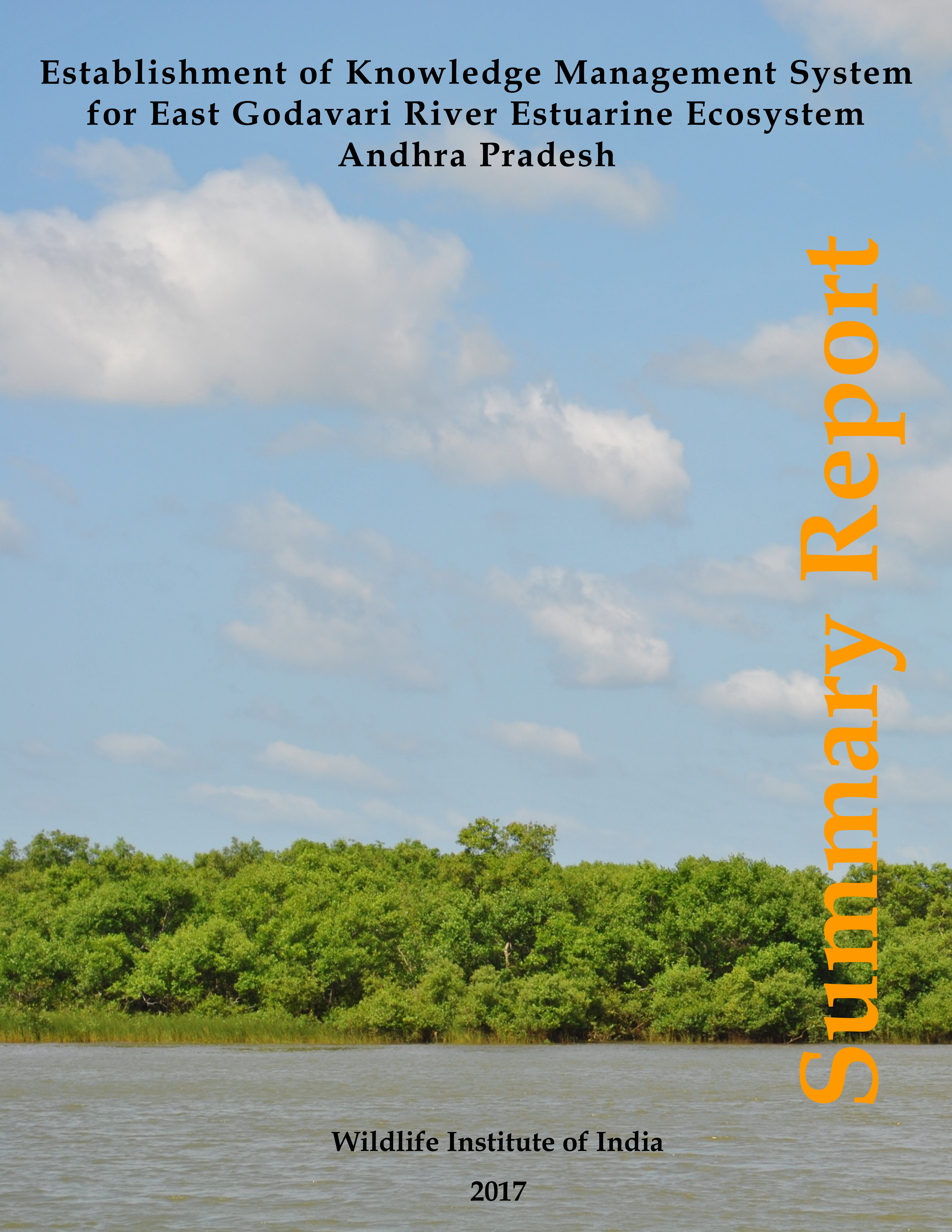
Establishment of Knowledge Management System for East Godavari River Estuarine Ecosystem Andhra Pradesh



Summary Report

Wildlife Institute of India

2017

The East Godavari River Estuarine Ecosystem (EGREE)encompassing the Godavari mangroves provides several ecosystem services ranging from food and livelihood security to shoreline stabilization and protection of life and assets from storm surges and hurricanes. Despite this, these ecosystems continue to be under a range of anthropogenic and non-anthropogenic pressure, and thereby continue being degraded and converted for alternate uses.

***G**lobal warming affect the marine and coastal ecosystems at greater extent. According to the Intergovernmental Panel on Climate Change, sea levels in India are expected to rise at the rate of 2.4 mm a year; in 2050 the total increase will be 38 cm.*

There are many causes to it which include conversion of mangroves to aquaculture, agriculture, and salt pans; effluent discharge from industries; eutrophication; siltation of Kakinada Bay and its rivers; anthropogenically -induced river flow change and erosion; and over-exploitation of mangrove forests, cattle grazing, fuel wood, boat manufacture and shells.

EAST GODAVARI RIVER ESTUARINE ECOSYSTEM

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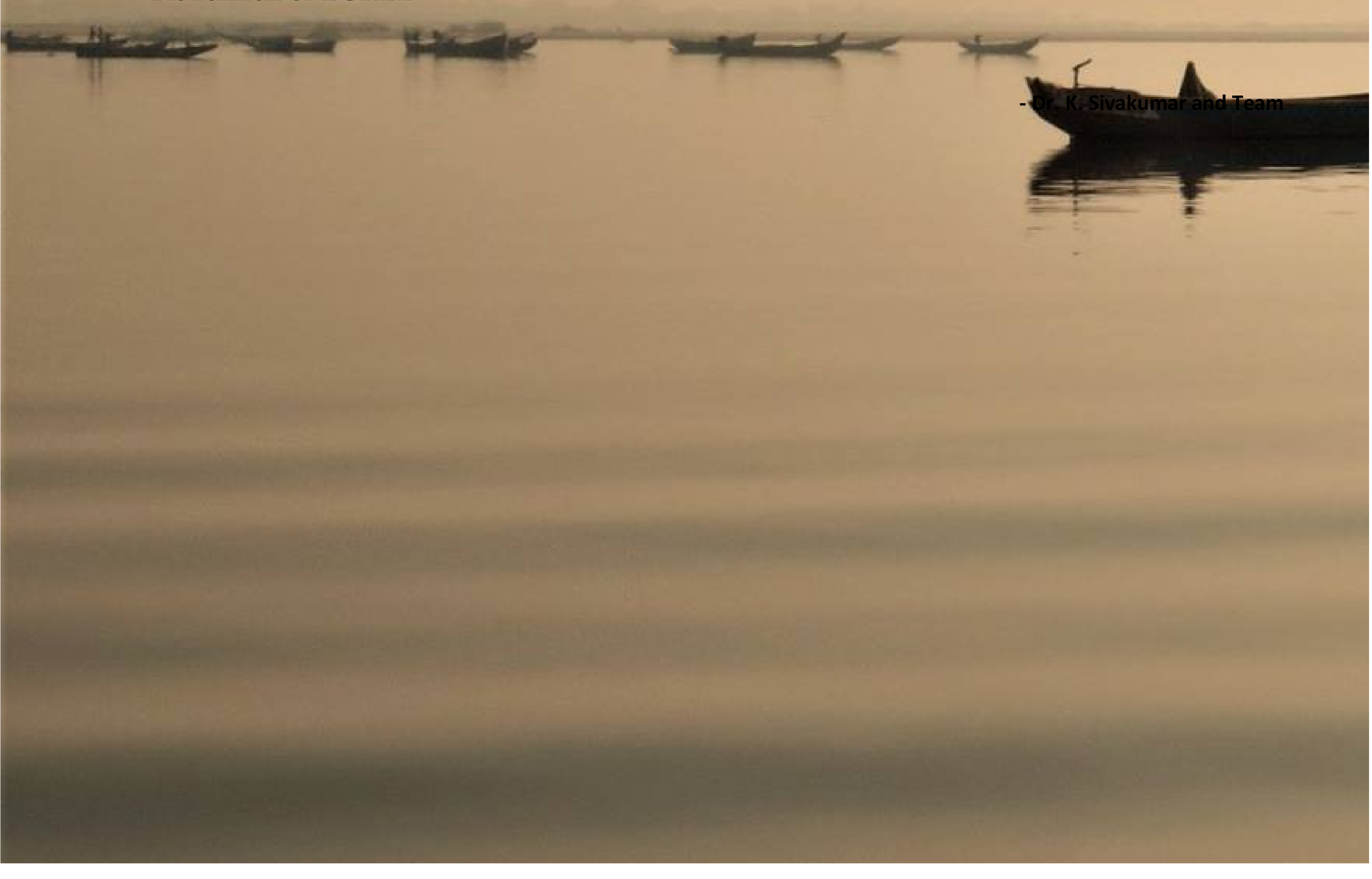

- Dr. K. Sivakumar and Team

The East Godavari River Estuarine Ecosystem (EGREE), encompassing the Godavari mangroves, is the second largest area of mangroves along the east coast of India. The area is rich in coastal and marine floral and faunal diversity and generates significant ecological and economic benefits such as shoreline protection; livelihood sustenance; and carbon sink services.

It is situated at the confluence of Godavari River with Bay of Bengal in the East Godavari district of Andhra Pradesh. The geographical scope of this study lies between 16°59'23" N, 82°18'16" E and 16°34'57" N, 82°18'38" E.

EGREE encompasses the vast delta of Godavari River along with other coastal habitats such as mangroves, river channel, floodplains, natural levees, bay, mudflats, tidal creeks, sand spits, beaches etc.

Presence of a 17 km-long spit, called Hope Island provides natural shelter to the coast and city of Kakinada. It has allowed the establishment of a major fishing harbor and the Kakinada Port, thereby accruing high economic values to the region.

It is an Important Bird Area (IBA), with a recorded population of 236 bird species, of which 88 are migratory, including several that are threatened.

In recognition of its national and global biodiversity significance, a part of the EGREE area is gazetted as Coringa Wildlife Sanctuary (CWLS).

In addition to its biodiversity value, EGREE also has enormous economic significance, with the last few decades witnessing rapid economic changes and the emergence of large-scale production activities.

These mangrove forests support a population of more than 79,400 people belonging to 44 mangrove-abutting villages. These villagers, mostly who are traditional fishermen, are directly dependent on the mangroves for their livelihoods as well as for firewood, fodder and timber.

These activities are impacting the overall ecological integrity of EGREE particularly the mangrove ecosystems, with associated impacts on the livelihoods of local communities.

The main production sectors currently operating in EGREE are fisheries, aquaculture, salt pans, tourism and manufacturing activities such as, oil and gas exploration, fertilizers, edible oil, rice products. Kakinada, a city located in EGREE is also one of the important ports of Andhra Pradesh and is being developed further into a 'Smart City'.

The Ministry of Environment, Forests and Climate Change and the Government of Andhra Pradesh with support from UNDP and GEF initiated the project 'Mainstreaming Coastal and Marine Biodiversity into Production Sectors in the East Godavari River Estuarine Ecosystem, Andhra Pradesh'.

In order to advice and monitor the implementation of this GOI-UNDP-GEF Project in EGREE, a National Project Steering Committee (NPSC) was constituted under the chairmanship of Additional Director General of Forests (Wildlife), Ministry of Environment and Forests (now Ministry of Environment, Forests and Climate Change).

The 1st meeting of the National Project Steering Committee (NPSC) of the project was held on 28th June, 2011 in the Ministry of Environment, Forests and Climate Change, New Delhi. In the meeting it was decided that Wildlife Institute of India (WII) would establish a ***Knowledge Management System*** *envisioned under the project and co-ordinate all activities related therein.*

Main goal of the project was to establish a Knowledge Management System (KMS) for East Godavari River Estuarine Ecosystem in Andhra Pradesh. It had four objectives viz. identifying research gaps, study the impacts of climate change, identify and assess the ecosystem services, and conducting a national workshop on mainstreaming biodiversity conservation into production sectors in EGREE.

First objective was successfully achieved which resulted in a report titled "A Bibliographic Review: Identification and Prioritization of research gaps in coastal and marine biodiversity conservation in the East Godavari River Estuarine Ecosystem (EGREE)". It resulted in identification of 58 research programs which were further prioritized under three categories, viz. short-term, mid-term and long-

Based on the IPCC projections, a risk map for the Coringa Wildlife Sanctuary was prepared. The entire EGREE region lies under 20 m elevation. The elevation contour of EGREE was divided into 5 categories in which areas lying less than 3 m elevation that are close to the shore have been predicted as areas under high risk of inundation.

Depth in the estuary ranges from less than 1 ft. to 34 ft. throughout the year. In winter season the mean depth in estuary was 9.05 ft. which decreased to 7.8 ft. and 7.6 ft. in summer and rainy seasons respectively but these differences between the seasons were not significant ($p > 0.05$).

Salinity values differed a lot between the habitats with the habitats closer to sea having higher salinity while the ones connected to the river or canals have lower salinity values. Salinity ranged from 0 ppt to 34 ppt.

In rainy season the salinity values were lowest in every habitat due to increased discharge of the river and flushing of the entire estuary. The overall salinity did not show significant seasonal differences ($p > 0.05$) but highly significant differences were observed in salinity values between the habitats ($p < 0.01$).

The water temperatures in the estuary ranged from 23°C to 34.2°C. Highly significant differences were observed in the water temperatures between the three seasons; as expected considerably lower temperatures were recorded during the winter season compared to summer and rainy seasons.

During summer and rainy seasons the mean water temperature recorded were 31.4°C and 30.2°C respectively while in winters mean temperature was 25.2°C.

The habitat-wise comparisons of the water temperatures in the three seasons revealed that during the rainy season, the differences between habitats were significantly higher especially in case of Gaderu creek (mean temperature = 32.7°C) which showed considerably more variations in water temperatures than other habitats.

The pH values across the estuary ranged between 7 and 10 with the highest mean value recorded during the summer season in Tulyabhaga creek (mean pH 9).

Seasonally there were few differences in pH but in contrast, there were high variations between the different habitats. During winter and summer seasons, pH values varied the most in Matlapalem creek than other habitats.

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Sl.No	Mangrove Species	Flowering season	Fruiting time
1	*Avicennia officinalis*	May -August	July-September
2	*Avicennia marina*	April -August	July-September
3	*Avicennia alba*	May -August	July-September
4	*Rhizophora apiculata*	January-May	April-September
5	*Rhizophora mucronata*	February-May	April-September
6	*Bruguiera gymnorrhiza*	August-July	February-August
7	*Bruguiera cylindrical*	October-March	January-July
8	*Ceriops decandra*	Year round	Year round
9	*Lumnitzera racemosa*	December-July	April-August
10	*Aegiceras corniculatum*	October-July	February-August
12	*Sonneratia apetala*	March-June	April-July
13	*Sonneratia alba*	December-April	January-April
14	*Excoecaria agallocha*	March-July	June-August
15	*Xylocarpus molluccensis*	May-August	July-September
16	*Xylocarpus granatum*	May-August	July-September


MANGROVES

35 species of mangroves belonging to 17 families were recorded in Coringa Wildlife Sanctuary. Sixteen are true mangroves and 19 are associated mangrove species. Avicenniaceae is the most abundant family followed by Rhizophoraceae and Euphorbiaceae.

Importance Value Index (IVI) that is the combination of relative density, relative basal area and relative abundance, was highest for *Avicennia marina* with IVI of 117.4, followed by *Avicennia officinalis* with 70.9 IVI and *Exocoecaria aggallocha* with 37.5 IVI. Supervised Classification in ERDAS Imagine, with 300 ground points also showed *Avicennia marina* to be the dominant species in Coringa WLS.

Ceriops decandra, a Near Threatened species had the fourth highest IVI value (22.1). It has been observed to be flowering and fruiting throughout the year, while for most of the other mangrove species flowering and fruiting occurred between March and September.

Generalized linear models of mangrove species at a community level showed salinity as the most dominating factor that influenced the density of mangroves negatively. It was followed by Phosphorus which also had a negative influence and then Ca which had a positive influence.

Aegicerous corniculatum, Sonneratia apetala and *Xylocarpus granatum* were present in the soil with a higher salinity range. *Avicinnea marina* preferred the medium salinity range, whereas *Excoecaria agallocha* and *Rhizophora apiculata* were at a low salinity range.

Avicinnea marina was distributed at a salinity range of 19 to 34 ppm, better growth was at a range of 28.37 to 32.5 ppm and the best preferred salinity was 31.75 ppm. *Avicinnea officinalis* was distributed at a salinity range of 14 to 36.5 ppm, the higher abundances were at a range of 21.3 to 32.25 ppm and the best was at 24 ppm.

Influence of salinity on structural components of the EGREE mangrove (i.e., density, Complexity Index, Importance Value Index, above ground biomass, carbon content etc.) revealed a significant negative relationship.

In case of relationship between salinity and carbon sequestration potential of individual mangrove species, except *Ceriops decandra, Excoecaria agallocha, Rhizophora apiculata and Lumintzera racemosa*, rest all the species showed a negative relationship.

In EGREE, the abundance of *Excoecaria agallocha* was mostly influenced by salinity, Na, pH, N, Ca, K, and P. Distribution of *Avicinnea officinalis* was more linked to Na, pH, salinity, Ca, P and nitrogen whereas K, Mg, salinity, pH and Na was important for *Avicinnea marina*. Sodium, pH, salinity and nitrogen controlled the density of *Bruguiera gymnorrhiza* mostly in the study area.

Rhizophora apiculata was influenced by salinity, pH, Na, K, Mg in the study area. *Ceriops decandra* distribution was mostly influenced by K, Na, pH, Mg and salinity.

Distribution of *Xylocarpus granatum* was mostly controlled by K, Mg, Salinity, Na and PH. K and Mg were controlling factors for *Sonneratia apetala* and *Aegiceros corniculatum* while K, Mg, P and Ca were controlling factors for *Lumintzera racemosa*.

Government of India has taken several steps to increase the mangrove cover in the country as a climate change adaptation strategy. The Forest Department in EGREE also undertakes an annual program of restoring the degraded portions of mangroves in and around Coringa WLS in which saplings of mainly *A. marina* are planted along artificially created fish-bone like creeks.

Our results suggest planting of *Aegicerous corniculatum*, *Avicennia officinalis*, *Bruguiera gymnorrhiza*, *Ceriops decandra* and *Sonneratia apetala* in addition to *A. marina* will help in strengthening the adaptive capacity of EGREE to impacts of climate change.

The distribution of mangrove species in Gaderu and Coringa River reveals that *Sonneratia apetala*, *Xylocarpus granatum*, *Avicinnea marina, Bruguiera gymnorrhiza* and *Aegiceros corniculatum* is preferring higher salinity as


MALACO-FAUNA

In 2014 sampling, a total of 153 macro-faunal organisms were encountered and are represented five major groups such as Gastropods, Bivalves, Polychaetes, Amphipods and Tanaids. Gastropods were the most dominant groups in terms of abundance (58 individuals/50 gm) while in terms of species composition polychaetes dominated with 8 species.

In 2015 sampling, a total of 351 macro-faunal organisms were encountered and are represented four major groups such as Polychaetes, Gastropods, Bivalves, and crustaceans. Polychaetes were dominant (77.5%) across the study area, followed by gastropods (13.7%), crustaceans (6.6%) and bivalves (2.3%) while taxa composition showed dominance for polychaetes with 16 taxa, followed by crustaceans with 8 taxa, gastropods with 6 taxa and bivalves with 3 taxa respectively.

Along spatial scale, both macro-fauna abundance and species diversity were highest in mangrove sites followed by mixing zone and mudflat sites. Polychaete abundance was homogeneous across all the sites in the study area while *Capitella* sp. and *Lumbrinereis* sp. were restricted to mangrove sites and *Prinospio* sp. was found only in mixed zones.

The presence of genus *Capitella* sp. indicates the possibility of high organic load as reported in studies from other regions. Similarly, the presence of genus *Prinospio* in the study area which is near mixing zone indicates that the turbidity of water column is generally high asreported in other studies. Filter feeding bivalve species such as *Tegillarca granosa* is found in mangroves because of higher amount of organic input while deposit feeding *Macoma* sp. is observed both in mixing zone and mud flat because of less stability of bottom sediment and high amount of food deposits.

Twenty four species of foraminifera reported from the subtidal and the intertidal environments of EGREE, with the species being present are *Ammobaculites glaessneri*, *Ammobaculites agglutinans*, *Ammodiscus tenuis*, *Ammomarginulina* sp., *Ammonia becarii*, *Ammonia tepida*, *Ammotium salsum*, *Asterorotalia pulchella*, *Bolivina striatulata*, *Buliminella elangitissima*, *Elphidium crispum*, *Elphidium williamsoni*, *Elphidium limpidum*, *Entzia inflata*, *Entzia macrescens*, *Entzia globigeriformes*, *Florilus* sp., *Lagena striata*, *Miliammina fusca*, *Miliammina obliqua*, *Nonion* sp., *Quinqueloculina seminula*, *Quinqueloculina stalkeri* and

Amongst the species observed, *Ammonia tepida* displayed the highest relative abundance while none of the other species bearing abundance greater than 10 %.

The number of benthic foraminiferal species observed from Kakinada bay was however greater. A total of twenty nine species were observed from the subtidal collections from Kakinada bay, amongst which *Bolivina ordinaria*, *Reophax nana*, *Nonionella depressulus*, *Nonionella stella*, *Quiqueloculina striata*, *Quinqueloculina vulgaris* and *Textularia earlandi* were present alongside the species already recorded from the Gautami estuary.

This ecosystem is particularly dominated by polychaetes, which are known to play important roles in bioturbation and thereby enhance nutrient cycling including carbon and nitrogen. Such ecosystem level functioning of different macrofaunal groups including polychaetes and gastropods enhance secondary production and ultimately contribute to the rich fisheries that makes this ecosystem so unique.

In the long-term there is a need to monitor the ecosystem level health of Godavari-Coringa mangrove ecosystem by establishment of robust 'indicator benthic macrofaunal species' which can be used as proxy to track anthropogenic changes including potential impacts from ocean acidification.

34 species of mangrove associated molluscan species have been recorded from Coringa WLS with 14 families, out of which 28 are gastropods and 6 are bivalves. *Cerethidea cingulata* (1004 individuals) and *Assimenia nitida* (633 individuals) were the two most abundant species. However, the relative frequency of these two species was very low.

Cerethidea obtusa and *Telescopium telescopium* were the two most frequent species. Ellobidae was the dominant family with 6 species followed by Potamididae with 3 species. But latter was the more abundant family with a total of 1146 individuals.

The overall density of mangrove associated molluscans recorded in the study was 22.4 individuals/m^2. Surprisingly the gastropod density was highest in the abandoned aquaculture ponds (72.4/m^2) compared to the natural (16.5/m^2) and planted sites (3.8/m^2). Among the species, *Cerithidium cingulata* had the highest overall density (11/m^2) but in natural plots its density was very low while it was not recorded at all from the planted plots. In case of the natural plots *Assimenia nitida* had the highest density (5.9/m^2) followed by *Cerithidium obtusa* (3.6/m^2); in the plantation plots *Pythia plicata* (1.31/m^2) and *Melampus sincaporensis* (0.9/m^2) had the highest densities.

Analysis showed the difference in assemblage of mangrove associated gastropod between the natural and planted habitats in Coringa WLS, Cluster Analysis using Ward's method and SIMPER tests were performed. The tests revealed that more than 75% of the differences were due to three species- *Assimenia nitida*, *Cerithidium obtusa* and *Neritica violacea* which had higher abundances in natural plots.

While species composition of mangroves in natural sites was more heterogenous, the restored sites have a predominantly open canopy cover and are naturally dominated by *Avicennia marina* followed by *Exocaecaria agallocha* along with *Suaeda* spp. which are possibly the remnants of previous vegetation. Evidently soil moisture has also been observed to be lower in restored sites when compared to the natural ones.

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Seventeen families were represented by a single species, six families were represented by two species, and five families were represented with three species each. Whereas families like Naticidae, Nassariidae and Veneridae were represented with maximum of five species and Trochidae, Turritellidae and Conidae families with 4 species.

Diapatra neapolitana *Nereis* sp. *Prionospio sp*

Mugil cephalus, is a commercially important species which showed a clear pattern of its distribution across the year in the sanctuary. In winters, the Nilarevu River seems to be the most preferred habitat for the species while in summers it's more abundant in Coringa and Tulyabhaga creeks.

ICHTHYOFAUNA

We have recorded 382 ichthyofaunal species belonging to 98 families and 25 orders . Out of these 153 species have been recorded from the Godavari estuary. Three threatened species (IUCN, 2010): *Epinephelus malabaricus* (Endangered), *Wallago attu* (Near Threatened) and *Platycephalus indicus* (Data Deficient) were recorded. *Oreochromis mossambicus* was the only exotic species recorded from the sanctuary.

We also observed that another exotic species, *Piarachtus brachypomus* (Pacu) is being stocked in aquaculture ponds near Coringa WLS or along the creeks draining into it. This may pose serious challenges to native fish community of the estuary.

In Kakinada Bay, particularly the average catch was very high in winters which decreased in summers followed by rainy season. On the contrary, in Giriymapeta creek the highest average catch was recorded in summers and lowest in winters.

Leiognathus equluus, *Mystus gulio*, *Tetraodon fluviatilis* and *Dendrophysa russelli* are the four most abundant species in the estuary out of which *Mustus gulio* and *Dendrophysa russelli* have high commercial values. In case of *Leiognathus equluus*, the relative abundance was highest in winter season while for *Mystus gulio* abundance was highest in summer season.

Results of CCA show that the most important parameter structuring the estuary as well as the fish diversity is salinity followed by water temperature.

Mystus gulio and *Oreochromis mossambicus* were found to be mainly distributed in the mangrove-lined creeks of Coringa and Tulyabhaga while species such as *Leiognathus equluus* and *Tetraodon fluviatilis* preferred habitats with relatively higher salinities such as Kakinada Bay.

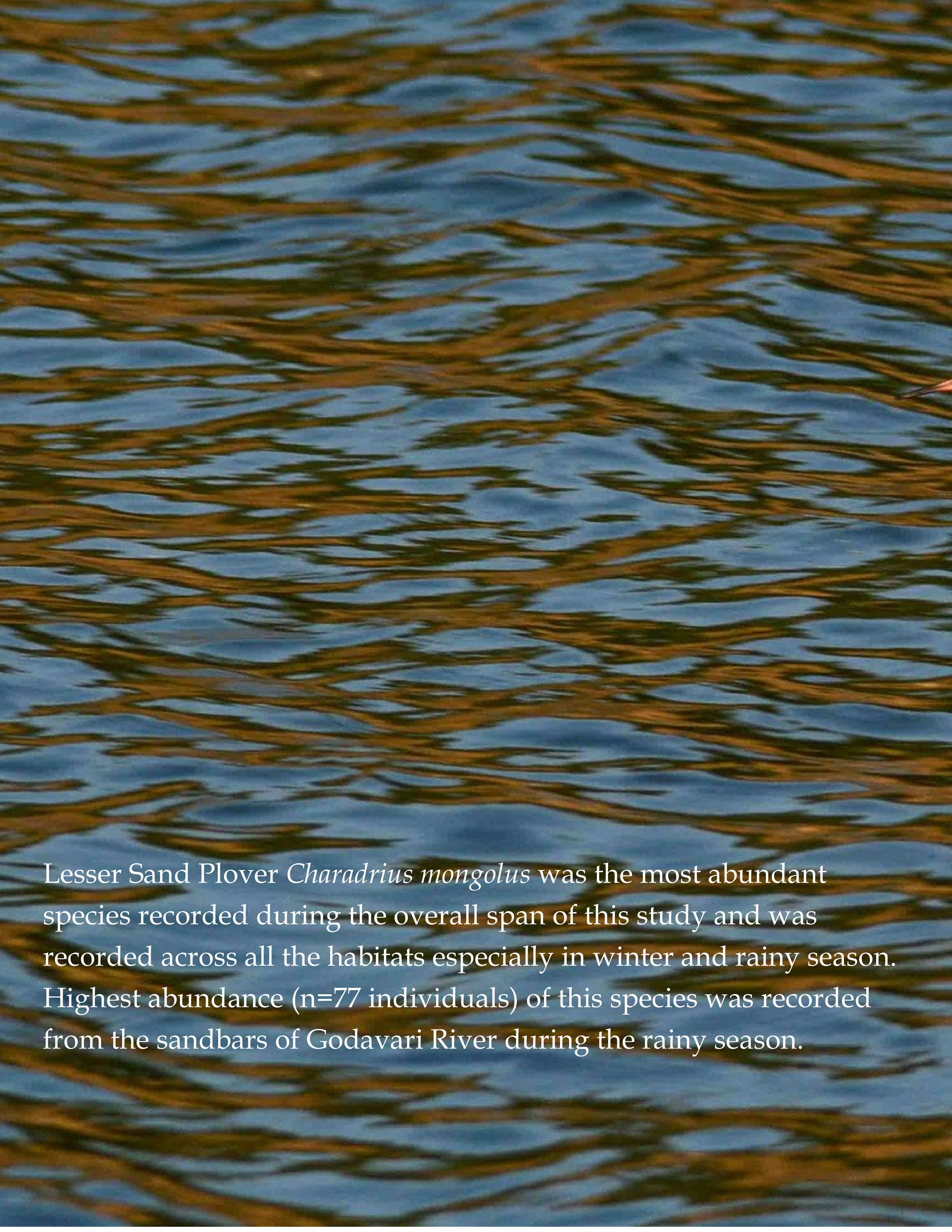
SIMPER results shows that *Leiognathus equluus*, *Mystus gulio*, *Tetraodon fluviatilis* and *Dendrophysa russelli* are also responsible for 65.9 % variations within assemblages of the five habitats. These results also clearly show the affinity of *Mystus gulio* as well as *Tetraodon fluviatilis* to the mangrove-lined creeks in the estuary.

It was found that the dynamic mixing of freshwater of Godavari River and the seawater from the Bay of Bengal have a strong influence in shaping the fish community . Patterns of fish assemblage vary with the variations in salinity across the estuary.

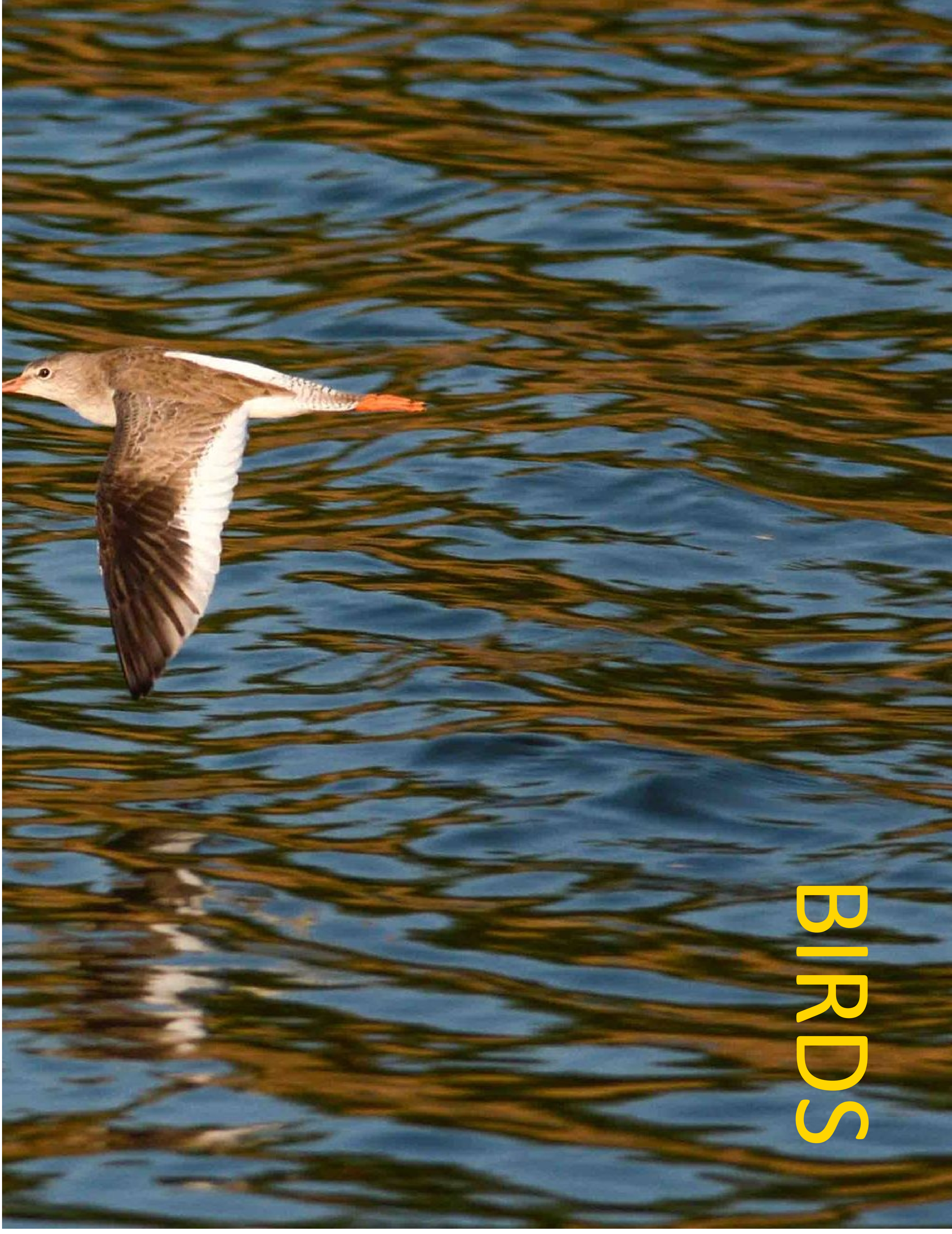
Commercial species such as *Mystus gulio* depend on freshwater flow into the mangroves while another commercially important group, mullets depend on tidal input of seawater into the estuary.

Similarly, diadromous species such as eels, *Tenualosa ilisha*, etc. also depend on the timing and amount of freshwater flow into the estuary.

Therefore, continuous minimum water flow from the Godavari River is of utmost importance to the fisheries of this estuary and in turn important for maintaining the livelihoods of hundreds of subsistence fishermen in the region.



Lesser Sand Plover *Charadrius mongolus* was the most abundant species recorded during the overall span of this study and was recorded across all the habitats especially in winter and rainy season. Highest abundance (n=77 individuals) of this species was recorded from the sandbars of Godavari River during the rainy season.



BIRDS

During the study period, 245 avian species belonging to 47 families were identified, which also includes opportunistic sightings. Among the 47 families, Scolopacidae (Waders) with 22 species and Ardeidae (Egrets and herons) with 17 species were the most dominant families in the study area, followed by Passeridae, Accipitridae (16 species), Charadriidae (15 species), Anatidae (14 species), Corvidae (13 species) and Laridae (12 species).

We recorded 12 globally threatened species out of which one is Endangered: Black bellied Tern *Sterna acuticauda;* two are Vulnerable: Indian Skimmer *Rynchops albicollis* and Woolly-necked Stork *Ciconia episcopu.*

Nine Near threatened species: Painted stork *Mycteria leucocephala*, Spot billed pelican *Pelecanu spelecanus*, Black headed ibis *Threskiornis melanocephalus*, Oriental darter *Anhinga melanogaster*, Pallid harrier *Circus macrourus*, Eurasian curlew *Numenius arquata*, Black tailed godwit *Limosa limosa*, Alexandrine parakeet *Pssitacula eupatria*, Ferruginous Pochard *Aythyanyroca*.

Our observations also indicated that around 59% of the recorded bird species were residents, 36% were winter migrants, 2.8% were local migrants and 2% were passage migrants.

In the mangrove forests of Coringa WLS, terrestrial species such as Blue tailed Bee-eater *Merops philippinus* and Jungle Myna *Acridotheres fuscus* were the most dominant while bird communities in other habitats such as the bay, sandbars and abandoned ponds were dominated by winter migrants (mostly waders).

Sandbars saw good congregations of winter migrants such as Northern pintail *Anas acuta* (total of 120 individuals recorded in winters) and Ruddy shelduck *Tadorna ferruginea* (n=70 individuals). We also recorded flocks of 150 Indian Skimmer *Rynchops albicollis* from sandbars near Yanam city.

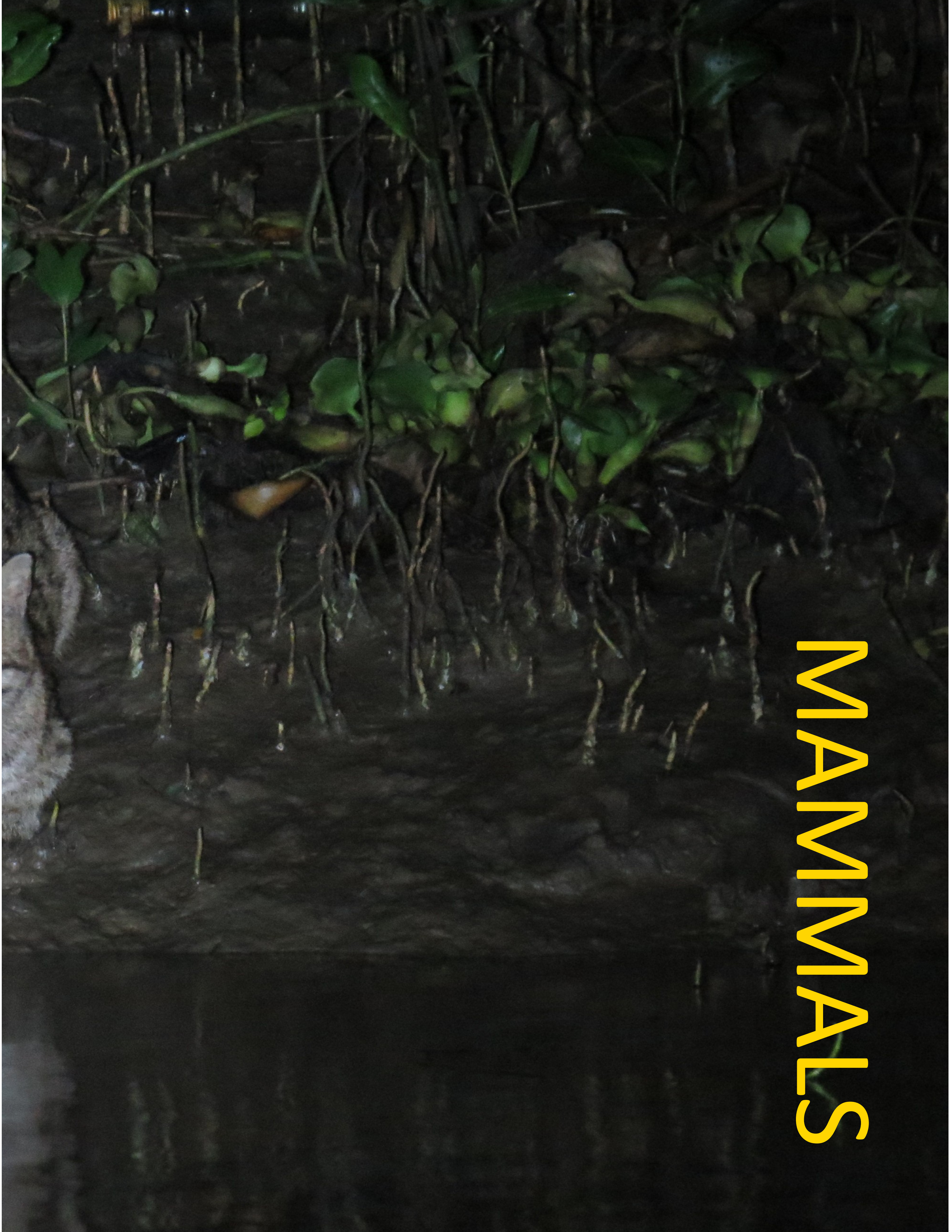
The mean species richness of avian diversity was highest in the mangrove sites (Margalef's richness index R_1=7.1) followed by the lagoon and sandbars (Margalef's richness index R_1 = 3.7 each) while the lowest was observed in abandoned aquaculture ponds (Margalef's richness index R_1=2.6).

Similarly, the mean species diversity and evenness were also highest in the mangroves (Shanon diversity index N_1=3.2, Simpson's Evenness Index 1-D=0.95). Since sampling efforts varied for the different habitats, inter-habitat comparisons were not possible.

The results showed that Insectivore was the most dominant group of birds as compared to other feeding guilds. Around 36% were Insectivorous, 31% omnivorous and 23% were carnivorous whereas Herbivores and Nectarivores constituted less than 2.5% of all the species.

Based on the results of the study, Godavari delta and its different types of habitats are very rich in supporting diverse avifauna. Abandoned aquaculture ponds which were surveyed during the study were also found to provide good alternate foraging sites for the aquatic birds such as waders. Therefore, these abandoned ponds can supplement conservation efforts of avifauna in the future.

Fishing cat *Prionailurus viverrinus* and Smooth coated otter *Lutrogale perspicillata* are listed as Vulnerable, and Indo-pacific humpback dolphin *Susa chinensis* is listed as Near threatened in IUCN Red List.


MAMMALS

In EGREE region, around 14 species of mammals belonging to 6 orders and 10 families (both terrestrial and aquatic) have been recorded. Of these 14 species, *Prionailurus viverrinus*, *Delphinus delphis, Susa chinensis, Stenella longirostris, Tursiops truncates* are listed in Schedule-I of Indian Wildlife Protection Act 1972, whereas *Macaca mulatta, Macaca radiate, Felis chaus, Paradoxurus hermaphrodites, Herpestes edwardsii, Canis aureus,* and *Lutrogale perspicillata* are listed in Schedule-II.

We studied the distribution patterns of terrestrial mammals in and around Coringa WLS, particularly the carnivores. It was found that most of these carnivores preferred the mangrove habitat, followed by aquaculture ponds and villages while habitats like mudflats and sandbars were least preferred by them.

Therefore, results suggest that the carnivore species in the region are dependent on the mangrove forests as they provide abundant supply of food coupled with relatively lower disturbance levels. However, presence of smooth-coated otters was found to be very close to the aqua-ponds and villages, making them highly vulnerable to human-animal conflict in such areas. The absence of any buffer between the mangrove forests and aqua ponds also make these carnivores highly vulnerable.

To estimate abundance of fishing cats in Coringa WLS, we did camera trapping in the sanctuary from December 2014 to September 2015 with 20 consecutive trap sessions.

With 107 captures of 54 different individual cats we estimated the abundance of 75.0±7.7 individuals (SE: 62.8 – 94.3). For SECR analysis, the data set with 54 individuals using 107 captures was used based on its higher capture probability (0.65).

The maximum likelihood SECR model was selected based on minimum AICc value, described the detection function with a hazard rate function. The density estimate was 0.53±0.94 (SE)/km^2.

Based on the camera trap records and direct sightings, fishing cats were found to be more active during low tides (65%) than high tides (35%) and when compared with the lunar phases, activity was more during waning gibbous (35.5% captures) and full moon (24% captures).

Occupancy survey based on interviews in the entire delta covering 143 villages had revealed a drastic decrease in the fishing cat distribution in the region. Questionnaire survey also corroborated the positive influence of mangroves on occurrence/abundances of fishing cats.

Coringa Wildlife Sanctuary and surrounding Reserve Forests are therefore very good habitats for this threatened small cat and can be considered as a major stronghold for this threatened cat in the delta.

Since we predicted further loss of mangrove cover in the region in future as well as sea level rise, we might lose important habitats for fishing cat by 2050.

But if a buffer is created around these mangroves for their landward migration coupled with enhanced protection this impact can be mitigated. We also suggest species recovery programme for fishing cats in the region.

Otters were found to prefer areas near the villages where the entire resources essential for them were present. Intensity of otter signs was highest along creeks with medium width of 20 to 60 metres. Number of signs decreased when the width of creek was more than 60 m or less than 20 m. This shows that the otters preferred the creek with medium width.

Additionally, maximum intensity of otter signs was found in plots with average depth of 1.7 to 2.8 metres and the intensity decreased with increased depth. This could be due to decreased efficiency of predation by otters with increasing depth.

Otters were observed to be basking and grooming in *Suaeda maritima* patches in and around Coringa WLS. But statistical analysis did not reveal any significant relationship between intensity of signs and *Suaeda* patches.

One of the most abundant fish Tilapia (*Orechromis mossambicus*) is usually found near the bank vegetation along the creeks near villages also abundant food resources are available along the villages in the form of aquaculture. Thus, regarding dietary requirement of Otters creeks near villages seems to be an ideal place.

Diet analysis of smooth coated otters show that *Mystus gulio* is the major prey in the Coringa WLS, which constitute 17.8% of weight of all food items found in the spraints (score bulk estimate).

Mystis gulio is also the second most abundant fish species found in Coringa WLS. It was followed by *Oreochromis mossambicus* (Tilapia) which constituted 14.6% of weight of all food items (score bulk estimate) and 12.4% for frequency of occurrence method.

Gerres sp. and *Mugil cephalus* constituted 10.3% for score bulk estimate (11.1% for frequency of occurrence) and 13.9% for score bulk estimate (11.9% for frequency of occurrence) respectively. Another abundant fish species in Coringa WLS, *Dendrophysa russelli* was never encountered in the spraints of otters.

Interestingly, Red bellied Pacu *Piaractus brachypomus* an exotic species recently introduced in the region was also encountered in the spraints with 1% constitution for both the methods.

Major aquaculture fish species in EGREE were also found in the spraints of Otter. Of the five species, *Labeo rohita* was the most abundant cultured fish in the spraints of otters which constituted 6.8% for score bulk estimate and 4.7% for frequency of occurrence method. *Cirrhinus mrigala* constituted 2.7% for score bulk estimate and 7.7% for frequency of occurrence indicating higher preference of all cultivated species.

About 60% of the people interviewed believe that all three species such as otters, fishing cat and jackals visit aqua farms and feed on the farm fishes. However, few people (5%) felt that only Otter and Fishing cat feed on fishes from farms but not jackals. Interestingly, about 2% of respondents felt that

About 90% of the people interviewed could identify otters along with fishing cats and jackals, which were also known to feed fishes and shrimps of farms. All the respondents who could identify Otters could also identify other two species. But, those who could identify fishing cats and jackals were not necessarily could correctly identify otters. This reveals that both fishing cat and jackals may or may not be sympatric with otters.

And about 75% of the people interviewed believed that otters were high threat to aquaculture as compared to fishing cat and jackals. This is due to their behaviour of feeding in groups, whereas fishing cats and jackals live solitarily or in smaller groups.

Majority of fishermen (65%) believed that there was a decline in the sightings of otters and they also believed that the population had been decline in the region. But about 13% of them felt that there was an increase in Otter population over the years; most of these respondents also believed that they incurred heavy losses of income due to fish depredation by otters in their aqua farms.

Generalized Linear Model (GLM) with Poisson distribution revealed that both income and education of fishermen positively influenced their perspectives towards conservation importance of otters in the region.

However, our study show that the diet of otters in Coringa WLS is mainly composed of the species found naturally in the creeks than those species which are artificially cultured in the aqua ponds. Though our study also found that likelihood of occurrence of otters was higher near villages.

To some extent otters are perceived as bigger threats to the aqua ponds than fishing cats and golden jackals but it is due to their innate behaviour of living in families.

Another major reason could be the location of aqua ponds around Coringa WLS which are often right next to the sanctuary or to creeks. If a buffer is created between mangroves and the aqua ponds this conflict might be decreased in future.

The major threats are: Aquaculture pond proliferation around the mangrove forests with no buffer; Coastal development and urban sprawl; Unsustainable fishing practices both inland and offshore; Over exploitation of resources such as fuel wood, crabs, shells etc.; Decrease in freshwater and sediment flow due to various reasons, most important being upstream barriers such as dams; Water pollution; Cattle grazing inside the mangrove forests; Plantation of Casuarina and Coconut; Natural gas exploration and dredging activities inside as well as around the mangroves; Expansion of port and shipping activities; Invasion of exotic species both in mangrove forests and the aquatic habitats; Tourism; Natural calamities such as cyclones, storms, etc.; Mean sea level rise; Increase in surface temperatures (both land and water); Increase in salinity; Increase in

CLIMATE CHANGE

Since we predicted further loss of mangrove cover in the region in future as well as sea level rise, we might lose important habitats for fishing cat by 2050. But if a buffer is created around these mangroves for their landward migration coupled with enhanced protection this impact can be mitigated. We also suggest species recovery programme for fishing cats in the region.

The Fifth Assessment Report of the IPCC also notes the role of humans in the current warming trends: *"It is extremely likely that more than half of the observed increase in global average surface temperature from 1951 to 2010 was caused by the anthropogenic increase in greenhouse gas concentrations and other anthropogenic forcing together".* As per IPCC's Fifth report (2014a) the average temperature of Earth's surface (combined land and ocean surface temperatures) has risen by 0.85°C, over the period from 1880 to 2012.

The global average temperatures have increased by 0.85°C (land and ocean surface temperatures combined). The upper 75 m of the ocean warmed by 0.11°C per decade between 1971 and 2010.

According to some new analysis, there is a 66% likelihood that emissions consistent with RCP8.5 will lead to a warming of 4.2° to 6.5°C, and a remaining 33% chance that warming would be either lower than 4.2°C or higher than 6.5°C by 2100. It has been projected that under RCP8.5, warming will increase until the end of the century in India and monthly Indian summer temperatures will reach about 5°C above the 1951–80 baselines by 2100 in the multi-model mean.

The models project considerable rise in sea level in the South Asian region. For 4°C increase in temperatures, sea-level rise is projected to be approximately 100–110 cm in South Asian coastlines while 60–80 cm rise is projected for 2°C rise by the end of the 21st century (relative to 1986–2005). This is generally around 5–10% higher than the global mean.

Similar predictions of enhanced precipitation have been made for South Asia particularly northwest coast to the south-east coast of peninsular India, which might experience ~30% increase in annual mean rainfall.

Models also project significant increases in inter-annual and intra-seasonal variability in the south-west monsoons.

Main aspects of the dynamics of an estuarine ecosystem are freshwater inflow and sediment accumulation, both of which will get altered in the changing climate.

EGREE is also under tremendous pressure due to the anthropogenic activities present in and around the region. The region is one of the main hubs of fisheries, both marine and freshwater in the state. It is also one of the main contributors to export of marine fishes in India. Substantial part of the mangrove forests is being converted to aquaculture ponds. The region is also one of the richest sources of natural gas and oil in the country, which makes the ecosystem highly vulnerable to water and thermal pollution.

EGREE is dominantly an estuarine ecosystem and therefore mostly in a state of flux. But due to high rate of industrial development and urbanisation it is highly stressed and in such a situation it becomes extremely difficult to tease out the impacts of climate change and man-made changes. The same phenomenon also makes estuarine ecosystems one of the most vulnerable to climate change.

There has been no systematic scientific work/documentation with respect to the impact of climate change on the estuary or the mangroves in EGREE. Among the different weather features, precipitation, and atmospheric temperature along with pollution levels are highly relevant to the various aspects of this important ecosystem. Wind also will be an important feature in future.

To assess the present status and identify the major threats to EGREE and its associated biodiversity the land use/land cover patterns and changes were analysed.

The land use land cover (LULC) map of EGREE was developed to ascertain the status of mangroves and surrounding land use types. The total mangrove cover in the East Godavari district, as on April 2013 has been calculated to be

Based on the change detection analysis of the Land Use Land Cover map of EGREE and on our field observations, some observations regarding to changes in the landscape were made. These observations have also been supplemented by scientific literature which indicates changes in temperatures and sea level rise in the region. Since our study period was very less for any climate change study, these observations cannot be implied to be direct evidences of climate change.

EGREE landscape is dominated by agriculture, covering about 1364 km^2. The agricultural fields are well interspersed with Coconut Plantations, which cover 212 km^2 area in the landscape. Aquaculture Ponds are spread over 120.5 Km^2 and Salt Pans occupy 2.59 Km^2.

With inputs from the ground validation data, the mangrove region in EGREE has been digitized and related with both 2012 and 1989 images. It was found that about 29 sq.km of mangrove cover has been lost between 1989 and 2012. Of these, 12.62 sq.km mangrove areas were lost from the seaward side while 16.4 sq.km mangroves areas lost from landward side due to aquaculture and other human use. An additional 18 Km^2 of mangrove patches are at risk of reclamation. Because of their proximity with aquaculture ponds, it is highly probable that these mangroves will get reclaimed into Aqua ponds.

We have found the total mangrove cover in the East Godavari district to be 195.3 Km^2 as opposed to 197 Km^2 in a study dated 2001 indicating that there has been a loss of about 1.7 Km^2 of Mangrove forests in the East Godavari District. However, there also has been a considerable recovery of 15 Km^2 of the degraded mangrove patches due to the Mangrove sapling plantation program carried out yearly by the Andhra Pradesh Forest Department in collaboration with MS Swaminathan Foundation.

Though the comparisons among the results of the different studies show some irregularity, it is clear that there has been decline in mangrove cover in the landscape and this necessitates regular monitoring of the region for changes in mangrove cover.

Rather, the ground truth survey revealed that there are some patches which have become dry, have remnants of mangrove and are at risk of invasion from *Prosopis* sp.

The biggest change has been the spread of aquaculture ponds which expanded from little above 100 sq.km to nearly 175 sq.km, an increase of 75% in just a span of 5 years. Another feature which needs attention is that major proliferation of the aquaculture ponds in this region in recent years have taken place just adjacent to the mangrove forests and other coastal wetlands.

The highest conversion to aqua ponds has been that of the agricultural lands (68%) followed by open/fallow land (21%). Just 1% of the mangroves have been converted into aqua ponds but the situation might worsen in future in lieu of the impacts of climate change.

Changes in land cover which were driven by economic developmental activities were also observed in EGREE. In total, these development activities claimed 2 sq. km of area in 5 years, but a further rise in such reclamation is expected after the state bifurcation and declaring Kakinada as a 'Smart City'.

A lot of changes in the shoreline have also been observed. About 50m of coastline in the north of Kakinada near Uppada village has been observed to be receded. Barring few areas where new accretions have been observed, most of the shoreline particularly along the sanctuary, Hope Island and Sacremento Islands seems to be retreating. It was found that the areas under high risk lie closer to the western side of Kakinada Bay, while there is a lesser risk of inundation in the eastern parts as it is closely bounded by the Kakinada Spit.

About 3.1 sq.km area of mangroves in CWLS is being predicted to be adversely affected due to sea level rise by 2050. Further, it is also predicted that by 2050, minimum 30 ha of mangroves at the western most side would be inundated permanently or die out.

In contrast in the seaward side of the Coringa WLS most of the sand is getting deposited on the mangroves and a landward movement of mangroves has been noted. At several places on this side mangrove tree diebacks as well as ingress of sand into the mangrove forests have been observed.

The landward zones show low density of mangroves; these areas were formerly mangrove swamps but lost their contact with salt water due to the seaward extension of fresh water zone whereas the areas nearer to sea are flooded by high tides.

If the sediment accretion rate is lower than the rising sea level the mangroves will tend to move landwards in order to cope with it. Presence of aqua ponds and other land use classes around these forests act as obstructions to their landward migration and subsequently reduce their adaptive capacity to climate change. Mangroves eventually are restricted to a narrow patch and eventually die. This is known as 'Coastal Squeeze'.

During our field surveys, we have observed several signs of coastal squeeze in Coringa Wildlife Sanctuary such as invasion of exotic *Prosopis* sp. near villages along Tulyabagha creek and ingression of sand into mangroves towards seaward margins of CWLS.

As per a recent report by Indian Meteorological Department, the annual temperatures (average and maximum) and mean annual rainfall have significantly increased over the period of 1951 to 2010 in Andhra Pradesh. Surprisingly, the amount of rainfall during the monsoon season has shown a reduction than other seasons which experienced a rise in rainfall. In a review article by Jain and Kumar (2012) a decrease in rainfall has been shown for the Godavari River basin.

Bay of Bengal the frequency of cyclones in the peak month that is November has increased with one new cyclone forming in every 2 years. Among the four eastern states, Andhra Pradesh has experienced second-most number of cyclones (83) in these 122 years .

And is also among the most vulnerable states to cyclones and damages caused by them. This study also shows a correlation between sea surface temperature as well as rise in coastal temperatures and the incidence of cyclones. The areas with more warming in the eastern coast are experiencing a rise in number of cyclones than the ones which are relatively warming less.

The nearest tide gauge station to EGREE is Visakhapatnam which has recorded the net rate of Mean Sea Level Rise (MSLR) at 0.69 mm yr^{-1} in east coast for the period 1937-2000. Another recent study says the MSLR is 0.58 mm yr^{-1} for the period 1937-2009.

However, both studies indicate a rising trend in MSL in this region. Sea level rose in the country at a faster rate during the last 2 decades than the 20th century but cautioned that such short time periods are insufficient to infer whether this sea level rise is due to global warming or inherent natural variations.

EGREE accrues several important ecosystem services to the population of East Godavari district as well as to the state. But, available policies failed to internalize the benefits from these services in the policy decision making especially related to economic development. Therefore, it is important to mainstream the biodiversity conservation into various productions sectors of the region with active participation of all stakeholders.

As per the predictions of an increase in sea level and salinity rise due to climate change, the composition of mangroves in EGREE might undergo changes in near future. Further, it is also expected that carbon sequestration potential of majority of mangrove species in EGREE would be decreased in near future.

Government of India has taken several steps to increase the mangrove cover in the country as a climate change adaptation strategy. The Forest Department in EGREE also undertakes an annual program of restoring the degraded portions of mangroves in and around Coringa WLS in which saplings of mainly *A. marina* are planted along artificially created fish-bone like creeks.

But our results suggest planting of *Aegicerous corniculatum, Avicennia officinalis, Bruguiera gymnorrhiza, Ceriops decandra* and *Sonneratia apetala* in addition to *A. marina* will help in maintaining the diversity and strengthening the adaptive capacity of EGREE to the impacts of climate change.

ECOSYSTEM SERVICES

For the Godavari Estuary, this service was valued at US$ 2,700 per ha, which extrapolates to approximately US$ 90,000 annually for the entire area. Role of Godavari mangroves as resource repository and regulation of environmental disasters has been highlighted by several authors including Raman, 1995; Satyanarayana, 1997; Chandra Mohan et. al. 1997; Rönnbäck et.al., 2003; Moberg and Rönnbäck 2003; Danielsen et.al., 2005; and Guebas et.al., 2006.

An integrated framework was adopted for assessment and evaluation of goods and services from Godavari mangroves comprising policy analysis; stakeholder analysis; function analysis; function valuation; and communication and dissemination to various stakeholder groups.

Provisional services of EGREE are food (subsistence and commercial fisheries, aquaculture and rice cultivation); raw materials (fuelwood, thatching and construction materials, timber, shells and clams used for cement industry and in poultry industry); water (for personal use by local villagers, for aquaculture ponds, irrigation and other industries); and medicinal (shells also used in pharmaceutical industries, some mangrove species have minor medicinal properties used by locals).

Regulatory services of EGREE are carbon sequestration and storage; cyclone protection and moderation of extreme climatic events; prevention of erosion and nutrient trapping; water purification etc.

EGREE also provides several habitat/supporting services such as providing habitats for threatened species such as fishing cats, smooth coated otters etc. and feeding and resting grounds for migratory bird species. It also helps in maintaining the genetic diversity of threatened as well as commercially important species of fishes, molluscs, mangroves and other marine species. It is an important feeding ground of several fish species many of which sustain subsistence fisheries in the region. It also provides cultural services (e.g. this area is treated equal to Rameshwaram) such as eco-tourism and act as natural educational repositories. It also provides immense health, mental and aesthetic services to the local population.

Social profile of the region shows that around 44 villages are located around mangroves in EGREE where major occupation is fishing (more than 40%) and agriculture. Out of these 44 nearly 9 are highly dependent on mangroves of CWLS.

EGREE accrues several important ecosystem services to the population of East Godavari district as well as to the state. But, available policies failed to internalize the benefits from these services in the policy decision making especially related to economic development. Therefore, it is important to mainstream the biodiversity conservation into various productions sectors of the region with active participation of all stakeholders.

Role of Godavari mangroves as resource repository and regulation of environmental disasters has been highlighted by several studies. EGREE mangroves have protected minimum 75,000 people from cyclone and safeguarding life and properties of entire Kakinada town as well as seven villages that are in close proximity to EGREE.

Efforts to understand the level of ecosystem service provision within the Godavari estuary have focused on fisheries and to a limited extent on storm protection and carbon sequestration. The economic valuation of ecological services provided by mangroves as a support system for fisheries was done by Dehairs (2003). For the Godavari Estuary, this service was valued at US$ 2,700 per ha, which extrapolates to approximately US$ 90,000 annually for the entire area.

For the ecosystem services, we conducted questionnaire surveys in 12 villages which depend mostly on Coringa mangroves for livelihood and used Probit modelling for evaluating the extend of ecosystem services from these villages.

Probit model with all parameters had an AIC Value of 167.58 and with 3 main parameters like Education, Income and Climate change awareness had an AIC value of 166.53. Hence, nature education will work better in this region for support of sustainable EGREE.

Majority of the respondents were subsistence fishermen. Average household income in these villages was around Rs. 3400/- per month. 34.2% of the people surveyed accepted that they collected timber from CWLS but almost every respondent agreed that the mangroves are very important for the sustenance of their lives and livelihoods.

A non-parametric method was used to calculate Willingness to Pay of the local communities in EGREE. The mean annual WTP calculated is Rs. 636.85 per household.

While education level had a positive influence over the WTP, Household income and awareness levels had negative influence. Respondents with higher level of education, lower household annual incomes and better knowledge of climate change were willing to pay more than others. Hence, nature education will work better in this region for support of sustainable EGREE.

Only 39.7% of the people surveyed were aware of climate change and its impacts. This awareness was an important factor in determining the WTP of the local communities. A person with limited knowledge on Climate change was willing to pay less for the conservation of EGREE. Thus, there is a need to create more awareness among people in EGREE towards Climate change.

The economic value of by-catch from Kakinada Bay was also calculated. The number of heaps of by-catch the local fishermen collected from Kakinada Bay ranged from 11 to 23 heaps/day. Each heap was being sold at Rs.10 per kilogram. Each heap usually consists of 10 to 12 kilograms of bycatch. However, compared to important fish catch of EGREE region that cost about Rs.12.4 crore/year, commercial value of bycatch was meagre (Rs. 3 lakhs/ year) but the damage to the biodiversity due to bycatch collection is enormous.

Trawling is one of the most destructive fishing techniques in the world. During our surveys we observed extensive trawling in Kakinada Bay leading to huge amounts of by-catch and high damage to the benthic habitats of the

Therefore, such destructive fishing activity should be prohibited inside the bay and the use of sustainable fishing gears should be strictly implemented by the authorities. Fishing gears with square mesh and TED need to be made mandatory in the region.

Recent research has highlighted the valuable role that coastal and marine ecosystems play in sequestering carbon dioxide (CO_2). The carbon sequestered in vegetated coastal ecosystems, specifically mangrove forests, sea grass beds, and salt marshes, has been termed "blue carbon". Although their global area is one to two orders of magnitude smaller than that of terrestrial forests, the contribution of vegetated coastal habitats per unit area to long-term Carbon sequestration is much greater.

Carbon sequestration potential of mangroves in Coringa WLS was also assessed. Highest carbon sequestration potential was observed in *Aegicerous corniculatum* (45.46 %), followed by *Avicennia officinalis* (44.81%), *Bruguiera gymnorrhiza* (44.37%), *Ceriops decandra*(44.33%) and *Sonneratia apetala*(44.18%). *Excoecaria agallocha* (44.01%) *and Xylocarpus spp.* (44.05%).

Avicennia marina had a carbon sinking potential of 43.95% and *Rhizophora apiculata* of 43.97%. Among all the mangrove species, *Lumnitzera racemosa* had the least potential for carbon sinking (39.83%).

A significant negative trend was observed in the relationship between carbon contents of the mangrove vegetation and salinity gradient. Mangroves carbon content was decreased from 174.41 to 74.66 MT/ha with increased salinity in the Coringa WLS. Similarly, the above ground biomass of the mangrove showed significant negative relationship with the increased salinity level.

We estimated the total stock of carbon in mangroves of Coringa WLS to be 148 mt/ha carbon. This translates into an approximate Carbon Sink Potential value of Rs. 254,208/ha.

The major threats apart from climate change are identified which are then used to assess vulnerability of different biotic groups of EGREE. Five groups of organisms (Mangroves, Mangrove-associated molluscs, Sharks and Rays, Shorebirds, and Terrestrial mammals) were selected for vulnerability assessment based mainly on importance to the local communities as well as on availability of information and level of exploitation in EGREE

VULNERABILITY ASSESMENT

Vulnerability assessments have become important tools to define, identify and classify potential threats of climate change and other stressors in a system (Lardy et al. 2012) which often integrate ecological, sociological, and economical information.

They help in identifying the most important threats as well as the inherent weaknesses in the system which in turn leads to formulation and implementation of management plans and policies with enhanced mitigative and adaptive capacities.

There are three components of Vulnerability: Exposure, sensitivity, and adaptive capacity. Stability of an ecosystem relies on its sensitivity, ecological resilience, and elasticity to the climatic stressors (or non-climatic stressors).

Impacts are driven by exposure of the ecosystem to climatic pressure and its stability. Finally, vulnerability is a function of impacts and adaptive capacity of the ecosystem.

Vulnerability of EGREE to each threat was assessed using Species Vulnerability Index which is based on Wachenfeld *et al.* (2007). The method employed is a qualitative method to help in identifying the most serious and immediate threats to the ecosystem.

Qualitative methods are less-time consuming and can be very helpful in scenarios where quantitative data are very less or have high uncertainties.

Mangroves were found to be highly vulnerable to expansion of aquaculture ponds, sea-level rise, decrease in freshwater flow, coastal development, natural gas explorations and dredging, cattle grazing, expansion of port etc.

Mangrove associated molluscs are found to be highly vulnerable to over exploitation, uncontrolled trawling and by-catch in Kakinada Bay, sea level rise and water pollution.

Shorebirds are found to be highly vulnerable to sea level rise, port expansion, salinity increase, water pollution and oil and dredging activities.

Sharks, Rays and Skates are found to be very highly vulnerable to over fishing and by-catch collection, Expansion of port and shipping operations, Dredging and exploration activities, Coastal development, and Water pollution.

Terrestrial mammals of Coringa WLS are found to be very highly vulnerable to disturbances due to fishing, habitat degradation, destruction of mangroves, Aquaculture Ponds, Coastal Development, increase in sea level, decrease in freshwater flow, and increase in salinity.

We also assessed the current status of important features & attributes of EGREE which were identified to be the mangrove forests, Kakinada Bay, Hope Island, Tidal mudflats, Riverine sandbars, threatened terrestrial mammals. We assessed the robustness, sensibility, and vulnerability of each of these attributes to Climate change.

Tidal mudflats which occupy $1/3^{rd}$ of the sanctuary area act as important foraging grounds to several threatened bird species such as Black tailed godwit, Painted stork, Eurasian curlew etc. But they are highly vulnerable to unregulated extraction of shells and clams and expansion of Kakinada port.

Our various studies point to a landward migration of mangroves in EGREE with higher accretion rates towards western side particularly in Coringa WLS. Despite this the situation of mangroves is highly vulnerable due to high anthropogenic disturbances such as proliferation of aquaculture ponds, and dredging and drilling activities in the region.

With the decrease in freshwater and sediment flow due to major projects in the landscape such as Polavaram Dam, the mangroves will fail to withstand the sea-level rise and salinity fluctuations due to climate change in future.

Kakinada Bay has higher salinity than the mangrove-lined creeks of Coringa WLS. Recruitment of mangroves was observed to be good on the southern part of the bay but erosion has been observed in the north-western part near Uppada.

Urbanisation, expansion of Kakinada Port, dredging activities at its mouth, increase in traffic of cargo vessels in future will increase vulnerability of the bay to sea level rise in future. Destructive fishing practices are also being carried out in the bay, which also poses serious threats to the ecological integrity of this habitat.

The situation of threatened mammals is also sensitive. Though protected inside the sanctuary but outside PA it is different. Their population is declining due to habitat destruction brought about by changes in land use patterns and industrialization in the region.

Since the discourse on climate change and global warming started in 1979 and then the inception of UNFCCC in 1994, the world has focused mainly on mitigating the impacts by reducing emission of greenhouse gases, mainly CO_2.

However, the recent spate in extreme climatic events in the country such as flash floods in Uttarakhand, floods in Kashmir and Chennai, and the increased frequency and intensity of cyclones in the eastern coast of India has brought forth the need to develop adaptive mechanisms as tools to tackle the impacts of climate change.

In many cases, natural ecosystems such as mangroves and coral reefs provide better shoreline protection than the engineered hard structures. Another advantage of soft measures is that the coastal ecosystems such as mangroves have the natural property to adapt to the stresses existing in coastal areas.

Mangroves, for example, in suitable situations can migrate landwards in response to increasing sea levels by higher rates of accretion. Additionally, these soft measures also provide several other benefits to the local communities such as fisheries, nutrient recycling and enrichment, groundwater recharge, as well as tourism and improved aesthetics.

The existing natural ecosystems require minimum maintenance and therefore, costs are highly reduced.

East Godavari district is already bearing the brunt of the possible impacts of climate change. Cyclones during north-east monsoons and thunderstorms are annual feature, as is severe heat wave during the summers.

Unless immediate measures are taken, the capacity of this landscape to mitigate and adapt to the more severe impacts of climate change will be highly reduced, rendering the local population under serious threat.

East Godavari district is blessed to have been endowed with extensive patches of mangrove forests; the northern patches are protected as Coringa Wildlife Sanctuary and are well connected to each other as well as the river but southern patches are highly fragmented and discontinuous due to various anthropogenic disturbances.

Therefore, to be climate-ready it is important to understand the important role of rich biodiversity of this district in protecting against the negative impacts.

A healthy, intact mangrove cover is considered to be among the best natural defense systems for coastal regions against drivers of climate change, particularly sea level rise. They act as important barriers against the various forces of nature and provide a valuable ecosystem service of protecting the local communities.

Following the super cyclone of 1996 when the region suffered huge losses several inhabitants of Masanitippa and Kandikuppa (devoid of mangroves) migrated to potentially safer villages adjacent to Coringa Wildlife Sanctuary.

Like mangroves, other coastal ecosystems such as coastal forests, sandy beaches, dunes and sand spit also have the ability to attenuate wave energy and provide some extent of protection to sea level rise. In the study area, a 12km long sand spit (aptly named Hope Island) is strategically located around Kakinada Bay providing natural protection to the Kakinada port and the city.

We also observed proliferation of Casuarina plantations in the East Godavari district. Though they are also known for dissipating wave energy but due to shallow root systems have weak resilience to storm surges and are therefore ineffective during monsoon storms and cyclones.

Studies by Tanaka et al. in 2007 and 2008 suggest a mixed species plantation of *C. equisetifolia* and *Pandanus odoratissimus* (commonly known as screw pine) instead of a monoculture of the former species.

In estuarine ecosystems, oysters and mussels play the role of engineers by building reefs which have the capacity to decrease the wave energies and stabilize sediments and shorelines. In EGREE, oyster and clam colonies can be seen growing along the subtidal creeks in mangrove forests, and were once abundant in western and southern parts of Kakinada Bay. However, uncontrolled extraction by locals for export and trawling inside the bay were observed to be destroying them which are vital for strengthening EGREE's potential to cope from climate change.

Freshwater flow is a critical factor for maintenance of physical and biological features of estuaries and other near-shore habitats. In East Godavari district, which is intimately linked to Godavari River, the construction of the Indira Sagar Multipurpose Project (Polavaram Dam) will lead to negative effects on river flow and the biodiversity and ecosystem functioning of East Godavari district .

To assess the capacity of EGREE to adapt to climate change, strength, and weaknesses of different aspects in the region were analysed. In context of policy, current laws are sufficient to deal with wildlife and forest management but are not properly implemented. Further the laws to curb pollution and protect coastal zones are insufficient.

Site design of Coringa Wildlife Sanctuary is good considering that it is the third largest mangrove forest in India and constitutes of some large and well-connected patches. The staff also seem to be dedicated and the management has been successful in mangrove restoration as well as protection of Olive ridley turtles during nesting season.

On the other hand, there is a shortage of staff well-trained in coastal and aquatic monitoring of the sanctuary. Other coastal habitats in the region such as sandbars, sand spit, mudflats, and bay need better protection. In the sanctuary, itself, locals engage in various extractive activities often without any regulation.

Another crucial weakness observed during the study is the absence of any or very less buffer area between the sanctuary and aquaculture ponds. This also increases conflict of locals with fishing cats and otters present inside CWLS.

Recent research has highlighted the valuable role that coastal and marine ecosystems play in sequestering carbon dioxide (CO_2). The carbon sequestered in vegetated coastal ecosystems, specifically mangrove forests, sea grass beds, and salt marshes, has been termed "blue carbon". Although their global area is one to two orders of magnitude smaller than that of terrestrial forests, the contribution of vegetated coastal habitats per unit area to long-term Carbon sequestration is much greater.

Complexity of index (CI) that represents the structural complexity of mangrove communities at each site shows statistically significant negative correlation soil salinity. Lower salinity level represents a better index and it is decreasing as we proceed to higher salinity.

When policy makers talk about the carbon credit they mostly focus on the terrestrial forests in terms of carbon sink. The blue carbon concept will provide an impetus to consider this valuable ecosystem for more carbon storage due to their greater sink capacity in comparison to terrestrial vegetation.

If mangrove area is included in total carbon sink source, then this would not only absorb more carbon from the atmosphere and India would be able to achieve their binding target to reduce their carbon emission in a prescribed time provided by IPCC and it would also be a better option to attract several stakeholders for carbon credit options.

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