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Towards reducing the data gap in the conservation efforts for sea turtles in Bangladesh

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ABSTRACT

Despite having 3 of the 11 most endangered Regional Management Units (RMUs) of sea turtles globally, the Bay of Bengal in the South of Bangladesh is undergoing construction of a regional marine road network and tourism infrastructure to boost connectivity and stimulate the economy. Policy makers in developing countries like Bangladesh often face difficulty in prioritizing conservation efforts due to lack of reliable data. In the case of the endangered sea turtles, there is a gap in sea turtle nesting and hatchling data inventory. Therefore, this study presents a comprehensive dataset of all recorded sea turtle nesting, hatchlings, death and habitats, derived by reviewing past literature of Bangladesh. This led to identifying the environmental features that influence turtle nesting behavior based on field surveys. Our results suggest that sea turtles prefer nesting on elevated, broader beaches which are closer to vegetation and away from anthropogenic structures. The beach profile survey shows that more than half of the beaches suffer from anthropogenic disturbances. Satellite image analysis of the study area over the past 30 years revealed a declining trend of beach area after 2008. The beach area has been reduced from 19.44 km^2 (1989) to 14.92 km^2 (2018) eventually leading to beach width depletion. The results derived from this study can contribute in identifying the most degraded beaches where ecosystem restoration is urgent, as well as, recommending coastal specific policies and guidelines for protecting endangered sea turtle populations.

1. Introduction

In the age of Anthropocene, human activities have profound impacts on the functioning of earth systems; altering the biogeochemical cycles, atmospheric composition, land use, natural resource reserves and biodiversity distribution (Steffen et al., 2015; Chapin Iii et al., 2000). This increasing rate of anthropogenic disturbances over the past 10,000 years have especially altered the diversity of life forms on this planet (Schipper et al., 2008; Hoffmann et al., 2010) instigating the sixth major extinction in the history of civilization (Chapin Iii et al., 2000). Biodiversity change is being considered a global phenomenon (Sala et al., 2000) and hence many conservation efforts have been underway focusing mostly on the terrestrial ecosystems. In contrast, the marine domain harbors a much more diverse range of species and habitats, although commensurate conservation efforts are yet to be undertaken. Thus, the marine environment is not as well researched (Broderick, 2015).

According to a study of the marine fauna, sea turtles face the highest threat of defaunation (McCauley et al., 2015). In conservation biology, sea turtles are emblematic keystone species spread over the tropical and subtropical belt, covering diverse habitats throughout their lifecycle. They play a significant role in the marine ecosystem, especially the coral ecosystem but are currently threatened by the growing influence of land use change, pollution and global warming (Kelly et al., 2017) with a declining population worldwide (Razaghian et al., 2019). IUCN red list categorizes sea turtles as follows: critically endangered (*Eretmochelys imbricata*, *Lepidochelys kempii*) (Mortimer and Donnelly, 2008; Wibbels and Bevan, 2019) endangered (*Chelonia mydas*) (Mancini et al., 2019), vulnerable (*Lepidochelys olivacea*, *Dermochelys coriacea, Caretta caretta*) (Abreu-Grobois and Plotkin, 2008; Wallace et al., 2013; Nel and Casale, 2015) and data deficient (*Natator depressus*) (Red List Standards & Petitions Subcommittee, 1996). This global assessment, however, does not comprehensively reflect the national and regional status of sea turtles. To overcome this challenge, IUCN Marine Turtle Specialist Group (MTSG) has generated a novel model, the Regional Management Unit (RMU), based on biological and remote sensing telemetry data on a national scale for all seven species of marine turtles (Tanzer et al.,

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2017; Wallace et al., 2010). 58 RMUs were identified, where 19 were labeled to be in the highest state of threat i.e. "High Risk-High Threats". Among these 19 RMUs, 11 came under the national boundary. These 11 RMUs contain the highest threatened marine turtle population, requiring the most immediate conservation action. In the regional frame, 5 of the 11 most endangered RMUs reside in the Indian Ocean, which also happen to have the highest average score of data uncertainty for both threats and risks (Wallace et al., 2011). Bangladesh is part of a larger marine ecosystem and its waters have 3 of the 11 most endangered RMUs:

1. North-East Indian Ocean- *L. olivacea* (arribada) - threatened
2. North-East Indian Ocean- *L. olivacea* - threatened
3. North-East Indian Ocean- *E. imbricata* - critically endangered.

One of the key objectives of this study is to compile all published records on nesting sea turtles and hatchlings, as well as their mortality rates in Bangladesh. As part of Bay of Bengal Large Marine Ecosystem (BOBLME), Bangladesh boasts a wide-ranging marine ecosystem to its south containing extensive aqua region and rich biodiversity (Mukul et al., 2008). However, it lacks data on marine characteristics and productivity, with no comprehensive inventory on the geomorphic and physio-chemical attributes of the coastal ecosystem (Islam, 2003). Furthermore, the marine areas adjacent to Bangladesh, Myanmar, Sri Lanka and India (BOBLME) are home to the world's most endangered sea turtles. Among them; populations of the three species of marine turtles which frequent the marine area and shoreline of Bangladesh for nesting, namely; *L. olivacea* (Olive ridley), *C. mydas* (Green sea turtle) and *E. imbricata* (Hawksbill turtle). Olive ridley turtles are the most commonly present species of sea-turtle in Bangladesh (Islam, 2002b).

In order to preserve the habitat of threatened sea turtle population, habitat identification is a major priority. It is also important to have a comprehensive database of sea turtle nesting sites as well as identifying sub-adult and adult numbers (YalçınÖzdilek et al., 2018). However, road construction has a notable footprint on the landscape ecosystem including fragmentation and sediment compaction (Li et al., 2004). Coastal tourism and development, starting globally in the 19th century has caused habitat isolation and biodiversity loss (Davenport and Davenport, 2006). In an effort to exhibit the recreational prospects of one of the largest sandy beaches of the world, the Bangladesh government has constructed an 80 km long stretch of road along the beach from Cox's Bazar (Kalatali) to Teknaf (Rahaman and Rahman, 2013) in 2017. In spite of having a parallel highway road (Teknaf-Shahparirdwip (Z1009)), this marine driveway (part of Mirsharai-Teknaf Marine Drive road project) has been built in order to connect a broader regional network covering Myanmar, China and India (Asian highway network) (Sabrang, 2016; Urban Development Directorate, 2017). The construction of this road has an immense impact on the beach ecosystem and the sea turtle habitats and has led to significant changes in the beach area due to enhanced human access and presence in these areas of interest. Due to the increased accessibility provided by this road, the areas and beaches adjacent to this road have experienced a surge of human presence, vehicles, speed boats, jet skis, debris, litter, construction of resorts, hotels and tourist amenities. Furthermore, different structures like geo-textile bags, concrete blocks and boulders were placed to preserve the integrity of the road structure from beach erosion, tidal surges and cyclones. Not only do these elements have impacts on beach morphology, but also created other ways of disturbing the marine ecology (Mahamud and Takewaka, 2018).

To understand these impacts, we analyzed multispectral satellite data spanning over 30 years to observe changes in beach area and conducted field surveys to develop a beach profile. Identification of future nesting sites and habitats is essential to engineering an effective plan to conserve the endangered turtle species (Kelly et al., 2017). We explored the environmental factors that are associated with nesting (n = 6) and non-nesting sites (n = 27) from 33 different beaches using a decision tree algorithm, a powerful tool for feature importance analysis to predict the areas that require the most attention for sea turtle nesting habitat. As such, this study will explore the characteristics of the nesting habitats of these species of turtles to gain a better understanding of the change they have undergone recently and how they can be preserved. Moreover, owing to the absence of a complete sea turtle inventory, we have compiled records by reviewing existing literature of sea turtle studies in Bangladesh. Therefore, this study mainly emphasizes on the impacts of construction of the marine drive on the beach ecosystem and highlights the historical land use changes that took place in the area. It also presents a compilation of records on sea turtles from existing literature, field survey and satellite data analysis in order to reduce the knowledge gap.

2. Materials and methods

A schematic of the methodology of this study has been illustrated below (Fig. 1). The methodology used in this study (Fig. 1) is classified into three categories based on the objectives. In the first part (Fig. 1(A)) the available literature on sea turtles of Bangladesh is reviewed, which yields the habitat, species and number of sea turtles nesting within the geographical boundary of Bangladesh. In the second part (Fig. 1(B)) a field survey of the most threatened sea turtle habitats in Bangladesh is conducted in order to find the pattern of nesting and the non-nesting pattern of sea turtles and current status of the beach profile. This part demonstrates how the machine learning technique using decision trees can be employed to classify nesting and non-nesting sites. Lastly, with the aid of satellite image analysis (Fig. 1(C)) the change of surveyed beach area from a historical perspective (1988–2018) is calculated.

2.1. Study area

For the compilation of records of past sea turtle nesting, habitats and hatchlings, the whole coastal boundary of Bangladesh is considered as the study area, stretching from the Sundarbans to Cox's bazar (Fig. 2(A)). Among all the habitats of sea turtle in Bangladesh, Cox's bazar coastline experienced the most amount of environmental degradation due to its booming tourism and regional road network construction, thus this area becomes an area of interest for marine biodiversity conservation. The study area considered for field survey and satellite image analysis is situated in the east coast of Bangladesh, in the administrative district of Cox's bazar which boasts the world's longest sandy beach (Dey et al., 2015), providing 140 km of nesting habitat for the threatened Olive Ridley and Green turtles. The study was conducted along the coast between Cox's bazar and Teknaf belt (21.38 N and 92.01 E to 20.85 N and 92.26 E) where 33 beach locations were surveyed covering 65 km (Fig. 2(B)). Here the nesting time of turtles primarily range from July to April and October to November (Islam, 2002a,b). A local NGO, Marine Life Alliance (Marine Life Alliance, 2016, 2019), employed citizen scientists and volunteers from local community to look after sea turtle nests.

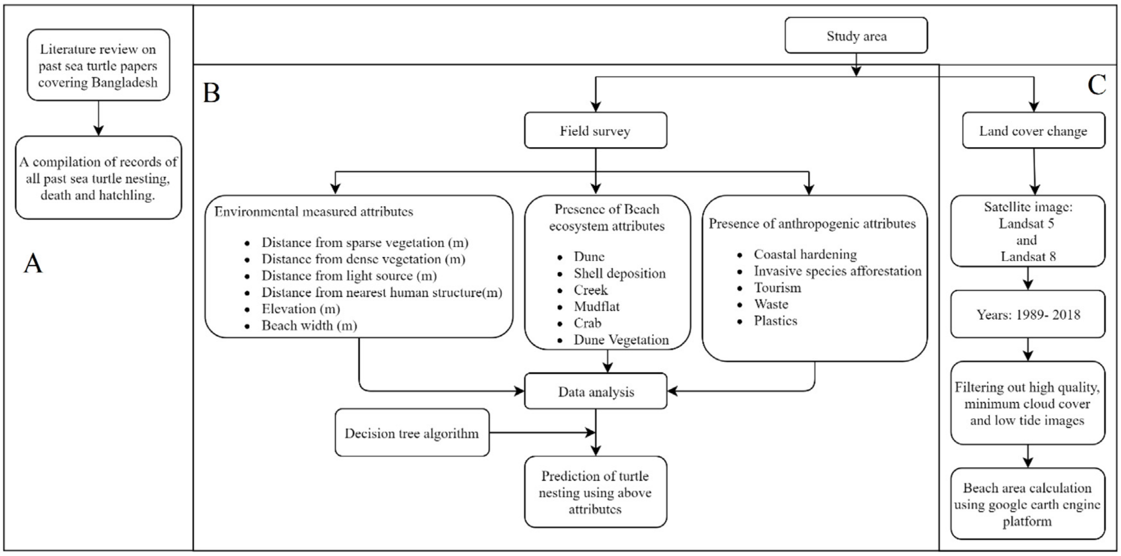


Fig. 1. Schematic of the whole methodological workflow.

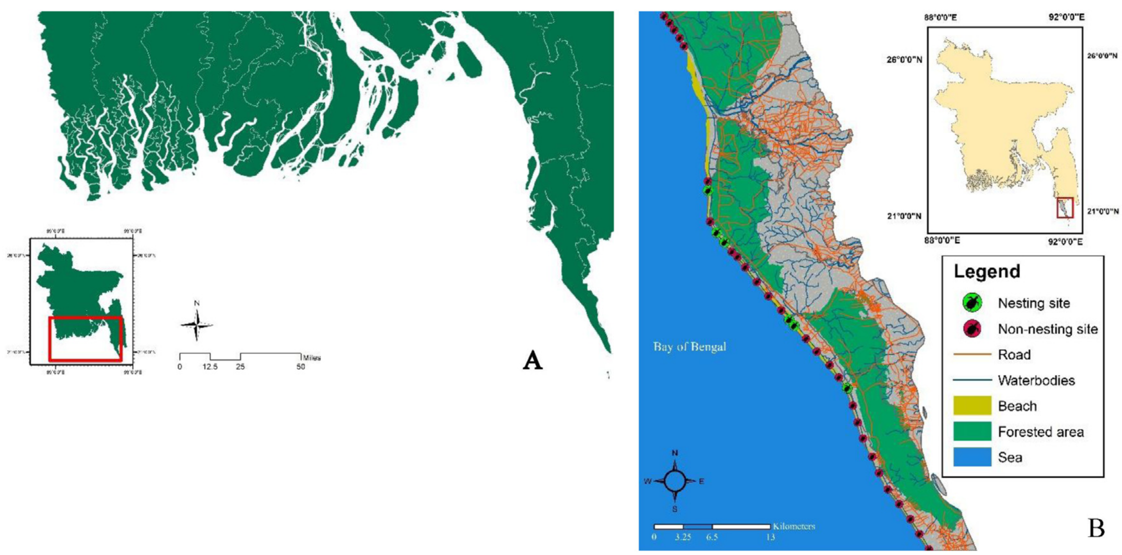


Fig. 2. Location of study area (A) considered for literature review and (B) considered for field survey, machine learning modeling and satellite image analysis.

2.2. Literature review for compilation of records of sea turtle from past studies

There are only a few published reports which attempted to present a database on sea turtle nesting in Bangladesh territory (Hossain et al., 2013; Marine Life Alliance, 2016). To reduce this data gap on sea turtles of Bangladesh, we have compiled a record of past sea turtle nesting, hatchlings, and deaths by going through existing studies (Supplementary Table 1, Supplementary Table 2 and Supplementary Table 3).

2.3. Data collection and measurements

The field survey was conducted during 2016 and 2017. A total of 33 transects were taken at an interval of 1 km (the intervals between transect 5–6 and 7–8 are large (more than 1 km) due to inaccessibility) as sample size for this study, covering 65 kilometers of the beach exploring the nesting locations (n = 6) (Supplementary Fig. 1(a)) and non-nesting locations (n = 27). The non-nesting sites are locations where turtles did not nest, thus these sites are naturally suitable for turtle nesting but no nesting was recorded in those locations during our survey. To identify the factors that influence turtle nesting for each beach site and the anthropogenic impacts on shores, three different features (Table 1) were used in the study: (i) environmental attributes following Roe et al. (2013); Kelly et al. (2017) and Serafini et al. (2009) which include; distance from sparse vegetation (DFSV) (m), distance from dense vegetation (DFDV) (m), distance from light source (DFLS) (m), distance from nearest anthropogenic structure (DFAS) (m), elevation (E) (m) and beach width (BW) (m). They were used for all 33 beaches. For non-nesting sites we measured the environmental attributes based on a point that is theoretically appropriate for turtle nesting on that beach. The acquired data from field survey were cross checked using the ArcMap platform. (ii) Beach ecosystem attributes (dune (D), shell deposition (SD), creek (C), mudflat (MF), crab, dune vegetation (DV)) and (iii) anthropogenic influence attributes (coastal hardening (CH), invasive species afforestation (ISA), tourism (T), waste (W) and plastics (P)). The features from the two attributes (beach ecosystem attributes and anthropogenic

Table 1
List of three different features surveyed in this study.

No	Feature	Unit	Description	Reference
	Environmental measured attributes			
1	Elevation	m	Height from the mean sea level	Roe et al. (2013)
2	Distance from sparse vegetation	m	Euclidean distances of the nest from the nearest sparse vegetation	Serafini et al. (2009)
3	Distance from dense vegetation	m	Euclidean distances of the nest from the nearest dense vegetation	Serafini et al. (2009)
4	Distance from nearest anthropogenic structure	m	Euclidean distances of the nest from the nearest anthropogenic structure.	Kelly et al. (2017)
5	Distance from light source	m	Euclidean distances of the nest from the nearest artificial light source	Kelly et al. (2017)
6	Beach width	m	Euclidean distances of the sand zone from sea level to vegetated zone	Serafini et al. (2009)
	Beach ecosystem attributes			
7	Dune presence	–	Presence or absence of dune	–
8	Shell deposition	–	Presence or absence of sea shells	–
9	Creek	–	Presence or absence of creek	–
10	Mudflat	–	Presence or absence of mudflat	–
11	Crab	–	Presence or absence of crab	–
12	Dune vegetation	–	Presence or absence of dune vegetation	–
	Anthropogenic attributes			
13	Coastal hardening	–	Presence or absence of sand bags, tetrapods and slabs to protect the road	–
14	Invasive species afforestation	–	Presence or absence of Jhau trees (*Casuarina equisetifolia*)	–
15	Tourism	–	Presence or absence of tourist and tourist facilities	–
16	Waste	–	Presence or absence of any kind of waste	–
17	Plastics	–	Presence or absence of plastics	–

influence attributes) were recorded as 0 for absence and 1 for presence (Supplementary Fig. 1)

2.4. Data analysis: The decision tree machine learning algorithm

Decision tree analysis refers to interpreting the trained tree for extracting information about the semantics between features and target/features. It is an efficient tool for ecological data analysis (De'ath and Fabricius, 2000). The decision tree (Breiman, 2017) is a predictive model where successive decisions in a binary tree result in making (predict) a final decision about the class/magnitude of a sample. Tree traversal occurs from the root node to a leaf node where the final decision is taken. The decision tree is trained on samples, where it uses a numeric metric at each iteration i.e. gini impurity, entropy or some other metric to assess the position of a split of a node. After a decision tree is trained, it can be used for predicting the class on new samples and visualized to quantify and understand the relationship between the features and the target/response. There has been a study on the application of decision trees for behavioral prediction of sea turtles (Nishizawa et al., 2013) but no study exists which uses a decision tree model for predicting if a location is suitable for nesting using spatial features.

The first application of the decision tree model has been done for land use classification (where the features are satellite image bands), the results of which can be used for temporal monitoring of beach area. For the second application of decision trees, the features were fields of the survey data on the 33 transects in the study area, the target/response being presence of turtle nesting sites. Analysis was performed to reveal the impact of these features on the presence of nesting sites. This study outlines a decision tree model based on the above mentioned 17 features (Table 1) (from 3 different attributes) in order to predict the locations where immediate actions are required to safeguard the nesting habitat of the sea turtle in the future. The decision tree model was trained and interpreted using the sklearn package (Pedregosa et al., 2011) in Python (Rossum, 1995).

2.5. Land cover mapping: Satellite image classification to investigate beach area change

The installation of coastal structures leads to the eviction of natural dynamics of a beach followed by disruption in natural processes like accretion and erosion patterns, eventually leading to beach width shortening (Roe et al., 2013). To understand the impacts of marine drive road construction and the coastal hardening process, we investigated 30 years (1989–2018) of satellite images through Google Earth Engine platform to monitor beach shortening events using the decision tree as a land use classification algorithm.

The decision tree is a popular algorithm for performing land cover classification (Friedl and Brodley, 1997; Friedl et al., 1999; Hansen et al., 2000; Pal and Mather, 2003). Satellite images capture electromagnetic radiation signatures from the Earth's surface in discrete intervals known as 'bands'. These bands have been used as the features of the decision tree being employed for land use classification (Table 2). The cloud cover of the utilized satellite image scenes was close to 0% (mean cloud cover of 0.01%), while image quality of most images was 90% (Supplementary Table 4). Since shoreline area changes with tide, we opted to take the low tide images for the selected years (Table 2). Satellite image collection, preprocessing and classification were performed using the Google Earth Engine platform (Google earth engine is a planetary scale geo-processing platform. Datasets can be extracted, computed on and manipulated using application programming interface (API) via a programming language, python and java script (https://earthengine.google.com/)) (Gorelick et al., 2017). Maps were generated using ArcMap 10.2.

3. Results and discussion

3.1. Compilation of records of sea turtles from past studies

As mentioned earlier, proper identification of sea turtle habitats and a reliable dataset of sea turtle nesting sites help understand population size and trends over time, and where to focus conservation efforts. Thus, based on the review of past studies, we show the details of individual numbers of sea turtles and their nesting habitats (Fig. 3). In terms of number, Olive ridely (*L. olivacea*) occurs the most, in nesting, hatchlings and death statistics. Green turtle (*C. mydas*) is the second highest with respect to nesting. There have been recordings of Hawksbill in the years from 1997 to 2001, but no data for subsequent years. Although the remains of Leatherback and Loggerhead have been spotted on several occasions, there is no nesting data currently available. The highest magnitude of nesting has been observed to occur at the Southernmost part of Bangladesh; Saint Martin's Island and the Cox's bazar belt (Bordal, Inani, Sonadia islands,

Table 2
The satellite image bands used in this study.

Satellite	Years	Sensor	Path/ Row	Spatial resolution	Feature/Band
Landsat-5	1989, 1994, 1997, 2001, 2003, 2006, 2009,2010	Thematic Mapper (TM)	136/45	30 m	Blue
					Green
					Red
					Near Infrared (NIR)
					Shortwave Infrared (SWIR) 1
					Thermal
					Shortwave Infrared (SWIR) 2
Landsat-8	2016, 2017, 2018	Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS)	136/45	30 m	Ultra blue (coastal/aerosol)
					Blue
					Green
					Red
					Near Infrared (NIR)
					Shortwave Infrared (SWIR) 1
					Shortwave Infrared (SWIR) 2
					Panchromatic
					Cirrus
					Thermal Infrared (TIRS) 1
					Thermal Infrared (TIRS) 2

Teknaf, Monakhali and Moheshkhali) and other locations from South Western region viz. Kochopia, Sandweep, Dubla Island, Egg islands Sundarbans (Supplementary Table 1, Supplementary Table 2 and Supplementary Table 3).

3.2. Field data analyses

This section discusses the data analysis of 33 line transects collected through field survey. Descriptive statistics were utilized to compare environmental measured attributes between nesting sites and non-nesting sites. In Fig. 4, it can be observed that turtles dug nests in locations of the shore closer to vegetation. The same observation was made in previous studies (Pazira et al., 2016; Kelly et al., 2017; Karavas et al., 2005; Chen et al., 2007; Serafini et al., 2009; Turkozan et al., 2011; Hart et al., 2014; Katselidis et al., 2014). Turtles seem to prefer elevated broader beaches since nesting was seen to be concentrated on beaches of width between 80 m and 156 m (mean = 113.167 m). The reason for this preference is that, areas with lower elevation and beach width have higher risk of flooding (Roe et al., 2013) but it is more vulnerable to predation risk to hatchlings. Unlike distance from vegetation, distance from artificial light source has a negative relationship with turtle nesting i.e. turtles were seen to nest in locations where distance from light source was in the interval of 100 m to 294 m. This result concurs with previous studies (Witherington, 1992; Kamrowski et al., 2012; Mazor et al., 2013). A similar trend is also seen in case of coastal structures. Turtle nesting was more concentrated further away from anthropogenic structures and in beaches with less coastal hardening, as was observed in preceding studies exploring coastal development and turtle nesting (Weishampel et al., 2003; Roe et al., 2013; Kaska et al., 2010). Turtle nesting is more likely to happen at locations in the presence of dunes and less coastal hardening (Table 3).

Our analysis shows that tourism and road network are likely to place immense pressure on the natural structure of the beach. We identified 6 beach ecosystem attributes (7–12, Table 1) and 5 anthropogenic attributes (13–17, Table 1) and then analyzed their presence in the surveyed transects. Dunes were present in 63.63% of beaches while dune vegetation was present in 39.39%. Mudflat, a noteworthy biota for harboring biodiversity was present in 33.3% of beaches. Shell deposition is known to play a significant role in beach sand composition and was observed in 45.45% of beaches. Coastal hardening structures like slabs, tetrapods and sea bags were noticed in more than one third of the surveyed beaches. Invasive species afforestation, mainly Jhau (*Casuarina equisetifolia*), affecting the growth of dune vegetation was in more than two thirds of the beaches. Presence of waste, tourism and plastics is seen to have a significant footprint. The magnitude of impacts of coastal hardening on sea turtle nesting and beach ecosystem is incorporated in Table 3(the entire collected dataset is shown in Supplementary Table 5).

Table 3
Presence of beach ecosystem and anthropogenic attributes from the 33 surveyed beaches.

Attributes	Overall (%)	Nesting site (%)	Non-nesting site (%)
Dune	63.63	100	55.56
Shell deposition	45.45	33.33	48.15
Creek	66.67	66.66	66.67
Mudflat	33.33	16.67	37.03
Crab	54.54	50	55.56
Dune vegetation	39.39	83.33	29.63
Coastal hardening	39.39	16.67	44.44
Invasive species afforestation	69.69	50	74.07
Tourism	51.51	33.33	55.56
Waste	69.69	66.67	70.37
Plastics	42.42	50	40.74

3.3. Turtle nesting site classification for feature impact analysis

The use of decision trees as a tool for feature impact analysis in order to classify turtle nesting sites is described in this section. The nodes in Fig. 5(a) are of two types — internal node (with four lines of text in the box) and terminal node (with three lines of text in the box). For the internal nodes, the first line states the feature that is being used to partition the samples as well as the numeric threshold, the second line shows the entropy dissimilarity of remaining samples to be partitioned, the third line shows the number of remaining samples in the node to be partitioned and the fourth line denotes the ground truth frequency of labels for the remaining samples in the node. We considered, 'value = $[s_0, s_1]$', s_0 as the number of samples of class 0 (nesting site absence) and s_1 as the number of samples of

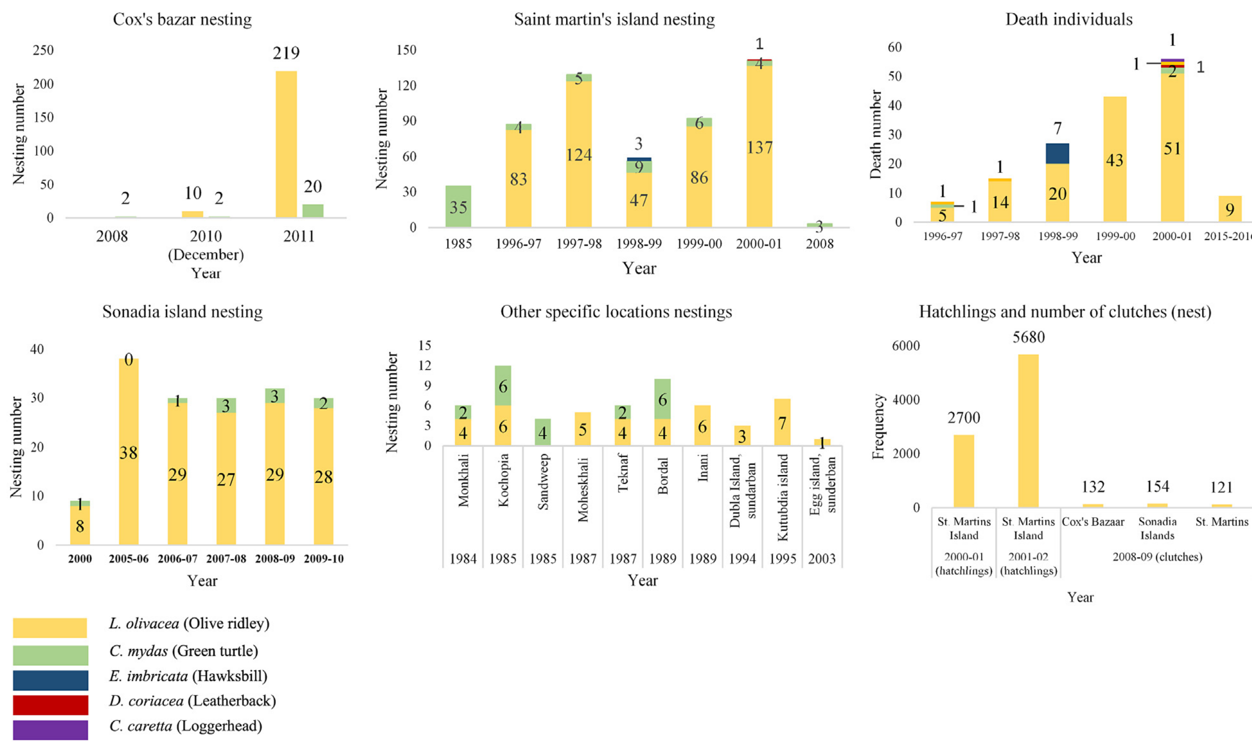


Fig. 3. Cumulative dataset of sea turtles of entire Bangladesh, retrieved from past literature (Islam, 2002a; Groombridge and Luxmoore, 1989; SWOT Report, 2011; Islam et al., 2011; SWOT Report, 2010; Hossain et al., 2013; No Respite for the Marine Turtle, 2004; Aziz, 2016; Islam, 2002b).

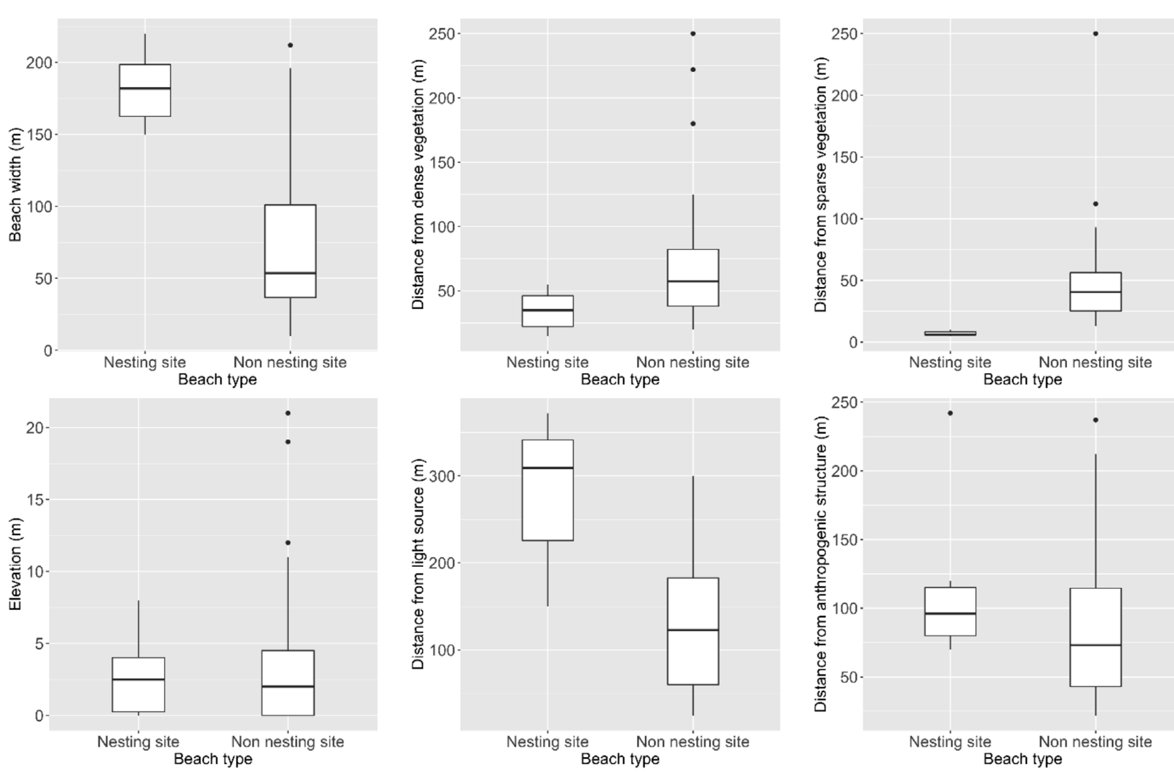
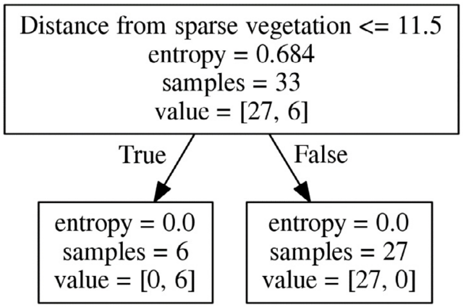
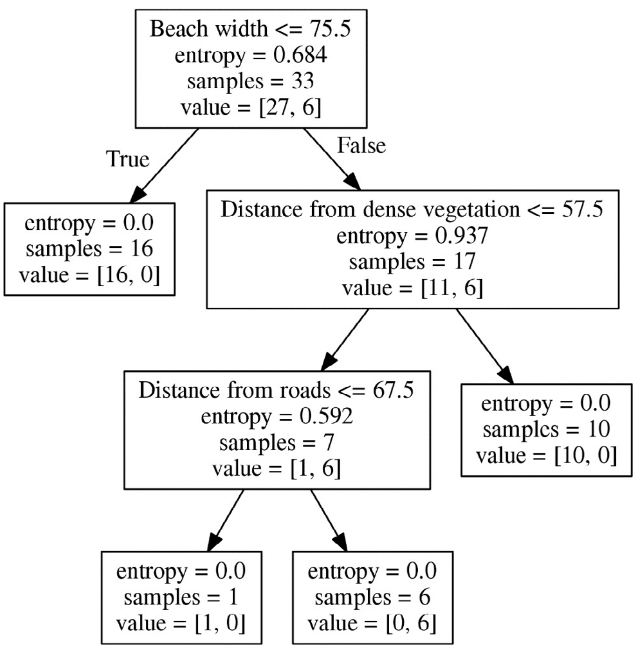


Fig. 4. Comparative picture of environmental measured attributes of nesting and non-nesting sites.

class 1 (nesting site presence) in the node. The 2nd, 3rd and 4th lines of text in internal nodes are analogous to the 1st, 2nd and 3rd lines of terminal nodes. Since the terminal nodes represent final decisions, there is no relevance of a feature at that step. A decision tree is constructed during training of the algorithm and starts with the root. At every node, the tree tries to choose a previously un-selected (remaining) feature which partitions the feature space such that the dissimilarity of constituent samples (gini impurity and entropy) are minimized. If a feature exists that is able to partition the samples into two classes, then no



(a)



(b)

Fig. 5. Decision trees (a) constructed from using all 17 features (b) constructed upon exclusion of feature 'Distance from sparse vegetation'.

other nodes are created since the sole feature is effective enough to distinguish samples. This case is observed in Fig. 5(a) which shows that, if the distance of the site from sparse vegetation is less than or equal to 11.5 m, then it is a turtle nesting site, or else, it is not. However, an unwanted side effect of the efficiency of the feature 'Distance from sparse vegetation' is that no other nodes are created. No further useful information can be extracted about other features from the dataset.

To gain more information about the features, the feature 'Distance from sparse vegetation is excluded, resulting in dataset of 16 features. The constructed decision tree in Fig. 5(b) provides an array of information. If the beach width is less than or equal to 75.5 m then 16 of the 27 samples of class 0 in the root node are partitioned to a terminal node, otherwise the 'Distance from dense vegetation' for the remaining samples are considered. If the distance of the site from dense vegetation is not less than or equal to 57.5 m, then 10 of the 11 remaining samples from class 0 are partitioned to a terminal node. The distance of the sites from roads is considered for the remaining 7 samples (1 of class 0 and 6 of class 1). If the distance from roads is less than or equal to 67.5 m then the sample is not a nesting site and thus the only remaining sample of class 0 is partitioned to a terminal node. The 6 samples of class 1 (nesting site present) are partitioned to another terminal node.

3.4. Land use and land cover change of the study area

The image classification using Landsat images has been summarized in this section. The rate of beach cover change was computed along the study area. Fig. 6 illustrates the spatial pattern change of different land cover classifications for 30 years (from 1989 to 2018). Results of land use change (Fig. 7) analyses suggest that the beach area has reduced from 19.44 km^2(1989) to 14.92 km^2 (2018). Road construction and coastal development can be a major influencing factor in the decrease of beach area by 26%. The beach area in 2018 (yellow colored) became steeper since 1989.

Relationship of beach area with time (Fig. 7(a)) shows a negative trend, determined by the value of the slope. We further calculated the R^2 and equation of the regression line at four intervals (1989–2001, 2001–2006, 2006–2010 and 2010–2016) to see the temporal variation. Fig. 7 shows two trends from 1989 to 2018: (i) The beach area shows (Fig. 7(b)) an equilibrium state from 1989 to 2009 with some ups and downs, signifying different accretion and erosion cycles. The coast has a natural process to achieve a position of equilibrium through adjusting its layout (Pandian et al., 2004). (ii) Post 2009 ($R^2 = 0.93$) emphasizes on a stark downfall of beach area due to acceleration of construction work of marine drive road after 2008 (Sabrang, 2016). The change in beach width seems to be driven by the dynamics of economic development policies. Similar results of anthropogenic land use influence on the beach are observed in past studies (Reece et al., 2013; Halmy et al., 2015; Dewidar, 2002; Misra and Balaji, 2015).

4. Conclusion

The dwindling sea turtle population is of prime importance to biologists (Kikukawa et al., 1999). Bangladesh has gained attention for endangered sea turtle hotspots since 3 of the 11 most endangered sea turtle populations nest here. Lack of comprehensive and continuous turtle nesting and habitat data inventory coupled with construction of regional road network along its longest coast, Bangladesh is faced with severe challenges at the crossroads of environmental conservation and economic development. After reviewing past articles, the cumulative dataset of sea turtle nesting, habitat, death and hatchlings serves as a blueprint for taking conservation actions based on locations (Cox's bazar and Saint martin's island) and priorities. However, there needs to be robust and dynamic monitoring in place along with data collection plan for sea turtle nesting and hatchlings. Field surveys show the turtles prefer to nests closer to vegetation and broader beach in terms of width, while exhibiting an inverse relationship of turtle nesting with distance from artificial light source and man-made structures. Additionally, this paper highlights how a machine learning based algorithm, such as the decision tree can be employed in predicting future turtle nest locations based on environmental attributes in the most threatened habitats, which can be a useful tool for conserving the future turtle biota. During classification, in terms of accuracy, the main challenge was the size of the dataset. Nevertheless, we speculate that in the future when large scale marine datasets with more features including beach ecosystem and marine attributes become available, this model can be firmly tested. Meanwhile, this model can be used for determining if potential locations are suitable sea turtle nesting sites regardless of geographical boundary, especially in countries where detailed datasets are available. Beach profile based on the presence of beach ecosystem and anthropogenic

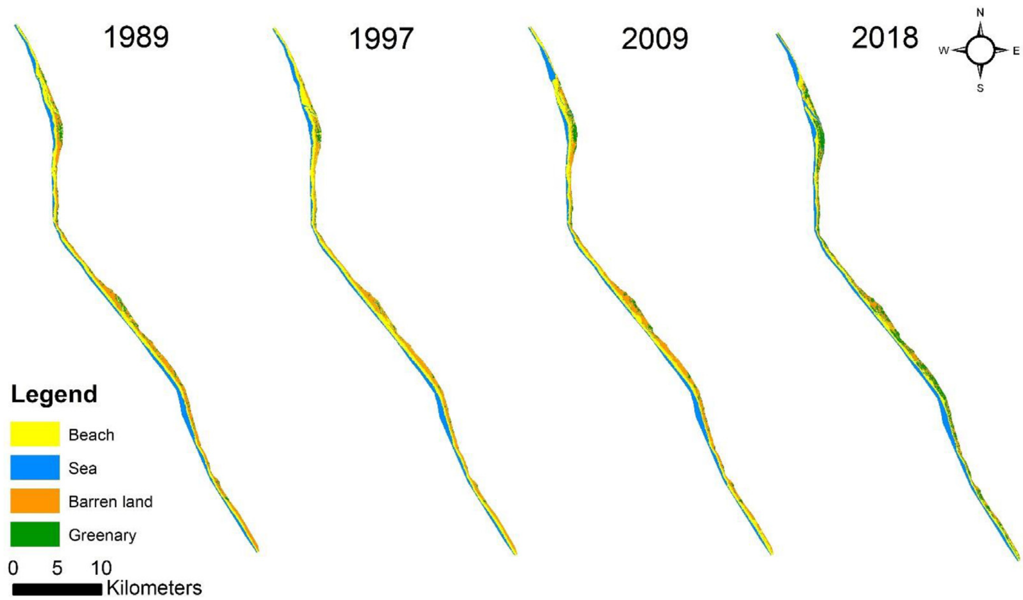


Fig. 6. Land use/land cover of the studied area from the classification of Landsat images for a time interval of 30 years (1989–2018).

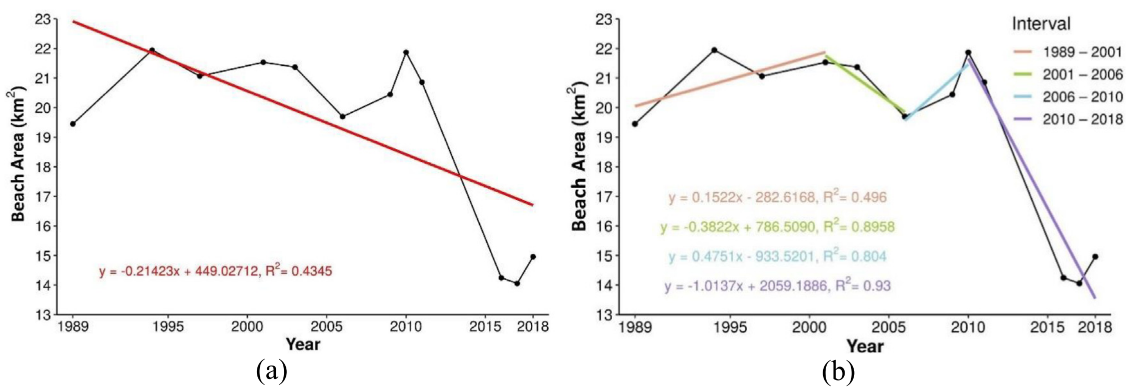


Fig. 7. Temporal pattern of beach area loss for the study area from 1989 to 2018: (a) Linear regression for 30 years (1989–2019); (b) Linear regression carried out at four temporal intervals. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

attributes exhibits the anthropogenic contribution to beach pollution, inefficacious natural resource management and disruption in natural processes. Satellite image analysis provides insights into how ineffective coastal development has altered the width of beach of the study area from a historical narrative. Further studies can be done to see if aquatic processes do play any role in the beach area loss apart from human driven land use change. This study opens the way for other new studies which can focus on the relationship of soil pH, temperature, moisture contents, soil properties and composition on sea turtle hatching in this region. Additionally, with the aid of high-resolution spatial images, surface models can be employed to explore the geomorphic relations with more features and datasets of sea turtle nesting, taking the whole Bangladesh coast as a study area. This will pave the road to identify priority areas where beach restoration is urgent.

This study presents significant conservation measures and priorities for the 3 endangered sea turtle populations and in the broader domain of sustainable coastal management while acknowledging accuracy is constrained by the size of the dataset. Conservation of life below water and marine resources is one of the 17 goals of 2030 agenda for sustainable development (Gupta and Vegelin, 2016). Thus, conserving a keystone species like the sea turtle and proper management of coast should be in the national agenda of every nation. Bangladesh is a signatory state of "Memorandum of Understanding on the Conservation and Management of Marine Turtles and Their Habitats of the Indian Ocean and South-East Asia", which means that the nation is under the agreement of safeguarding the stressed sea turtle population of its own and neighboring regions (Hykle, 2000). To initiate a continuous and sustainable sea turtle conservation program (Fig. 8) necessitates concerted participation of both the Ministry of Fisheries and Livestock and the Ministry of Environment, Forest and Climate Change. Besides, other stakeholders i.e. local citizens, fishermen, hotel owners, marine conservation NGOs and academicians need to be involved in the sea turtle conservation efforts. These stakeholders can take actions to stop movement of cars on marine drive road after a certain period at night. The budding tourism industry can help motivate tourists to participate in beach patrolling and beach cleaning programs as in the case of Cyprus (Broderick and Godley, 1997; Society for the Protection of Turtles, 2019). As a part of corporate social responsibilities, hotels can play an instrumental role by funding the program and shutdown lights after a certain allocated time after nightfall, so that sea turtles coming to nearest beach do not face light pollution. Opportunities for the urban youth to volunteer can also have a profound positive impact on sea turtle nesting.

The fundamental question relevant to the protection of the world's longest sea beach regards the necessity of the marine road

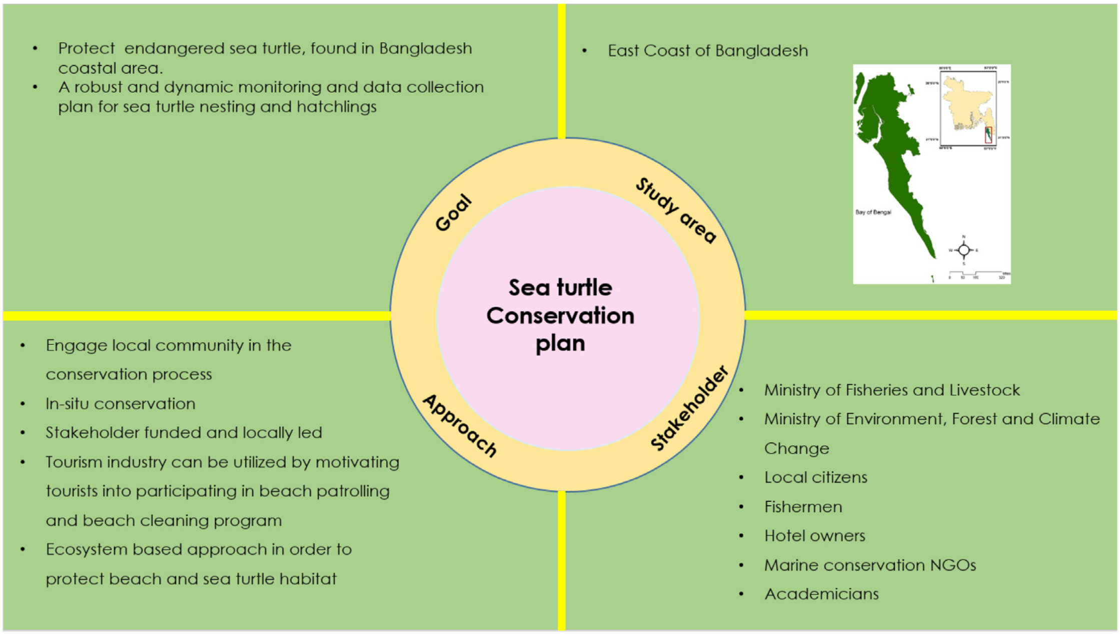


Fig. 8. Framework for sea turtle conservation plan for east coast of Bangladesh.

near the beach given the proximity of an existing parallel road (1 km away). The efficacy of the marine road from a long-term perspective is a topic of discussion for policymakers. Disruption of fundamental coastal processes can have detrimental environmental impacts that can be further exacerbated by the impacts of climate change. The risk mentioned should not be ignored. Thus, for implementing efficient coastal belt management, we recommend an ecosystem-based approach rather than coastal hardening. Considering the importance of conserving marine resources, Bangladesh should devise conservation and coastal management policies taking advice from the experts, locals, stakeholders, and rally collective support from all departments involved in the chain of marine resources for a common goal.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Riasad Bin Mahbub: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing - original draft, Writing - review & editing. **Nahian Ahmed:** Visualization, Methodology, Investigation, Validation, Software, Writing - review & editing. **Farah Yeasmin:** Data curation, Investigation, Resources, Writing - original draft, Writing - review & editing.

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Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.rsma.2020.101151.

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