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09

Ecological Status Assessment of Dr. Salim Ali Bird Sanctuary and Estuarine Areas of Chorao Island

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Indo-German Biodiversity Programme
Conservation and Sustainable Management of Coastal and Marine Protected Areas

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(The Energy Resources Institute -TERI)

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Indo-German Biodiversity Programme
Conservation and Sustainable Management of Coastal and Marine Protected Areas

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List of Acronyms

Al	Aluminium
BOD	Biological oxygen demand
CMPA	Coastal and Marine Protected Areas
Cr	Chromium
Cu	Copper
DBH	Stem Diameter
DO	Dissolved oxygen
Fe	Iron
GBH	Trunk girth at breast height
HT	High tide
ICPOES	Inductively coupled plasma-optical emission spectrometer
LT	Low tide
Mn	Manganese
MoEFCC	Ministry of Environment, Forests and Climate Change
MPAs	Marine protected areas
MT	Mid tide
Ni	Nickel
NOAA	National Oceanic and Atmospheric Administration
OC	Organic carbon
OM	Organic matter
Pb	Lead
PRIMER	Plymouth Routines In Multivariate Environmental Research
S.A.B.S.	Dr. Salim Ali Bird Sanctuary
SPM	Suspended particulate matter
TC	Total carbon
TN	Total nitrogen
Zn	Zinc

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Executive Summary

This study provides a rapid ecological baseline assessment of Dr. Salim Ali Bird Sanctuary (S.A.B.S.) and its vicinity based on the three key biophysical indicators, viz. (i) habitat distribution and human impact, (ii) population and community structure and composition and (iii) environmental indicators (water and sediment quality). The sanctuary has been selected as a pilot site for implementing the Coastal Marine Protected Area (CMPA) measures in order to improve conservation and sustainable use of the biodiversity, which was evaluated based on the results of ecological baseline assessment. The following are the key results of the rapid baseline assessment of S.A.B.S. and its vicinity.

Habitat distribution and human impact–The different habitats at S.A.B.S and its vicinity consist of mangrove forests, paddy fields, *khazans*, river stretches, nallahs, ponds, mudflats, fish farms, orchards and human settlement areas. The contour map of Chorao Island shows the presence of two adjacent peaks with an elevation of approximately 90 m. The major habitat of S.A.B.S is the mangrove ecosystem. Also very noticeable are the mudflats and many criss-crossing creeks/channels, with a total length of approximately 13.3 km. Besides, the newly formed Mankule Island has mudflats as its major habitat, followed by mangroves. The mangrove forest structure was determined based on the tree density, tree height, DBH, percentage cover of understorey, number of saplings/seedlings and degree of deforestation. The assessment of these parameters showed that the average tree height and girth at S.A.B.S. were 9.95 ±0.96 m and 26.2 cm - 72.6 cm, whereas at Mankule Island it was between 12.01 ±0.7m and 39.7–59.1 cm, respectively. Based on the tree height and DBH, the S.A.B.S. and Mankule Island were described as forests with intermediate structural development. The average percentage cover of understorey at S.A.B.S was 6.31

±6.48 and was mainly represented by four species viz, *Acanthus ilicifolius, Derris heterophylla, Porterasia coarctata* and *Clerodendrum inerme*. No understorey was found at Mankule Island in the surveyed quadrats; however, drone aerial images show patches of *Porterasia coarctata* covering the mudflat. Further, the average numbers of saplings/seedlings at S.A.B.S. and Mankule Island were 75 and 65, respectively, and their number was considerably high at the low intertidal zone, indicating a good natural regeneration potential.

Population and community structure and composition – The floral community in the S.A.B.S was represented by nine species and four associated mangrove species. *Avicennia marina* was the most dominant species, followed by *Rhizophora mucronata, Sonneratia alba,* and *Avicennia officinalis*. At Mankule Island, the flora was dominated by *Sonneratia alba* followed by *Avicennia marina* and *Avicennia officinalis*. The composition of the mangrove species showed large variations at the intertidal zone. At the lower intertidal zone *Rhizophora mucronata* was the dominant species, at the mid zone it was *Avicennia marina* and *Bruguiera cylindrica*, and the high tide zone was dominated by *Avicennia marina*. The mean abundance of floral species was about 18 ± 8 in S.A.B.S. and 18 ± 1 in Mankule Island per 100 m^2.

The benthic macrofauna was represented by eight groups. Among these, polychaetes were the most abundant, followed by crustaceans, gastropods and bivalves. *Cerithidea* sp. and *Telescopium* sp. were the most abundant forms of gastropod observed at most of the sampled locations. The commercially important bivalve *Polymesoda erosa* was also a common species found in S.A.B.S. The total abundance of benthic macrofauna ranged between 248/m^2 and 4224/m^2 and the biomass ranged from 69.1 g/m^2 to 496 g/m^2. The total biomass at Mankule Island was relatively low compared to S.A.B.S.

In S.A.B.S., the flora species diversity ranged from 1.24 to 1.86, with a high diversity and species richness at the low intertidal zone. The species were evenly distributed, and the species evenness ranged between 0.82 and 0.99. The macrofaunal diversity ranged from 1.12 to 2.16, while the species richness varied from 1.45 to 3.21. The faunal species diversity and evenness was higher at the low intertidal zone, whereas the species richness were found to be higher at the mid-tidal level. Further, the macrofaunal species diversity and species richness were found to be higher at S.A.B.S. compared to Mankule Island, whereas the species evenness remained the same at the two localities.
Environmental indicators (water and sediment quality) – Both biotic

and abiotic water components were measured for the water quality. The TRIX index values obtained indicated that the water quality was good to high. The presence of pathogenic bacteria was recorded at a few stations.

The average pore water salinity showed an increasing trend from the low tide to high tide zones and also with depth. The sediment composition at both S.A.B.S. and Mankule Island was characterized as silty loam, as the percentage of silt was relatively high compared to sand and clay. The average organic content of the sediment was 5.97 ±3.09 percent and 5.58 ±1.58 percent at S.A.B.S. and Mankule Island, respectively. The sediment also showed the enrichment of heavy metals, particularly Fe and Mn, which reflect the inputs related to mining activities. The sediment characteristics, i.e., sand, silt and clay, showed a good correlation with the macrobenthic fauna such as gastropods and burrows (crabs).

Overall, the mangrove forest condition at S.A.B.S.is healthy based on the 3 point scale, which show a high floral and macrofauna species diversity that is evenly distributed. Further, the deforestation is at a minimum– in fact the percentage of mangrove cover is increasing adjacent to the sanctuary, thus increasing the buffering capacity linked to the impact of adjacent human settlement areas. The water quality assessment also showed typically a good to very high quality based on the TRIX index, except for the presence of pathogenic bacteria at a few stations. Since the area is influenced by anthropogenic activities such as tourism, fishing, and commercial and ferry transport, it is of utmost importance that these impacts be kept to a minimum so as to conserve and sustainably manage the biodiversity of the habitat.

Chapter 1

Introduction

Coastal areas and near-shore marine areas are among the world's most productive yet highly threatened ecosystems. These ecosystems provide immense services toward the sustaining capacity of the environment for human well-being as compared to most other systems. In India, the coastline spans 13 coastal states and union territories, and sustains the livelihoods of over 20 million people. Nevertheless, uninterrupted human activities have greatly stressed coastal ecosystem services, resulting in a quantifiable influence that has reduced its resources and biodiversity. Further, global climate change is likely to increase pressure on these ecosystems. Besides, existing conservation measures, and particularly implementation, are posing a challenge in addressing the rapidly evolving problems at the coast, and, as a result, these ecosystems are now under threat. Therefore, contributing to the protection and conservation of coastal ecosystems is a crucial element in the way forward.

Marine protected areas (MPAs) have been in the spotlight recently as alternative approaches to management of biodiversity, ecosystems and resources. MPAs serve primarily to protect critical habitats and representative samples of marine life and help restore the productivity of these areas to avoid further degradation. The Government of India initiated efforts for conservation and management of marine and coastal ecosystems, especially the highly productive mangrove forests and coral reefs, upon realizing their importance. Conservation programmes have developed and evolved, but the management objectives have yet to reach maturity due to several issues and problems.

Background and Objectives

The German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) with the co-operation of the Ministry of Environment, Forests, and Climate Change, Government of India (MoEFCC), the importance of sustainability and conservation programmes in India has been recognized, and the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH has been commissioned to implement the Project

'Conservation and Sustainable Management of Existing and Potential Coastal and Marine Protected Areas (CMPA)' jointly with the MoEFCC in India.

The overall objective of the project is 'to contribute to the improvement of the conservation and sustainable use of biodiversity in the pilot protected areas, while taking into consideration the economic circumstances of the local population'. The CMPA Project goal is to improve the protection of biodiversity by promoting participatory approaches for the conservation and management of existing coastal and marine protected areas, taking into account the economic well-being of the local population. It also supports the creation of new protected areas in the future.

Dr. Salim Ali Bird Sanctuary at Chorao Island, Goa, has been selected as a pilot site for the implementation of the CMPA Project. In order to reach the intended goal with respect to the conservation and sustainable use of biodiversity at the pilot area, it was suggested that an ecological status assessment study be carried out, which would serve as a benchmark against which the impact of the project can be monitored. This study intends to assess the management effectiveness of the mangrove ecosystem of Dr. Salim Ali Bird Sanctuary, a coastal marine protected area, and to evaluate its ecosystem status using a suite of biophysical indicators for rapid assessment of the ecological baseline.

About the Study

Mangrove ecosystems are heterogeneous habitats with an unusual variety of animals and plants adapted to the environmental conditions of highly saline, frequently inundated, soft-bottomed anaerobic mud. The mangrove habitat is three dimensional, formed from a horizontal zone extending from the land towards the sea and a vertical zone from the ground to the treetop. Due to the vertical extent of the trees, true terrestrial organisms occupy the upper levels, while true marine animals occupy the bases and the extensive surface area of the prop roots and pneumatophores. The mangrove community is also characterized by sediment-dwelling macrofauna, including epifauna and infauna. The main macroinvertebrates associated with mangroves are insects, crustaceans, gastropods and molluscs. The crustacean fauna is dominated by brachyuran crabs. A diverse abundance of prawns and shrimp is harboured by mangroves. Another group of crustaceans, the barnacles, is also found abundantly on mangrove roots and pneumatophores. Gastropod snails are the most common inhabitants of mangroves and are deposit feeders, or herbivores, feeding on algae growing on tree bark. Bivalve molluscs, such as encrusting oysters and mussels, are found attached to roots. Mangrove sediment surfaces mainly harbour gastropods and crustaceans. The macrobenthos is characterized by annelids such as polychaetes. Most organisms occur in the upper 20 cm of the substratum, although some polychaetes and decapods can occur at greater depths. More extensive reviews of the mangrove-associated fauna and their occurrence in the mangrove ecosystem may be found in Nagelkerken (2008) and Hogarth (2015).

A framework that was developed by the Leibniz Center for Tropical Marine Ecology (ZMT) in Bremen, Germany taking into account the recommendations contained in the IUCN Guidebook "Natural and Social Indicators for Evaluating Marine Protected Area Management Effectiveness" for rapid baseline assessment of ecological status of mangrove ecosystems was employed. This assessment was based on the above key biophysical indicators.

A rapid baseline assessment of the ecological status of Dr. Salim Ali Bird Sanctuary and its vicinity, particularly the newly formed mangrove island in the Mandovi River, was carried out to provide an ecological baseline of the following key biophysical indicators:

- Habitat distribution and complexity
- Human impacts

- Population and community structure and composition
- Environmental indicators (water and sediment quality)

The result obtained from this suite of biophysical indicators and a baseline study concept will help evaluate the status of the ecosystem prior to the implementation of the CMPA measures.

Chapter 2

Methodology

Study Area

Chorao Island

Chorao is an estuarine island located in the backwaters of the Mandovi river, and lies between the coordinates 15°25' - 15°30'N and 73°45' - 73°59'E. It is the largest of the riverine islands in Goa. Chorao is divided by creeks and backwaters that have tidal variations, a network formed from the Mandovi and Mapusa rivers and the Cumbharjua canal. Access to these channels by motor boat is restricted to the high tide, but the channels are accessible by canoe even during the low tide. It is a natural island essentially a projection of basalt wherein the land surface has become extended peripherally as a result of heavy siltation through the sedimentation of the Mapusa River, Norora creek and Mandovi estuary up to the current edge of the estuarine water. Upon establishment of mangrove swamps, their root system trapped fine sediments, and in this manner, land was built up along low coasts. The mangroves have gradually overgrown areas that were earlier utilized for paddy cultivation and fish farming, making the land unsuitable for agriculture in recent times. The established mangrove vegetation occupies about 2.5 km^2 of the island.

The ecosystem on Chorao is fragile. The most important ecosystem of the island – the mangrove forests – mainly occurs within the protected area of Dr Salim Ali Bird Sanctuary. Natural mudflats are found along the banks of the river Mandovi. Naturally occurring forest cover is also to be found at Chorao, as are areas for agriculture and aquaculture in the form of paddy fields, *khazans*, orchards, and fish farms (Figure 1).

Dr. Salim Ali Bird Sanctuary

The Dr. Salim Ali Bird Sanctuary (S.A.B.S.) is the state's only protected area of estuarine status situated on the western tip of Chorao Island (Figure 1). The estuary has an average water column depth of ~4 m and exerts tidal influence characterized as both diurnal and semidiurnal tides propagated at the speed of 6 m/second. It is classified as a macrotidal and monsoonal estuary, with spring tides >2 m. The run-off during the monsoon period of June–October

Figure 1
Map of Chorao Island Showing S.A.B.S. and Mankule Island

Source: Google earth

is substantial with the remaining period i.e., November – May. This is a result of the efflux of fresh water that takes place during the monsoon, which is over 95 percent, making the water of the estuary limnetic from head to mouth during the monsoon season. The sanctuary, with an area of 178 ha, and established in 1988, has extensive mangrove vegetation and is covered by a criss-cross network of water channels. Prior to the establishment of the mangrove forest, it was land that was reclaimed by erecting bunds and dykes that were used for paddy cultivation. However, over a period of time, the bunds were damaged due to tidal forces and were not restored. With discontinuation of paddy cultivation resulting in salt water intrusion, mangrove species have gradually grown in the fields into mangrove forests. The dominant genera of mangroves found in the sanctuary are *Avicennia, Rhizophora,* and *Sonneratia*. The sanctuary is home to a multitude of coastal resident and migratory birds as well as a wide assortment of terrestrial and marine life.

Mankule Island

During the latter portion of the 1970s, a natural mudflat was formed in the middle of the Mandovi River, wedged between the Chorao and Divar islands due to the depositional activity of the river. The newly formed island is located between the co-ordinates 15°30'N and 73°50'E. This small mudflat island had no vegetation until the early 1980s; however, with the passage of time, the mudflat has been covered with vegetation and is grown over with different species of mangrove tree (Figure 1). As a part of this study, the diversity of the mangrove species and the epibenthic fauna were assessed, and the site was taken as a reference site outside Dr. Salim Ali Bird Sanctuary.

Figure 2
Aerial Photograph of S.A.B.S. and Mankule Island

LT-low tide, MT-mid-tide and HT-high tide and random sampling (Actual location marked on Google Earth using GPS coordinates)

Sampling Methodology

Habitat mapping of Chorao Island and its vicinity was carried out using geo-referenced satellite pictures which were analysed for different habitat types. Human land-use areas were mapped and measured. The mapped habitat areas were entered into a base AutoCAD map. A topography map of Chorao Island was prepared based on the Google Earth images.

The survey was carried out in the months of February–April 2015 in the priority habitats of the MPA, i.e., mangroves forest and the newly formed Mankule Island. The sampling was designed to assess the benthic macrofauna and mangrove species at both sites. A stratified random sampling design was made based on the intertidal zones i.e., low, mid, and high intertidal areas and all the parameters were measured along transects perpendicular to the shoreline from the low to the high intertidal area. The total length of a transect was site-specific, which depended on the length of the intertidal zone.

A total of six transects were marked in the MPA area (S.A.B.S) and one in Mankule Island. At Dr. Salim Ali Bird Sanctuary, the presence of numerous tidal creeks, bunds and dykes built initially for paddy cultivation has created a criss-cross network across the entire area. As a result, the intertidal areas vary considerably in size. Accordingly, in order to include the representation of the far interior mangroves areas of the sanctuary, four random samplings were also carried out as depicted in Figure 2. GPS coordinates were recorded for the actual locations of all samples at the time of sampling as shown in Table 1.

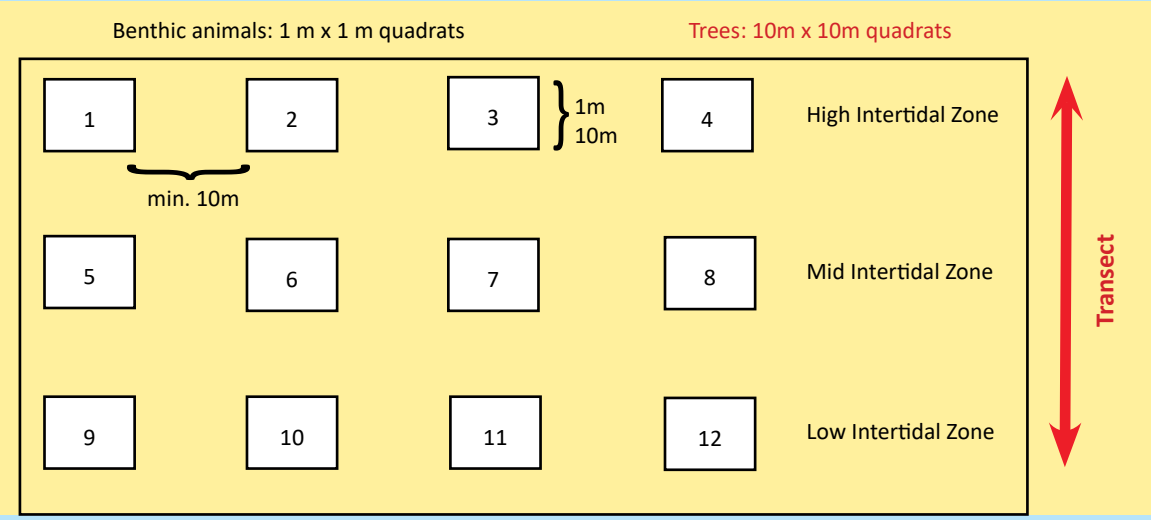
Mangrove Vegetation Sampling

For the mangrove vegetation sampling along each transect, 12 plots, each with an area of 10 m x 10 m, were marked. Four replicate plots were randomly selected in each intertidal zone, where the distance between each plot was at least 10 m. The 10 m x 10 m vegetation plots were demarcated by erecting PVC posts at

Table 1
Sampling Stations with the GPS Coordinates

Station/Zone	Low Tide	Mid Tide	High Tide
Transect 1	15°30'41.07"N; 73°51'50.56"E	15°30'44.93"N; 73°51'50.65"E	15°30'47.79"N; 73°51'49.98"E
Transect 2	15°30'38.94"N; 73°51'3.85"E	15°30'42.99"N; 73°51'0.93"E	15°30'46.10"N; 73°51'0.80"E
Transect 3	15°30'49.70"N; 73°50'45.51"E	15°30'47.40"N; 73°50'47.70"E	15°30'46.40"N; 73°50'50.10"E
Transect 4	15°31'22.10"N; 73°51'38.10"E	15°31'16.50"N; 73°51'40.60"E	15°31'12.40"N; 73°51'41.60"E
Transect 5	15°31'19.63"N; 73°51'7.18"E	15°31'14.50"N; 73°51'7.20"E	15°31'10.38"N; 73°51'10.58"E
Transect 6	15°30'42.29"N; 73°51'29.22"E	15°30'46.14"N; 73°51'29.09"E	73°51'29.09"E; 73°51'29.22"E
Mankule	15°30'37.41"N; 73°52'22.37"E	15°30'35.95"N; 73°52'23.95"E	
Random 1	15°31’10.00”N; 73°51’46.00”E		
Random 2	15°30’56.90”N; 73°51’57.60”E		
Random 3	15°31’2.80”N; 73°51’26.04”E		
Random 4	15°30’57.70”N; 73°51’8.50”E		

Figure 3
Sampling Design for Determining Community Composition in Different Intertidal Zone.



Four replicates were taken at each zone. Single plot of 1 m x 1 m for benthic fauna and 10m x 10m for mangrove flora were surveyed

the four corners of each plot. The mangroves community structure and composition and population were investigated within each plot in all the three zones (Figure 3). At Mankule Island the area was completely submerged during high tide and hence the sampling station consists of only the low and mid intertidal zone and no high tide zone. GPS-tagged photos were taken of all trees in a transect. The placard of the respective species was placed in front of a GPS camera and both the placard and the actual species were photographed (Figure 4). The girth and the height were also recorded. The images of the geo-tagged species of each type were then exported to Google Earth using a Robo-Geo application by providing a uniquely coloured icon.

In each 100 m^2 plot, the following parameters were recorded:

- Total number of tree species and number of individuals per species (> 1.3 m height)
- Geo-reference tagging of each identified mangrove tree species

Figure 4
Geo-tagging of the Mangrove Species along with Measuring of the Tree Girth

- Trunk girth at breast height (GBH) at a height of 1.3 m for each species
- Height of each tree species (> 1.3 m height) using Ravimeter
- Number of seedlings/sampling (<1.3 m height)
- Associated vegetation
- Percentage of understorey (herbaceous plants, shrubs and vines which cover the ground)

Benthic Macrofauna Sampling

For the benthic macrofauna, samples were collected in four replicates at each intertidal zone with a plot size of 1 m x 1 m. A 1 m^2 foldable quadrat frame was constructed using PVC pipes and joints. Each plot was randomly marked at least 10 m apart at each zone (Figure 3). The epibenthic fauna, commonly gastropods, bivalves and crustaceans, that were present on the mud surface within the plot were collected and identified. Besides, any other live organisms present on the floor of the mangrove forest in the plot were also collected and identified. Furthermore, a metal quadrat, of 25 cm x 25 cm size up to a depth of 10 cm, was used to collect benthos samples from the sediment within the same 1 m^2 plot (Figure 5). The sediment was scraped within the quadrat to a depth of about 8–10 cm with the help of a hand shovel and transferred to a large Ziploc plastic bag. The benthic organisms in the sediment samples were recovered after sieving the samples through a 0.5 mm mesh sieve. The residues retained on the sieve were preserved in 10 percent formalin containing Rose bengal solution. In the laboratory, the sieved samples were transferred to a large, white-bottomed tray, and the animals were sorted by hand. The sorted organisms, counted under a stereoscopic microscope, were then identified to the taxonomic level. In the present study, qualitative and quantitative assessments of the benthic macrofauna were carried out. The organisms were counted and identified up to taxa under a stereo-microscope and a few groups were identified up to the lowest taxonomic levels. The biomass was also estimated by using the wet weight method (g/m^2).

Figure 5
Sampling of Epibenthic in 1 m x 1 m Quadrat and Infauna in 25cm x 25 cm Metal Quadrat in the Mangrove of S.A.B.S.

Environmental Sampling

At each transect, sediment cores were collected using an acrylic tube, about 10 cm long, with a diameter of 5.5 cm. Core sampling of the sediment was made at the low, mid and high intertidal areas. The core was sub-sampled on site at 2 cm intervals. The sub-samples were placed in labeled Ziploc plastic bags and were immediately transferred to the laboratory for further analysis. The samples were analysed for pore water salinity, organic content, grain size and heavy metal content.

For pore water salinity, the sliced sediment samples were centrifuged at 4000 rpm for 20 minutes and after that the pore water was immediately filtered and transferred to plastic vials and analysed for salinity using a portable salinometer after calibration with deionized water.

The organic content was analysed using a Thermo Scientific™ FLASH 2000 organic elemental analyser and UIC Inc. coulometer CM5230 acidification unit. The total inorganic carbon of the finely powdered sediment was determined using a coulometer and the total carbon of the same sample was measured with an elemental analyser. The estimate of the total organic carbon was derived from the difference between the total carbon and total inorganic carbon contents.

Grain size analysis of sediments was carried out on 125 sub-samples of the cores collected from seven transects and four random samples. A known amount of sediment was wet sieved through a 1-mm sieve to remove the roots. The sediment was then treated with hydrogen peroxide to remove organic matter. The sediment was wet sieved to separate the sand fraction (500 µm to > 63 µm) from clay and silt. The sand fraction retained in the sieve was collected dried and further fractioned dried sieved size fraction of (250 µm, 100 µm) and weighed. The sediment fraction < 63 µm was dispersed with 0.5 ml of 1 percent sodium hexametaphosphate solution and further analysed to measure the size fractions of silt and clay, using a Malvern Laser Particle size analyzer (Mastersizer2000). The percentages of sand (500 µm to > 63 µm), silt (<63µm to 6 µm) and clay (<6 µm) were calculated in each sample.

Figure 6
Map of S.A.B.S Showing the Stations of Water Sampling

Metal analyses of sediments were carried out for 50 sediment samples from seven transects and two random samples. About 50 mg of the powdered sediments was transferred into Teflon beakers and 10 ml of acid mixture (6:3:1 of HF, HNO_3 and HClO, respectively) was added to each beaker, kept overnight and then dried on a hot plate at 180 °C. The procedure was repeated until the samples in the beakers were completely digested. The final residue was dissolved with 5 ml of 1:1 of 0.1 M HNO_3, and the final volume was made up to 25 ml, using HNO_3 solution. A similar digestion procedure was followed for the reference standard (SGR-1b) and blank (without sediment). Sample solutions were analysed for heavy metals, i.e. Fe, Al, Cr, Mn, Ni, Zn, Pb and Cu, using an Agilent Technologies inductively coupled plasma-optical emission spectrometer (ICP-OES) equipped with an auto-sampler. The instrumental precision during the analytical session was monitored by analysis of an in-house standard solution and known samples run were after every 10 samples.

Further, separate samples of water were collected just below the water surface near the sampling sites to determine the quality (Figure 6). The sampling covered the entire MPA study area, and also included a reference sample taken near the control site. Both abiotic and biotic parameters were measured, including temperature, salinity, dissolved oxygen, pH, turbidity, nitrate and phosphate, chlorophyll a, total suspended matter and suspended organic matter and bacteria/ pathogenic content (*E.coli*). The water samples for the physicochemical parameters (except DO) and chlorophyll a were collected using a clean bucket. The water samples for analysing dissolved oxygen (DO) was directly taken into 300 ml BOD bottles without agitation and fixed with manganous sulphate and alkaline potassium iodide immediately after collection. The temperature of the of water was recorded using a standard mercury thermometer and the pH value using a Scan 2 digital pH meter which was calibrated by standard buffers before

Figure 7
DJI Phantom Vision 2 Drone Used for Aerial Photography of the Mangroves Habitat

every use. The transparency was measured using a Secchi disc. The chlorophyll a content of phytoplankton was estimated using the acetone extraction method. Chlorophyll *a* (Chl *a*) was measured using modified Parson et al (1984). Suspended particulate matter (SPM) was measured by weight loss method after filtering a known volume of water on ash pre-weighed GF/F glass filter paper. Analyses of nutrients, i.e., nitrate, nitrite, inorganic phosphate, silicate and ammonia, were carried out using an auto analyser. Organic matter was analysed using the gravimetric method after filtering a known volume of water on pre-weighed ashed GF/F glass filter paper and ashing at 450 OC for 4 hours.

Habitat Mapping and Aerial Photography

Habitat mapping of the entire Chorao Island, Dr. Salim Ali Bird Sanctuary and Mankule Island was carried out by exporting aerial images from Google Earth into the AutoCAD application. The satellite image of Chorao Island was superimposed on the survey plan and all the features which could be easily identified were marked. The different habitat types were traced and marked with different colours and the total areas were recorded. Ground truthing was also carried out wherever required.

For aerial photography of the mangrove area, a DJI Phantom Vision 2 drone was used (Figure 7). It has a communication distance of around 1000 m in an open area. It was observed that from a height of 30–50 meters all the mangrove species could be identified. Photographs were taken at these heights above the mangroves to identify them. The photos taken from the drone were geo-tagged, which means that the longitudes and latitudes of the spots where the photos were taken were also recorded. Using the Robo-Geo application, the photographs were exported to the Google Earth KML format (Keyhole Markup Language). Then the photos were inserted in AutoCAD and identified species were marked with polygons of separate colours for each type of species, along with a legend. By aligning the photos on the Google Earth and by using a reference point, the polygons were transferred/traced on Google Earth application.

Data Analysis

The abundance of faunal organisms was expressed as individuals per square meter and the flora density was measure in per 100 m^2. Biodiversity indices such as species diversity,

richness and evenness univariate measures were analysed using the computer software PRIMER (Plymouth Routines In Multivariate Ecological Research ver. 6).

Chapter 4

Results and Discussion

The outcomes of the project are presented with respect to the three key biophysical indicators that largely assess the ecological baseline of the selected MPA site. The three biophysical indicators habitat distribution and human impacts, population and community structure and composition and environmental indicators (water and sediment quality) for Dr. Salim Ali Bird Sanctuary and its vicinity.

Habitat Distribution and Human Impacts

Habitat Mapping

Detailed habitat maps depicting the different habitat types were drawn for the entire Chorao Island, Dr. Salim Ali Bird Sanctuary and Mankule Island. Chorao Island has different habitats, which include mangrove forests, paddy fields, *khazans*, a river, nallahs, ponds, mudflats, fish farms, orchards and human settlement areas,

Table 2
Different Habitat Types of Chorao Island

Habitat	Area (ha)	Area (km^2)	Proportion of Habitat (%)
Paddy	471.68	4.72	24.87
Khazan	135.02	1.35	7.12
Mangrove	323.92	3.24	17.08
River	168.13	1.68	8.86
Nalla	93.01	0.93	4.90
Ponds	5.45	0.05	0.29
Fish farms	14.53	0.15	0.77
Mudflats	29.90	0.30	1.58
Orchard	378.30	3.78	19.94
Settlement	276.85	2.77	14.60
Total	**1896.79**	**18.97**	**100.00**

Figure 8
Map Showing Different Habitat Types of Chorao Island

as shown in Figure 8. The settlement areas are located within the range of the 1 km buffer zone, which may pose a threat to the protected area.

The areas of all the major habitats are given in Table 2. The mangrove area is around 17 percent of the total Chorao Island which is higher than that of the current settlement area.

Figure 9 provides the elevation information of Chorao Island with its contour map drawn with 10-m intervals. The maximum height of two adjacent peaks is approximately 90 m.

The habitat of S.A.B.S. was further marked out taking into account its mangroves, mudflats, criss-cross creeks/canals and also aquaculture ponds located adjacent to the MPA. The details of these habitats are given in Figure 10 and Table 3. The visible creeks of the aerial images were marked and their total length and area were measured. These are approximately 13.3 km and 0.15 km^2, respectively. However there exist several other narrow creeks, which are not visible through aerial images due to the presence of thick mangrove cover.

Further, the habitats of the newly formed Mankule Island, which includes mangroves and mudflats, are shown in Figure 11. The

Figure 9
Contour Map of Chorao Island

total area of the island is approximately 35.0 ha with mangrove coverage of around 6.45 ha.

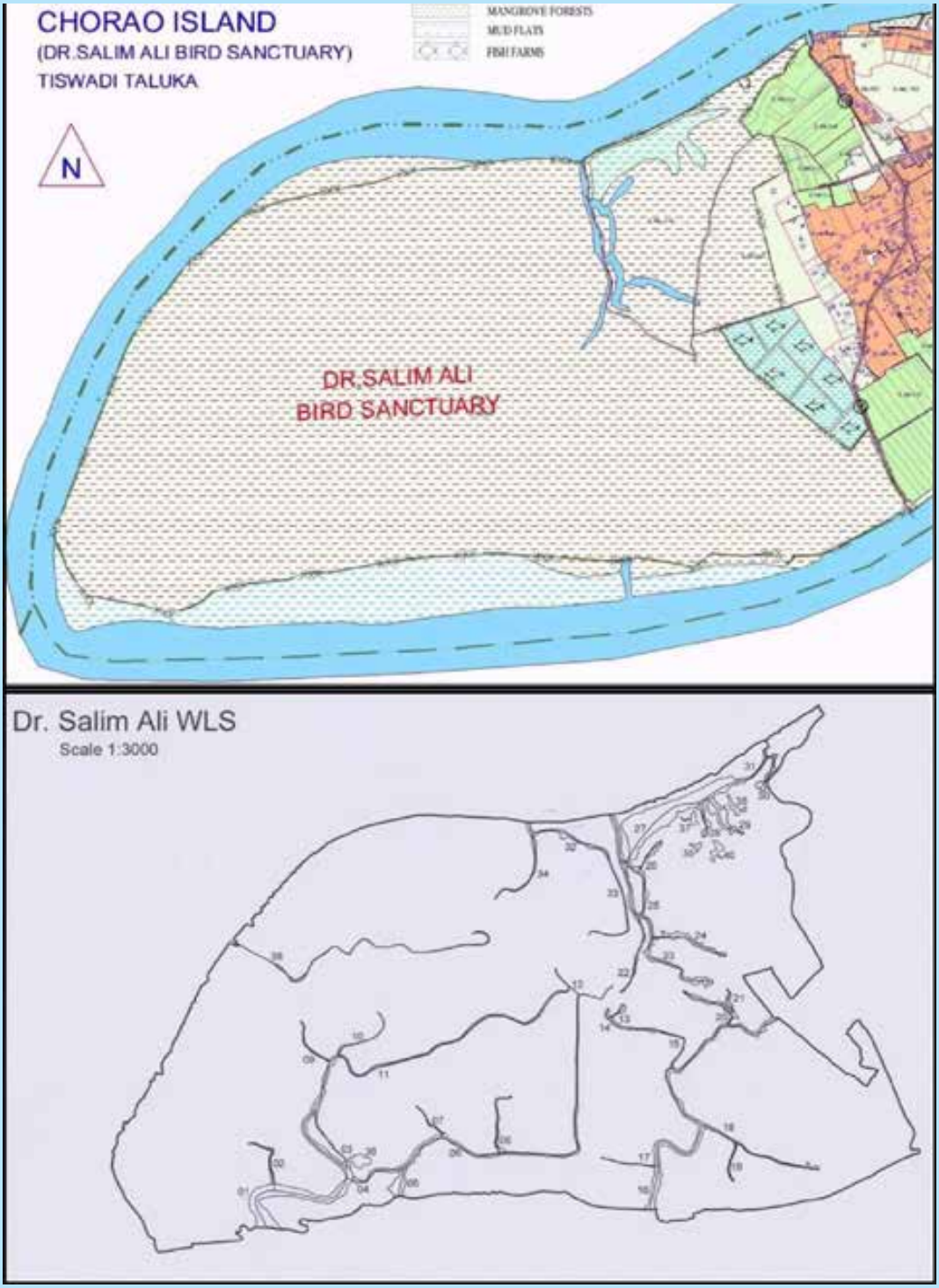
Assessment of Mangrove Forest Structure

The mangrove habitat distribution was assessed based on its average tree density and height, percentage cover of understorey, stem diameter (DBH), number of saplings/seedlings as detailed in Table 4.

The average tree height at Transect 1 - 6 at low, mid, and high intertidal zones ranged between 7.8 m and 11.4 m, and at Random stations it ranged between 9.4 m and 10.7 m, whereas at station Mankule it ranged between 11.5 m and 12.5 m at low and mid tide, respectively (Table 4).

The high average tree height recorded at the newly formed Mankule Island is due to the great coverage of *Sonneratia* species followed by *Avicennia* species, as these species normally grow tall. Similar was the case with S.A.B.S. as these species' height normally ranged between 8 m and 16 m, as compared to other species such as *Bruguiera cylindrica*, *Kandelia candel*, and *Rhizophora* species, which are relatively short. Further, the average tree height at the low tide zone was moderately low, i.e., 9.6 m. This zone was dominated by *Rhizophora sp.* as compared to the mid and high intertidal zones.

Figure 10
Maps Showing Creeks and Different Habitats of S.A.B.S. and Adjacent Areas



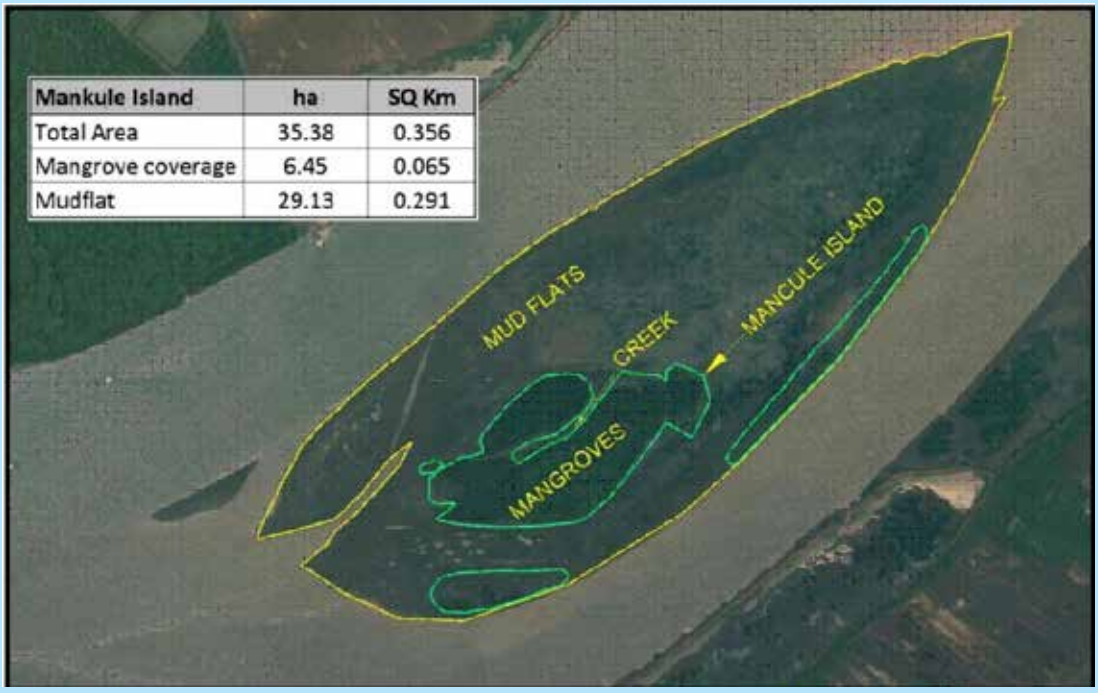
The overall average tree heights at S.A.B.S. and Mankule were 9.95 ± 0.96 m and 12.01 ± 0.7 m, respectively. As the average tree height depicts the age of the mangrove forest, on a five point scale as shown in Figure 12, the study area is ranked number four.

The average girth of the trees at Transect 1 - 6 at low, mid and high tidal zones ranged between 26.2 cm and 72.6 cm, and at Random stations it ranged between 40.8 cm and 56.8 cm, whereas at station Mankule it ranged between 39.7 cm and 59.1 cm at low and mid tides, respectively

Table 3
Habitats Details of S.A.B.S. and Adjacent Areas

Habitat (Area)	Area (ha)	Area (km²)
MPA (S.A.B.S.)	178.00	1.78
Mudflats	29.09	0.03
Fish farms	8.15	0.08
Creeks	15.27	0.15
Total Mangrove area including area adjacent to S.A.B.S.	292.00	2.92
Width (m)	**No. of Creeks/Canals**	**Length (m)**
0 – 5	6	2233
5 – 10	15	4020
10 – 15	7	2521
15 – 20	4	2490
More than 20	3	1765
Total	**35**	**13029**

Figure 11
Habitat Areas of Newly Formed Mankule Island



(Table 4). Further, the percentage cover of the understorey at S.A.B.S. was mainly represented by four species, viz, *Acanthus ilicifolius, Derris heterophylla, Porterasia coarctata* and *Clerodendrum inerme*. Among these *Acanthus ilicifolius* was the most dominant species, found at all the sampled locations, followed by *Derris heterophylla*. *Acanthus ilicifolius* was commonly seen at the boundaries of the creeks/channels. The average percentage cover of the understorey

Table 4
Mangrove Habitat Structure Characteristics and Distribution

Station (Zone)		Density per 100 m²	Height Range (m)	Average Height (m)	DBH Range (cm)	Average DBH (cm)	Understorey (%)	No. of Sapling/seedling
Transect 1	LT	16.50	3 - 13	8.8	10 - 110	38.6	5.5	24
	MT	31.50	5 - 13	10.7	10 - 70	33.7	6.8	0
	HT	9.25	5 - 14	11.4	12 - 135	51.2	0.5	43
Transect 2	LT	12.50	5 - 14	10.1	12 - 280	59.2	0.4	52
	MT	44.50	3 - 12	7.8	10 - 82	26.2	0.0	51
	HT	19.00	3 - 14	7.8	10 - 120	40.5	16.3	112
Transect 3	LT	18.75	6 - 13	10.1	11 - 100	36.2	3.1	54
	MT	11.50	4 - 15	10.2	20 - 150	53.4	0.5	57
	HT	18.28	3 - 15	10.0	11 - 200	51.4	13.8	41
Transect 4	LT	18.00	3 - 13	10.4	11 - 133	64.8	6.3	76
	MT	21.50	4 - 14	10.1	10 - 135	50.4	21.3	58
	HT	16.75	3 - 14	10.7	12 - 112	61.3	0.3	2
Transect 5	LT	20.25	3 - 16	9.1	11 - 195	61.8	15.5	298
	MT	6.75	4 - 14	11.1	20 - 170	72.6	0.0	6
	HT	8.75	3 - 14	10.4	16 - 190	65.0	3.8	326
Transect 6	LT	16.75	3 - 16	9.1	11 - 195	61.8	13.8	209
	MT	18.75	3 - 13	10.6	10 - 70	35.4	11.3	76
	HT	19.75	5 - 13	10.2	10 - 83	39.5	0.0	10
R 1		10.75	2 - 13	10.7	10 - 93	46.3	11.3	60
R 2		17.00	4 - 13	10.1	9 - 259	56.8	3.8	12
R 3		13.25	3 - 14	10.2	10 - 100	43.6	1.3	4
R 4		18.50	4 - 14	9.4	10 - 110	40.8	3.8	92
Mankule	LT	18.50	9 - 14	11.5	15 - 80	39.7	0.0	124
	MT	17.50	7 - 14	12.5	12 - 125	59.1	0.0	6

was found to be highest at Transect 4 (9.27 percent) followed by Random 1 (11.25 percent) and Transect 6 (8.33 percent). The understorey coverage was not recorded at the station surveyed in Mankule Island however, large patches of *Porterasia coarctata* were observed in the mudflat area of the Island. The average of the understorey coverage in S.A.B.S. is approximately 6.3 percent. The percentage cover of the understorey in our study area on a six-point scale ranged between 1 and 3 as shown in Figure 13.

With regard to saplings/seedlings, among the transects, the highest numbers of saplings were observed at Transect 5 high tide zone and the least numbers of saplings were observed at Transect 4 high tide, and among the random stations higher numbers of saplings were observed at Random 4 and the least numbers were observed at Random 3. At station Mankule, the higher numbers of saplings were observed at low tide and the least numbers were observed at high tide (Table 3). The average number of saplings at the low tide zone was considerably higher, i.e., 119, than those of the mid and high intertidal zones, i.e., 41 and 89, respectively.

Human Impact

The study area is influenced by different anthropogenic activities. The sanctuary is

Figure 12
Habitat Areas of Newly Formed Mankule Island

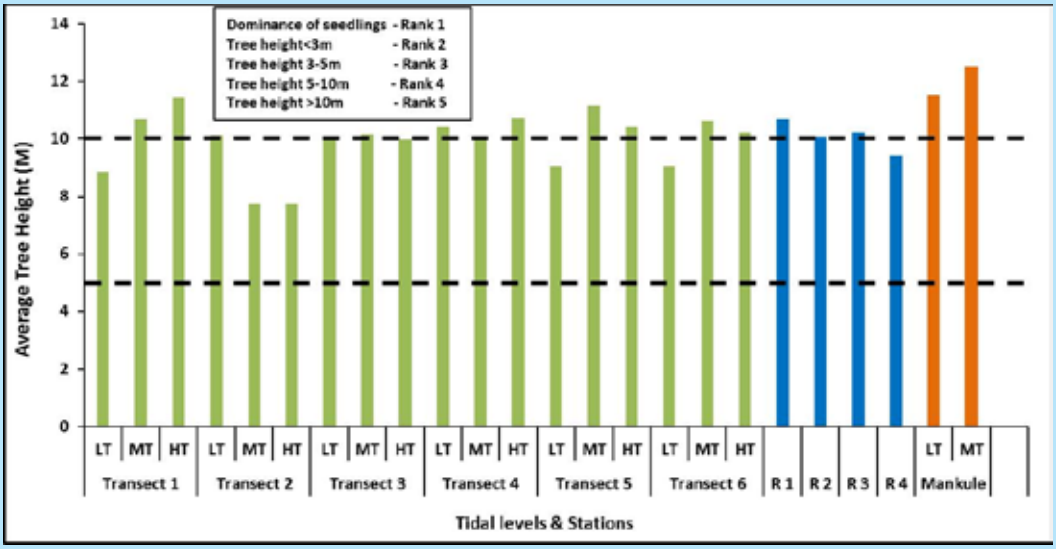
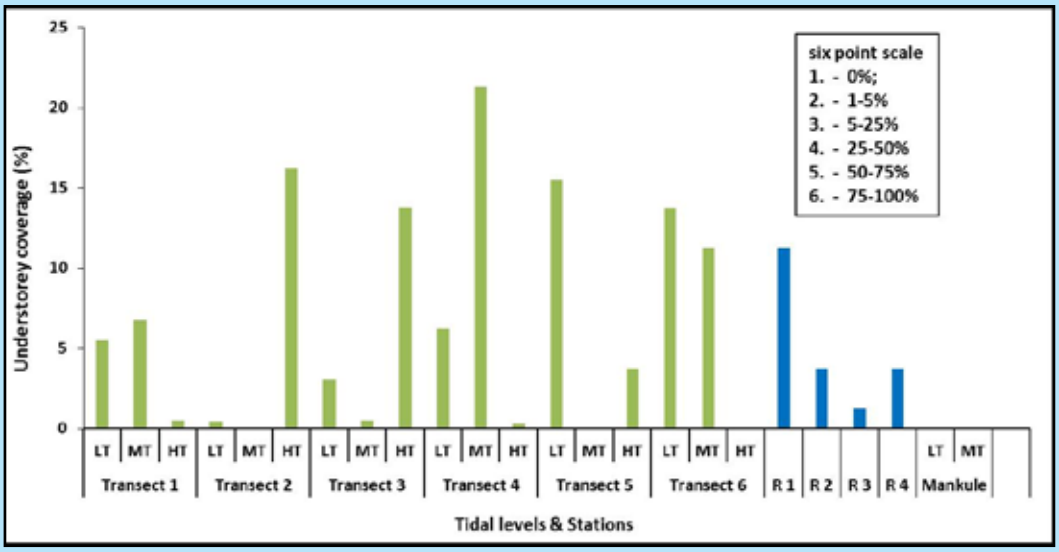


Figure 13
Habitat Areas of Newly Formed Mankule Island



physically connected to the landmass of the island of Chorao, and the most proximate landmasses are of human settlement and agriculture (Figure 8). The other proximate landmasses are located across the rivers Mapusa and Mandovi. Towards the south-west, across the river Mandovi is the capital city of Panjim. As a result human activities impart a significant imprint on the sanctuary, such as disposal of garbage, untreated sewage, and pesticides usage in agriculture. During our survey in the sanctuary the presence of garbage was commonly seen across the sanctuary. Garbage was also seen in the interiors of the mangrove forest that resulted due to tidal influence. The presence of coliform bacteria in some of the water samples collected reveals the disposal of untreated sewage. Therefore, dumping of garbage and unregulated disposal of sewage may cause deterioration of the health of the mangrove forest.

Tourism is one of the most important activities

carried out at the sanctuary, where the visitors directly visit the sanctuary for sightseeing and bird watching. The forest department, which is an authority regulating and monitoring the sanctuary, also caters to the tourist visitors by operating boat tours within the visitor designated area of the sanctuary. Over the years, the sanctuary has been progressively receiving a steady stream of visitors. On the other hand, there are also private operators who offer boat rides into the sanctuary, which are regulated and monitored to a limited extent, and as a result it is likely that they may enter into the sanctuary at non-designated visitor areas and cause disturbance.

Fishing is the second important activity which occurs in the area. Among the different types of fishing activities, there are two broad categories of fishing that are undertaken within the sanctuary. These include catching fish using stake nets and catching crabs or crabbing. Occasionally there are also some individuals who gather bivalves from the sanctuary.

Other activities are undertaken in close proximity to the sanctuary in the Mapusa river section of the estuary. This section has received an increasing number of jetties offering mooring space for small commercial operations and a range of boats, fishing trawlers, tourist boats and private yachts. Besides, there are ferries that connect Chorao with its surroundings which are managed by the River Navigation Department of the Government of Goa. This results in much petroleum hydrocarbons in the surrounding water bodies and disposal of waste resulting from the cleaning of boats into the surrounding water column. During our survey, we observed the presence of petroleum residues on the sediment surface of the mangrove area as well as a visible oily film in the water of the criss-cross creeks. Further, both the Mapusa and Mandovi rivers are transport routes used by barges for the transportation of mining ore. As a result there is heavy metal accumulation, particularly Fe and Mn in the surrounding water bodies and sediments.

Forest Condition

The mangrove forest condition was assessed based on the tree density and height, DBH, percentage of understorey cover and degree of deforestation. According to Pellengrini et al (2009), a mangrove forest with a maximum structural development has DBH between 27 and 29.9 cm and a mean height of the most developed trees between 17.7 and 21.2m, a forest with intermediate structural development has a DBH between 4.5 cm and 14.8 cm and a mean height of most developed trees between 5.7 and 13.7 m, and a forest with low structural development has a DBH between 1.6 and 3.1 cm, and mean height of most developed trees between 2.4 and 4.7 m. Therefore the mangrove forest at Salim Ali Bird Sanctuary could be described as being a forest with intermediate structural development as the mean height is from 7.8 to 10 m. In the case of Mankule Island, its forest can also be described as one with intermediate structural development. Further, the degree of deforestation at S.A.B.S. is minimal. In fact in the last decade there has been an increase in the coverage of mangroves in the adjacent areas thus increasing the buffering capacity of the sanctuary linked to the human settlement areas (Misra et al, 2015). Besides, the abundance of saplings and seedlings gives an indication of natural regeneration occurring. Large numbers of saplings are observed in the low tide zone of transects 6 and 5 and in Mankule Island, which indicates that S.A.B.S. and Mankule have good regeneration potential. The low tree heights in these transects allowed seedlings to colonize the area as there was more light available for them to grow.

Population and Community Structure and Composition

Species Composition and Diversity of Mangroves

The study provides a baseline for the distribution, abundance, and diversity of flora in the selected locality (Dr. Salim Ali Bird Sanctuary and Mankule Island). The floral community in the area was represented by nine species and four associated mangrove species. Table 5 lists the averages of

Table 5
Mangrove Species Distribution in S.A.B.S. and Mankule Island

Station (Zone)		*Avicennia officinalis*	*Avicennia marina*	*Sonneratia alba*	*Rhizophora mucronata*	*Rhizophora apiculata*	*Bruguiera cylindrica*	*Kandelia candel*	*Aegiceras*	*Excoecaria agallocha*
Transect 1	LT	3	2	3	7	0	3	0	0	0
	MT	4	20	2	1	0	3	0	2	0
	HT	2	3	4	1	0	1	0	0	0
Transect 2	LT	0	4	1	8	0	0	0	0	0
	MT	5	0	0	3	0	37	0	0	0
	HT	0	13	2	2	0	2	0	0	0
Transect 3	LT	1	9	0	2	1	6	0	1	0
	MT	10	0	1	0	0	0	0	0	0
	HT	0	15	2	1	0	0	0	0	0
Transect 4	LT	1	12	3	2	0	0	0	0	0
	MT	2	10	1	5	0	3	0	0	2
	HT	1	14	1	1	0	0	0	0	0
Transect 5	LT	3	2	0	14	0	1	0	1	0
	MT	1	4	1	1	0	1	0	0	0
	HT	0	8	0	1	0	0	0	0	0
Transect 6	LT	3	3	0	11	0	1	0	1	0
	MT	2	11	3	1	0	1	0	1	0
	HT	0	8	10	1	1	0	0	0	0
R 1		1	7	2	1	0	0	0	0	0
R 2		2	10	4	1	1	0	0	0	0
R 3		0	2	7	4	1	0	0	0	0
R 4		1	7	5	4	0	1	0	2	0
Mankule	LT	1	0	12	6	0	0	0	0	0
	MT	3	9	4	2	0	0	0	0	0

species from four replicates sampled at each zone in 100 m^2. Similar species compositions were reported in the surrounding estuarine areas of Goa (Untawale et al 1973, 1982; Untawale & Parulekar 1976; Jagtap 1985; Jagtap & Singh 2004). In the six transects, *Avicennia marina* was the most dominant species, followed by *Rhizophora mucronata, Bruguiera cylindrica* and *Avicennia officinalis*. Among the Random stations, *Avicennia marina* was again the most dominant species followed by *Sonneratia alba* and *Rhizophora mucronata*. Station Mankule was dominated by *Sonneratia alba*, followed by *Avicennia marina* (Table 5). Each species that found in the marked quadrat of the sampling site was identified, geo-tagged photos taken and the DBH reading noted.. These tagged species were then exported in the Google Earth images with their GPS location as shown in Figure 14.

The total abundance of mangrove species was calculated and presented as shown in Figure 15. Among the stations sampled, the abundance of species was found to be highest at Transect 2, and the least abundance was observed at Transect 5 and Random 1 (Figure 15). The high abundance of mangroves in Transect 2 was due to the presence of dense cover of *Bruguiera cylindrica* at the mid tide zone. Overall, the mean abundance of species was about 18 ± 8 in S.A.B.S. and 18 ± 1

Figure 14
Geo-tagged Identified Mangrove Species at Each Location in S.A.B.S. and Mankule Island

in Mankule Island per 100 m^2. The abundance of mangroves in the surrounding estuarine areas reportedis in a similar range (Jagtap 1985).

The species compositions of the mangroves in S.A.B.S and Mankule Island are presented in Table 6. *Avicennia marina* was the most abundant species (~ 40 percent) found at station S.A.B.S., followed by *Rhizophora mucronata* (~ 15percent) and *Sonneratia alba* (~ 16 percent), and the least abundant species found were *Kandelia candel*, *Excoecaria agallocha* and *Rhizophora apiculata*. Mankule Island was dominated by *Sonneratia alba* (~ 43 percent) followed by *Avicennia marina* (~ 25 percent). *Avicennia officinalis* is the least abundant species found at Mankule Island. the abundance of species was similar to the earlier reported studies in the Mandovi and the surrounding estuaries of Goa (Kumar Trinadh & D'Souza 2013).

The composition of the mangrove species also showed an intertidal variation at S.A.B.S. The four major mangrove species that are dominant at each of the three tidal zones are:

At low tide zone - *Rhizophora mucronata* (39.7 percent), *Avicennia marina* (24.6 percent), *Bruguiera cylindrica* (11.7 %) and *Avicennia officinalis* (10.2 percent).

At mid tide zone - *Avicennia marina* (30.6 percent), *Bruguiera cylindrica* (29.9 percent), *Avicennia officinalis* (18.3 percent), and *Rhizophora mucronata* (10.0 percent).

At high tide zone - *Avicennia marina* (54.7 percent), *Sonneratia alba* (19.3 %), *Rhizophora mucronata* (9.3 percent) and *Bruguiera cylindrica* (6.3 percent).

A similar succession pattern was reported in the nearby estuarine areas of Goa by Untawale et al. In particular, there was an abundance of Rhizophora sp. in the low intertidal zone.

Further, the distribution of the floral species

Figure 15
Total Abundance of Flora in S.A.B.S and Mankule Island

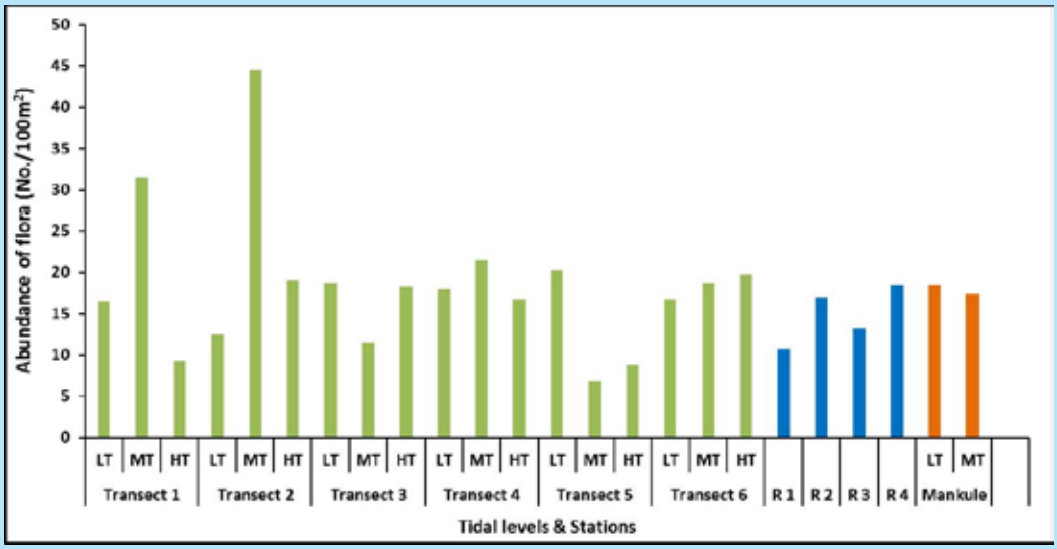
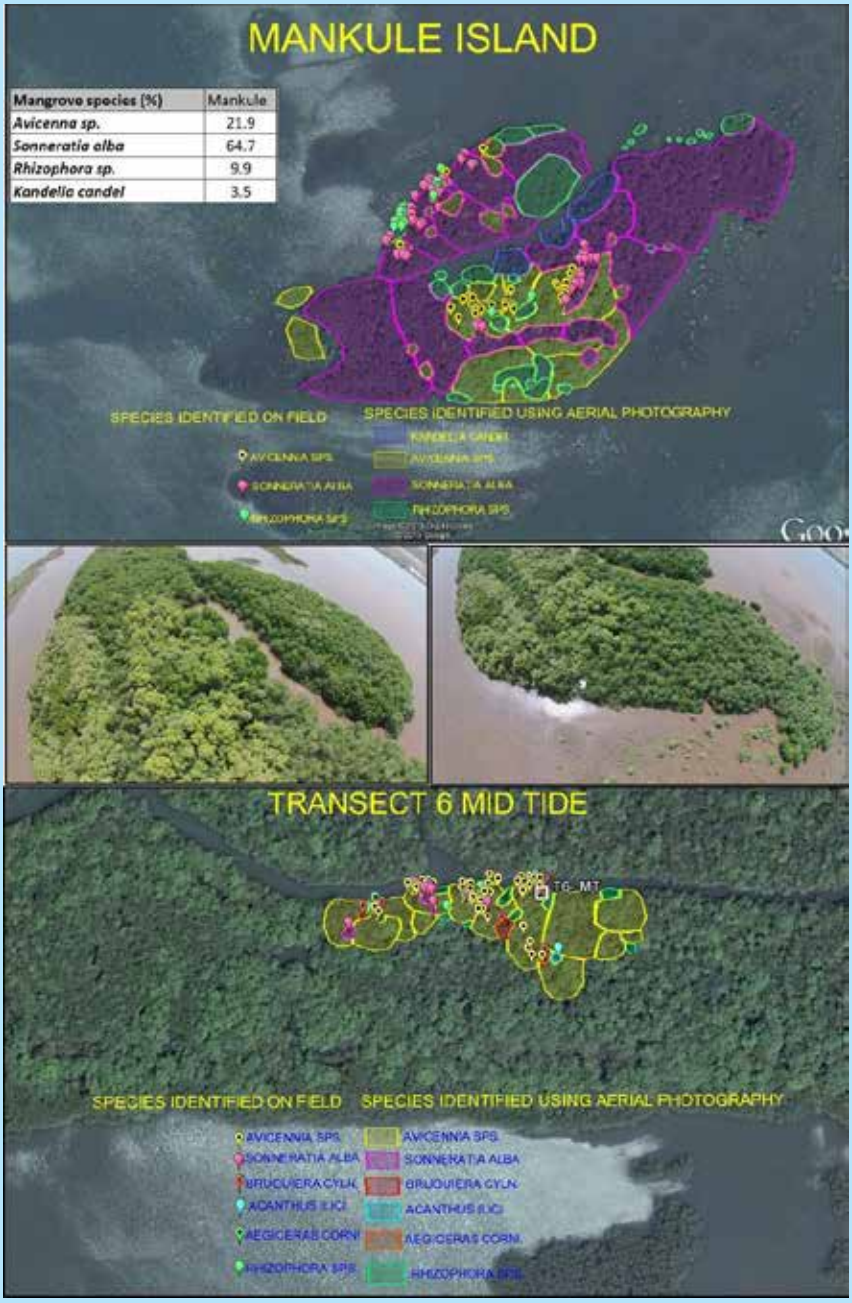


Table 6
Mangrove Species Composition in S.A.B.S and Mankule Island

Mangrove species (%)	S.A.B.S	Mankule Island
Avicennia officinalis	8.6	9.7
Avicennia marina	39.3	25.0
Sonneratia alba	15.4	43.1
Rhizophora mucronata	15.8	22.2
Rhizophora apiculata	0.9	--
Bruguiera cylindrica	11.1	--
Kandelia candel	0.2	--
Aegiceras corniculatum	1.9	--
Excoecaria agallocha	0.4	--
Others *Acanthus illicifolius* ***Derris heterophylla*** ***Porterasia coarctata*** ***Clerodendrum inerme***	6.3	--

was also monitored through the use of aerial photography. For Mankule Island, low altitude images and videos were taken using a drone, which can be used to recognize the mangrove species cover. The geo-tagged images taken were then aligned with Google Earth images and the species cover was identified and marked. Figure 16 shows the distributions of the mangrove species on Mankule Island based on the analysis of the aerial images. The percent distribution of the identified species based on the aerial images and on field data showed comparable results. For example, *Sonneratia alba* was a dominant species in the Mankule Island followed by Avicennia sp. and Rhizophora sp. (Table 6 & Figure 16). Similar species distributions can be mapped for other transects as shown in Figure 16 (bottom image - Transect 6 mid tide). Nevertheless this method can be considered a way forward in the identification of vegetation cover within a habitat.

Figure 16
Distribution of Mangrove Species in Mankule Island and Transect 6 (mid-tide) Based on the Analysis of the Drone Aerial Images

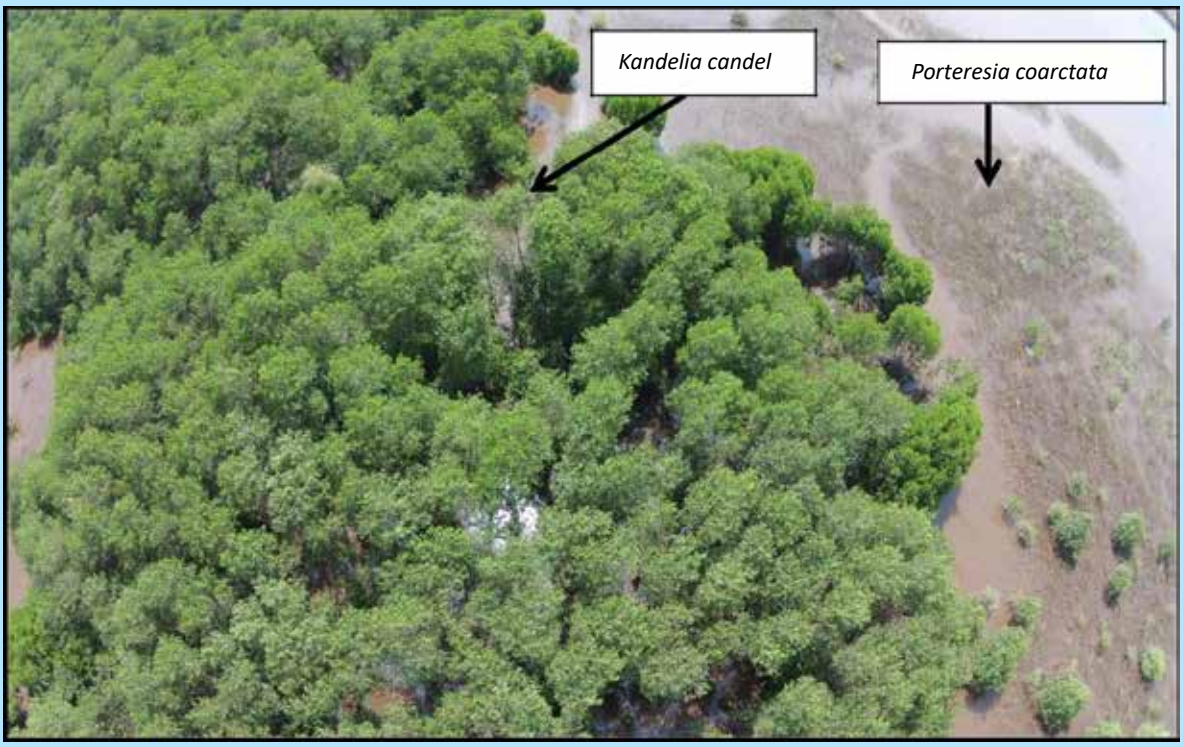


Mangrove species (%)	Mankule
Avicenna sp.	21.9
Sonneratia alba	64.7
Rhizophora sp.	9.9
Kandelia candel	3.5

Moreover, with the help of the aerial images, two further floral species were identified at Mankule Island. These are *Kandelia candel* and *Porteresia coarctata*, which were actually not found in our transect survey. Figure 17 is the drone aerial photo of the section of Mankule Island showing *Kandelia candel* and *Porteresia coarctata* colonizing mudflats. The mudflat area covered with the *Porteresia coarctata* helps in stabilizing the sediment, which further facilitates the growth of mangroves.

The diversity indices for the flora were calculated for Transects 1 - 6, the random stations and Mankule Island (Table 7). At the transects, the species diversity (Shannon index) ranged from 1.24 to 1.86; the species richness fluctuated between 1.45 and 3.05; and the species evenness

Figure 17
Aerial Photograph of the Section of Mankule Island Showing *Kandelia Candel* and *Porteresia coarctata* Coverage in the Mudflat Area



(Pielou's evenness) ranged from 0.83 to 0.99, whereas at the Random stations the species diversity (Shannon index) ranged from 1.38 to 1.69; species richness fluctuated between 2.21 to 3.28 ; and the species evenness (Pielou's evenness) ranged from 0.82 to 0.94 (Table 7). At station Mankule, the species diversity (Shannon index) ranged from 1.10 to 1.35; the species richness fluctuated between 1.60 to 2.63 ; and the species evenness (Pielou's evenness) ranged from 0.98 to 1.00 (Table 7). Based on the mean values, the species richness and diversity was relatively high in S.A.B.S. compared to Mankule Island (Table 8), whereas species evenness was higher in Mankule. Similarly tidal variations are observed in S.A.B.S. wherein the diversity and species richness were high in the lower intertidal zone.

Species Composition and Diversity of Macrofauna

Species belonging to eight macrofaunal groups were recorded from the study area. Among these, the polychaetes were the most abundant group, followed by the crustaceans, gastropods and bivalves (Table 9). The macrofaunal composition was similar to that reported in earlier studies from the Mandovi and the surrounding estuaries of Goa (Paruleka et al 1980; Parulekar & Ansari, 1986; Ansari et al 1986; Ansari et al 2007, Gaonkar et al 2013). Polychaetes were the most abundant species reported in all these studies.

Random identification of the polychaetes showed the presence of species such as *Nereis* sp., *Capitella* sp., *Sternaspis scutata* and the family Cossuridae. The Crustaceans were mostly dominated by groups such as isopods, amphipods, and brachyurans. Crabs identified mostly belonged to taxa sesarmidae, portunidae (*Portunus pelagicus*), paguridea and ocypodidae (*Uca vocans* and *Uca annulipes*). Among gastropods *Cerithidea* sp. and *Telescopium sp.* were the most abundant forms observed at most of the sampled locations (Figure 18). *Telescopium telescopium* was a major species that was found in S.A.B.S. Large beds *of Cerithidea sp*. were observed in the lower intertidal zones of both Islands, where

Table 7
Diversity Indices of the Flora at the Study Area

Stations (Zones)		S (Total Number of Species)	d (Species Richness)	J' (Evenness)	H' (Shannon index)
Transect 1	LT	7	2.63	0.96	1.86
	MT	6	2.26	0.94	1.69
	HT	5	2.22	0.99	1.59
Transect 2	LT	5	2.23	0.93	1.50
	MT	4	1.45	0.90	1.24
	HT	6	2.42	0.93	1.67
Transect 3	LT	7	2.70	0.95	1.85
	MT	5	2.43	0.89	1.43
	HT	7	3.05	0.86	1.68
Transect 4	LT	4	1.64	0.95	1.31
	MT	6	2.34	0.96	1.72
	HT	5	2.28	0.83	1.33
Transect 5	LT	5	2.01	0.91	1.46
	MT	5	2.20	0.96	1.55
	HT	5	2.64	0.83	1.33
Transect 6	LT	5	2.04	0.92	1.48
	MT	6	2.35	0.96	1.72
	HT	5	2.09	0.85	1.36
R 1		6	3.28	0.82	1.47
R 2		5	2.21	0.89	1.44
R 3		5	2.40	0.85	1.38
R 4		6	2.48	0.94	1.69
Mankule	LT	3	2.63	1.00	1.10
	MT	4	1.60	0.98	1.35

Cerithidea cingulate was in abundance. Beds of *Elysia* sp. were also observed at few locations.

Elysia sp were also reported from the Mandovi estuaries of Goa by Jagtap et al (2009). Gastropods belonging to *the taxa Neritidae, Ellobiidae and Muricidae* and nudibranchs were also observed in small numbers at few of the sampling locations. The bivalves mostly comprised species such as *Polymesoda erosa* and other small juvenile forms. A lot of reports are available on the ecology of *Polymesoda erosa* from Chorao Island (Clemente & Ingole 2009; 2011; Clemente *et al,* 2013). Oysters belonging to species *Saccostrea* and **Crassostrea** were also observed.

Total abundance of fauna was found to be the highest at Transect 4 mid-tide (4224/m^2) and the least abundance was observed at Transect 6 high-tide (248/m^2) (Figure 19). the average faunal abundance was found to be higher at S.A.B.S compared to Mankule Island. The macrobenthic faunal abundance recorded was more or less the same as those reported in the studies conducted in the surrounding estuarine areas (Ansari et al,2007) and also the shelf region along the west coast of India (Harikantra et al 1980).

Faunal groups also showed some tidal variations. Although polychaetes were abundant group of macrofauna in all samples, however its

Table 8
Mean Biodiversity Indices of Flora at S.A.B.S and Mankule Island

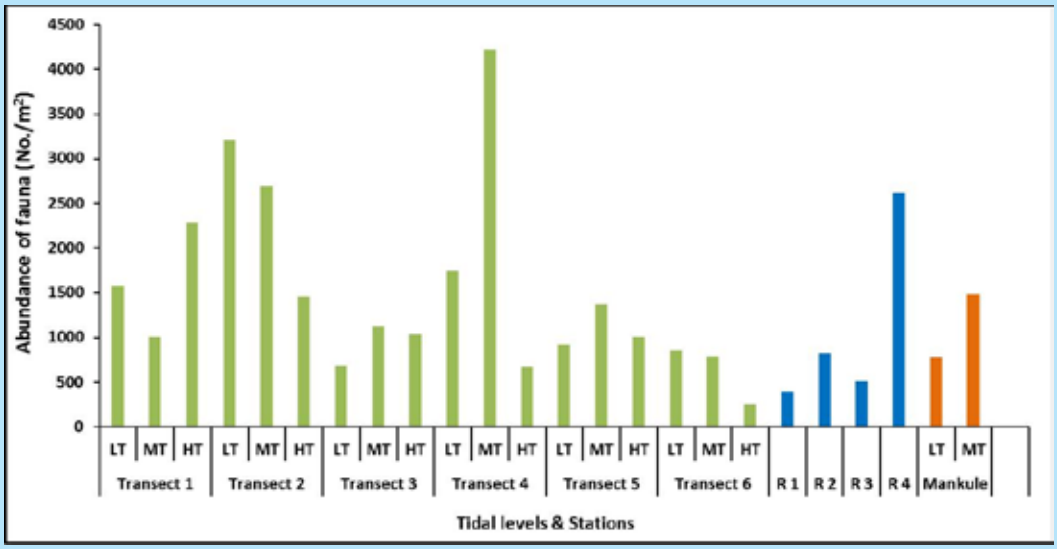
Floral Diversity	S (Total Number of Species)	d (Species Richness)	J' (Evenness)	H' (Shannon Index)
All stations (S.A.B.S)	9	3.97	0.81	1.78
Low-tide	9	3.66	0.88	1.92
Mid-tide	7	2.70	0.92	1.79
High-tide	7	3.07	0.88	1.72
Random stations	8	3.77	0.82	1.71
Mankule Island	4	1.60	0.98	1.35

Figure 18
Photos of Some of the Species That were Present in the S.A.B.S. and Mankule Island

Table 9
Macrofaunal Groups Recorded at the Study Area

Station (Zone) →	Transect 1			Transect 2			Transect 3			Transect 4			Transect 5			Transect 6			Random stations			Mankule		
Taxa ↓	**LT**	**MT**	**HT**	**LT**	**MT**	**HT**	**LT**	**MT**	**HT**	**LT**	**MT**	**HT**	**LT**	**MT**	**HT**	**LT**	**MT**	**HT**	**1**	**2**	**3**	**4**	**LT**	**MT**
Polychaeta	912	976	2260	2832	2664	1264	464	1096	952	1692	4080	660	756	1344	940	732	732	160	360	820	476	2504	544	1408
Crustacea																								
Brachyura	0	0	0	11	4	8	8	8	0	0	0	4	4	4	0	0	4	12	8	2	0	8	4	0
Hermit crab	0	0	0	1	0	0	0	0	0	0	0	0	0.5	0	0	1	1	1	1	0	0	1	1	0
Shrimp	0	0	0	5	0	0	0	0	0	8	4	4	0	0	0	0	0	0	0	0	4	0	0	11
Harpacticoida	32	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	4	0	0	0	0	0
Amphipoda	16	0	0	0	0	0	0	0	0	12	4	0	0	4	0	24	0	0	0	0	8	0	4	0
Cumacea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
Isopoda	424	0	4	229	8	64	0	8	68	4	124	0	0	0	0	32	0	0	0	0	4	0	172	27
Ostracoda	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0
Bivalvia																								
Polymesoda erosa	0	1	1	1	1	0	0	1	1	1	0	1	0	0	0	1	1	0	1	1	1	1	0	0
Other bivalves	0	4	16	0	0	4	8	0	0	0	0	0	8	4	4	52	12	24	0	0	12	0	48	37
Gastropoda																								
Telescopium telesco	1	2	2	0	3	1	0	4	7	1	4	2	5	2	2	6	3	3	1.5	2	4	5	1	2
Cerithidea sp.	180	16	0	128	8	92	204	0	8	0	4	0	148	0	48	0	4	44	0	0	0	88	0	0
Elysia sp.	0	4	0	0	0	0	0	4	0	13	0	0	0	9	6	0	1	1	0	0	2	0	0	0
Nudibranch	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	4	16	0	0	0	0	0
Other gastropods	0	0	0	0	0	16	0	0	0	0	0	0	0	0	8	0	8	0	0	1	0	0	0	0
Turbellaria	12	0	4	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0
Nematoda	8	0	0	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oligochaeta	8	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fish																								
Periophthalmus sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Fish larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0
Total (no./m2)	**1585**	**1011**	**2287**	**3207**	**2688**	**1457**	**684**	**1121**	**1036**	**1743**	**4224**	**671**	**921**	**1367**	**1008**	**851**	**786**	**249**	**392**	**826**	**511**	**2611**	**775**	**1490**

Figure 19
Total Abundance of Fauna in S.A.B.S and Mankule Island



dominance is greatly increased in the mid-tide zone, whereas crustaceans, gastropods and bivalves were mostly found at the low-tide level (Figure 20). The composition of the fauna also showed an intertidal variation at S.A.B.S. The four major faunal groups that were dominant at the three tidal zones are:

Low tide zone - Polychaeta (70.2 percent), Crustacea (7.7 percent), Gastropoda (6.5 percent) and Bivalvia (0.7 percent).

Mid tide zone - Polychaeta (94.9 percent), Crustacea (1.6 percent), Gastropoda (0.8 percent) and Bivalvia (0.2 percent).

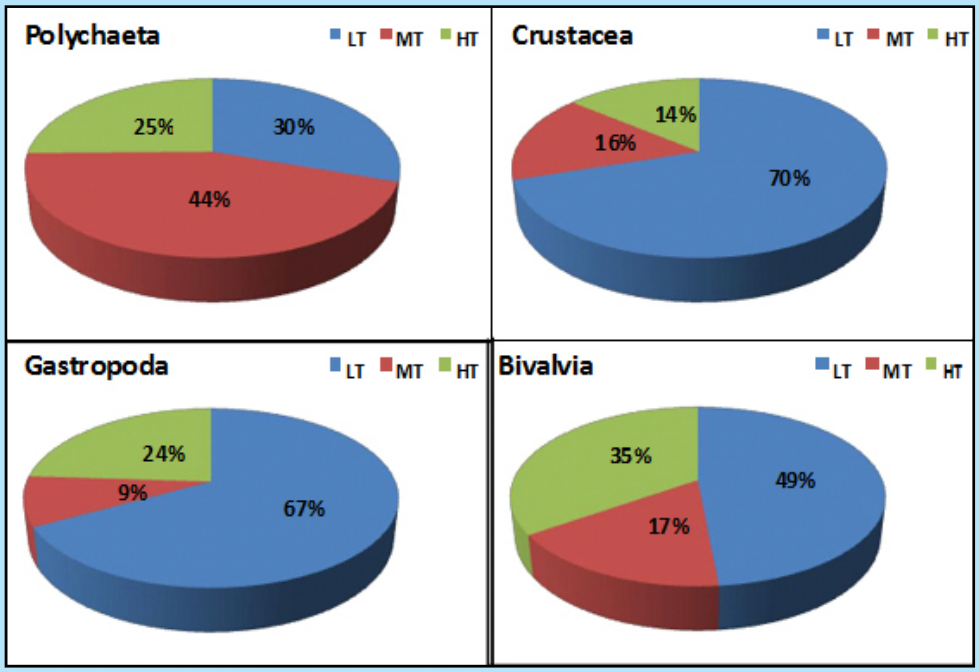
High tide zone - Polychaeta (89.1 percent), Gastropoda (3.5 percent), Crustacea (2.4 percent) and Bivalvia (0.7 percent).

The diversity indices for the fauna were calculated for all the stations (transects 1 - 6, Mankule and Random 1 - 4). At transects 1- 6, the species diversity (Shannon index) ranged from 1.25 to 1.91; the species richness ranged from 1.09 to 3.21; species evenness (Pielou's evenness) ranged from 0.78 to 0.92, whereas at the Random stations, species diversity (Shannon index) ranged from 1.12 to 1.86; the species richness fluctuated between 1.72 and 2.21, and the species evenness (Pielou's evenness) ranged from 0.70 to 0.90. At station Mankule, the species diversity (Shannon index) ranged from 1.61 to 1.76; species richness ranged from 1.69 to 2.31, and the species evenness (Pielou's evenness) ranged from 0.85 to 0.90 (Table 10).

The species diversity and species richness were found to be higher at S.A.B.S. as compared to Mankule Island, whereas the species evenness remained the same at both locations. Tidal variations were also observed to occur to some extent. the species diversity and evenness were higher at the low-tide level, whereas species richness was found to be higher at the mid-tide level (Table 11).

The biomass of the soft and hard forms was measured and is presented in Figure 21. Among the transects sampled, the total faunal biomass was found to be the highest at Transect 3 high-tide (496 g/m^2) and the least biomass was observed at the same transect at low-tide level (69.1 gm-^{2}). Among the Random stations, the highest biomass was observed at Random-3 (817.5 gm-^{2}) and the least biomass was observed at Random-1 (103.7 gm-2). At station Mankule, the biomass was observed at mid-

Figure 20
Percentage Distribution of Major Macrofauna in the Intertidal Zones of S.A.B.S.



tide level whereas the biomass was high at the low-tide level (Figure 21).

The biomass of the soft forms mostly comprised polychaetes, whereas the biomass of hard forms included organisms like hermit crabs, *Polymesoda, Periophthalmus* sp., and other brachyuran crabs.

The number of crab holes present in each quadrat was recorded. These crab holes were not dug for crabs and it was assumed that each crab hole was occupied by a single crab and that the number of crab holes therefore equals the number of crabs present in the quadrat. The numbers of crab burrows recorded are given in Figure 22. Among the transects, transect 2 low-tide showed a greater number of burrows, whereas transect 5 high-tide showed a lower burrows. Among the random stations, more number of burrows were observed at Random 2, whereas fewer burrows were observed at Random 1. At Mankule, more burrows were observed at the low-tide level when compared to the mid-tide level (Figure 22).

Environmental Indicators (Water and Sediment Quality)

Water Quality

Physico-chemical parameters

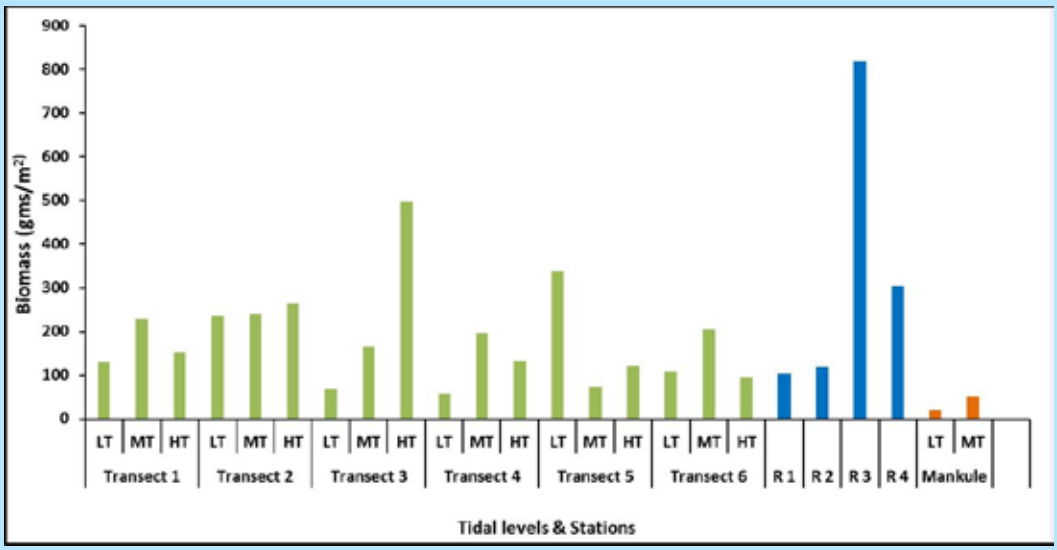
The physico-chemical conditions of the estuary surrounding the study site were recorded at six stations, which include two interior stations inside S.A.B.S., during both the high tide and the ebb tide at each (Table 12).. During the study period, the surface water temperature ranged between 30-32°C, and at the interior of S.A.B.S. it was noted to be in the range of 31-32 °C. The pH varied from 7.48 to 7.77 and salinity varied from 28 to 35 ppt. High salinity was recorded in the interior of S.A.B.S. during the ebb tide due to the effect of evaporation. The variation in salinity in the study area is mainly influenced by the tidal flow. The data recorded are similar to those of the pre-monsoon season, with high salinity and temperature. The pH was also in the range as measured by others in the Mandovi estuary (Gonsalves et al 2009 Shenai Tirodkar et al 2012 Shynu et al 2015).

At all stations, the water columns were shallow,

Table 10
Mean Diversity Indices of Fauna at the Study Area

Floral diversity	S (Total species)	d (Species Richness)	J' (Evenness)	H' (Shannon index)
All stations (S.A.B.S)	19	5.38	0.84	2.46
Low-tide	15	4.05	0.87	2.37
Mid-tide	15	4.41	0.85	2.30
High-tide	12	3.57	0.82	2.04
Random stations	15	4.30	0.86	2.33
Mankule Island	10	2.90	0.84	1.93

Figure 21
Biomass of Fauna Recorded at the Study Area

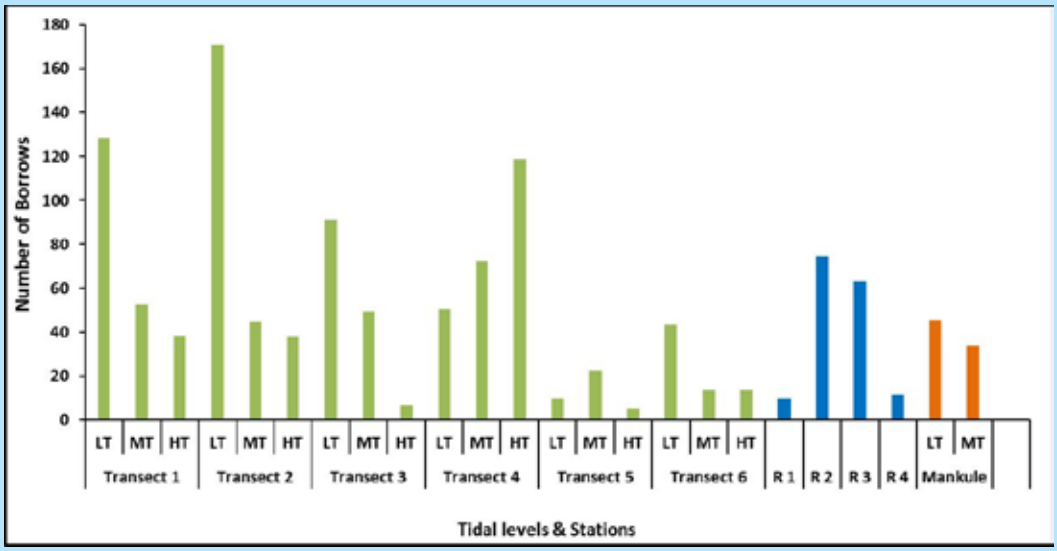


but a marked difference in depth was noted among the stations. The maximum depth of 7 m was recorded at station 5 on the Mapusa river side, which has a jetty close by. the water transparency in terms of Secchi depth indicates that the water was relatively more transparent in the Mapusa River followed by the Mandovi estuary and was turbid in the interiors of S.A.B.S., particularly at station 6 during high tide. This could be attributed to new building up of artificial mudflats by the State Forest Department for increasing the sightings of birds during tourist visits. Overall, the water was relatively turbid as the sampling stations were close to the mangrove areas/mudflats.

The dissolved oxygen concentration ranged from 2.3 to 5.4 mgs/l, where the highest dissolved oxygen value (5.4 mg/l) was recorded at station 2 along the Mandovi estuary and the lowest value (2.4 mg/l) was at station 7 in the interior of SABS during the high tide. A comparable range of DO was recorded in Mandovi estuary by Jagtap et al (2006). Overall, lower values of DO were observed in the interior of SABS as compared to the surroundings of the island. Decaying organic matter, which increases the organic load, resulting in very high BOD, was abundant in the mangroves, and may also cause depletion of dissolved oxygen.

The distribution patterns of suspended particulate matter (SPM) in water samples collected from transect stations along the estuary reveal a gradual increase in the concentrations of SPM from Mandovi estuary

Figure 22
Number of Crab Burrows Recorded at the Study Area



to its confluence with the Mapusa river. The SPM concentration within the estuarine stations is low, with a concentration of 78.3 mg/l. Higher concentrations of SPM were observed within the Mapusa river, with a concentration of 102 mg/l. However, in the interior of S.A.B.S., the suspended particulate matter was low, in the range of 15.3 to 17.5 mg/l, with the exceptional increase at high tide at station 6. This could again be due to the build-up of artificial mud flats in close proximity to the sampling location, which during high tide created a disturbance and increased the turbidity in its vicinity and upstream. A pattern similar to the that of the suspended particulate matter was observed for organic matter. The high SPM and OM values that were recorded were probably due to the influx during high tide near the mangrove and mudflat with a signature of organic matter, mostly detrital.

The nutrient concentrations, especially those of nitrogen and phosphorus, are key water quality parameters. In mangrove ecosystems, nutrients are considered to be the most important parameters that influence the growth, reproduction, and metabolic activities of the biotic components. In order to evaluate the quality of the water at S.A.B.S., a multivariate index of trophic state, TRIX, was used (Vollenweider et al 1998). The oxygen saturation rate and the, chlorophyll-a, dissolved inorganic nitrogen and dissolved inorganic phosphorus concentrations were used to obtain the TRIX index using the formula:

TRIX a = (log10 [chl.a x Ab % O x DIN x DIP]+K) / M, where:

- Chl.a : Concentration of chlorophyll a in mg/m^3
- Ab %O: Absolute value of the percentage of dissolved oxygen saturation [Abs(100-%O)]
- DIN : Dissolved inorganic nitrogen =(nitrate-NO3 + nitrite-NO2 + ammonium –NH^4), in mg/m
- DIP : Dissolved inorganic phosphorus in mg/m^3
- TP: Total phosphate in mg/m^3
- K = 1.5 , M = 1.2: scale values

The TRIX index is scaled from 0 to 10 as shown below:

0<TRIX≤4	High-quality
4<TRIX≤5	Good
5<TRIX≤6	Moderate
6<TRIX≤10	Poor and degraded

The TRIX results obtained at the different stations are shown in Table 12. They range from 3 to 5.4, which demonstrates that the water in the estuary is typically of good to high quality.

Table 11
Spatial Variation in Physico-chemical Parameters in Water and TRIX Index

Station	Water colour	Temp oC	pH	Salinity	Water depth (m)	Secchi depth (cm)	DO (mg/l)	SPM (mg/l)	OM (mg/l)	NO^2 µM	NO^3 µM	PO^4 µM	NH^3 µM	TRIX	SiO^3 µM
Mandovi River side															
Station 1 15°30'50.26"N 73°52'30.50"E	Brownish	30	7.72	28	2.5	70	3.24	42.8	29.7	0.01	0.19	0.01	1.47	3.31	11.4
Station 2 15°30'35.87"N 73°51'25.80"E	Brownish	30	7.77	29	1.5	70	5.41	48.9	32.2	0.06	0.51	0.01	1.52	3.05	9.4
Station 3 15°30'31.00"N 73°50'51.10"E	Greenish	30	7.72	30	1.4	70	5.30	39.2	28.9	0.12	0.01	0.01	1.55	3.53	9.7
Mapusa River side															
Station 4 15°31'23.66"N 73°51'10.03"E	Greenish	31	7.77	31	1.1	95	3.57	51.2	37.5	0.25	0.54	0.25	1.65	3.81	17.4
Station 5 15°31'38.81"N 73°52'8.41"E	Greenish	31	7.72	31	7.0	85	3.68	48.3	34.3	0.24	0.61	0.02	1.75	4.79	7.9
Interior Creeks of S.A.B.S.															
Station 6 15°30'55.71"N 73°51'46.47"E	Brownish	31	7.65	32	1.9	45	2.70	42.0	19.9	0.20	0.56	0.39	2.20	5.40	15.0
Station 6 Ebb	Brownish green	32	7.48	31	1.6	70	2.70	15.3	8.4	0.57	0.14	0.01	1.82	3.76	17.1
Station 7 15°30'58.60"N 73°51'8.81"E	Greenish	31	7.67	30	2.5	85	2.38	17.5	10.9	0.34	1.60	0.01	0.01	4.05	12.2
Station 7 Ebb	Brownish green	31	7.72	35	2.0	60	3.00	15.8	9.5	0.48	0.21	0.30	1.83	5.12	17.2

The biotic component of the water was also monitored for bacteria/pathogenic microorganisms and chlorophyll-a (Table 13).

The chlorophyll-a concentrations ranged from 0.801 to 5.4 mg/l. An overall high chlorophyll-a concentration was observed in the interior of S.A.B.S., which could be attributed to high productivity in the mangrove areas. The chlorophyll-a concentration in Chorao island follows a cyclical pattern with low values during monsoon and high values during the pre-monsoon. The chlorophyll-a concentration in the range from 1.9 - 23.4 mg/l was recorded by Gaonkar et al (2013). The presence of *E. coli* in the Mapusa River side and at the confluence of the Mandovi and Mapusa River could be attributed to human settlements near the study site.

Sediment Characteristics of S.A.B.S. and Mankule Island

The sediment samples were analysed for total carbon (TC), organic carbon (OC), total Nitrogen (TN), pore salinity, metal ions and grain size at different depths up to 10 cm in 2-cm sections. The detailed data of the analysis are presented in annexures I, II and III. Table 14 has the mean values of the sediment characteristics at different tidal zones at each transect. The OC in the sediments is a function of both the deposition rate of the

Table 12
Spatial Variation in Biotic Parameters of the Water

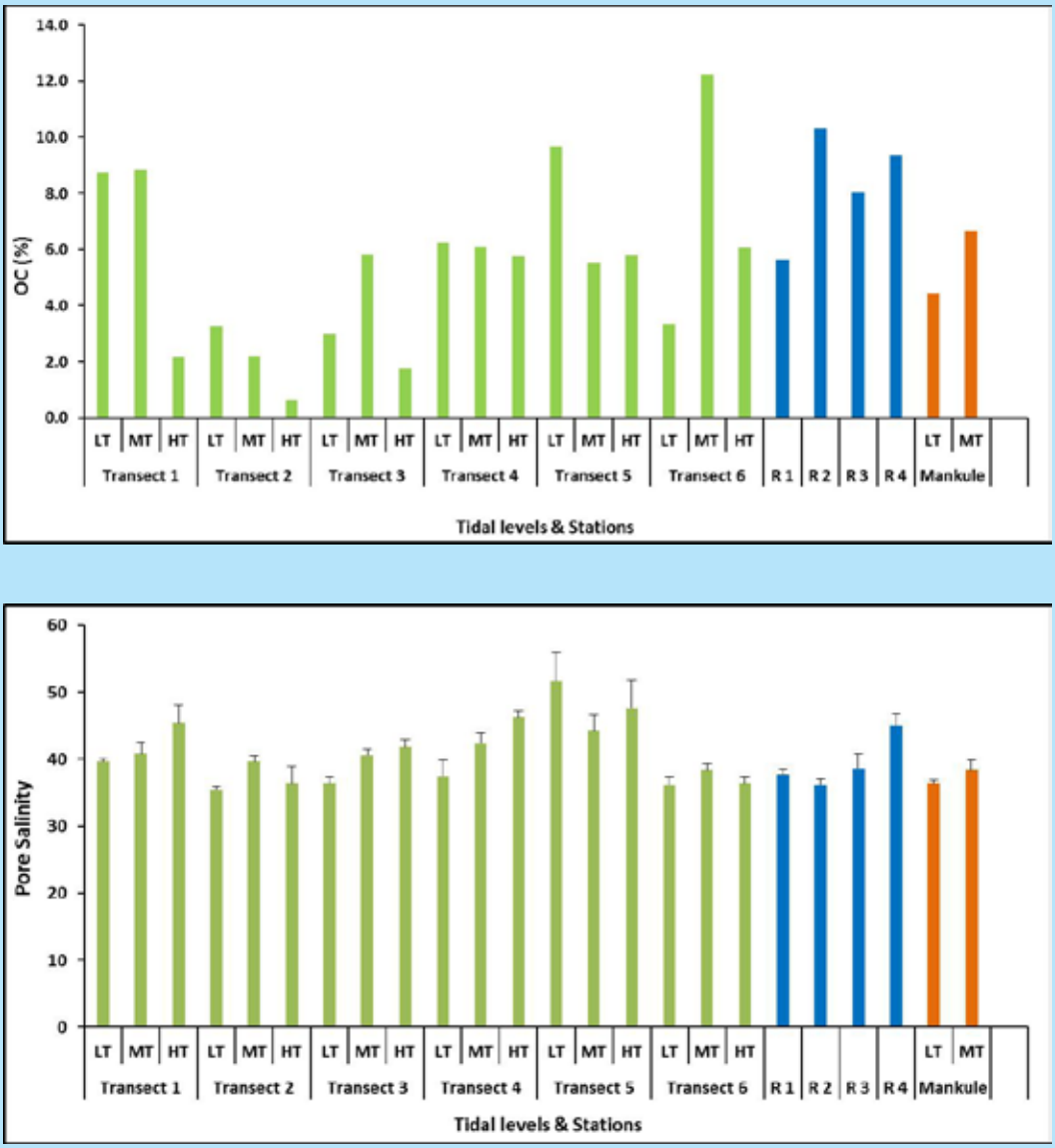
Station	Chlorphyll a mg/l	Bacterial Count (CFU/100 ml)	
		Total	Coliforms
Mandovi River side			
Station 1	1.60	5 x 103	ND
Station 2	0.80	4 x 103	ND
Station 3	1.40	1.2 x 104	3 x103
Mapusa River side			
Station 4	1.60	1.0 x 104	ND
Station 5	2.60	1.3 x 104	2 x 103
IInterior creeks of S.A.B.S.			
Station 6	4.40	9 x 103	ND
Station 6 Ebb	5.40	6 x 103	ND
Station 7	4.20	1.3 x 104	ND
Station 7 Ebb	5.40	9 x 103	ND

sediment and decomposition and regeneration within the sediment. The OC values varied from 0.64 percent to 12.24 percent at S.A.B.S. and from 4.45 percent to 6.67 percent at Mankule. High percentage of OC is recorded in the mid-tide zone of transect 6, followed by sediments in the interior of S.A.B.S. at random R2, R3 and R4 (Figure 23).

Transect 1 also showed a considerably high amount of organic carbon. The high organic carbon in the mangrove sediments may be due to the fine nature of the sediments (clay and silt sediments) and high rate of sedimentation and decomposition of mangrove foliage and other vegetative remains in the sediments. The mean concentration of the total carbon (TC) in the sediments was 5.93 percent (range between 1.77 and 12.24 percent). Kumar and Khan (2013), measured the organic carbon percentage in a range from 0.94 to 4.64 percent in the mangroves of Pondicherry, India. The estuarine sediment near Chorao Island showed an OC range from to 4.21 percent (Prajith et al 2015). The high organic carbon in the mangrove sediments may be due to the fine nature of sediments (clay and silt sediments) and high rate of the edimentation and decomposition of mangrove foliage and other vegetative remains in the sediments.

The pore water salinity in the core sediments of the sampled transect showed an increasing trend from low tide to mid tide and to high tide. It ranged from 35 to 51 ppt in the low tide zone, with an exceptional increase in salinity at transect 5 and in Random 4. At transect 5, the location was bounded by the dykes and probably the water mixing takes place only during the high tide. Hence there is more evaporation of the sediment water due to longer exposure. A similar case could be also observed at Random 4 location, which is located in a deep interior portion of S.A.B.S. The mid tide pore salinity ranged from 38 to 44 ppt, followed by high tide, ranging from 36 to 47 ppt (Figure 23). In the case of Mankule island, the salinity ranged from 36 to 38 ppt, indicating that the sediments are constantly exposed to seawater and during the high tides the Island was completely inundated. Further, the pore salinity also increased with depth, with a higher range of salinity at a depth of 8-10 cm. High salinity values ranging from 35 to 45 ppt in Pichavaram and Muthupet mangroves during the dry seasons have been reported, and in some of the pockets of the Muthupet mangrove the salinity was as high as 75 ppt (Selvam, 2003). Salinity has been reported to influence greatly the succession and dominance of various aquatic organisms. Increasing the

Figure 23
Variation in Organic Carbon and Pore Water Salinity at Different Tidal Zones in S.A.B.S. and Mankule Island



salinity will cause a profound impact on animals such as benthic forms and shrimps.

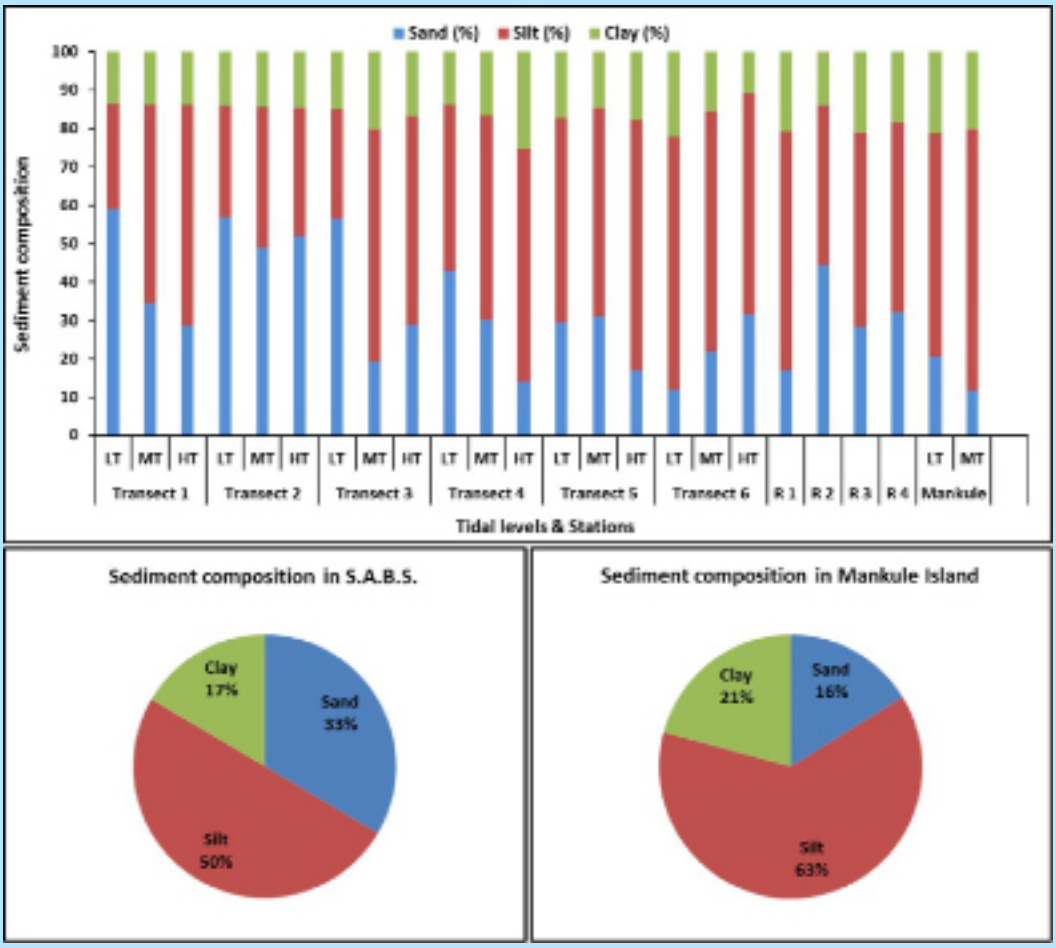
The mean sediment composition indicates that there is little clay in the S.A.B.S. mangrove ecosystem (Figure 24). The mean silt and sand contents of the sediment collected from S.A.B.S were about 50 percent and 33 percent, respectively. Similarly, in the case of Mankule Island the mean silt composition was 63 percent and clay 21 percent. However, in transects 1, 2 & 3 high sand contents recorded, as these sediment samples were collected from the mudflat, indicating that there is deposition of sand due to wave action and tidal influence. Overall, the sediment structure in the mangrove ecosystem of S.A.B.S. and Mankule Island is silty loam. The presence of large amounts of silt and clay particles in the core sediments is due to the existence of mangroves with areal root structures in this region. These root structures trap floating detritus and reduce the flow and ultimately create conditions conducive for suspended clay and silt particles settling in the estuary (Veerasingam et al 2015). A similar silty clayey sediment texture was reported in the core sediment collected in the estuary near the Chorao Island (Prajith et al 2015).

Table 13
Sediment Characteristics of the Mangrove Habitat of S.A.B.S. and Mankule Island

Station (Zone)		TC (%)	OC (%)	TN (%)	Pore Salinity	Sand (%)	Silt (%)	Clay (%)
Transect 1	LT	8.74	8.72	0.53	39.6	59.1	27.5	13.4
	MT	8.84	8.82	0.55	40.8	34.4	51.8	13.8
	HT	2.21	2.14	0.24	45.4	28.7	57.6	13.7
Transect 2	LT	3.28	3.26	0.24	35.4	56.9	29.2	13.9
	MT	2.26	2.17	0.16	39.6	48.9	36.7	14.4
	HT	0.74	0.64	ND	36.4	52.1	33.4	14.6
Transect 3	LT	2.98	2.96	0.20	36.4	56.5	28.4	15.1
	MT	5.82	5.80	0.44	40.6	19.2	60.6	20.2
	HT	1.77	1.75	0.09	41.8	28.9	54.2	16.9
Transect 4	LT	6.42	6.22	0.44	37.4	42.8	43.5	13.6
	MT	6.38	6.08	0.45	42.4	30.2	53.3	16.5
	HT	5.76	5.75	0.40	46.2	13.9	60.8	25.3
Transect 5	LT	9.66	9.65	0.66	51.6	29.6	53.1	17.3
	MT	5.51	5.50	0.49	44.2	31.0	54.4	14.5
	HT	5.78	5.77	0.37	47.6	17.0	65.3	17.7
Transect 6	LT	3.35	3.34	0.76	36.2	12.0	65.9	22.1
	MT	12.24	12.24	1.02	38.4	22.0	62.4	15.6
	HT	6.07	6.06	0.86	36.4	31.4	57.7	10.9
R 1		5.63	5.62	0.38	37.6	17.1	62.0	20.9
R 2		10.36	10.32	0.70	36.2	44.4	41.7	13.9
R 3		8.05	8.04	0.58	38.6	28.5	50.5	21.0
R 4		9.39	9.35	0.64	45.0	32.1	49.6	18.3
Mankule	LT	4.46	4.45	0.31	36.4	20.6	58.1	21.4
	MT	6.69	6.67	0.49	38.4	11.8	68.0	20.2

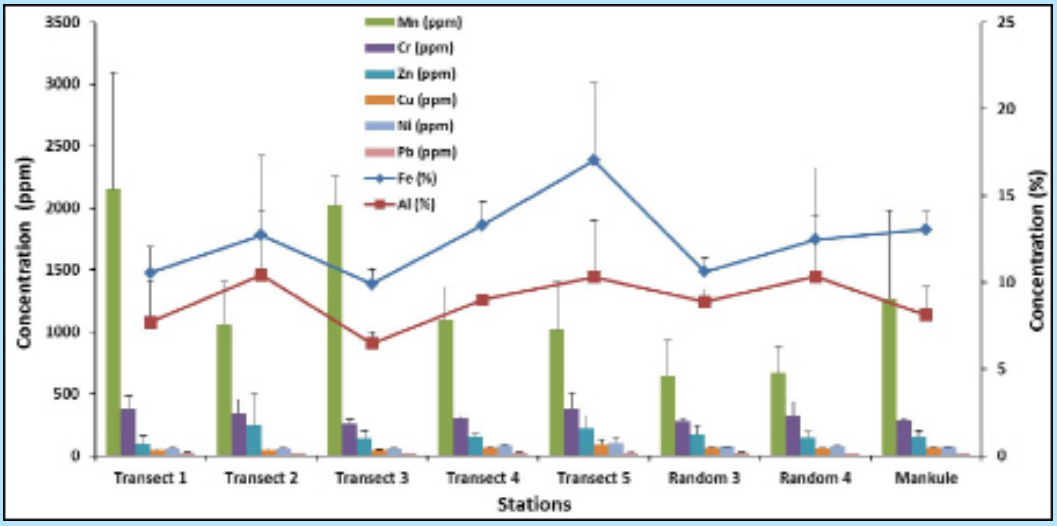
The vertical profiles of heavy metals in the sediments show enrichment of Fe in the range 11 - 22.9 percent. In the case of sediments from Mankule Island, enrichment of Fe was observed in the range 11.6 – 14.4 percent (Figure 25). The sediment samples from the interior of SABS showed Fe in the range 9.7 – 11.4 percent. Overall, the concentration of Fe was high in Transect 5 and in the interior of S.A.B.S. Random 4 showed Fe concentration of 19.9percent. In the case of Al in the soil sediments, the concentration varied within the range 6.3 -17 percent and 11.6 – 14.4 percent in S.A.B.S and Mankule Island respectively. The concentration of Mn in the soil sediments in the transects of S.A.B.S. varied within the range 673 – 3285 ppm, and in the case of Mankule Island the sediment showed Mn concentration in the range 879-1536 ppm. The Mn concentrations in the sediments from the interior of S.A.B.S. ranged from 482 to 1155 percent. Overall the highest concentration of Mn was observed in transect 1. The enrichment of Fe and Mn reflects the intensity of anthropogenic inputs related to iron ore processing in the upstream region of the estuary and also during the transportation of the ore. The concentrations of other minor elements, i.e., Cr, Zn, Cu, Ni and Pb, showed similar trends in both S.A.B.S. and Mankule Island (Figure 25). The presence of high amounts of Fe and Mn and similar concentrations of other metals in the Mandovi

Figure 24
Average Percent Composition of Sand, Silt and Clay of the Sediments at Different Intertidal Zones at S.A.B.S. and Mankule Island



Below Figures are average percentage values of all samples.

Figure 25
Heavy Metal Distribution in the Sediment of S.A.B.S, and Mankule Island



estuary have been reported (Sappal *et al 2014; Prajith et al 2015;*Shynu et al 2015). The Estuarine mudflats are potential sites for deposition of organic matter derived from terrigenous, marine, atmospheric and anthropogenic sources and are mainly associated with fine grained particles which get trapped in this environment, thus acting as traps for trace metals.

Relationship Between Benthic Fauna and Environmental Factors

An attempt was made to correlate the environmental parameters with benthic macrofaunal abundance and groups. The sediment composition, i.e., sand, silt and clay, showed a significant relationship with gastropods and number of borrows. There was no significant correlation with the total faunal abundance ($p < 0.1$).

A positive correlation was observed for sediment sand versus gastropods ($r = 0.633$; $p > 0.01$) and burrows ($r = 0.51$; $p > 0.01$). In contrast, silt showed significant negative correlation with gastropods ($r = -0.651$; $p > 0.01$) and with borrows ($r = -0.592$; $p > 0.01$). Further, the correlation between clay and gastropods was negative ($r = -0.343$; $p > 0.1$) but showed no relationship with burrows. This shows the preference of the organisms for the sediment characteristics of the habitat.

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Annexures

Annexure I

Pore Water Salinity of the Sediment in S.A.B.S. and Mankule Island

Station (Depth, cm)		Low Tide	Mid Tide	High Tide
Transect 7	(0-2)	39	38	41
	(2-4)	39	40	45
	(4-6)	40	42	47
	(6-8)	40	42	47
	(8-10)	40	42	47
Transect 6	(0-2)	35	38	34
	(2-4)	36	40	35
	(4-6)	36	40	35
	(6-8)	35	40	38
	(8-10)	35	40	40
Transect 5	(0-2)	38	39	40
	(2-4)	36	41	43
	(4-6)	36	41	42
	(6-8)	36	41	42
	(8-10)	36	41	42
Transect 4	(0-2)	35	41	45
	(2-4)	36	42	45
	(4-6)	36	42	47
	(6-8)	40	42	47
	(8-10)	40	45	47
Transect 3	(0-2)	45	40	44
	(2-4)	50	45	42
	(4-6)	53	45	50
	(6-8)	55	46	51
	(8-10)	55	45	51
Transect 2	(0-2)	35	40	38
	(2-4)	38	38	36
	(4-6)	36	38	36
	(6-8)	36	38	36
	(8-10)	36	38	36
Transect 1	(0-2)		36	
	(2-4)		38	
	(4-6)		38	
	(6-8)		38	
	(8-10)		38	

Annexure I (*Contd...*)

Station (Depth, cm)		Low Tide	Mid Tide	High Tide
Transect	(0-2)		35	
	(2-4)		36	
	(4-6)		37	
	(6-8)		37	
	(8-10)		36	
Transect	(0-2)		35	
	(2-4)		38	
	(4-6)		40	
	(6-8)		40	
	(8-10)		40	
Transect	(0-2)		42	
	(2-4)		45	
	(4-6)		46	
	(6-8)		46	
	(8-10)		46	
Transect	(0-2)	36	36	
	(2-4)	37	38	
	(4-6)	37	39	
	(6-8)	36	40	
	(8-10)	36	39	

Annexure II
Sediment Composition of S.A.B.S. and Mankule Island

		Sand (> 63 µm)			Silt (4 - 63 µm)			Clay (< 4 µm)		
Station (Depth, cm)		Low Tide	Mid Tide	High Tide	Low Tide	Mid Tide	High Tide	Low Tide	Mid Tide	High Tide
Transect	(0-2)	76.4	38.2	27.5	16.3	51.6	59.8	7.3	10.2	12.7
	(2-4)	57.9	30.0	20.8	29.6	58.3	63.7	12.4	11.7	15.6
	(4-6)	60.3	27.4	25.0	26.3	56.3	60.0	13.5	16.3	15.0
	(6-8)	52.1	46.2	34.3	33.6	43.0	52.4	14.3	10.7	13.3
	(8-10)	48.6	30.0	35.7	31.8	49.8	52.1	19.6	20.3	12.2
Transect	(0-2)	28.0	57.8	22.6	48.2	32.4	51.8	23.8	9.7	25.6
	(2-4)	60.3	53.4	39.6	28.0	33.8	40.8	11.7	12.8	19.7
	(4-6)	68.9	40.1	70.3	20.9	42.5	20.3	10.2	17.4	9.4
	(6-8)	64.2	44.3	62.1	23.4	40.4	29.0	12.4	15.3	8.9
	(8-10)	63.1	48.9	65.7	25.2	34.4	25.0	11.7	16.7	9.3
Transect	(0-2)	58.7	36.9	39.6	25.7	48.2	45.7	15.6	14.9	14.7
	(2-4)	56.4	14.2	31.8	28.0	63.8	55.1	15.6	22.0	13.1
	(4-6)	53.4	15.6	36.6	32.8	62.4	48.5	13.8	22.0	14.9
	(6-8)	56.2	9.7	21.9	29.0	68.3	58.2	14.8	22.0	19.9
	(8-10)	57.9	19.6	14.6	26.7	60.3	63.6	15.4	20.1	21.8
Transect	(0-2)	40.6	55.8	24.5	48.2	34.7	59.2	11.2	9.5	16.3
	(2-4)	45.5	15.7	9.7	42.1	64.5	65.2	12.4	19.8	25.2
	(4-6)	49.2	26.6	14.2	37.9	53.7	61.3	12.9	19.7	24.4
	(6-8)	49.0	18.6	9.7	37.7	61.6	59.7	13.2	19.8	30.6
	(8-10)	29.8	34.3	11.6	51.9	51.9	58.6	18.3	13.8	29.8
Transect	(0-2)	28.7	12.9	42.1	54.6	68.2	47.9	16.8	18.8	10.0
	(2-4)	38.8	33.6	8.5	47.7	52.4	74.3	13.5	14.0	17.2
	(4-6)	28.1	38.9	8.9	53.6	48.1	71.6	18.2	13.0	19.5
	(6-8)	23.7	40.0	13.3	56.6	47.8	67.2	19.7	12.2	19.6
	(8-10)	28.7	29.9	12.0	53.2	55.5	65.5	18.1	14.6	22.5
Transect	(0-2)	17.4	14.7	42.7	59.7	69.7	48.5	22.9	15.6	8.82
	(2-4)	3.2	17.5	43.7	72.1	67.0	47.8	24.7	15.4	8.49
	(4-6)	6.9	14.6	55.8	71.8	68.3	37.0	21.3	17.1	7.15
	(6-8)	23.7	52.1	7.8	58.5	38.7	78.1	17.8	9.2	14.09
	(8-10)	8.7	11.2	7.1	67.6	68.2	77.0	23.7	20.6	15.84
Transect	(0-2)	6.1			69.5			24.4		
	(2-4)	14.4			59.4			26.3		
	(4-6)	20.9			59.1			20.1		
	(6-8)	20.1			66.2			13.7		
	(8-10)	24.3			55.7			20.0		
Transect	(0-2)	49.9			40.2			9.9		
	(2-4)	37.5			47.6			14.9		
	(4-6)	25.7			55.0			19.3		
	(6-8)	48.5			37.8			13.7		
	(8-10	60.3			28.1			11.6		

Annexure II (*Contd...*)

		Sand (> 63 µm)			Silt (4 - 63 µm)			Clay (< 4 µm)		
Station (Depth, cm)		**Low Tide**	**Mid Tide**	**High Tide**	**Low Tide**	**Mid Tide**	**High Tide**	**Low Tide**	**Mid Tide**	**High Tide**
Transect	(0-2)	28.2			52.3			11.6		
	(2-4)	23.1			52.4			19.5		
	(4-6)	30.2			51.2			24.5		
	(6-8)	24.4			52.4			18.7		
	(8-10)	36.5			44.1			23.1		
Transect	(0-2)	30.8			51.9			19.4		
	(2-4)	23.9			57.0			17.3		
	(4-6)	38.2			46.1			19.1		
	(6-8)	46.7			37.6			15.7		
	(8-10)	20.7			55.3			15.6		
Transect	(0-2)	21.8	22.8		53.8	60.1		24.1	17.2	
	(2-4)	3.3	2.3		70.3	75.7		24.4	22.0	
	(4-6)	22.2	13.6		59.1	66.1		26.4	20.3	
	(6-8)	19.9	18.0		60.1	62.7		18.7	19.4	
	(8-10)	35.6	2.2		47.0	75.4		20.0	22.4	
								17.4		

Annexure III

Heavy Metal Concentrations of the Sediments in S.A.B.S. and Mankule Island

Station (Depth, cm)		Fe (%)	Al (%)	Mn (ppm)	Cr (ppm)	Zn (ppm)	Cu (ppm)	Ni (ppm)	Pb (ppm)
Transect	(0-2)	12.0	7.4	3284.6	428.3	139.8	50.4	59.0	20.1
	(2-4)	11.2	7.5	2141.4	349.0	92.6	49.0	47.8	20.3
	(4-6)	11.6	11.8	672.7	287.0	164.6	65.6	78.5	34.7
	(6-8)	8.8	6.0	2221.6	298.7	0.0	35.8	49.7	16.6
	(8-10)	9.2	5.8	2447.2	544.3	95.6	44.9	46.5	13.9
Transect	(0-2)	9.3	8.0	1090.1	277.8	91.1	42.1	48.3	26.2
	(2-4)	10.8	8.8	750.7	286.5	123.1	49.8	59.9	18.9
	(4-6)	10.1	8.6	663.4	269.0	202.3	60.0	69.9	21.6
	(6-8)	20.5	17.0	1443.8	547.8	115.8	53.9	64.3	21.0
	(8-10)	13.0	9.8	1341.5	315.1	704.1	55.6	64.0	23.5
Transect	(0-2)	9.1	6.0	2270.7	245.6	170.6	45.3	55.3	17.0
	(2-4)	9.6	6.0	1669.3	247.2	87.1	48.3	53.9	17.8
	(4-6)	9.1	6.3	1922.0	232.1	237.2	48.2	55.1	14.8
	(6-8)	10.5	6.6	2153.1	287.7	94.1	55.0	62.1	24.0
	(8-10)	11.0	7.5	2091.7	303.1	100.9	56.6	63.3	25.9
Transect	(0-2)	11.4	8.5	1110.5	287.5	193.0	67.5	86.7	23.4
	(2-4)	12.9	8.9	892.2	287.3	151.6	70.2	79.7	25.6
	(4-6)	13.7	9.2	981.3	312.0	140.0	70.6	83.1	31.1
	(6-8)	13.2	9.0	958.3	297.2	140.3	69.5	82.8	26.4
	(8-10)	15.2	9.4	1551.7	332.7	155.2	67.1	84.6	22.3
Transect	(0-2)	20.8	15.4	1464.9	467.0	244.8	127.9	141.2	32.7
	(2-4)	22.9	11.6	1414.6	568.7	387.4	140.3	147.2	37.8
	(4-6)	13.3	8.0	726.9	292.1	152.7	65.4	75.7	20.6
	(6-8)	13.8	7.6	719.8	278.4	197.0	64.0	74.8	22.1
	(8-10)	14.4	8.9	772.2	309.8	150.6	65.4	80.5	24.0
Random	(0-2)	10.2	8.2	1155.0	265.1	162.9	67.3	76.9	23.2
	(2-4)	9.7	8.3	545.2	254.8	125.6	69.3	78.0	20.6
	(4-6)	10.3	8.5	477.7	259.4	197.6	64.4	77.7	27.9
	(6-8)	11.4	9.7	568.4	317.3	280.6	62.5	75.6	29.1
	(8-10)	11.6	9.6	481.8	287.4	103.8	64.4	78.5	24.4

Annexure III (*Contd...*)

Station (Depth, cm)		Fe (%)	Al (%)	Mn (ppm)	Cr (ppm)	Zn (ppm)	Cu (ppm)	Ni (ppm)	Pb (ppm)
Random	(0-2)	9.7	8.4	705.0	257.6	239.3	60.7	72.2	24.8
	(2-4)	10.6	9.0	559.4	278.6	137.9	61.1	77.8	22.1
	(4-6)	11.0	9.1	490.0	270.5	118.3	59.1	74.2	19.8
	(6-8)	19.9	16.6	1024.1	530.2	126.6	66.2	83.1	23.0
	(8-10)	11.0	8.6	572.1	277.9	108.6	60.1	76.5	21.5
Mankule	(0-2)	12.3	7.9	1522.5	276.1	138.9	66.1	75.9	21.5
	(2-4)	12.7	7.8	1536.5	320.6	108.7	67.2	73.2	22.7
	(4-6)	13.3	7.8	981.0	292.9	285.7	67.9	77.7	22.3
	(6-8)	13.3	8.1	879.1	286.2	139.0	67.4	78.3	18.3
	(8-10)	14.4	8.1	934.7	297.4	108.1	65.8	79.4	19.5
Mankule	(0-2)	11.6	7.4	2632.2	266.0	111.4	64.0	69.9	21.9
	(2-4)	11.9	7.1	1211.2	263.2	148.9	60.8	68.5	24.2
	(4-6)	13.7	7.6	1098.2	286.5	235.6	68.6	73.7	21.8
	(6-8)	13.3	11.1	941.6	290.7	147.0	62.0	68.6	26.1
	(8-10)	13.9	8.3	953.4	291.3	121.3	64.2	73.2	23.0

About the Study

This study provides a rapid ecological baseline assessment of Dr. Salim Ali Bird Sanctuary and its vicinity based on the three key biophysical indicators, viz. (i) habitat distribution and human impact, (ii) population and community structure and composition, and (iii) environmental indicators (water and sediment quality). The sanctuary has been selected as a pilot site for the implementation of the Coastal Marine Protected Area (CMPA) measures in order to improve the conservation and sustainable use of biodiversity, which will be evaluated based on the results of the ecological baseline assessment. The key results of the study are organized along the three biophysical indicators given above.

The CMPA Project

The project "Conservation and Sustainable Management of Coastal and Marine Protected Areas" (CMPA) is a project of Indo-German technical cooperation. It is funded by the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) and implemented by the Ministry of Environment, Forests and Climate Change (MoEFCC), Government of India, and the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH on behalf of BMUB.

Established to support the achievement of the Aichi targets of the Convention on Biological Diversity, the project's overall goal is to contribute to conservation and sustainable use of biodiversity in selected areas along the coast of India. Taking into consideration the economic importance of the coastal zone for large segments of the population, the project's approach is people-centered, thus ensuring the support for conservation by those depending on coastal ecosystems.

CMPA Technical Report Series

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Ecological Status Assessment of Dr. Salim Ali Bird Sanctuary and Estuarine Areas of Chorao Island

July 2015

Implemented by

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Conservation and Sustainable Management of Coastal and Marine Protected Areas