Applications of satellite derived meso-scale features and *in-situ* bycatch to understand sea turtle habitats along the Indian Coast

Sea turtles in Indian waters are impacted by incidental catch in fisheries, coastal development, habitat loss and depredation of eggs[1]. Incidental catch in fishing gear is considered to be one of the major factors responsible for declining population of sea turtles and other marine megafauna[2,3]. Turtles are particularly vulnerable to entanglement and drowning in gillnets and associated gears, as the rough skin on their head and flippers catches easily on the meshes of these nets[4,5]. Incidental bycatch of sea turtles at a hooking rate of 0.108 for every 1000 hooks during the exploratory tuna longlining was carried out by the Fishery Survey of India in the Indian Exclusive Economic Zone (EEZ) during 2005–2008. Maximum hooking rate of 0.302% of 1000 hooks was reported from the Bay of Bengal[6]. It is observed that the biological and physical oceanographic processes are closely coupled at some locations of oceans, indicating an enhanced production where fishery resources accumulate for foraging. Remotely sensed data on chlorophyll-*a* concentration (CC) and sea-surface temperature (SST) has been used in India for identifying meso-scales features like eddies, fronts, rings for potential fishing zones (PFZs) forecast[7,8]. In this study, we used CC, SST and sea-surface height anomaly (SSHa) derived from space-borne data to correlate the reported instances of sea turtle interactions in the tuna longline fishery for identification of areas with high risk of sea turtle bycatch.

Figure 1 shows the area of study. Datasets and their sources included in the study are listed in Table 1. Data on the sea turtle bycatch in the experimental longline fishing targeting yellowfin tuna conducted onboard four tuna longline research vessels of Fishery Survey of India namely *Yellow fin*, *Matsya Vrushti*, *Matsya Drushti* and *Blue Marlin* during 2005–2008 were used to estimate the bycatch rate in long line. Sea turtles were incidentally caught in the long line gear either by entangling in the ganglion and float line or are hooked in the mouth. Abundance index is expressed in terms of hooking rate (HR), the number of turtles caught per 1000 hooks.

Weekly IRS-Ocean Colour Monitor images were corrected for atmospheric effects[9], and CC computation was carried out using OC_2 algorithm[10], then resampled to 4 km for comparison with SST and SSHa images. OSCAR (Ocean Surface Current Analysis–Real time) which is a 5-day modelled product[11] derived using quasi-linear and steady flow momentum equations has also been used for the study.

Maximum rates of turtle bycatch in the exploratory long line were observed along the Orissa coast in the Bay of Bengal. The pattern of seasonal variability in satellite derived SSHa, SST and CC and oceanic features was studied in the context with sea turtle incidental catches. Meso-scale oceanographic features within the geographic range covered by turtles were most intense in off Orissa/Andhra coast.

Turtle bycatch per 1000 hooks is higher in east coast as compared to the west coast which can be explained by the existence of mass nesting sites along the east coast (Table 2). In terms of oceanographic variables, there is a discernable difference in CC for both coasts. Similar is in the case of SSHa but there is less observed variation in SST values for both coasts.

Satellite derived SSHa, SST, CC and wind/current data are important in defining sea turtle habitat. The images derived from multi satellite sensor show the bycatch points along the productive edges of eddy (Figure 2) and frontal features (Figure 3). The bycatch points were found associated with meso-scale oceanographic features observed in satellite derived chlorophyll, SST and SSHa (Figures 2 and 3). OSCAR-generated surface current vectors indicate their locational influence on turtle bycatch. Also, the bycatch locations are along the current direction. In case of Figure 2 bycatch points are distributed around the boundary zone of nutrient-rich cyclonic eddy's cold core. Species caught in these areas are olive ridley (*Lepidochelys olivacea*) and green (*Chelonia mydas*) turtles. Planktons are patchily distributed in the oceans, although certain factors may lead to elevated levels of productivity at meso-scales (tens of kilometers), including the presence of oceanographic features such as rings, eddies and fronts[12]. These features essentially persist for longer durations. Oceanographic conditions may vary in different ocean basins and sometimes meso-scale features may move/swift and dissipate fast. However, the relatively static nature of mesoscale features in oceans suggests that sea turtles and many fishes like tuna, sharks targeting these features for foraging at oceanic features[13,14]. Meso-scale

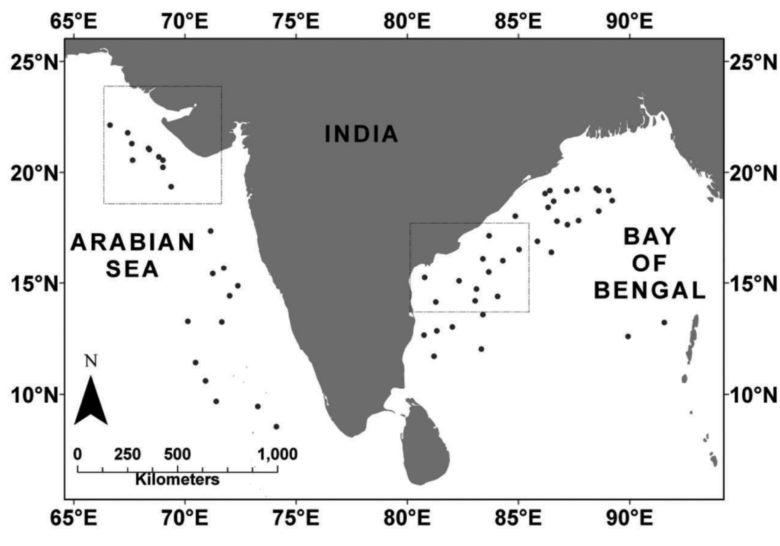

Figure 1. Map showing the study area and locations of sea turtle bycatch during 2005–2008. Two boxes indicate the area selected for analysis.

Table 1. Data sources for the study

Environmental parameter	Data source	Resolution
Sea turtle bycatch data	Fishery Survey of India	Geolocation of bycatch
Chlorophyll-*a* (Chl-*a*) concentration	OCM and OCM 2	Resampled to 4 km
Sea-surface temperature (SST)	MODIS Aqua 8 day Level-3 product from Oceancolor Portal	4 km
Sea-surface height anomaly (SSHa)	Jason-1 level 2 cycles from PODAAC ftp data portal	1/16th of degree with loess interpolation
Sea-surface current vectors	Ocean Surface Current Analysis–Real time (OSCAR)	1/3rd of degree
Sea turtle nesting grounds	WWF-India published report	Geolocation of nesting sites
Fishing vessels type	Handbook of Fisheries Statistics 2011, Ministry of Agriculture	State level datasets

Table 2. Basic statistics of bycatch along with satellite-derived oceanographic variables

	Mean (± SD)	CI (95%)	*n*
West Coast (Arabian Sea)			
Turtles per 1000 hooks	2.13 (± 0.83)	0.38	21
SST	28.33 (± 1.03)	0.46	21
Chl-*a*	0.25 (± 0.13)	0.08	21
SSHa	18.41 (± 4.9)	2.23	13
East Coast (Bay of Bengal)			
Turtles per 1000 hooks	2.94 (± 0.46)	1.18	19
SST	28.53 (± 0.88)	0.42	19
Chl-*a*	0.13 (± 0.04)	0.02	12
SSHa	16.99 (± 8.05)	3.88	19

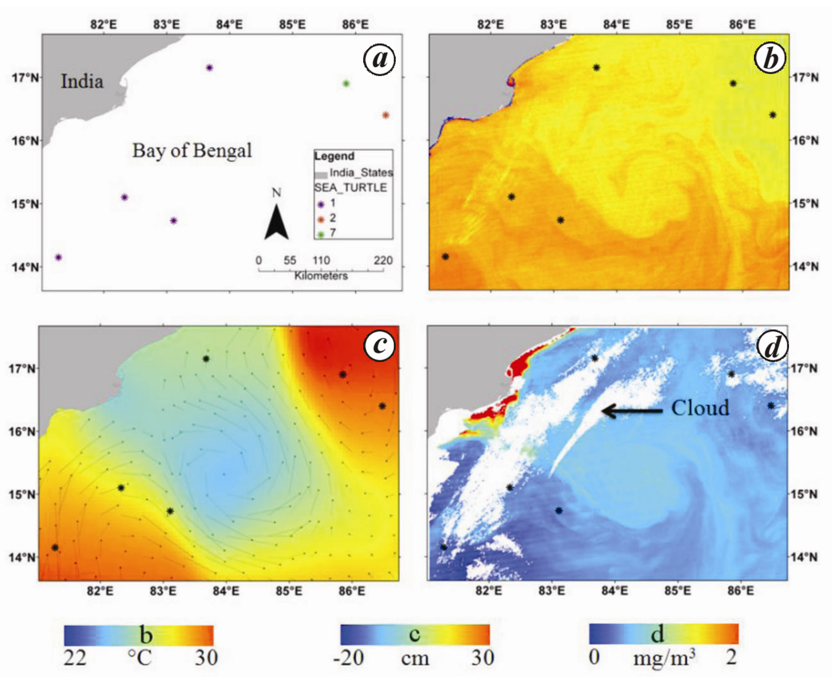

Figure 2. Distribution of sea turtle bycatch (***a***) and their relationship with weekly satellite-derived SST (***b***), SSHa along with current vectors (***c***) and CC (***d***) from 9 to 18 February 2005, off Andhra coast. Most of the points are found in the vicinity of eddy feature.

oceanographic features support well-structured food chains and are selectively targeted by planktivorous animals like fishes and turtles[15].

The oceanic circulation is responsible for differential distributions of food resources in the ocean, determining the distribution of planktonic primary producers. In particular, eddies may concentrate nutrients and organisms, and thus represent patches of high prey abundance targeted by foraging turtles. The foraging movements are related to specific oceanographic elements such as meso-scale eddies, convergence or upwelling areas, which concentrate the macro planktonic resources on which fishes, arthropods and other animals feed. The turtles also take advantage of the profitable foraging opportunities offered by these features, often remaining associated with them for prolonged periods. Hence, due to their foraging habitat preferences, they are encountered during tuna long line fishing operations. The locations of bycatch points in and around meso-scale feature are clearly indicative of importance of meso-scale features, (the hotspots), the spatial distribution of their prey where turtles target foraging. The areas of highest bycatch should be avoided for fishing operations.

It appears that bycatch is more concentrated along meso-scale features like eddies, fronts which are foraging grounds and in the migrations route of turtle for nesting along the coast as well as revisit to sea. It appears that meso-scale features are common foraging ground of sea turtles and tuna, thus competing for feeding the same areas.

Figure 4 shows the bycatch point concentrations with reference to surveyed turtle nesting site density and types of fishing gear along the East coast of India. There is a higher turtle bycatch density off Orissa coast which is supported by a higher density of turtle nesting sites. Similarly there is also a higher concentration of bycatch off Tamil Nadu coast. Also both these areas have a higher density of nesting sites, thus indicating the frequency of turtles in the coastal areas. When these results are analysed along with types of fishing crafts, it reveals that both the areas have a higher share of motorized and mechanical crafts as

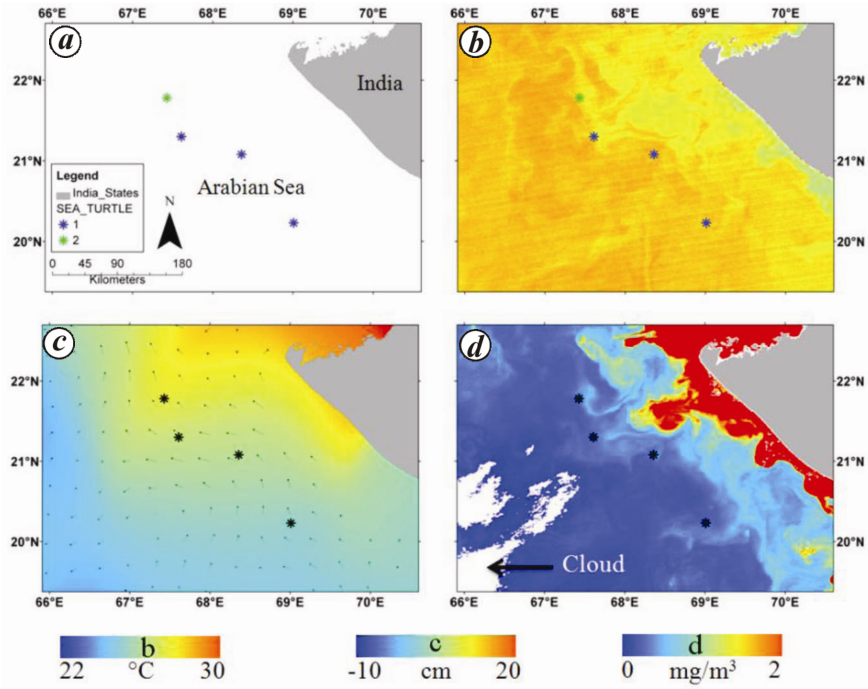

Figure 3. Distribution of sea turtle bycatch (***a***) and their relationship with weekly satellite-derived SST (***b***), SSHa along with current vectors (***c***) and CC (***d***) for 18–26 November 2007, off Gujarat coast. Points of the bycatch are near the front features.

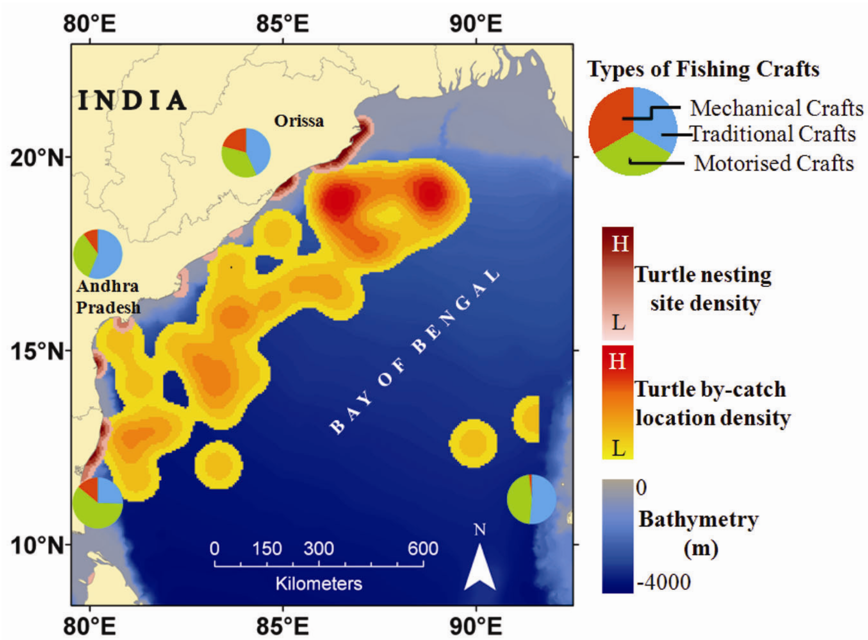

Figure 4. Concentration of bycatch points with respect to turtle nesting sites and state-wise share of types of fishing crafts operated along East Coast.

compared to traditional crafts. Thus these results make it more crucial to understand turtle habitat both in their foraging grounds and nearer to the coasts where they revisit.

Figure 5 depicts distribution of the number of bycatch location with respect to the three considered variables. In case of SST, there is a wide range in which turtles are observed (26–31°C), of this the higher frequency is between 28°C and 29°C. In case of CC it is observed that in the range of 0.1–0.5 mg m^{-3} there is exceptionally high frequency as compared to other bins, most of the bycatch

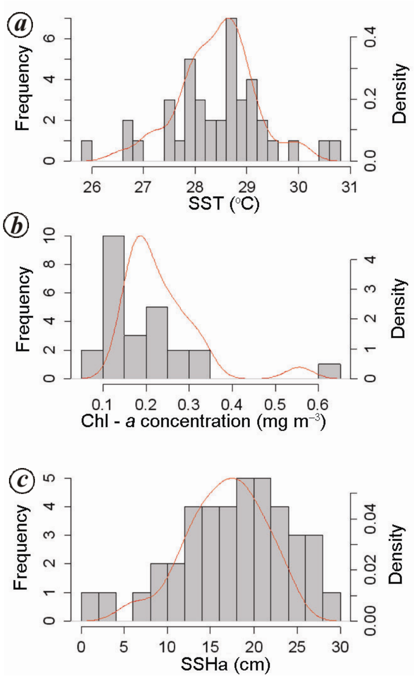

Figure 5. Histogram (grey bars) and density (red line) plots showing distribution of number of bycatch points with SST (***a***), CC (***b***) and SSHa (***c***).

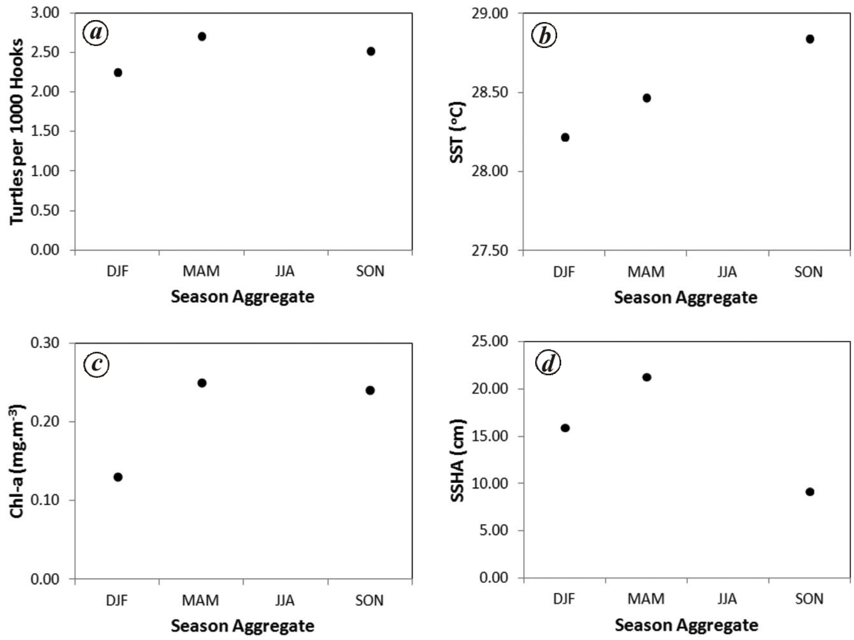

Figure 6. Seasonal pattern of bycatch (***a***) along with averaged SST (***b***), CC (***c***) and SSHa (***d***). Here, months are aggregated as December–January–February (DJF), March–April–May (MAM), June–July–August (JJA) and September–October–November (SON).

locations have chl-*a* values < 0.35 mg m^{-3} except for one (0.6 mg m^{-3}). SSHa shows a continuous distribution in the 0–30 cm range. Higher number of bycatch points occurs in the 15–25 cm range with peak at 18–22 cm range. Identified peaks are preferred ranges for respective parameters.

Figure 6 shows the mean bycatch per 1000 hooks, SST, CC and SSHa during seasonal trend. The period from June to August has been eliminated from the study due to persistent cloudy condition. Relation of seasonal triads of bycatch reveals that there is a comparatively higher bycatch recorded in March to May also higher CC and moderate temperature and higher SSHa values. These months also correspond to time where shores have higher turtle movements due to nesting activities[16]. In December to February, which are winter months, it is observed that there is a slight lower mean bycatch as compared to other months. Bycatch points recorded were in lower CC areas having lower SST.

Remote sensing enables detection of sea turtle foraging grounds. Maximum percentage of bycatch was observed off Orissa coast in the Bay of Bengal. More turtle bycatch was observed in the vicinity of features like eddies, fronts. It appeared that tuna and sea turtles are competing for food in the same forging ground. Hence, turtles are encountered in tuna long line fishing operations. Turtle telemetry data along with remote sensing data are suggested for defining residency and seasonal migration routes of sea turtles and can be avoided for fishing operations.

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DHYEY BHATPURIA[1]
H. U. SOLANKI[1,*]
SIJO VARGHESE[2]
PRAKASH CHAUHAN[1]

[1]*Space Applications Centre, ISRO, Ahmedabad 380 015, India*
[2]*Fishery Survey of India, Kochi 682 005, India*
**For correspondence.*
e-mail: himmatsinh@sac.isro.gov.in