* attempted to nest on a beach located 50 km away from the tagging area while *Saavni* nested 5 km away from the first nesting beach. A shift in movement behaviour was observed for these turtles 15 days prior to the second nesting event, as they moved closer to the nesting beaches, showing reduced movement during this period.

Table 2: Details of locations received during the breeding phase of tracking.

Turtle	Tag ID	Tagging date	Departure from nesting ground	Duration	Location Quality						
					3	2	1	A	B	0	Grand Total
Prathama	228068	25-01-2022	06-03-2022	39	13	21	25	55	118	49	281
Saavni	228069	25-01-2022	26-02-2022	31	6	8	20	42	95	56	227
Vanashree	228070	14-02-2022	18-03-2022	27	1	1	7	51	158	39	257
Rewa	228072	15-02-2022	11-03-2022	22	2	7	14	19	113	29	184
Bageshree	238996	22-02-2023	22-02-2023	0	na	na	na	na	na	na	na
Guha	238997	22-02-2023	13-03-2023	17	1	12	24	28	75	42	182
			Grand Total	136	23	49	90	195	559	215	1131


Prathama
41 days
611 km²
Saavni
31 days
142 km²
Vanashree
26 days
246 km²
Rewa
22 days
181 km²
Guha
22 days
735 km²
Overlapped areas
315 km²
Kashid
Srivardhan
Velas
Anjarle
Kolthare
Guhagar


River Savitri
River Vashishti
River Jaigad
50% KDE
95% KDE
0
25
50 km

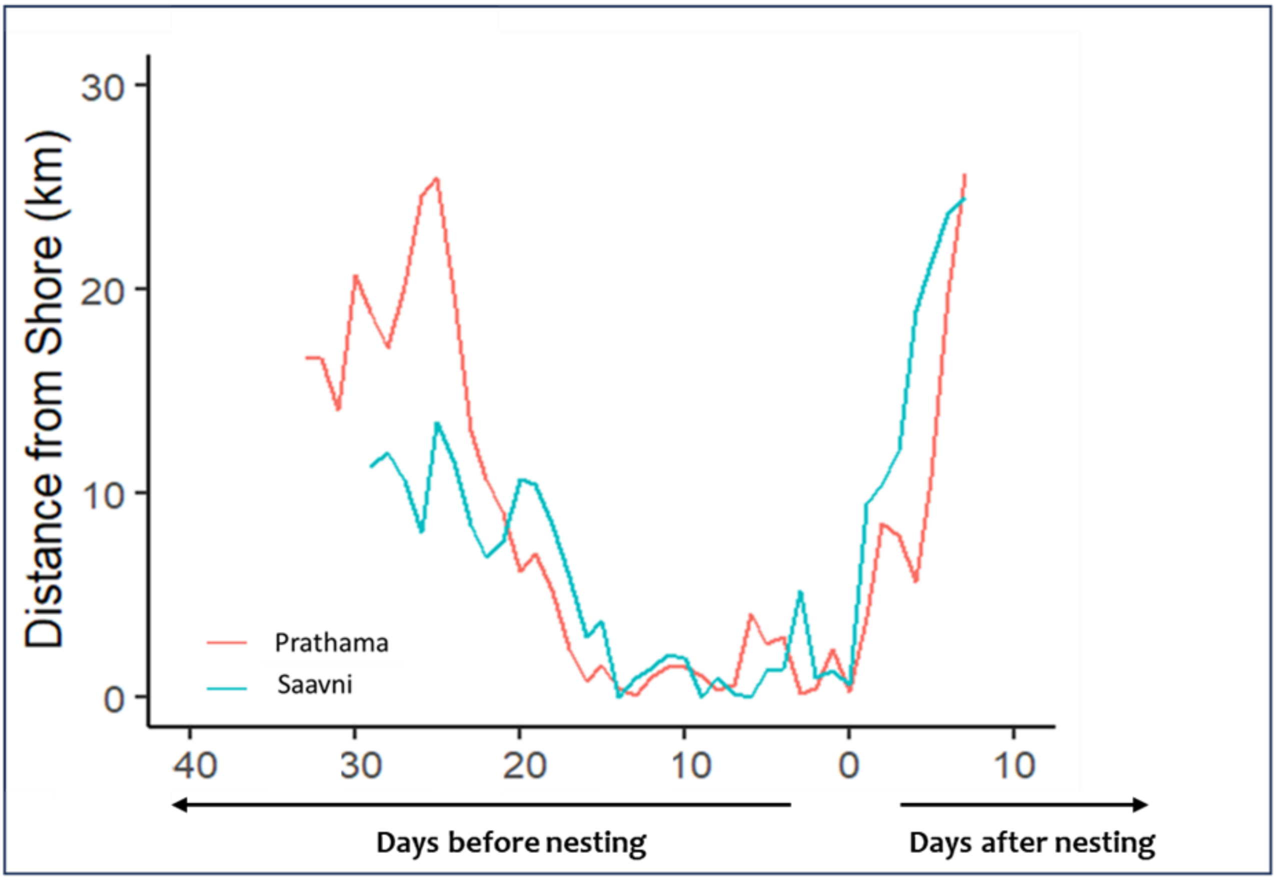
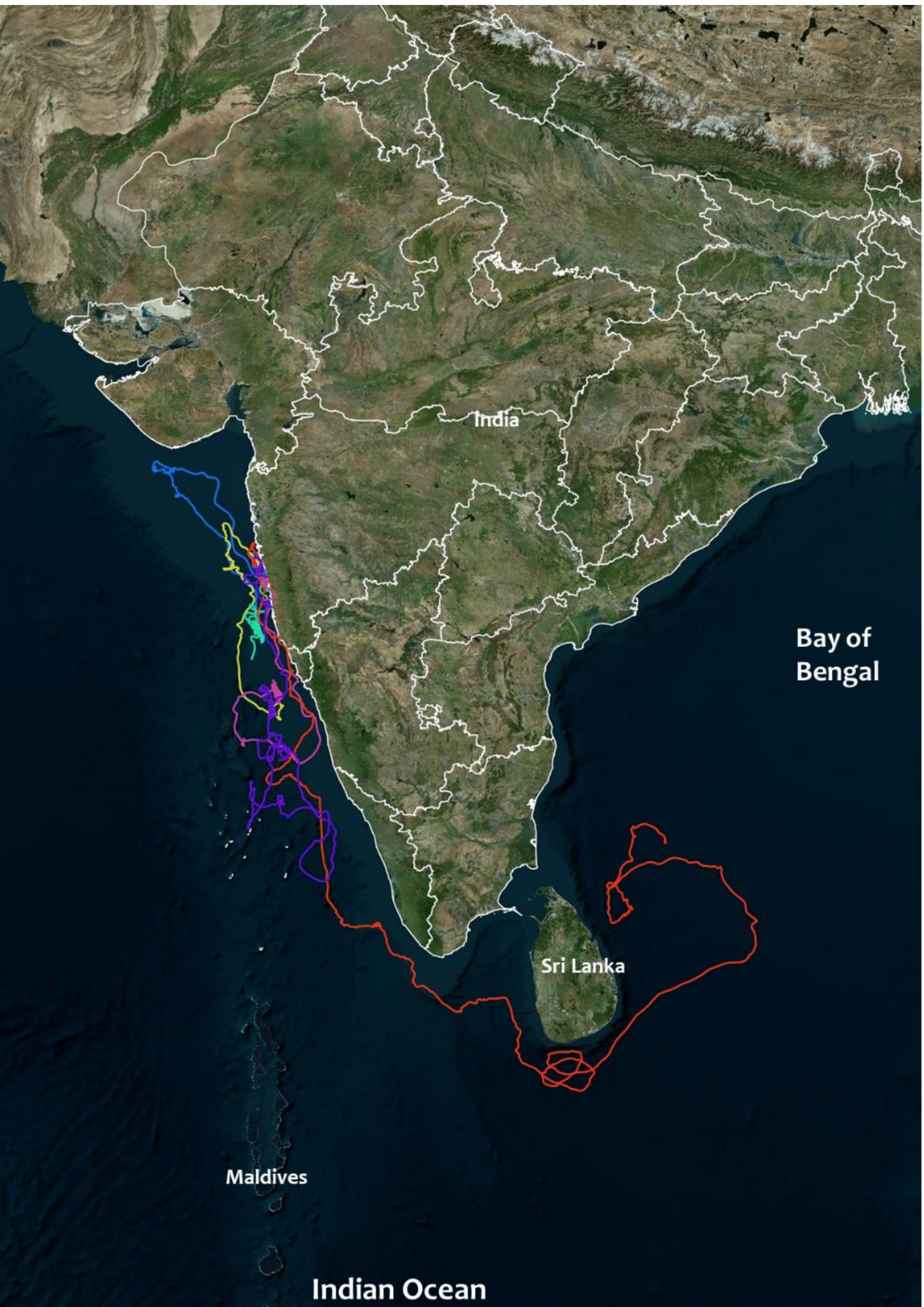


Figure 3 (Top). Change in the distance from shore by two turtles during inter-nesting period. Zero on x-axis represents second nesting event. A decline in shore distance is visible about 15 days from nesting event.

Image 1 (Bottom). Saavni (left) observed by Maharashtra Forest Department staff nesting on Kelshi beach 5 km (straight line distance) from Anjarle and nesting attempts (Right) of Prathama on Dabhol beach 50 km (straight line distance) from Velas.


Pakistan
Oman
Arabian Sea
Socotra Island
Turtle
Prathama
Saavni
Vanashree
Rewa
Bageshree
Guha
Indian Ocean


India
Bay of Bengal
Sri Lanka
Maldives
Indian Ocean

Post Breeding Movements

The post-breeding movement of the turtles was tracked for 80-166 days. *Prathama* and *Saavni*, tagged in January 2022, were observed heading northward during the beginning of post-breeding migration while the other turtles started migrating southward. *Rewa,* from 2022 tagging session and *Bageshree,* from 2023, were observed to migrate through shallow nearshore waters during the early migratory phase. Turtles tracked in 2022 showed movements primarily restricted to the continental shelf of the west coast, with occasional movements into deeper parts of the Arabian Sea. In contrast, the turtles tagged in 2023 exhibited more extensive movement into the open waters of the Arabian Sea. *Bageshree* and *Guha* initially moved in the shelf area but later transitioned to deeper waters later in the tracking period. *Guha* moved to waters near Lakshadweep Islands and returned to the shelf break, while *Bageshree* crossed Sri Lankan waters, residing in the Bay of Bengal.

Individual variations in the movements and migratory behaviour of tagged turtles were observed during this study. In the migratory phase, turtles were observed to move with a median speed of 1.1km/h (range: 0.2-1.29). Except in the case of Rewa, it was found to increase significantly when the turtles migrated through open waters. *Bageshree* showed higher movement persistence for most part the tracking

period, while *Vanashree* had low movement persistence. On the other hand, *Prathama*, *Saavni*, *Rewa*, and *Guha* demonstrated significant changes in movement persistence during the tracking period. The stop-over of turtles was observed in waters off Gujarat, Karnataka and South Eastern Sri Lankan coast. Details of individual turtle movement are provided separately in the next section. This section also has figures showing variation in MPI (λ_t).

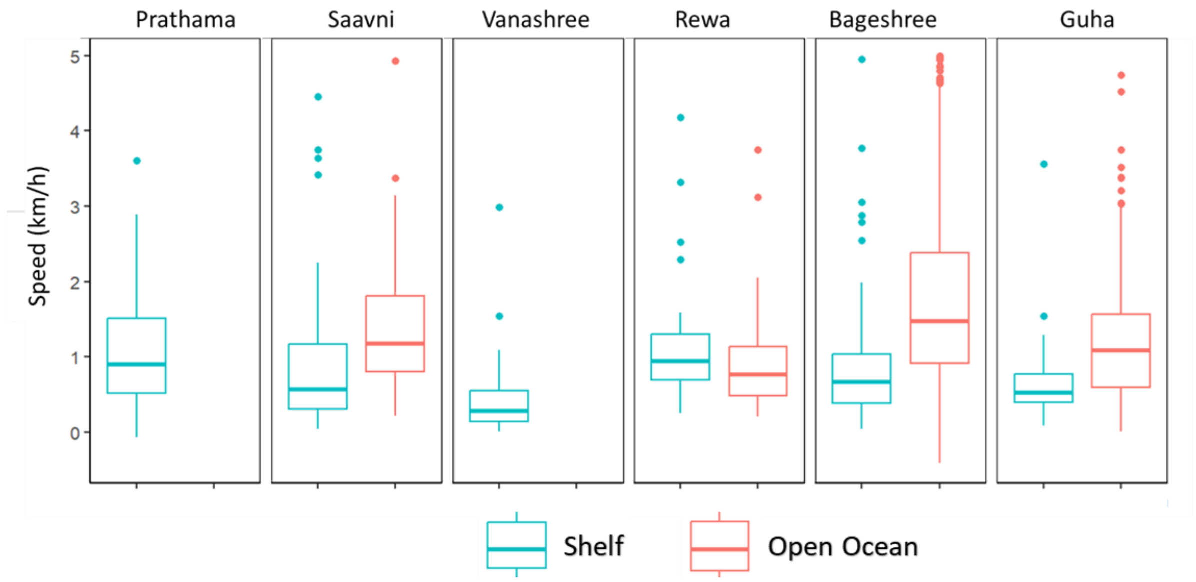
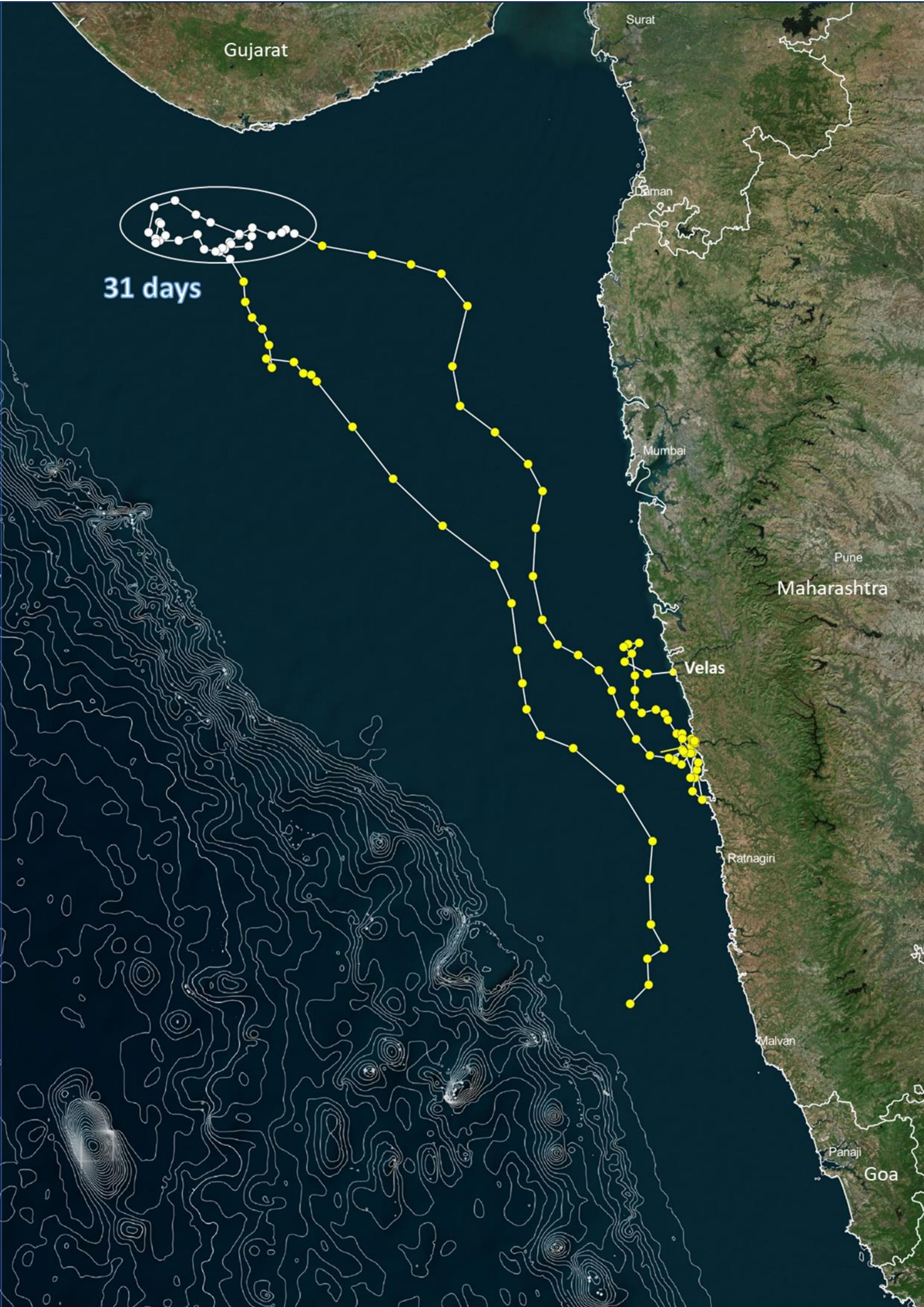


Figure 5. Travel speed of turtles during the migratory phase in shelf area and open ocean, calculated using distance and time difference between good quality locations. Except for Rewa, an increase in the travel speed is observed in open ocean migration.

Prathama (120 days)

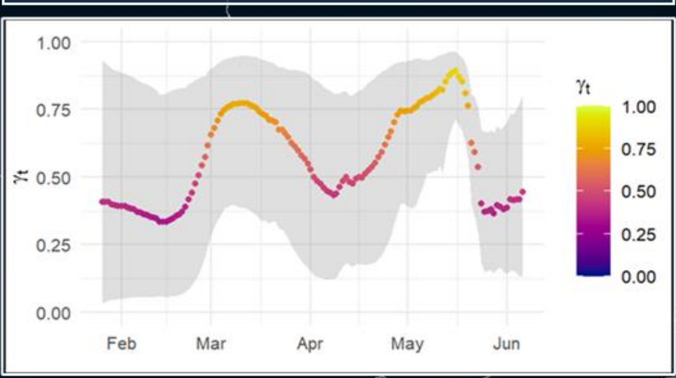
Prathama (Tag ID: 228068) was tagged on 25th January 2022 at Velas beach where it was found nesting. This turtle was observed to nest again after 34 days of tagging on Dhabol beach. It departed from the nesting area on 28th February 2022 after laying the second nest and started to migrate north. It moved to the area off Gujarat coast in 31 days and stayed there in a less mobile phase. After staying in this phase for 20 days, it showed a change in movement behaviour and started migrating south till 24th May 2022, when the transmission stopped. The last location of this turtle was off Kunkeshwar coast in the Sindhudurg district.

Tag ID	Tagging Location	Tagging Date	Weight (kg)	Clutch size	CCL (cm)	CCW (cm)	SCL (cm)	SCW (cm)	Tracking days	Distance covered
228068	Velas	26-01-2022	38.5	106	68.5	70	63.8	57.7	120	1450

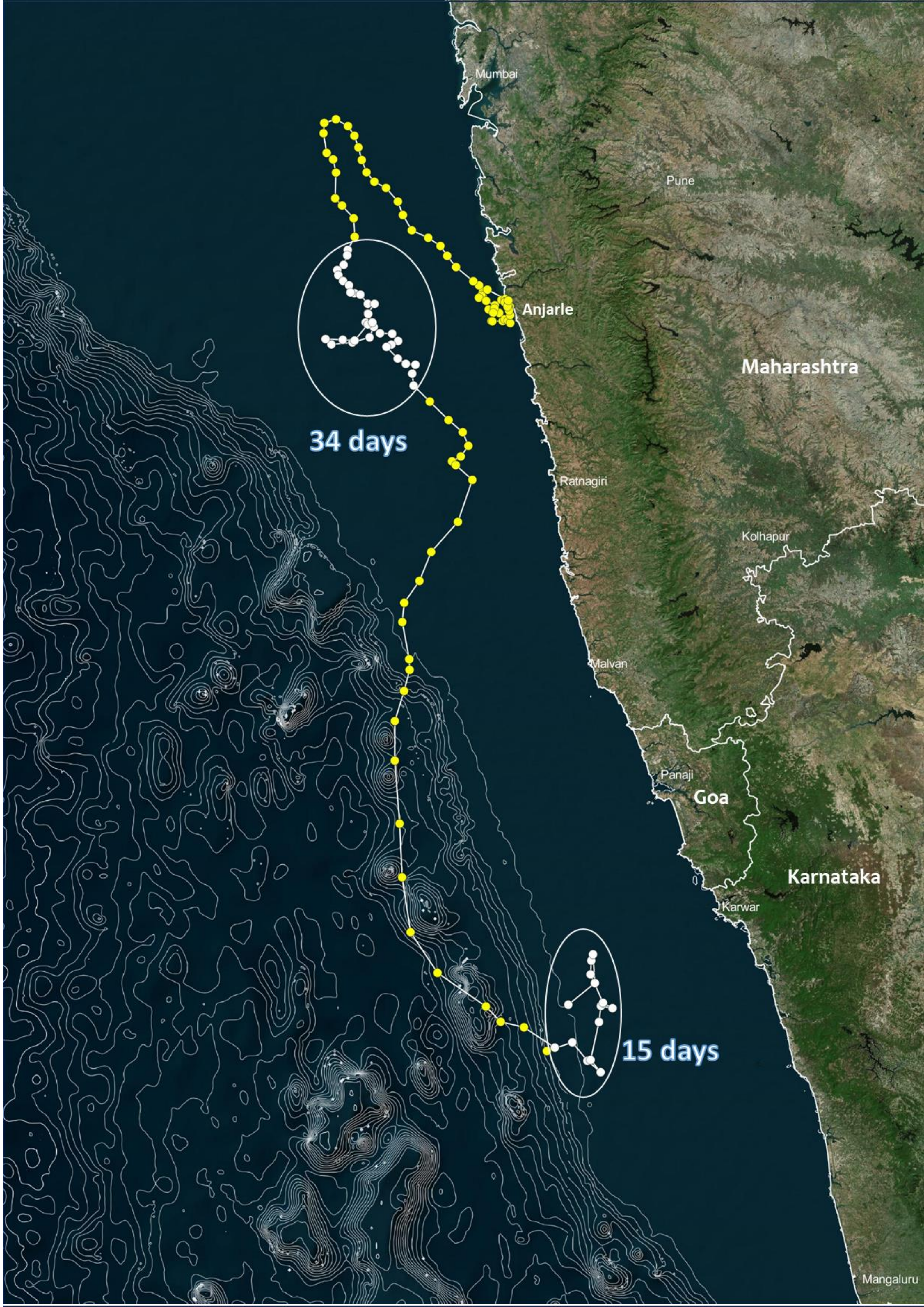

Gujarat
Surat
Daman
31 days
Mumbai
Pune
Maharashtra
Velas
Ratnagiri
Malvan
Panaji
Goa

Saavni (132 days)

Saavni (Tag ID 228069) was tagged on 25th January 2022 at Anjarle beach. It stayed in the nearshore waters around Anjarle and nested after 31 days of tagging. It departed from the nesting area on 24th February 2022 after laying a second nest with clutch of 78 eggs at Kelshi beach. It moved northward during the first mobile phase, reaching area off the Mumbai coast, and turned back. It started migration south where it strayed briefly to the deeper waters, and returned to the shelf area. There, its movement reduced and it stayed in a less mobile phase and probably foraged until the end of transmission. The last location for this turtle came off the Karwar coast of Karnataka.

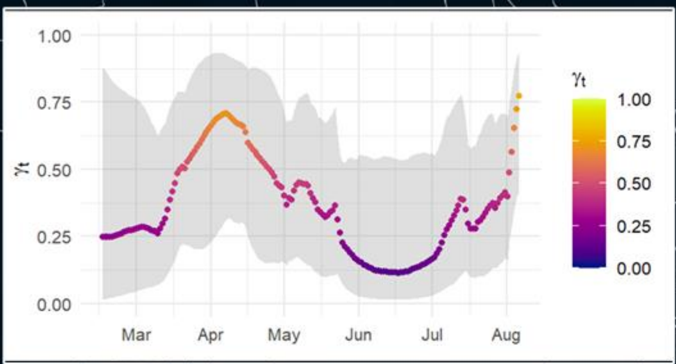


Tag ID	Tagging Location	Tagging Date	Weight (kg)	Clutch size	CCL (cm)	CCW (cm)	SCL (cm)	SCW (cm)	Tracking days	Distance covered
228068	Anjarle	26-01-2022	34	78	67.2	67.5	62.2	55	132	1157

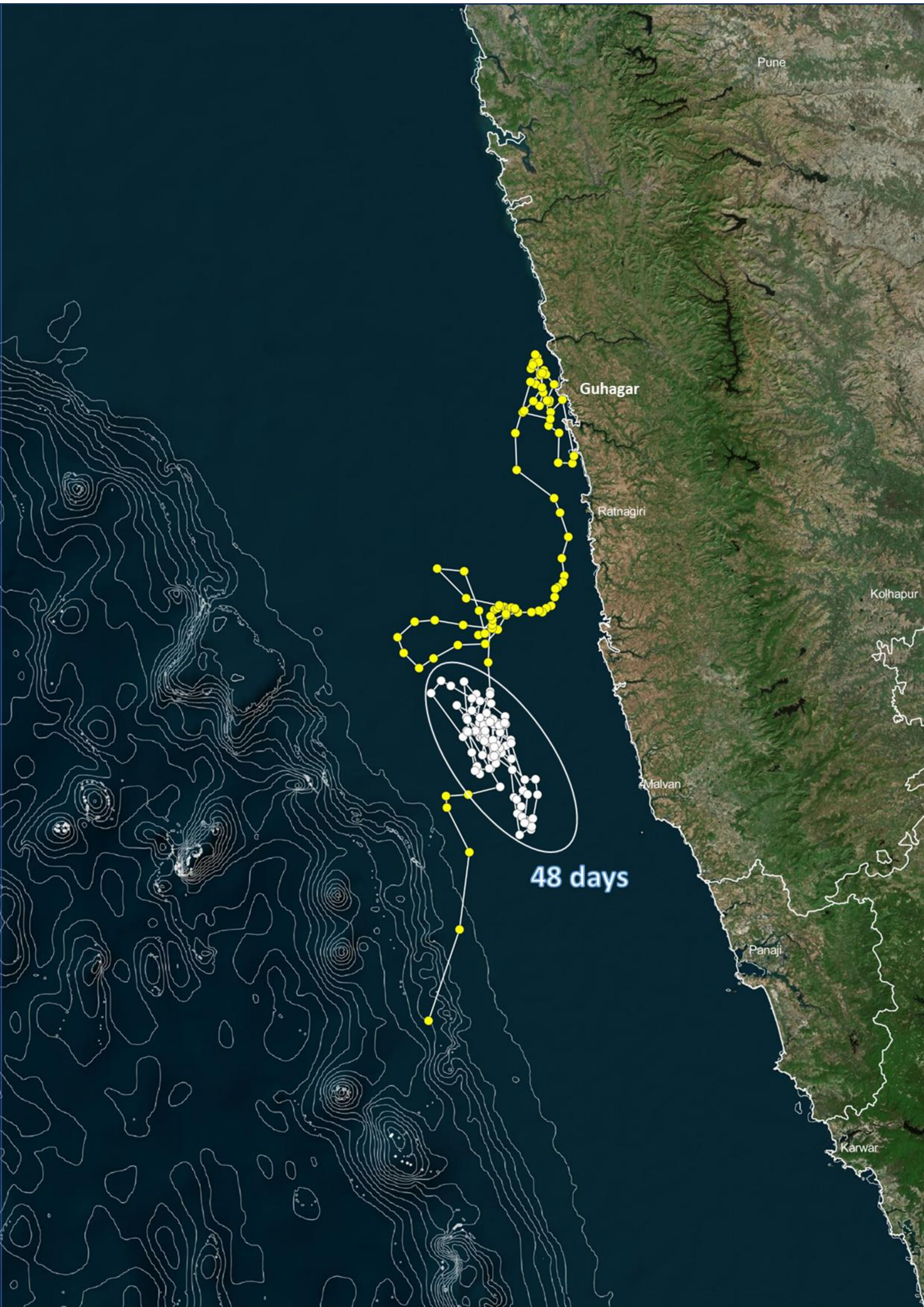

Mumbai
Pune
Anjarle
Maharashtra
34 days
Ratnagiri
Kolhapur
Malvan
Panaji
Goa
Karnataka
Karwar
15 days
Mangaluru

Vanashree (173 days)

Vanashree (Tag ID 228070) was tagged on 14th February 2022 at Guhagar beach of Ratnagiri district. This turtle showed a very distinct movement pattern among the four turtles and showed the lowest displacement from nesting area. The turtle stayed in the nesting area for 31 days, followed by slow movement for 48 days off the Maharashtra coast. The turtle settled off the Maharashtra coast and probably foraged for 94 days before the transmission stopped transmission off the Malvan coast.

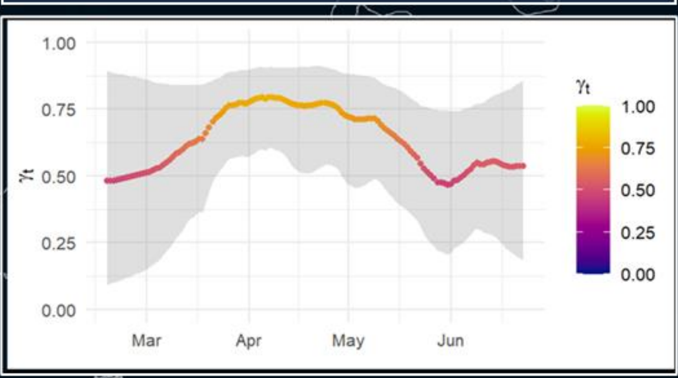


Tag ID	Tagging Location	Tagging Date	Weight (kg)	Clutch size	CCL (cm)	CCW (cm)	SCL (cm)	SCW (cm)	Tracking days	Distance covered
228068	Guhagar	14-02-2022	34.25	116	67.5	68	63.9	56.8	173	1288

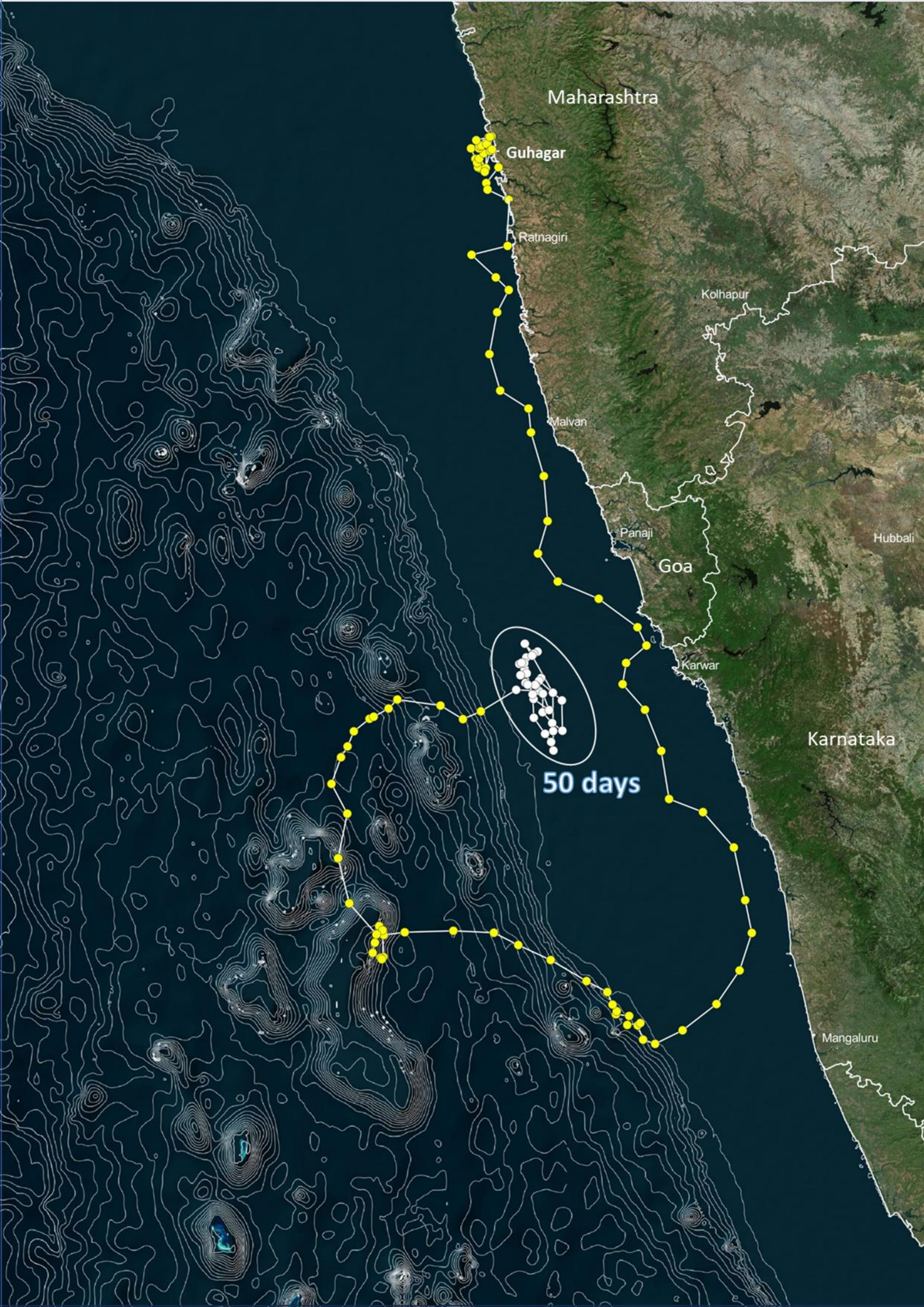

Pune
Guhagar
Ratnagiri
Kolhapur
Malvan
48 days
Panaji
Karwar

Rewa (128 days)

Rewa (Tag ID 228072) was tagged on 15th February 2022 at Guhagar beach. It stayed in the nesting area for 21 days post tagging and then started moving southwards along the nearshore habitat. After moving to southern Karnataka, it turned westward and moved to deeper waters for a brief period and back to the shelf area off the Karwar coast. After showing a migratory behaviour for 56 days post-nesting, it settled for 50 days and probably foraged off Karnataka and Maharashtra coast. This was the same area where Saavni was observed to stop at the end of its tracking. Rewa stopped transmission off the Karwar coast.



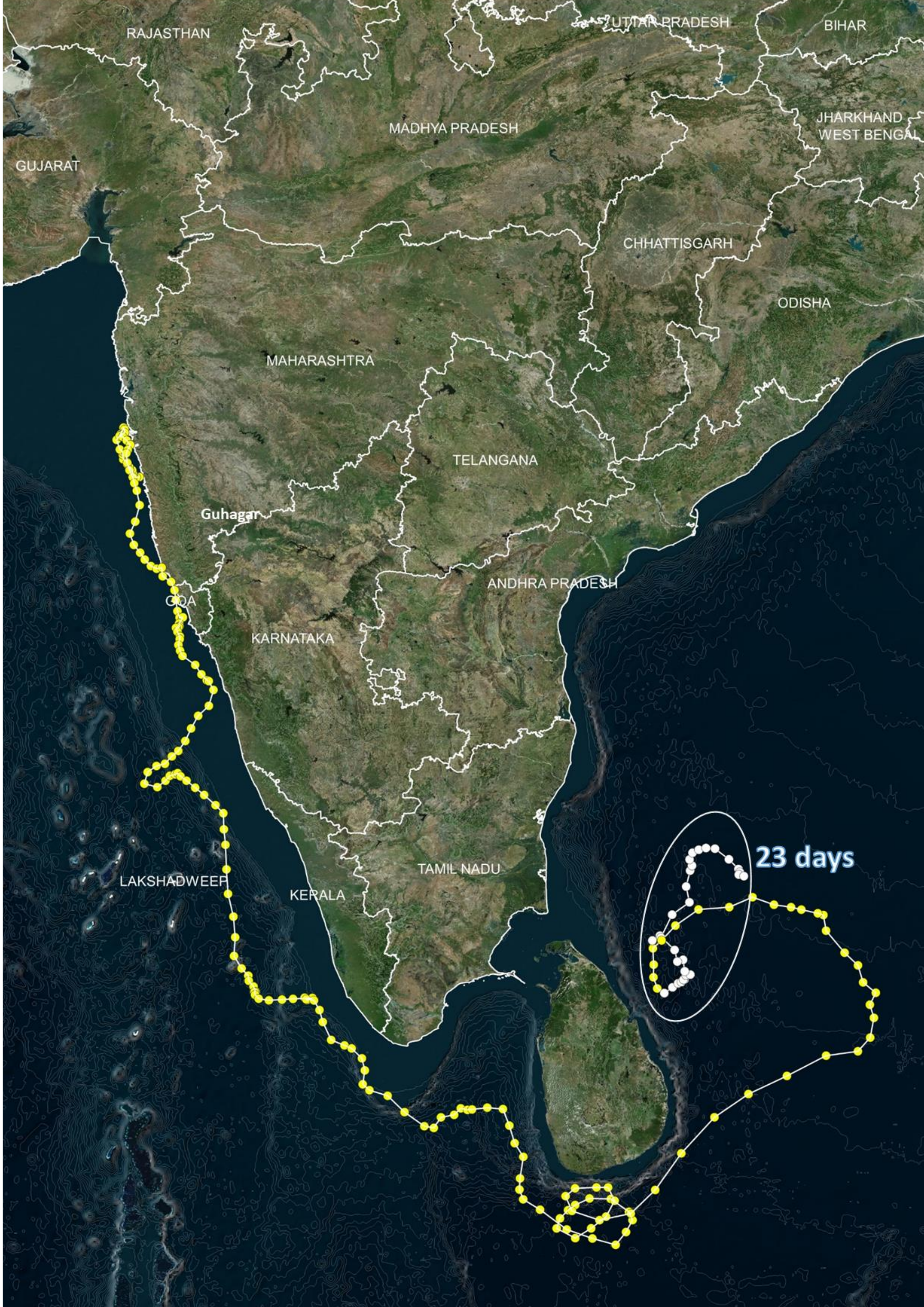
Tag ID	Tagging Location	Tagging Date	Weight (kg)	Clutch size	CCL (cm)	CCW (cm)	SCL (cm)	SCW (cm)	Tracking days	Distance covered
228068	Guhagar	16-02-2022	37	116	67.5	66	64.3	58.2	128	1538


Maharashtra
Guhagar
Ratnagiri
Kolhapur
Malvan
Panaji
Goa
Hubbali
Karwar
50 days
Karnataka
Mangaluru

Bageshree (212 days)

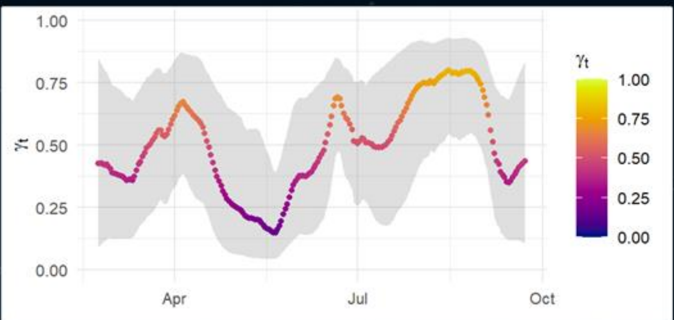
Bageshree (Tag ID: 238996) was tagged in Guhagar on 22[nd] February 2023. It laid 85 eggs before getting tagged. The turtle started moving along the coast as soon as it was released. It first moved north and after 15 days started moving south. It moved along the coast till central Karnataka and then moved to deeper waters near continental shelf and continued the southward movement. It moved to waters off south Sri Lankan coast. After moving to this area, it had circular movement. The movement persistence of this turtle showed high values during the whole of tracking duration and the turtle stopped in waters off northeastern Sri Lankan waters.

Tag ID	Tagging Location	Tagging Date	Weight (kg)	Clutch size	CCL (cm)	CCW (cm)	SCL (cm)	SCW (cm)	Tracking days	Distance covered
228068	Guhagar	22-02-2023	37.3	85	66	67	62.4	57.2	212	5267


RAJASTHAN
UTTAR PRADESH
BIHAR
MADHYA PRADESH
JHARKHAND
WEST BENGAL
GUJARAT
CHHATTISGARH
ODISHA
MAHARASHTRA
TELANGANA
Guhagar
ANDHRA PRADESH
GOA
KARNATAKA
23 days
LAKSHADWEEP
TAMIL NADU
KERALA

Guha (151 days)

Guha (Tag ID 238997) was tagged along with Bageshree in 22nd February 2023 at Guhagar. The turtle remained in breeding area for 22 days before starting the southward migration. Like Rewa, this turtle moved along the coast till Goa coast and then moved towards the continental shelf edge. It remained in this area for about a month and had low movement persistence. Then it started south-westward movement and reached north of Kadmat island in Lakshadweep. By the end of tracking, the turtle moved eastward and remained in shelf break off Karnataka. The turtle moved a total distance of 3122 kilometres and showed high variation in movement during the tracking period.



Tag ID	Tagging Location	Tagging Date	Weight (kg)	Clutch size	CCL (cm)	CCW (cm)	SCL (cm)	SCW (cm)	Tracking days	Distance covered
228068	Guhagar	22-02-2023	36.3	107	64.6	68	60.3	55.8	210	3122


MAHARASHTRA
GOA
KARNATAKA
ANDHRA PRADESH
20 days
18 days
16 Days
TAMIL NADU
KERALA
LAKSHADWEEP

Diving behaviour

A total of 7650 individual dives performed by the turtles were recorded during the tracking period, of which 1205 dives were from nearshore waters during the breeding phase. During the post-breeding phase, 3066 dives were performed in the continental shelf area (<150 m depth), and 3379 dives were performed in the open ocean area (>150 m depth). The average dive depth of the turtles during the breeding phase was 15.7 ± 8.2m, and these dives were on an average, 27.2±15 minutes long. In the post-nesting phase, the average dive depth was 61.43 ± 36 meters, and were 31.9 ±18 minutes long. There were significant differences in median dive depth and dive duration between individuals. The turtles performed a greater number of U-shaped dives in the continental shelf when compared to when they were in deeper waters (depth>150 m).

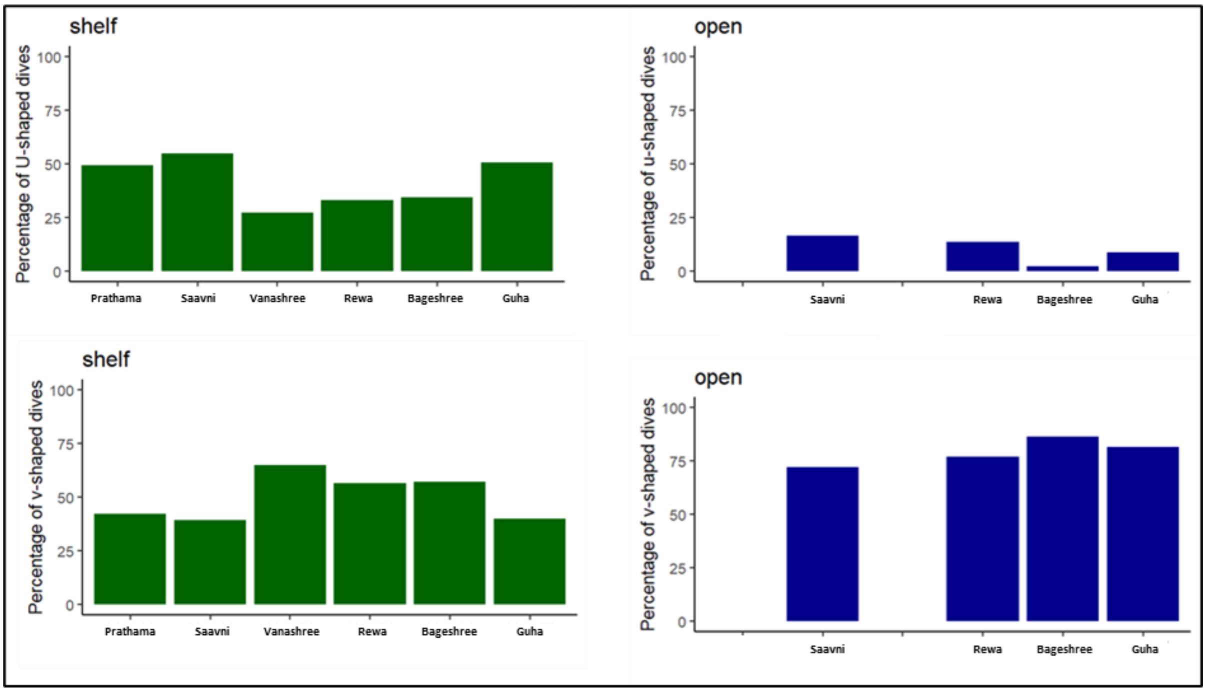


Figure 7: Proportion of U-shaped dives (first row) and V-shaped dives (second row) observed in the continental shelf area (represented in green) and deeper open ocean areas (represented in blue) for different turtles

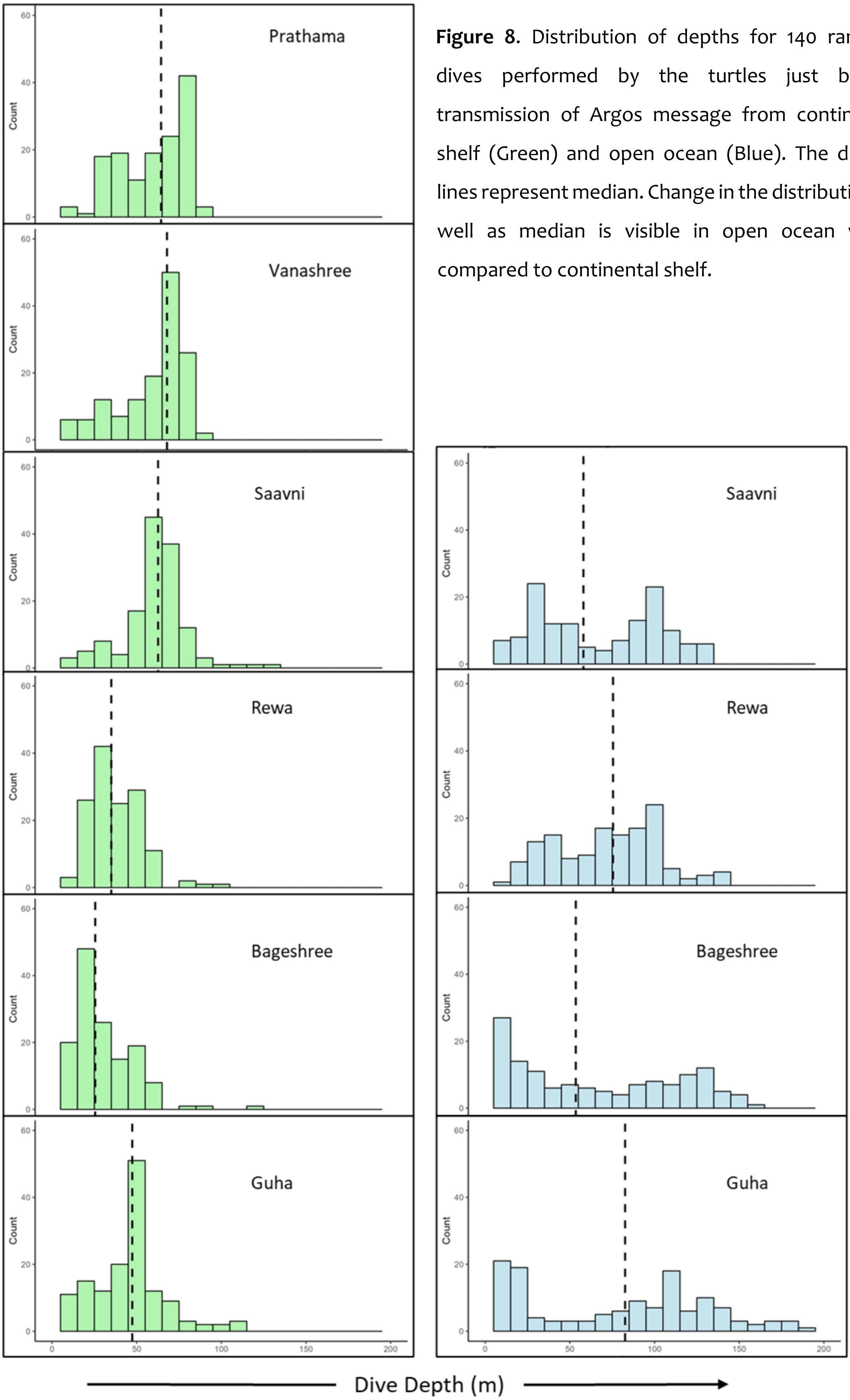
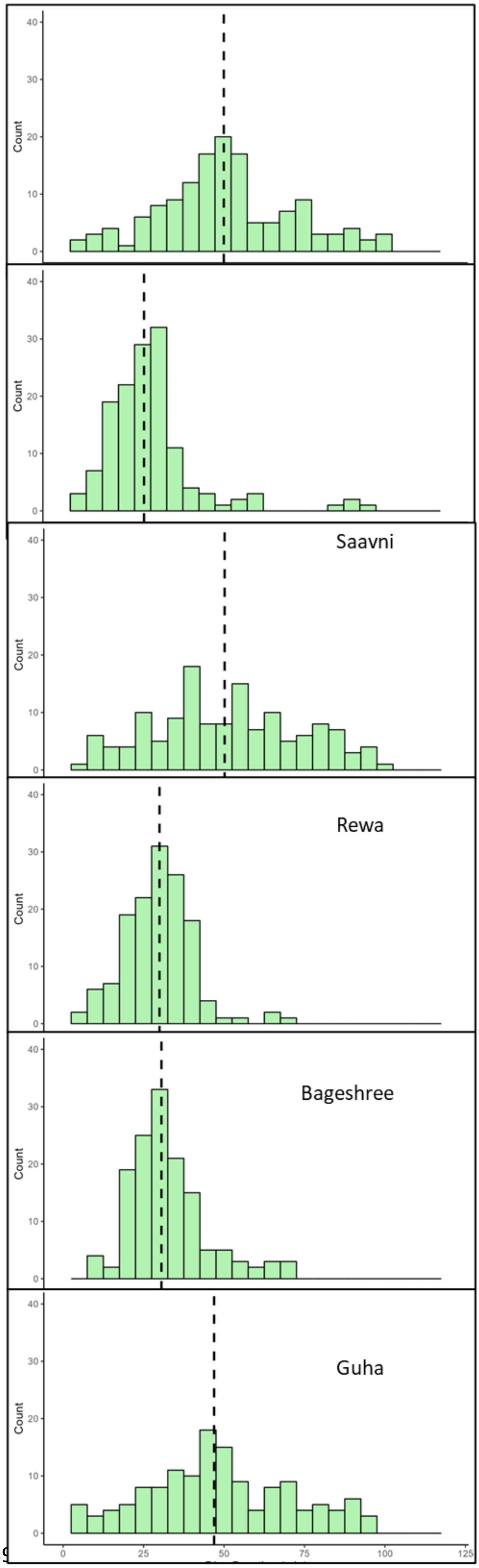
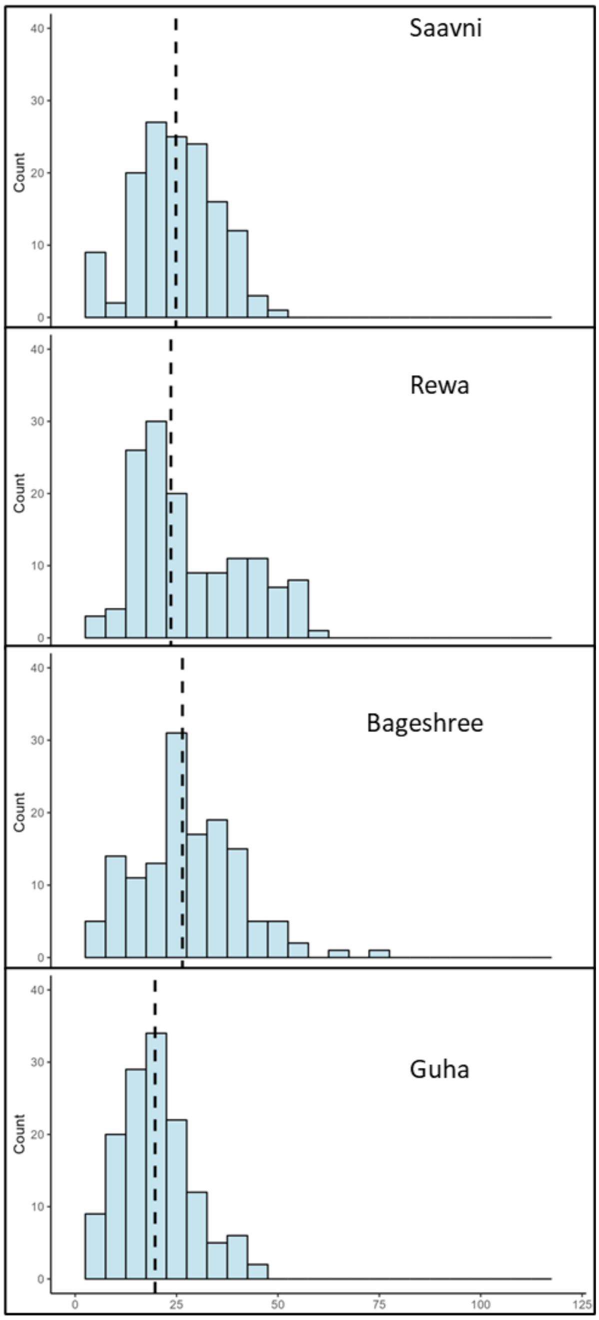


Figure 8. Distribution of depths for 140 random dives performed by the turtles just before transmission of Argos message from continental shelf (Green) and open ocean (Blue). The dotted lines represent median. Change in the distribution as well as median is visible in open ocean when compared to continental shelf.

Figure.9: Distribution of dive lengths for 140 random dives performed by the turtles just before transmission of Argos message from continental shelf (Green) and open ocean (Blue). The dotted line represents median. A unimodal distribution is observed with reduced median dive length in case of Saavni and Guha





The overall mean dive duration of the turtles was 30.8 min, ranging between 0.75 and 102 mins. The median dive length of the turtles during the nesting phase was 27.22 min (range 1.1 to 97.8 min), while in the post-breeding phase, it was 31.9 min (range 0.75 to 102 min). The median dive length on the continental shelf was 35 min (Range 1.1 to 102 min), while that for the open ocean was 23.4 min (Range 1 to 74.3 min.). During the post-breeding phase, the dive duration rarely exceeded 50 mins, whereas, on shelf areas, dive durations reached the recording limit of the tags (102 mins) on many occasions.

The dive depth recorded during the post-breeding phase of the turtles showed a unimodal distribution without a significant difference between day and night dives. However, in the open ocean, the dives had a bimodal distribution, and the day and night dives turtles were found to be significantly different. The day dives in the open ocean were generally deeper, with a median depth of 98.75 m, while the night dives were relatively shallower, with a median depth of 32.75 m. This pattern was not observed in the dives performed in the shelf area, which had a median day dive

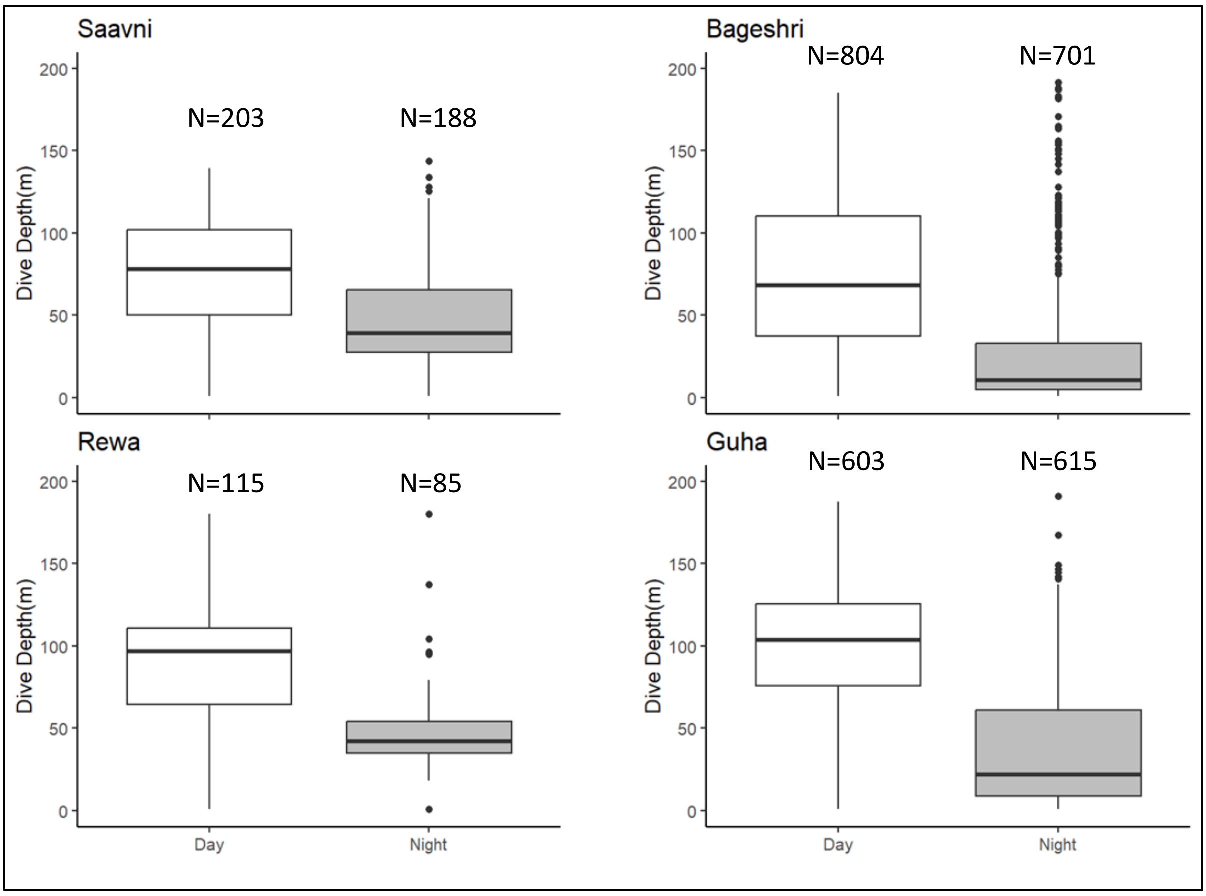


Figure 8. Depth of the dives performed by the turtles during the day and night in waters deeper than 150 meters. The diving depths during the day were found to be significantly deeper than the night dives.

depth of 50m and night dive depth of 47.75m. Turtles like *Prathama* and *Vanashree*, which stayed in the shelf area throughout the tracking period, had a median dive depth greater than the shelf dive depths of *Rewa*, *Bageshree* and *Guha*, which moved into the open ocean area.

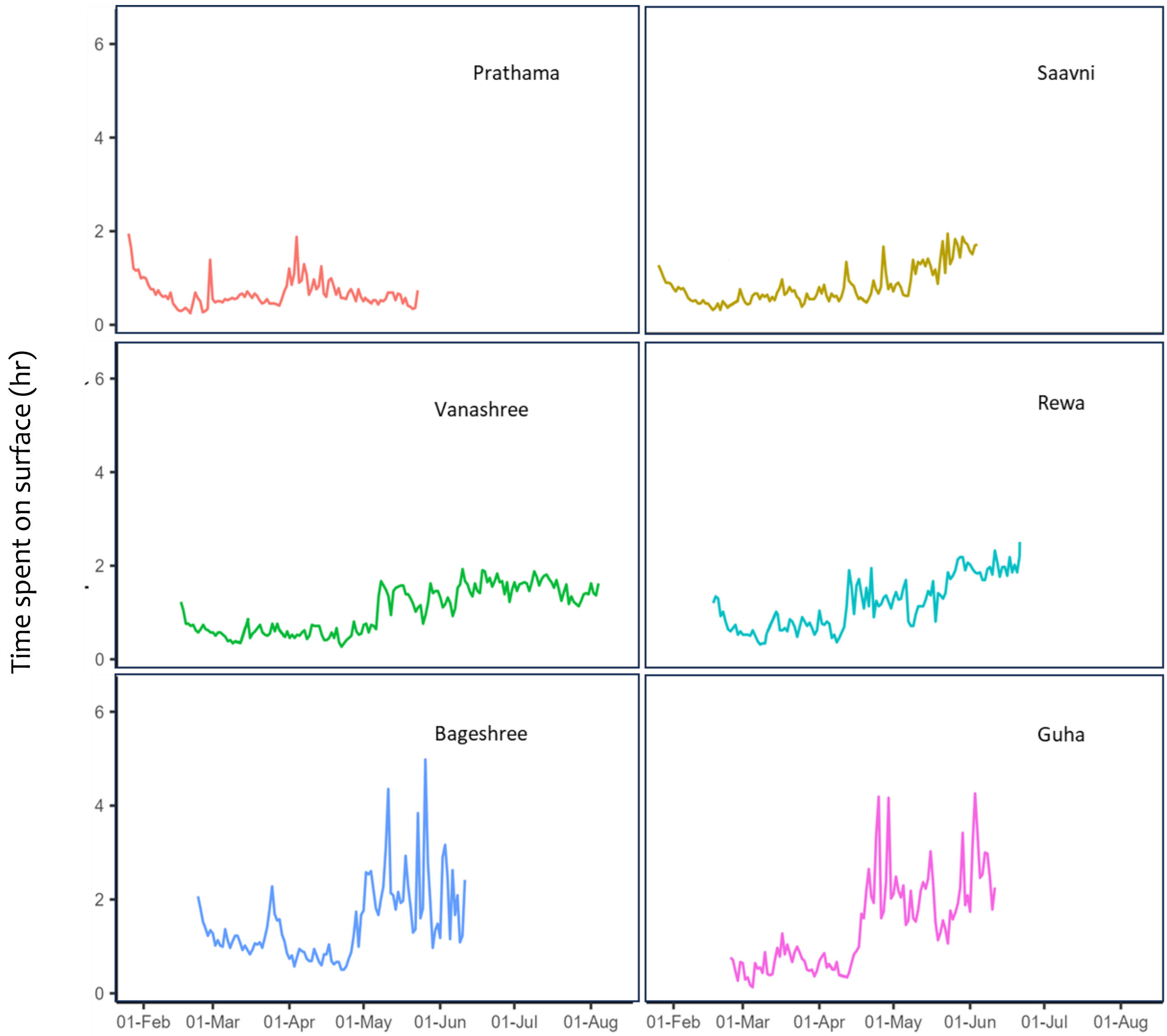


Figure 10: Change in daily duration spent on the surface by turtles during the tracking period. The turtles tagged in 2022 showed a steady increase in surface duration, while the ones from 2023 showed large variations.

The median daily surface duration of the turtles varied between 0.59 and 1.29 hours for all individuals. As the post-nesting season progressed, an increase in surface duration was observed for all turtles. The turtles tagged in 2022 showed a gradual increase in surface duration, while those tagged in 2023 exhibited high fluctuations in daily surface duration in the later part of the tracking period. The median daily maximum depth reached by the turtles ranged between 51 and 123 meters. Prathama had the smallest median daily maximum depth, mainly due to the use of shallow regions during the tracking, while the largest median daily maximum depth was observed for Bageshree. Remarkably, the transmitters recorded some of the deepest depths ever recorded for olive ridley turtles globally. In the shelf area, the maximum depth of the turtles was restricted by the ocean floor depth, whereas in the open ocean, the daily maximum depths frequently reached more than 300 meters.

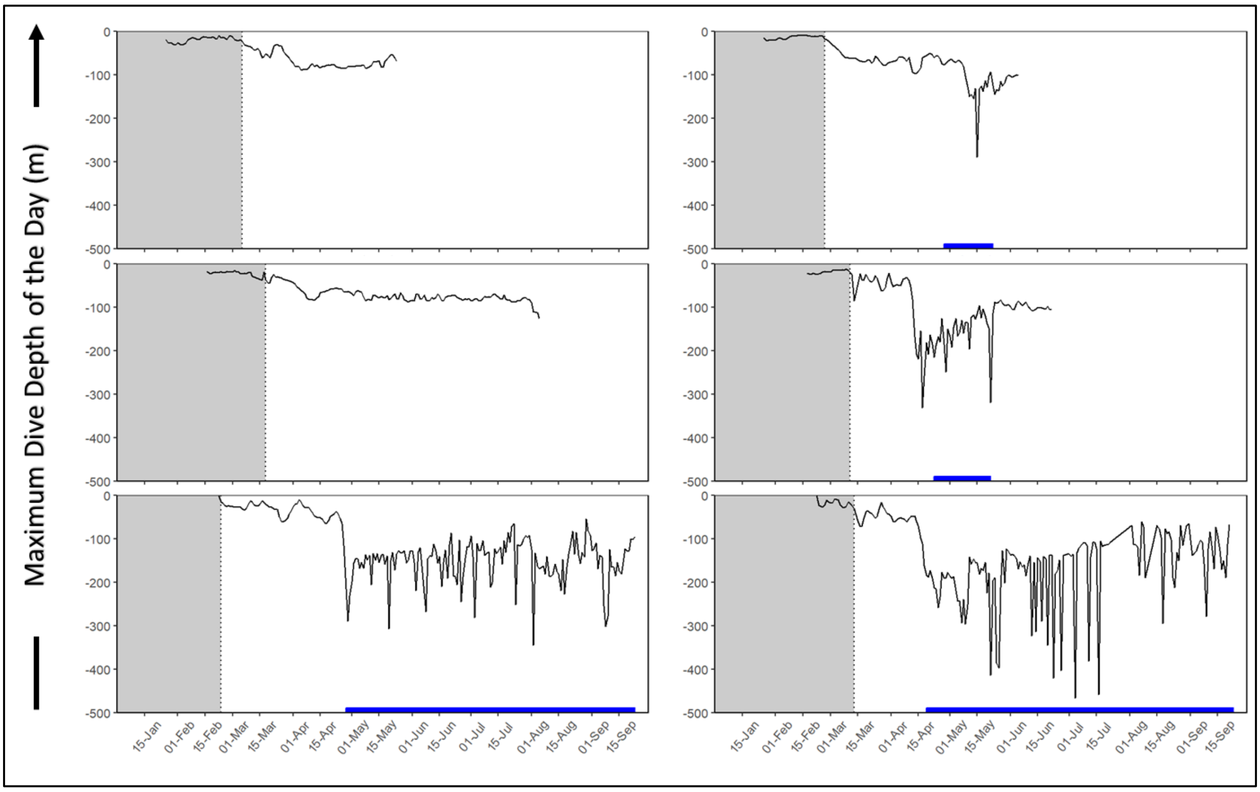


Figure: The maximum dive depth (m) of the day made by different turtles tracked during the study. The first four turtles were tracked during 2022, while the two others were tracked during 2023. The shaded area shown in the image is when turtles remained to near-shore waters during the nesting phase. The blue line indicates the period when turtles were in depths more than 150 m either in the continental shelf break or beyond in the open ocean.

Discussion

This is the first tracking effort to document the migration of solitary nesting olive ridley turtles from the west coast of India and provides detailed information on their movement patterns during the breeding and post-breeding phases. The preference for river mouths by olive ridley sea turtles during breeding is well known (Shanker, 2021). And in consonance with this, the high-use area of the tagged turtles in this study was primarily to three major river mouths in the region, namely Savitri, Vashishti and Jaigad. The combined core use of tagged turtles from this study covers an area of 869 km^2 which is about 19.6% of their home range and is equal to the 19% reported by Santos et al. (2019) for solitary nesting turtles in Brazil. The combined home range and core areas observed by Santos et al. (2019) extended to similar distance from shore but interestingly, these areas were up to 100 meter deep. In contrast to these findings for solitary nesting turtles, Kumar (2015) reported smaller core areas for arribada nesting turtles of the southern Odisha coast. The Odisha turtles remained to the Rushikulya river mouth, the site of the mass nesting beach, where they were captured and tagged, and ranged within 15 to 20 km along that coast. In this study the turtles being solitary nesters ranged over 75 km stretch of the coast, and their movement appears to be influenced by the presence of multiple river mouths, including the three major rivers mentioned above. The solitary nesting turtles of this study during the breeding phase remained nearshore, in shallow waters with depths less than 30 meters, similar to that reported from Australia (Hamel et al., 2008), Gabon (Dawson et al., 2017), and Odisha (Kumar, 2015).

As suggested by Kumar (2015) for olive ridley turtles of the Odisha coast and observed by Minamikawa et al. (2000) for loggerhead turtles, the freshwater from rivers might help the turtles to maintain buoyancy in shallow waters and save energy by taking rest on the sea floor during the breeding season. From the diving data, the relatively longer duration of U-shaped dives indicates the turtles spent lot more time resting during this period. The overall surface duration of turtles in the breeding areas also showed the turtles to spent more than 95% of time being underwater. The dives performed by the turtles at times extended more than the recording capacity of the tags (1 hour 40 minutes) in breeding season. The longer resting dives observed in the turtles coincides with the egg maturation phase, thereby conserve energy. This also indicates that the female turtles arriving in these waters to nest may not actively forage during the breeding phase. Given that the turtles likely arrive in these waters in December and reside until mid-March, a period of three to four months, and that the turtles to not feed during this entire period is clearly interesting and requires further investigation.

This tracking effort also revealed that the solitary nesting olive ridley turtles of the west coast represent at least two different populations as determined by their post-breeding movements. Five of the turtles in this study remained within the continental shelf with northernmost locations of turtles coming from waters off Gujarat and southernmost locations from Kerala. One turtle, showed much faster migratory movement than the others and moved to the south Sri Lankan waters and then crossing Sri Lanka to move to open waters of Bay of Bengal. Solitary nesting turtles tracked elsewhere have also showed variability in their post-nesting movements. The movement of the turtle Vanashree in this study is similar to turtles from Oman (Rees et al., 2012) and Australia (Whiting et al., 2007) that restrict themselves to the continental shelf waters. The migration of turtles through continental shelf to the areas off Karnataka resembles the movement of solitary nesting turtles of French Guiana (Plot et al., 2015), a few turtles of Brazil (Santos et al., 2019) and a few turtles from Odisha (Kumar 2015). The Movement of Bageshree into the open waters of the Arabian Sea and then to the Bay of Bengal resembles the movements of turtles from the Odisha coast (Kumar 2015), Central America (Plotkin 1995) and Bangladesh (Islam et al., 2016). It is the first such documentation of olive ridley turtles to move from Arabian sea to Bay of Bengal, though the nesting turtles from Bangladesh have been observed to move into the Arabian Sea post-breeding (Islam et al., 2012).

The areas off Karnataka and Kerala coast fall in the Malabar Upwelling Zone (Bakun 1998), where most turtles from this study had a spatial overlap and slowed their movements. This area has high productivity due to regional upwelling during the southwest monsoon months (Bakun 1998), and turtles from the Maharashtra coast might be using it as a foraging area. Sea turtles from different nesting populations has been documented to utilise same foraging area in different ocean basins (Eckert et al., 1999). The turtles from Bangladesh and Sri Lanka are also reported to use continental shelf of west coast (Sivakumar et al., 2010; Islam et al., 2016), likely for foraging. Interestingly, the turtles tagged in this study did not move into foraging areas of turtles from the Oman coast that fall in upwelling zones of the Persian Gulf mouth and Omani coast (Rees et al., 2012). Sea turtles movements are known to be associated with oceanic currents in many cases (Luschi et al., 2003) and this could also be true for Maharashtra turtles. The West Indian Coastal Current (WICC) that flows southwards from June till November (Shetye and Shenoi, 1988; Chaudhuri et al., 2020) is possibly a deciding factor in determining the southern movements of turtles. This south moving current and the movement of the turtles were synchronised and interestingly, the movement of turtle Bageshree to Bay of Bengal through southern Sri Lankan waters exactly followed the path of current. The effect of oceanic currents on movements of turtles will be explored for statistical inferences in the future.

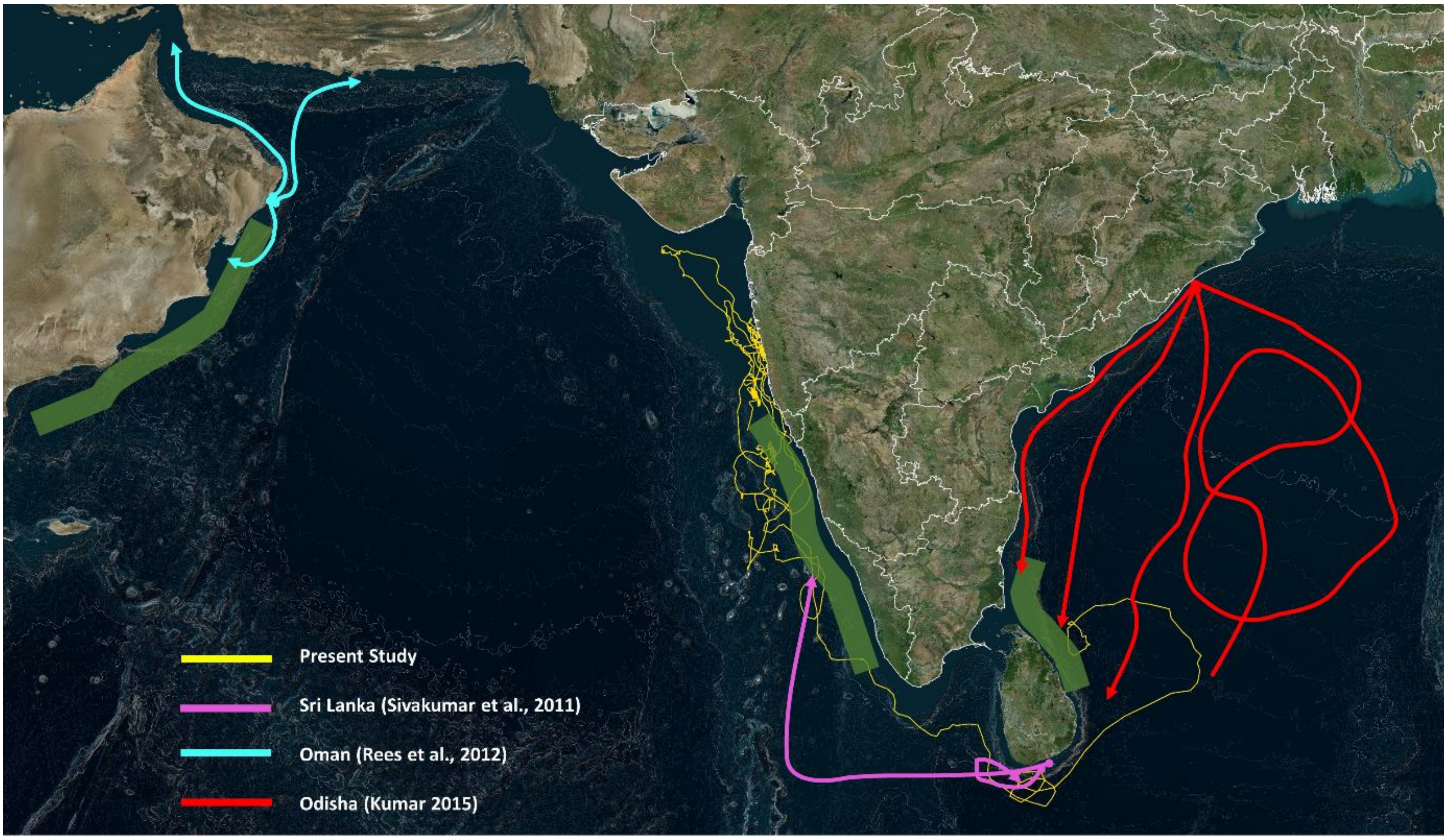


Figure 11: Movement of turtles from this study and patterns of olive ridley turtles from other regions. The movement of turtles shows use of green shaded areas that are the seasonal upwelling zones are highly productive and are the foraging areas of the turtles.

In this study, it is interesting to note that the tagged turtles limited their movements to up to the shelf edge and did not venture further offshore into the pelagic waters of the Arabian sea. This is unlike the movements of the arribada nesting populations of Odisha (Kumar,2016), and eastern tropical pacific (Plotkin 1995). Such restriction to shelf has been documented in olive ridley turtles before but only for the solitary nesting population from Oman (Rees et al., 2012) and North Australia (Whiting et al., 2007). The avoidance of the deeper waters of Arabian sea by the turtles of Oman and West coast of India is likely due to two factors. Firstly, the Arabian Sea is the world's largest oxygen-minimum zone zone (Morrison et al., 1998), and the resources in the open waters are low for the sustenance of turtles. Secondly, the continental shelf regions along the Eastern and

North-Western Arabian Sea is known to harbour high productivity due to seasonal upwelling (Bakun 1998) and turtles move to these areas to exploit the high prey abundance. Since the turtles were tracked for a limited duration, it will be much more interesting to observe where the turtles move during the time of years when there is no upwelling in these areas.

The diving behaviour observed during this study provide novel information for the olive ridley sea turtles of India. Since the olive ridley sea turtles from different populations occupy various habitat, a difference in the dive patterns is observed for turtles from different habitats. Studies from populations that only occupy continental shelf show dives that are restricted by the depth of sea floor (Chambault et al., 2016; McMahon et al., 2007; Rees et al., 2021). Since the turtles in this study displayed movement into different habitats, significant differences in the dive parameters were observed between the turtles. The diving depth of the turtles in this study during the period when they moved on the continental shelf showed restriction due to the floor depth and turtles were observed to perform more U-shaped dives. This pattern is observed for the turtles from North Atlantic (Chambault et al., 2016), Oman (Rees et al., 2021) and Australian (McMahon et al., 2007) populations. On contrary, when the turtles moved into deeper areas of shelf break and open ocean, the diving patterns were observed to change with turtles performing much deeper dives and a diel pattern in the diving depth was observed. Turtles from Eastern Tropical Pacific populations that were caught in the open ocean showed differences in the dive depths during day and night (Parker et al., 2003; Swimmer et al., 2006) while in north Atlantic Ocean turtles show slight but significant diel pattern (Plot et al., 2015). The turtles performing deeper dives in the day and shallower dives in the night is possibly due to the vertical migration pattern of the prey and a similar pattern have been reported for Leatherback turtles (Hays et al., 2004).

This study, though with a small sample size, provides crucial details regarding the habitat use in nearshore areas and the post-breeding movement of olive ridley turtles nesting along the Maharashtra coast. Further effort to track more turtles is required from Maharashtra and elsewhere on the West Coast to better understand the habitat use of olive ridley turtles from the region. It is also suggested that the turtles be tracked from the beginning of the nesting season to capture movements during the whole breeding phase. This will enrich our knowledge about turtle movements and critical areas where they reside. Overall, this would help create awareness among the fishermen on the turtle's presence, which will eventually reduce the incidental capture and mortality of turtles in the breeding areas.

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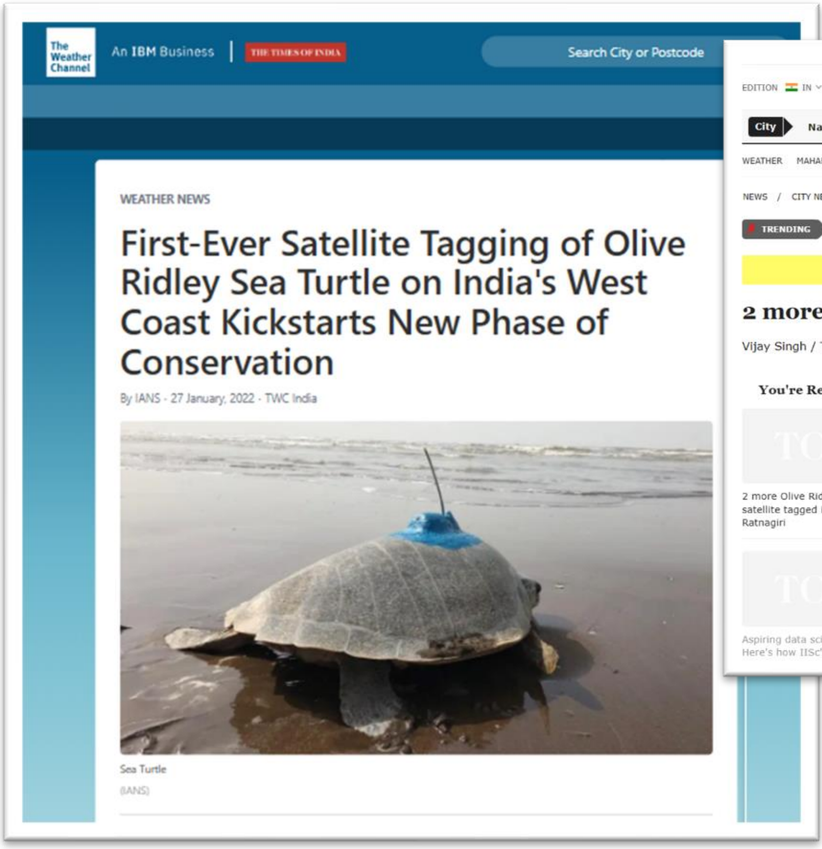
Appendix-I: News reports on Maharashtra turtle tagging



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First-Ever Satellite Tagging of Olive Ridley Sea Turtle on India's West Coast Kickstarts New Phase of Conservation

By IANS - 27 January, 2022 - TWC India

Sea Turtle

(IANS)

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THIS STORY IS FROM FEBRUARY 23, 2023

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Vijay Singh / TNN / Updated: Feb 23, 2023, 09:19 IST

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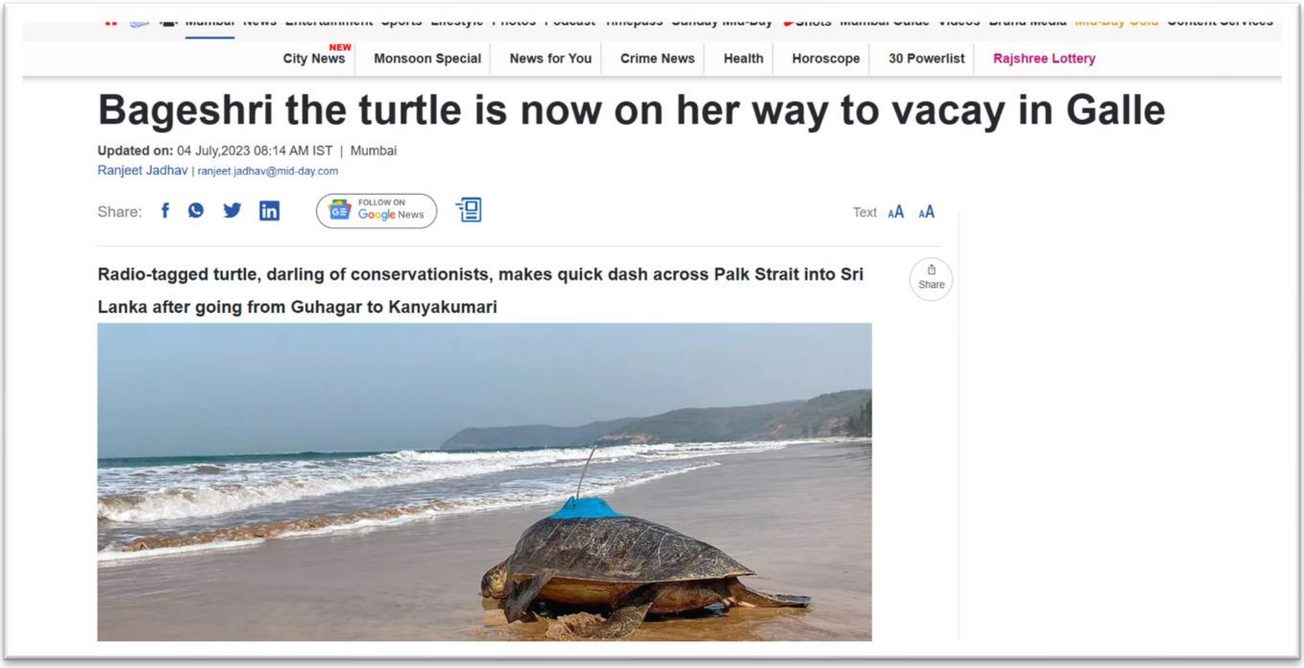

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Bageshri the turtle is now on her way to vacay in Galle

Updated on: 04 July,2023 08:14 AM IST | Mumbai

Ranjeet Jadhav | ranjeet.jadhav@mid-day.com

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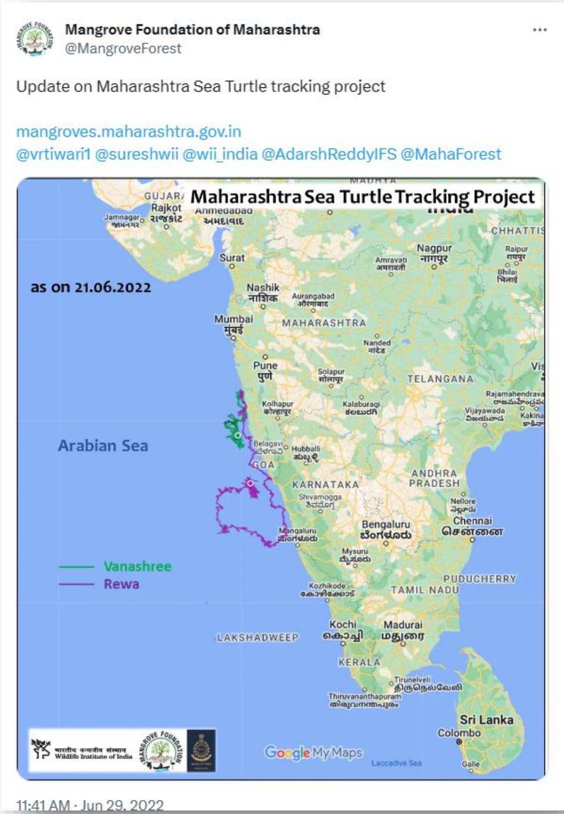
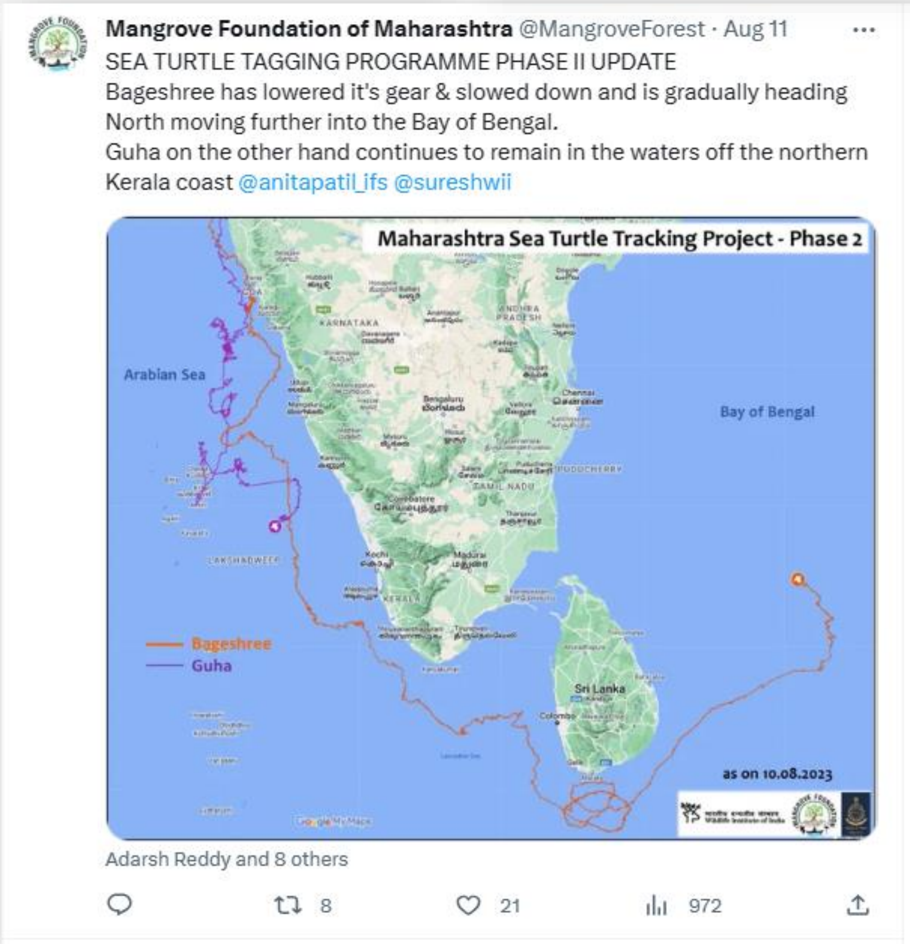
Radio-tagged turtle, darling of conservationists, makes quick dash across Palk Strait into Sri Lanka after going from Guhagar to Kanyakumari

Appendix-II: Weekly updated to public through social media





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Cover page modified from photo by Harshal Karwe
Page 1: Arribada nesting- Mohit M Mudliar
Page 3: Olive ridley turtle- Mohit M Mudliar
Page 7: Velas, Anjarle: Dinayar Hathikhanawala; Guhagar: Mohit Mudliar
Page 8: Solitary nesting turtle from Guhagar: Nidhi Mhatre
Page 9: Satellite transmitters- Mohit M Mudliar
Page 11: Equipment- Dinayar Hathikhanawala
Page 12-13: Tagging Activities: Mangrove foundation, Dinayar Hathikhanawala, Harshal Karwe
Page 14: Swastik Ganpat Gawde
Page 15: Renesting turtle- Mangrove Foundation; Renesting attempts- Mohan Upadhyay
Page 23: Olive ridley underwater- Dhritiman Mukherjee
Page 43: Tagged turtle- Dinayar Hathikhanawala

Contact Details

Dr. R. Suresh Kumar
Department of Endangered Species Management
Wildlife Institute of India, Post Box # 18, Chandrabani
Dehradun-248 001, Uttarakhand, India
Website: wii.gov.in, **Email**: suresh@wii.gov.in