

Establishment of Knowledge based management system for East Godavari River Estuarine Ecosystem

Final Report

Wildlife Institute of India



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

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Funding Agency:

GoI-UNDP-GEF-APFD EGREE PROJECT

Collaborating Agencies`

Ministry of Environment, Forests and Climate Change, Govt of India

State Forest Department, Government of Andhra Pradesh

United Nations Development Program (UNDP)

Wetlands International - South Asia

Indian Institute of Science Education and Research, Kolkata

Andhra University, Visakhapatnam

July 2017

ACKNOWLEDGEMENT

We are grateful to following organizations and its officials for their supports,
guidance and help for this project;

UNDP-GEF India Marine Programme

GoI-UNDP-GEF-APFD EGREE Project

United Nation Development Programme – India

Ministry of Environment, Forests and Climate Change, Govt of India

State Forest Department, Govt of Andhra Pradesh

EGREE Foundation

Wildlife Institute of India

Andhra University

IISER, Kolkata

Wetland International – South Asia

Indian Institute of Remote Sensing

CMFRI

All officials and staff from above mentioned organizations

People of EGREE and our field assistants

- Project Team



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Citation: Sivakumar, K, J.A. Johnson, Gopi G.V., Panna Lal, P.V. Rajashekar, P. Bhadury, Ritesh Kumar, Tarun Kathula, Tulsi Rao, Giridhar Malla, Paromita Ray, Priyamvada Bagaria, Dipak Anand and Leela Prasad, 2016. Establishment of Knowledge Management System for East Godavari River Estuarine Ecosystem, Andhra Pradesh. Technical Report, Wildlife Institute of India, Dehradun. Pp406.

Executive Summary

1. Global warming has already affected 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.
2. 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 floral and faunal diversity, and generates significant ecological and economic benefits such as shoreline protection, sustaining livelihoods and carbon sink services.
3. 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.
4. 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.
5. 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.
6. In recognition of its national and global biodiversity significance, the northern part is also protected as Coringa Wildlife Sanctuary (CWLS), which encompasses around 235.70 sq.km of mangrove forests.
7. 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'.
8. These activities are impacting the overall ecological integrity of EGREE particularly the mangrove ecosystems, with associated impacts on the livelihoods of local communities.
9. 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*'.
10. 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.
11. 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.

12. 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-term goals.
13. 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.
14. 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 ($p > 0.05$).
15. 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. As expected, 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 ($p < 0.01$).
16. 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.
17. 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.
18. 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.

Mangroves

19. 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.
20. 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.

21. *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.
22. 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.
23. *Aegiceros corniculatum*, *Sonneratia apetala* and *Xylocarpus granatum* were present in the soil with a higher salinity range. *Avicennia marina* preferred the medium salinity range, whereas *Excoecaria agallocha* and *Rhizophora apiculata* were at a low salinity range.
24. *Avicennia 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. *Avicennia 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.
25. 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.
26. In EGREE, the abundance of *Excoecaria agallocha* was mostly influenced by salinity, Na, pH, N, Ca, K, and P. Distribution of *Avicennia officinalis* was more linked to Na, pH, salinity, Ca, P and nitrogen whereas K, Mg, salinity, pH and Na was important for *Avicennia marina*. Sodium, pH, salinity, and nitrogen controlled the density of *Bruguiera gymnorhiza* 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*.

Malacofauna

27. In 2015 sampling, a total of 351 macro-faunal organisms were encountered from the study area and these organisms 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.
28. Along spatial scale, both macro-fauna abundance and species diversity were highest in mangrove sites followed by mixing zone and mudflat sites. Polychaetes abundances were 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.

29. 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* sp. in the study area which is near mixing zone indicates that the turbidity of water column is generally high as reported 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.
30. 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 striatolata*, *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 stalkerii* and *Textularia agglutinans*.
31. Amongst the species observed, *Ammonia tepida* displayed the highest relative abundance while none of the other species bearing abundance greater than 10 %.
32. 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*, *Quinqueloculina striata*, *Quinqueloculina vulgaris* and *Textularia earlandi* were present alongside the species already recorded from the Gautami estuary.
33. The study conclude that elevation and salinity majorly influence the assemblage structure of foraminifera.
34. 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.
35. 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.
36. In the mangrove forests of Coringa Wildlife Sanctuary, 34 species of molluscan species have been recorded that belong to 14 families. 28 are gastropod and 6 are bivalve 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.
37. *Cerethidea cingulata* and *Assimonia nitida* were the two most abundant species. However, the relative frequency of these two species was very low. Instead *Cerethidea obtusa* and *Telescopium telescopium* were the two most frequent species.
38. Analysis show that the gastropod assemblage of mangrove associated gastropods was different between the natural and restored habitats in Coringa WLS. The tests revealed that more than 75% of the differences were due to three species- *Assimonia nitida*, *Cerithidium obtusa* and *Neritica violacea* which had higher abundances in natural plots.

39. The overall density of mangrove associated molluscs recorded in the study was 22.4 individuals/m². The gastropod density was highest in the abandoned aquaculture ponds (72.4/m²) compared to the natural (16.5/m²) and planted sites (3.8/m²). In case of the natural plots *Assimonia nitida* had the highest density (5.9/m²) followed by *Cerithidium obtusa* (3.6/m²); in the plantation plots *Pythia plicata* (1.31/m²) and *Melampus sincaporensis* (0.9/m²) had the highest densities.
40. From this study on mangrove-associated gastropods, it is evident that the restored patches of mangroves inside Coringa WLS are still in the seral stages of succession due to which the associated macro-fauna differ significantly between the two habitats. There could be several reasons for this but difference in species richness and average heights of trees of the mangrove species seem to be important factors.
41. We also studied the molluscs caught by local fishermen as by-catch in Kakinada Bay. A total of 71 species of Gastropods and Bivalves were found belonging to 34 families and 49 genera. Of these Naticidae, Conidae, Bursidae, Nassariidae, Olividae and Aricidae families were the most species rich. 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.

Fishes

42. 382 ichthyofaunal species belonging to 98 families and 25 orders were recorded in the EGREE region. Out of these 382 species, around 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.
43. *Oreochromis mossambicus* was the only exotic species recorded inside the sanctuary. We also observed that another exotic species, *Piaractus 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 future.
44. In Kakinada Bay, 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.
45. *Leiognathus equulus*, *Mystus gulio*, *Tetraodon fluviatilis* and *Dendrophysa russelli* are the four most abundant species in the estuary out of which *Mystus gulio* and *Dendrophysa russelli* have high commercial values. In case of *Leiognathus equulus*, the relative abundance was highest in winter season while for *Mystus gulio* abundance was highest in summer season.
46. The most important parameter structuring the estuary as well as the fish diversity is salinity followed by water temperature.
47. *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 equulus* and *Tetraodon fluviatilis* preferred habitats with relatively higher salinities such as Kakinada Bay.
48. *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.

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

Birds

51. 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).
52. 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 episcopus*; and nine Near threatened species: Painted stork *Mycteria leucocephala*, Spot billed pelican *Pelecanus 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 *Aythya nyroca*.
53. 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.
54. 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.
55. 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).
56. 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* (70 individuals). We also recorded flocks of Indian Skimmer *Rynchops albicollis* from sandbars near Yanam city in consecutive years of the study period. One hundred and fifty was the highest number of individuals recorded in a single flock at the site.

57. The mean species richness of avian diversity was highest in the mangrove sites followed by the lagoon and sandbars, while the lowest was observed in abandoned aquaculture ponds.
58. 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.
59. 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.
60. 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 EGREE.

Mammals

61. From Coringa Wildlife Sanctuary and its surrounding areas, we recorded around 14 species of mammals belonging to 6 orders and 10 families (both terrestrial and aquatic). Of these 14 species, *Prionailurus viverrinus*, *Delphinus delphis*, *Susa chinensis*, *Stenella longirostris*, *Tursiops truncatus* are listed in Schedule-I of Indian Wildlife Protection Act 1972, whereas *Macaca mulatta*, *Macaca radiata*, *Felis chaus*, *Paradoxurus hermaphrodites*, *Herpestes edwardsii*, *Canis aureus*, and *Lutrogale perspicillata* are listed in Schedule-II.
62. In addition, 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.
63. 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 associated more with the mangrove forests as they provide abundant supply of food coupled with less disturbance and better protection.
64. 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.
65. 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 selected based on minimum AICc value, described the detection function with a hazard rate function. The density estimate was 0.53 ± 0.94 (SE)/km².
66. 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).

67. Occupancy survey based on interviews in the entire delta covering 143 villages 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.
68. 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.
69. Otters were found to prefer areas near the villages where most of the 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.
70. 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.
71. 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.
72. Diet analysis of smooth coated otters show that *Mystus gulio* is the major prey in the Coringa WLS, which constituted 17.8% of weight of all food items found in the spraints (score bulk estimate). *M. 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.
73. One of the most abundant fishes in Coringa WLS, the tilapia (*Oreochromis mossambicus*) is usually found along the banks of creeks. They are also stocked in aquaculture ponds near villages making them easily available to the otters. Therefore, this can be one more reason of recording higher signs of Otters near the villages.
74. 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.
75. 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.
76. About 90% of the people interviewed could identify otters along with fishing cats and jackals, which were also known to feed on fishes and shrimps of farms. All the respondents who could identify Otters could also identify other two species. Those who could identify fishing cats and jackals could not necessarily identify otters. This reveals that both fishing cat and jackals may not be sympatric with otters.
77. 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. Interestingly, about 2% of respondents felt that none of these animals visit their farms.

78. And about 75% of the people interviewed believed that otters were higher threat to aquaculture than fishing cat or jackals. This is due to their behaviour of feeding in groups, whereas fishing cats and jackals usually live solitarily or in smaller groups.
79. 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.
80. However, our study shows 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.
81. 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.
82. 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.

Climate change

83. 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.
84. The Fifth Assessment Report (AR5) 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.
85. 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. Observations also suggest a warming in the deeper layers with the largest warming observed in Southern Ocean below 3000m.
86. The global mean sea level has risen by 0.19 m between 1901 and 2010. The period over 1993 and 2010 experienced the highest rise in mean sea level (0.32 m yr⁻¹).
87. 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.

88. 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.
89. 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.
90. 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.
91. 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.
92. 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.
93. 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.
94. 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.
95. 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.
96. 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 195.3 Km².
97. EGREE landscape is dominated by agriculture, covering about 1364 km². The agricultural fields are well interspersed with Coconut Plantations, which cover 212 km² area in the landscape. Aquaculture Ponds are spread over 120.5 Km² and Salt Pans occupy 2.59 Km².
98. 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 Km² 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 in near future.

99. We have found the total mangrove cover in the East Godavari district to be 195.3 Km² as opposed to 197 Km² in a study dated 2001 indicating that there has been a loss of about 1.7 Km² of Mangrove forests in the East Godavari District. However, there also has been a considerable recovery of 15 Km² 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.
100. 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.
101. The biggest change in the landscape 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.
102. 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.
103. 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'.
104. 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 Sacramento 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.
105. 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.
106. Some positive changes have also been noted since around 2 sq.km of mangroves have stabilized on mud flats in the shore. Recruitment seems to be high in the intertidal creeks inside CWLS. 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.

107. 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.
108. 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'.
109. 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 ingress of sand into mangroves towards seaward margins of CWLS.
110. 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.
111. In another review article, data of 122 years of tropical cyclones in India from 1891 to 2013 was analysed. The potential of cyclones in India has increased during this period. Particularly in the east coast, i.e. 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.
112. 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.
113. We also identified the major threats (current and future) existing in EGREE based on LULC map, land-use change analysis and observations during our field surveys.
114. 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 ocean acidification.

115. 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.
116. 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.
117. 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.
118. 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.
119. 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.
120. Shorebirds are found to be highly vulnerable to sea level rise, port expansion, salinity increase, water pollution and oil and dredging activities.
121. 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.
122. Terrestrial mammals of Coringa WLS were found to be 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.
123. We also assessed the 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.
124. 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 Godavari basin such as Polavaram Dam, the mangroves will fail to withstand the sea-level rise and salinity fluctuations due to climate change in future.
125. 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 pose serious threats to the ecological integrity of this habitat.

126. Tidal mudflats which occupy 1/3rd 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.
127. The situation of threatened mammals is also sensitive. They are well protected inside the sanctuary but the situation outside it is different. Their population is declining due to habitat destruction brought about by changes in land use patterns and industrialization in the region.
128. IPCC (2007) defines 'adaptation' as "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities". Various types of adaptation can be distinguished: anticipatory adaptation, autonomous adaptation and planned adaptation.
129. Adaptation measures in coastal cities can be categorized into 2 types: 'hard measures' (engineering structures such as seawalls, storm surges, dykes and bulkheads) and 'soft measures' (natural systems such as beaches, salt marshes, mangroves, coastal forests etc.). Hard measures are more popular choices in the major Indian coastal cities to prevent damages from natural hazards including climate change and they have proved to be highly effective in many cases. However, they entail high construction and maintenance costs and if they fail, they can instead exacerbate problems of coastal erosion.
130. 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.
131. East Godavari district is already enduring the most 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.
132. 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.
133. 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.

134. 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.
135. We also observed proliferation of Casuarina plantations in the East Godavari district. Though Casuarina trees 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.
136. 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.
137. 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 considering the proposed dam in Polavaram, the Indira Sagar Multipurpose Project popularly known as Polavaram Dam.
138. To assess the capacity of EGREE to adapt to climate change, strengths, 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.
139. Site design of Coringa Wildlife Sanctuary is good considering that it is the third largest mangrove forest in India and constitutes some large and well-connected patches. The staff also seems to be dedicated and the management has been successful in mangrove restoration as well as protection of Olive ridley turtles during nesting season.
140. 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.
141. Local community are aware of the ecosystem services they receive from the mangroves and estuary of EGREE particularly the protection provided by mangroves in the region to cyclones and storms. But they extract several resources such as timber, fishes, crabs and shells and clams inside the sanctuary without any regulation. There is also a lack of knowledge among the locals

regarding 'climate change' and its potential impacts in future. They are also often not consulted or involved in the management of the sanctuary.

Ecosystem Services

142. The 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.
143. Ecosystem services are defined as "the direct and indirect contribution of ecosystems to human well-being". There are different types of ecosystem services: provisional, regulating, supporting and cultural.
144. 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.
145. 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).
146. 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.
147. 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.
148. 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.
149. 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.
150. 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.

151. 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 near EGREE.
152. 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.
153. To assess the other ecosystem services and awareness of the local communities regarding climate change, we conducted questionnaire surveys in 13 villages around Coringa WLS.
154. 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.
155. 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.
156. Probit modelling was carried out to identify the factors influencing the Willingness to Pay of people from these 12 villages. Model with 3 factors *viz.* Education level, Household Income and Climate change awareness was the best fitted one that affected the Willingness to Pay of the local communities.
157. 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.
158. 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.
159. 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.
160. 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 bay. Kakinada Bay is already vulnerable to the impacts of port activities and movement of vessels and frequent dredging. 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.

161. Recent research has highlighted the valuable role that coastal and marine ecosystems play in sequestering carbon dioxide (CO₂). 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.
162. 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%).
163. *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%).
164. 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.
165. 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.
166. 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.
167. 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.
168. 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.

Recommandations

1. EGREE has a vast patch of mangrove areas and provides a big hope for carbon storage. It is imperative to help stakeholders to increase the mangrove cover in EGREE by providing right species with high potential of carbon sequestration without compromising overall environment settings of the landscape/seascape. Further, the study found that the importance of polyculture plantation of mangroves that could enhance the overall biodiversity of the region. Therefore, mixture of *Aegicerous corniculatum*, *Avicennia officinalis*, *Bruguiera gymnorrhiza*, *Ceriops decandra*, *Sonneratia apetala* and *Avicinnia marina* plantation has been proposed for polyculture plantation in EGREE as well as other coastal areas of Andhra Pradesh. Increase in mangrove areas in the State would help to minimize the impact of climate change as well as it would further protect people in several ways. In this context, it is further suggested to convince various sectors in the region to take part in this plantation programme, which would mutually beneficial to all.
2. EGREE has several degraded patches in and around the boundary. Anthropogenic pressure is also high with respect to logging and aquaculture. EGREE Foundation of the Andhra Pradesh Forest Department has already taken some initiatives to restore some of these degraded mangroves around the Coringa WLS but the Foundation required to be supported to acquire all degraded mangroves around the WLS and restore it before the private parties convert these mangroves areas into aquaculture ponds or other developmental areas. These degraded areas can easily be restocked and more unused area can be converted in to mangrove patches by adopting the true species with respect to their carbon sinking potential so that they may absorb more carbon.
3. *Mystus gulio*, which is the most common and top predator cat fish that feed juveniles of most of commercially important breeding fishes including prawns in the estuarine as well as in mangroves areas. Fortunately, otters and fishing carts are predominantly feeding this predator fish and controlling its population which beneficial to fishermen in the region. Therefore, this information needs to be shared with people around EGREE, so that the negative thought about Otters and fishing cats would be stopped. Further, a recovery plan for otters and fishing cats in EGREE need to be developed and implemented as part of the ongoing Management Plan.

4. It was found that fishermen with poverty could not bear even the meager loss caused by otters to them. Further, the study found that less educated people against the otters in the region. Therefore, additional livelihoods and awareness education to those poor fishermen need to be provided for the long-term conservation of otters in the region. EGREE Foundation of Andhra Pradesh, a foundation established with support of GoI-UNDP-GEF Project to sustainably manage the Godavari estuarine has already initiated a programme in this regard that needs to be strengthened by focusing more on fishermen who are with low income.
5. Otter proof fencing for aquafarms especially those farms located along the Ramanapallam creeks required.
6. Developing eco- tourism with focus of otters and fishing cat in the sanctuary with the involvement of fishermen and small-scale farm owners can also change their attitude towards otters.
7. EGREE is the paradise of endangered fishing cat. Fishing cat is threatened by anthropogenic activities as well as climate change impacts. Like Otters, fishing cats also mostly survive on rodents found in the mangroves of EGREE, followed by crustaceans and fish as foods. It was also found that among fishes, *Mystus gulio* was eaten most. Therefore, fishing cat also can be projected as 'Fishermen Friend' to seek support of people for its conservation.
8. Disturbances due to fishing and illegal killings are seems to be major threats to fishing cat in EGREE. Further, the predicated impact of climate change would further shrink the distribution range of this species in future, therefore, education programme explaining the importance of this species and reasons for their declining needs to be told the people. A site-specific species recovery programme may be developed for fishing cat. Coringa WLS may be a better site for the 'Conservation Breeding' Programme of Fishing Cat, which is highly threatened and its distribution range significantly reduced in India. Central Zoo Authority of India and the National Tiger Conservation Authority may be consulted for this breeding programme.
9. This study has recognized a major link between sea and the Godavari River regulating the fish diversity patterns and processes. Therefore, it should certainly be a target for strategic management of fish diversity in the region. Further, the Godavari estuary is not just a link between two

habitats but it is also possibly acts as a nursery since the fish catch were dominated by juveniles; many of these species have high commercial values both locally and regionally. Potential increase of salinity due to climate change and obstruction of flow at upstream would affect the overall patterns and processes of fish diversity in the estuarine in near future. Therefore, minimum environmental flow must be assured from the Godavari River.

10. The problems caused by the reduction of the amount of sediment transported to the coast can only be solved with expensive engineering work, namely beach nourishment and ultimately shoreline protection. The stopping of floods results in marine sedimentary deposition in the river mouth, which can be solved only by dredging. Therefore, the management plan of the Coringa WLS or the management plan of the Godavari Estuarine Area should clearly list out all action plans required to nourish the shoreline and remove marine sediments regularly from the mouth so that the marine flow into the estuary is maintained. Further, the existing or proposed management plans of Coringa WLS and Godavari estuary should contain a disaster-preparedness plan with respect to the Indira Sagar Project as well as one with respect to climate change. In the Godavari estuary, where the river flow is greatly controlled by the dam, there is a time lag between the maximum rainfall and maximum discharge in the river. This delay can sometimes compromise the recruitment of estuarine fish species—this will cause some negative impacts on fish populations and shifts in the natural patterns of other biological communities. This is why a minimum flow from the dam should be allowed. Sometimes, it is difficult to make a compromise between effective nature conservation and the economical improvement of an area. Positive impacts in the local economy should be achieved through sustainable and rational growth of human activities in the area, including tourism. Tourism is regarded as one of the solutions for achieving economic development in the Godavari Estuarine Region. Therefore, the scope of eco-tourism in Coringa WLS may be extended to the estuarine region. But development of economically viable tourism in this region has to be ecologically sensitive and culturally appropriate. Therefore, protection of nature and understanding the worth of the natural patrimony that characterizes the Godavari estuary/mangroves should not be neglected or forgotten.
11. Mangrove forests are the major coastal ecosystem of the Godavari estuary and are among the richest and most productive ecosystems. A number of commercial and traditional products are provided by mangrove ecosystems. These include the nutrient enrichment for aquatic and

terrestrial flora and fauna. Mangrove vegetation plays an indirect but very important role in coastal protection. Mangrove forests provide unique ecological niches and habitats for a variety of marine and terrestrial animals. Similarly, estuarine and sandy beaches are known to be the nesting areas of sea turtles. Therefore, an integrated coastal zone management plan is required in the estuarine region of the Godavari River to address the entire gamut of issues related to conservation and sustainable use of the biodiversity of the region.

12. The functioning of the Godavari mangrove ecosystem is closely linked to terrestrial land use practices. In particular, changes in water-flow regimes affect mangroves, and overdrawing of ground water may increase the danger of aquifer salinization and contamination. Consequently, the coastal zone should be considered an integral component of overall regional land use planning and development so that appropriate land use policies and action programmes may be formulated. Priority should be given not only to rehabilitation of degraded coastal lands but also rational use of land on a sustainable basis, including planned development of sustainable forest/marine products. Many of the uses and services of mangroves are compatible with each other, such as honey collection, coastal protection and small-scale capture fisheries. Others are less so, and hence a zonation of the area according to primary land-use objectives is necessary. This underscores the need for a holistic approach within the framework of integrated coastal zone management planning.
13. Integrated management planning should also ensure that all goods, services and values are catered to. Management planning should therefore include periodic environmental impact assessment, and the actual management must be monitored periodically by environmental auditing.
14. The mangrove/estuarine management action plan cannot succeed without considering the requirements and aspirations of all the people. Success depends, inter alia, on being able to match management objectives with the interest of local populations and, through extension, securing their support and commitment. Therefore, a degree of "self management" should be encouraged among the various users of the mangrove environment so that they can be involved in protecting their own environment. In the recent past, there were a number of incidental captures of whale sharks off the mouth of the Godavari. The whale shark is one of most highly threatened sharks in the world, and it is protected under the Wildlife (Protection) Act, 1972. The Gujarat government initiated an innovative compensation programme for fishermen who release

incidentally captured whale sharks. Similar models may be adopted in the region to prevent killings of this species.

15. A lack of understanding of the importance of mangroves is an important cause of mangrove depletion and degradation. The state forest department should justify its mangrove management programme to the general public and other line departments. The authority should ensure that awareness and education programmes that inform the public about mangroves, their uses and services and how to maintain them, as well as government plans in relation to management of these resources, are developed and implemented. EGREE Foundation has already been undertaking various programs in this regard that need to be strengthened and supported.
16. This is important in the context of climate change and the Indira Sagar Project at Polavaram. All the degraded mangroves around the Coringa WLS may be considered to be declared either as eco-sensitive zone of Coringa WLS or a conservation reserve so that the necessary management interventions can be made to restore these mangroves habitats.
17. Banks of estuarine and downstream of Godari River were observed to be degraded due to regulated flow of water by Rajamundry Barrage, therefore, it is suggested that an area of width 50 m along either bank of the river, from the Rajamundry to the Godavari estuary, be declared an ecosensitive zone. A green belt needs to be developed in this ecosensitive zone using only native plants without disturbing the natural landscape. This would strengthen the bank stability that would save people as well as their properties.
18. Environmental flows are flows that are essential for maintaining the normal ecological services of a river. The Godavari River has a catchment area of 3,14,685 km² and a long-term average annual surface flow of 110 km³. The discharge of the river is highest during the south-west monsoons (June--September), when the region receives almost 80% of the average annual rainfall. After analyzing the minimum habitat requirements of downstream fishes of Godavari River, it is suggested the release of 26% cumecs from November to May, 30% cumecs during June and October and 35% cumecs from July to September. These suggested flows, which are the minimum required flow, are expected to provide the required environmental cues to the biota of the region as well as sustain the ecosystems and allow their biodiversity to perform the normal ecological services. It is important to note here that this is the minimum required flow for the functioning of the downstream ecosystems and for the normal

life cycles of the fauna and flora. Therefore, it should not be concluded that the animals and plants will survive forever with this minimum requirement.

19. Assemblage structure of foraminifera of EGREE is largely influenced by elevation and salinity. Therefore, foraminiferan may act as an indicator taxa to monitor the changes in the salinity and seascape of the region. Further, EGREE Foundation may use *Capitella sp.*, *Prinospio spp.*, and *Tagillarca granosa* to monitor the organic load of EGREE.
20. 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.
21. It was predicted the further loss of mangrove cover and habitats of fishing cat by 2050 in EGREE due to climate change. But this can be mitigated, creating a buffer (eco-sensitive zone) around these mangroves for their landward migration coupled with enhanced protection. Coringa Wildlife Sanctuary may act as 'Conservation Breeding Centre of Fishing Cat' and also 'Genetic Repository of Fishing Cat' of India.
22. The land use land cover (LULC) of EGREE has significantly changed in last three decades. Most of these changes were not good for sustaining the natural environmental settings of EGREE. Therefore, the Government should bring a policy to promote eco-friendly land use system that should neither degrade or encroach the mangroves and other natural habitats of EGREE.
23. 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. Therefore, sand spits of the region should be respected and protected.
24. It was found that that the landward migration of the mangroves in Coringa Wildlife Sanctuary but Aquaculture ponds adjacent to the boundaries are the major obstacles. Therefore, it will lead to the coastal squeeze of the mangroves in CWLS. Therefore, adequate 'Eco-sensitive

Zone' around Coringa Mangroves needs to be identified and conserved to prevent the coastal squeeze.

25. Role of Godavari mangroves as resource repository and regulation of environmental disasters has once again been highlighted by this study. 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 close proximity of EGREE. Therefore, conservation awareness programs should convey this message to the people.
26. The economic value of by-catch from Kakinada Bay was also calculated. The number of heaps of bycatch the local fisherwomen collected exclusively from EGREE was 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 was enormous. Therefore, Government should promote gear and crafts that avoid fishing the bycatch. Fishing gears with square mesh and TED need to be made mandatory in the region.

INTRODUCTION TO STUDY AREA



Introduction

Estuaries are semi-enclosed, transitional zones where freshwater and marine water mixes. They also act as interface between the terrestrial and aquatic ecosystems of the coast. The individual properties of each of them, the freshwater, marine and coastal interact with each other and give rise to a complex and dynamic estuarine ecosystem. Montagna *et al.* (2013) tried to identify the different sub-components of an estuary: source of freshwater (usually river), a tidal-estuarine segment, marshes, or mangroves (depending on latitude), bays and an inlet to sea. In India, most of the estuaries are river-dominated, particularly in the eastern coast.

Estuaries are well known for marine and coastal biodiversity, particularly as important habitats for fishes (Laegdsgaard and Johnson, 1995; Kathiresan and Bingham, 2001; Blaber, 2007). The high productivity of estuaries and high input of nutrients makes it a rich feeding ground for various marine fish species. For some diadromous species, it provides a gradual transition state making it easier for them to migrate into varying salinities. However, the most important role among all has been recognized to be that of a nursery ground for fishes (Blaber, 1980; Bell *et al.*, 1984; Robertson and Duke, 1987; Laegdsgaard and Johnson, 1995 etc.). These dynamic ecosystems also provide many important services to humans such as nutrient recycling, flood and cyclone protection, food production etc. Despite such high ecological and economical value, estuaries are perhaps the most threatened ecosystems in the world (Blaber et al. 2000).

It is estimated that around 23% of global population lives near the coasts (within 100 km and 100 m of sea level) and is mostly concentrated in rural settlements and smaller cities with high densities (Small and Nicholls 2003). However, coastal zones have been experiencing rapid growth and urbanization since past few decades now. Most megacities of the world are located along the coasts (including Mumbai, Kolkata, and Chennai) and majority of their inhabitants are dependent on estuaries for subsistence.

This spurt in human population coupled with urbanization is leading to widespread modification of coastal landscapes (Valiela 2006).

Human activities such as dredging, filling, draining or construction of hard structures along the coast have direct impacts on estuaries such as habitat loss and degradation. Damming of a river also leads to profound changes in estuaries and other coastal wetlands. Trapping of silt and sediments in reservoirs deprive the downstream habitats leading to coastal erosion, changes in nutrient recycling and circulation patterns. Impacts of dams and barrages on the movement of diadromous species such as Hilsa in India and Bangladesh are well known. Other anthropogenic activities such as discharge of sewage, over-exploitation of fishery resources, coastal waterways and ports, and introduction of invasive species also compound the potential threats to estuaries.



Figure 1: Landing center near Coringa Wildlife Sanctuary

In addition to the anthropogenic impacts, coastal landscapes are also vulnerable to sea level rise and other drivers of climate change. Various models now predict that the sea level will increase by 0.3 to 5.0 m, possibly inundating almost 1 million km² of coastal land (Klige, 1990; Daniels et al., 1993; Liu, 2000). Many tidal wetlands, estuaries, mangroves, and other shallow-water habitats might be lost if global warming continues at the predicted rates. Extremes in environmental factors, such as elevated water temperature or salinity, low dissolved oxygen, and low pH can be devastating for the marine life (Moyle and Cech, 2004) affecting their foraging, growth, and fecundity, altering metamorphosis, and affecting endocrine homeostasis and migratory behavior (Barton and Barton, 1987; Donaldson, 1990; Pörtner et al., 2001). Extreme climatic events such as cyclones and storms are also predicted to rise in intensity as well as in frequency, rendering the coastal habitats and settlements highly vulnerable to damages and erosion.

Due to their naturally stressed conditions, it therefore becomes difficult to differentiate between the direct impacts of anthropogenic disturbances and climate change on an estuarine ecosystem (Nicholls *et. al.* 2007; Lotze *et. al.*, 2006). In such a situation, estuaries are more vulnerable to the negative impacts of climate change (WWF report) than other natural ecosystems. Yet we understand very little of the critical processes in an estuarine ecosystem, and especially in the Indian scenario such information is almost non-existent.

Background to the project

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 floral and faunal diversity, and generates significant ecological and economic benefits such as shoreline protection, sustaining livelihoods and carbon sink services. In recognition of its national and global biodiversity significance, the northern part of the EGREE is also protected as Coringa Wildlife Sanctuary (CWLS). However,

like other parts of the world, this coast has also have witnessed rapid economic changes and emergence of large-scale production activities in the last few decades. 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'. These activities are impacting the overall ecological integrity of EGREE particularly the mangrove ecosystems, with associated impacts on the livelihoods of local communities. In this connection, 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*'.

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.

Objectives of the Project

As mentioned in the previous section, main objective is to establish a Knowledge Management System (KMS) for East Godavari River Estuarine Ecosystem in Andhra Pradesh. Under this component, following four objectives were identified:

1. Identifying research gaps in coastal and marine conservation in the East Godavari River Estuarine Ecosystem (EGREE).
2. To study the 'Payment for Ecosystem Services of East Godavari River Estuarine Ecosystem'.
3. To study the impact of climate change on East Godavari River Estuarine Ecosystem.
4. Conducting a National Workshop on mainstreaming biodiversity conservation into production sectors for the conservation of coastal and marine resources.

Research gaps in coastal and marine conservation in East Godavari River Estuarine Ecosystem (EGREE)

For a successful long-term conservation management project, scientific research-based information is imperative. Therefore, it became important to analyze the available information on the various aspects of the region and then to identify the research gaps in it. A thorough literature survey was conducted on published research and other information from EGREE region along with field visits to various institutions and discussions with concerned stakeholders. This led to identification of several research gaps in the biodiversity and management of the EGREE which were subsequently prioritized into different categories based on their importance. Before finalizing the document, a stakeholder's workshop was also held at the project site (Kakinada).

The research gap analysis was conducted with following objectives:

- i. To prepare a bibliography of existing information on research activities of EGREE*
- ii. To summarize all past and ongoing research in the EGREE*
- iii. To identify gap areas for research.*

Finally, 58 research programs were identified and prioritized under three categories, viz. short-term, mid-term and long-term goals. Detailed methodology and results of this objective can be found in the 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)*”.

Subject	No.of Publication	Percentage
Algae	2	0.3
Bacteria	1	0.1
Climate study	7	1.0
Crafts and Gears	12	1.7
Ethnobotany	15	2.2
Fauna	197	28.6
Flora	66	9.6
Fungi	5	0.7
Geology	20	2.9
GIS and Remote Sensing	22	3.2
Hydrology	65	9.4
Others	48	7.0
Sedimentology	87	12.6
Socioeconomics	7	1.0
Physical Studies	171	24.9
Pollution	2	0.3
Total	727	100

Table 1: Table showing detailed bibliographic review from EGREE

East Godavari River Estuarine Ecosystem (EGREE)

The East Godavari River Estuarine Ecosystem (EGREE) is situated at the confluence of Godavari River with Bay of Bengal in the East Godavari district of Andhra Pradesh. Godavari River is the second longest river of India and the largest in peninsular India. It originates in Western Ghats and after traversing a length of 1,446 km over a catchment area of 3,14,685 square kilometers it meets Bay of Bengal near Bhairavapalem village in Andhra Pradesh. EGREE encompasses the vast delta of Godavari River along with other coastal habitats such as river channel, floodplains, natural levees, mangroves, bay, mudflats, tidal creeks, sand spits, beaches etc. 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.



Figure 2: Sonneratia mangroves seen inside the Coringa Wildlife Sanctuary

EGREE is a highly dynamic landscape. Due to the high sediment load from Godavari River and frequent cyclones, this landscape continually undergoes changes. Studies have shown that after 1889 the river has changed its main course from Kakinada Bay in north to its present mouth near Bhairavapalem village (). Similarly, the sand spits present along the Kakinada Bay and at the mouth of the river also keep changing in their morphology and length. The sand spit along the bay, known as Hope Island has increased from its small size in 1864 to a 17 km-long spit now (). Hope Island provides natural shelter to the mangroves and villages along the Bay, and has allowed the establishment of a major fishing harbor as well as Kakinada Port, thereby having high economic value for the region. However, extensive patches of mangrove forests are the main features of this landscape. After the Sunderbans in West Bengal, the Godavari mangroves of EGREE are the largest mangrove forests in east coast of India.

Coringa Wildlife Sanctuary

The Godavari mangroves are the second largest area of mangroves along the east coast of India. Large parts of these mangroves are given protection under Coringa Wildlife

Sanctuary (CWLS) and six other reserve forests *viz.* Rathikalava, Masanitippa, Malatippa, Balusutippa, Kothapalem and Kandikuppa. As per earlier records, the total extent of mangrove cover in EGREE is around 321 sq.km.

To protect and manage the Coringa Wildlife Sanctuary (CWLS), Forest Department of Andhra Pradesh envisaged the following long-term objectives:

- 1) To maintain the natural ecosystem and conserve the rich ecological resources by strict protection through departmental staff as well as Eco development Committee members.
- 2) To restore and rehabilitate the land cover in the blanks by the afforestation after excavation of field channels.
- 3) To protect and preserve the wildlife in the area.
- 4) To reduce and rehabilitate endangered species by developing and improving their niches.
- 5) To reduce the dependence of the people on these forests
- 6) To reduce interference due to grazing, collection of shells etc.
- 7) To improve the socio-economic level of the people around the sanctuary by providing alternate livelihood and by reducing dependence on the forests.
- 8) To provide environmental education to the people for better appreciation and participation in conservation programmes.
- 9) To create the research base and data bank to monitor the population dynamics of Wildlife.
- 10) To maintain Eco-balance by harmonizing the life style of the people living in this area, with preservation of the Ecosystem, while preserving the cultural heritage of the people.
- 11) To reduce biotic interference from the buffer while eliminating it from the core.

The sanctuary itself has a long history behind it. Since 1893, the mangrove forests of this region were subjected to heavy exploitation to meet local demands of fuel wood. The area was under working from 1893 till 1978 (almost for a century continuously) by the Forest Department without any standards or proper scientific protocols. In addition, dependence of heavily populated villages and cities on the mangroves led to heavy felling and grazing which also added to widespread habitat degradation and fragmentation.

Coringa was one of the first 17 regular reserve forest blocks declared in Madras presidency on 1st January 1883 when Madras Forest Act came into force. Therefore, for more than 100 years the forests of Coringa Wildlife Sanctuary are being protected. Subsequently, any type of felling was stopped inside these mangroves. Later in 1978 to further enhance protection, it was declared as "*Coringa Wildlife Sanctuary*". Coringa Wildlife Sanctuary comprises 235.70 sq.km of mangrove forests in EGREE.

In order to fill the huge blank areas inside CWLS, Forest Department has been resorting to artificial regeneration of mangrove species since 1991 (MSSRF report). With the assistance of M.S. Swaminathan Research Foundation and the local communities, large parts of Coringa Wildlife Sanctuary have since been restored successfully using the fish-bone technique. Additionally, 20 eco-development societies were also constituted to involve the local villagers in preserving and protecting the flora and fauna of CWLS. A tourist facility also exists which plays an important role in disseminating the role and values of these mangroves to the local people and other tourists. However, the Forest Department is faced with huge challenges to protect CWLS in face of the increasing pressures from the aquaculture industry and increased urbanization of the surrounding cities. The high dependence of the local communities on these forests for food, fuel wood and subsistence often leads to conflicting situation with the Forest Department. These problems are magnified by the severe shortage of protection and frontline staff, and lack of modernization in the department.

Seasons and Temperature

EGREE experiences typical coastal climate with high humidity, often above 80% and a mean annual temperature of 25°C (Figure 3). Summers are extremely hot and humid whereas light winter ranges from November to February. The region experiences two monsoon seasons: South west monsoon extends from July to October while the North-east monsoon occurs from October to November. The monthly average rainfall pattern is given in Figure 3.

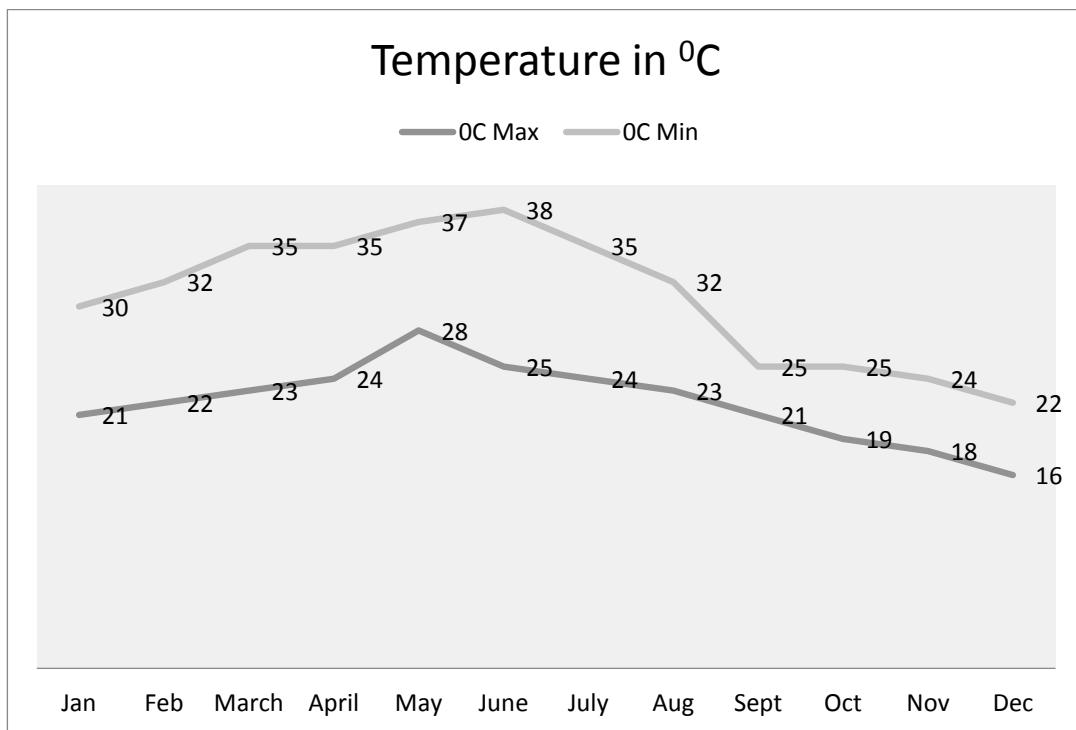


Figure 3: Temperature Profile of the EGREE Landscape

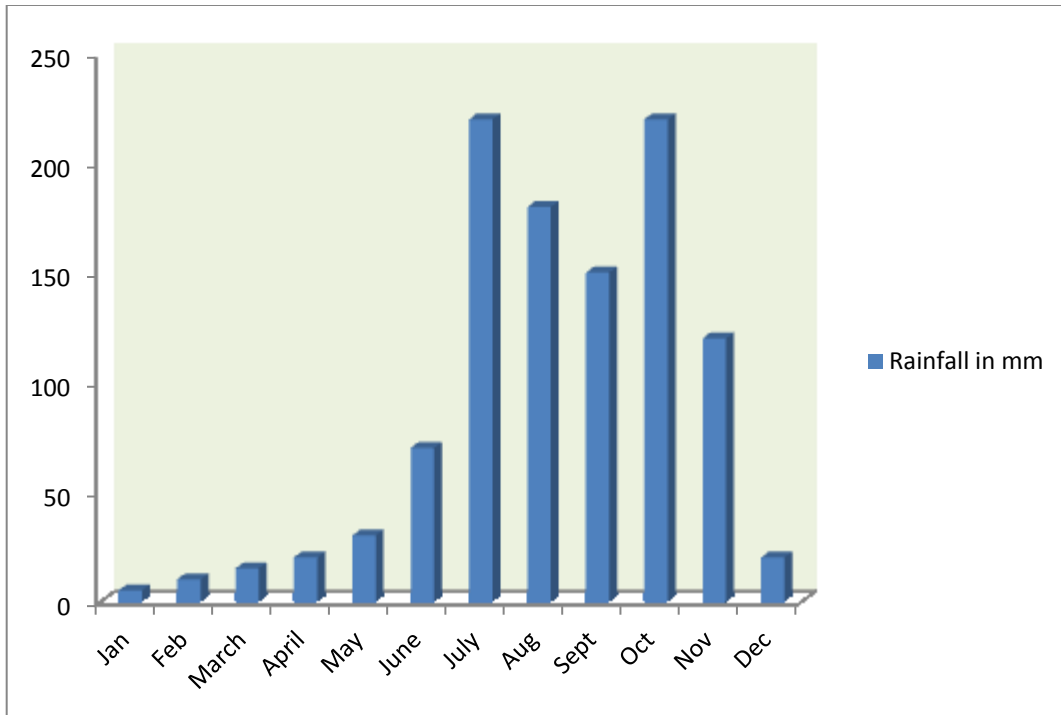


Figure 4: Monthly Average Rain Fall of the EGREE Landscape

Natural calamities (Cyclones and Droughts) and their periodicity

Located adjacent to Bay of Bengal, cyclonic storms are annual phenomenon in this region (Table 2). The cyclones usually last for 2-4 days and may inundate the low-lying areas depending upon their severity. This area was adversely effected due to repeated cyclones during the 17th and 18th centuries and Coringa which was once a large port for trade during those days got destroyed and had to be closed.

Table 2: List of cyclones in Andhra Pradesh

Sl. No	Year	Place
1	1789	Coringa
2	1839	Coringa
3	1969	Kakinada
4	1976	Machilipatnam
5	1977	Krishna
6	1979	Ongole
7	1982	Ongole
8	1987	Ongole
9	1990	Krishna
10	1992	Kakinada
11	1996	Kakinada
12	2003	Machilipatnam
13	2006	Krishna
14	2013	Machilipatnam
15	2013	Machilipatnam
16	2014	Visakhapatnam

A cyclone that made landfall near Kakinada in 1996 is the last one to have caused the most destruction in EGREE region. Reportedly 1077 people were confirmed to have died while several thousand went missing. Two villages were destroyed due to the cyclone. It caused huge damages to buildings, engineering structures and agricultural fields throughout the district with Kakinada the most severely hit.

Hydrology

The river Godavari originates near Nasik, Maharashtra, and travels 1465 km before flowing into the sea near Bhairavapalem village. As it enters the state of Andhra Pradesh it meanders through the steep valleys of Eastern Ghats, finally emerging into a vast flood plain after Polavaram village in West Godavari district. It then branches into two distributaries named as Vasistha and Gouthami near the Dowlaiswaram Barrage. The Gouthami River flows in eastern direction and meets the Bay of Bengal at two places, namely Bhairavapalem and Kothapalem villages. Similarly, the Vasistha River flows slightly in the south-eastern direction and drains into the sea at Antervedi and Odalarevu village. This project mainly focused on the Gouthami River and its distributaries.

Godavari River empties huge amount of water each year into the Bay of Bengal. This large volume of fresh water, loaded with silt and sediments, flows through many distributaries into the Godavari delta (Narasimhna Rao et al., 2010). As per the data of Central Water Commission (CWC), annual discharge of Godavari River is presented in Figure 4. River flow peaks during the months of August and September that also corresponds with the south-west monsoons in India, while discharge is very low in the dry season from January to May.

Gouthami River is the larger of the two distributaries of Godavari. It branches further into smaller rivers and creeks before meeting the Bay of Bengal. In Coringa Wildlife

Sanctuary (CWLS), the river is connected to Kakinada Bay in the northern part by two major tidal channels, the Coringa River arising at Yanam (under Pondicherry) and the Gaderu River arising at Bhairavapalem. There are other rivers such as the Matlapalem canal and number of smaller inter-tidal creeks that cut across the entire Sanctuary and ultimately drain into the Bay or join the sea.



Figure 5: Dowlaishwaram Barrage at Rajamundry

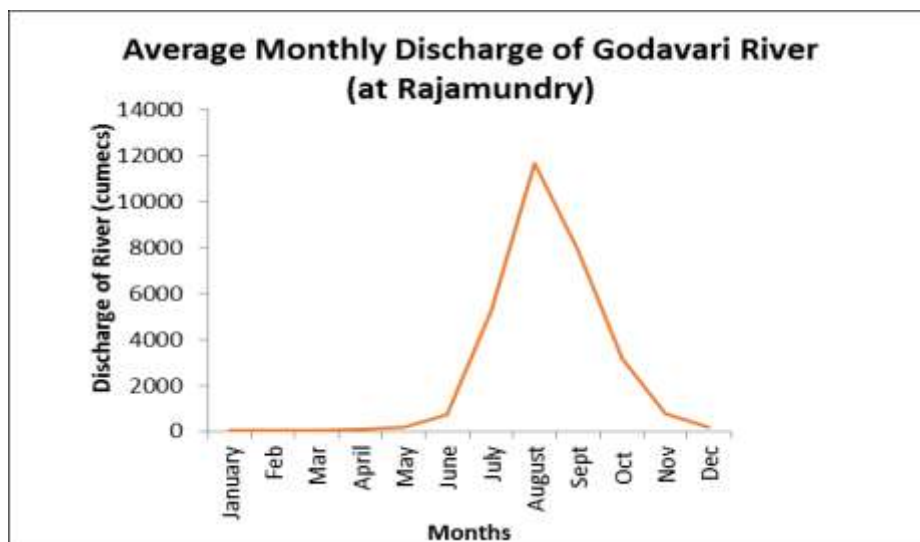


Figure 6. Monthly average discharge of flow from Godavari River.

The two major rivers of CWLS are described below:

Coringa River: This is a small river originating at the town of Yanam and enters the sanctuary area near Coringa village. It travels north to join the Kakinada Bay. Since it receives freshwater from Godavari River, salinity is relatively low but increases towards the mouth near Kakinada Bay. Major part of this river flows through the town of Yanam and other villages. Number of industries such as lime and cement manufacturing units, boat construction units and aquaculture ponds are also present along its banks.

Therefore, anthropogenic influence on this river is higher than Gaderu.

Gaderu: Gaderu river arises about 5 Km below Yanam, near Bhairavapalem village. It enters the sanctuary at the southern tip and nearly bisects the Sanctuary into two. It also travels north and ultimately joins the Kakinada Bay. There are smaller sub-tidal and inter-tidal creeks that originate from this river and meet the Bay of Bengal. Salinity in this channel and its creeks are relatively higher than other creeks of CWLS due to the direct connection with sea at several points. A locally important landing center for both estuarine and marine fishes is present at Bhairavapalem village along this river.

The entire sanctuary is tide-influenced with two cycles of high and low tides. During high tide water flows from north to south through Gaderu and Coringa, enters the sanctuary submerging the mud-flats through the innumerable network of creeks. In the spring tides, several parts of the mangrove forests also get submerged especially in the monsoon season. During low tide, water drains out from the sanctuary from south to north direction exposing the mudflats situated in western and southern parts of the Bay. In simple words, the drainage can be described from North to South during high tide and from South to North during low-tide through the two major rivers Gaderu and Coringa.

Terrestrial Flora and Fauna

As mentioned earlier EGREE is characterized by extensive tracts of mangrove forests. As per earlier reports, 35 species of mangroves have been reported here out of which 16 are true mangroves while rest are associated mangrove species. *Ceriops decandra*, is a Near Threatened species found here (IUCN, 2010) along with three rare species (Ravishankar et al., 2004).

In terms of faunal diversity this ecosystem is highly blessed. It is an Important Bird Area (IBA), with a recorded population of 236 bird species, of which 88 are migratory. Places such as Sacramento Island, Hope Island, Masanitippa, Yellayapeta serve as important nesting sites for migratory turtles, notably the endangered Olive Ridley turtle and Green turtle. Mangroves of Godavari delta are also home to one of the rare and elusive cats in the world- the Fishing cat *Prionailurus viverrinus*. In addition to that, Smooth coated otters *Lutrogale perspicillata* are also present in good population. Golden Jackal, Palm civet, Rhesus macaque are few other mammals present in the mangrove forests and the surrounding areas.

The rich aquatic fauna is the mainstay of this region which is evident in the fact that it is one of the important fishing grounds in the eastern coast of India. In a survey by Zoological Survey of India in 2001, around 2 species of sponges, 6 species of jelly fishes, 29 species of polychaetes, 21 species of crabs, and 64 species of molluscs and 314 fish species were reported from this region (ZSI, 2001).

Socio- Economic Status

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. Other villages and cities situated in the East Godavari district are also indirectly dependent on the mangroves due to the immense ecological services provided by this ecosystem.

Majority of the local fishermen engage in artisanal and subsistence fishing inside the mangrove forests. The mangrove-lined creeks of this region are known for their prawn fisheries which also form the foundation for the spurt of shrimp aquaculture industry in the region. Apart from this, other resources such as mollusks and crabs also provide an alternate source of livelihood for the local communities.



Figure 7: A typical '*kutcha*' house of local fishing community with roof covered by locally available grass species



Figure 8: Subsistence fishing in creeks of Coringa WLS

East Godavari River Estuarine Ecosystem: Issues and Threats

Despite the strong legal, policy and institutional framework, the mangrove, and coastal ecosystems of Andhra Pradesh in general, and the EGREE in particular, are under increasing threat. Godavari Delta, like many other deltaic systems in India, has been highly altered by human activities. Causes for the degradation of estuarine ecosystem include conversion of mangroves to aquaculture, agriculture and salt pans; rapid and unplanned urbanization; effluent discharge from industries; eutrophication; siltation of Kakinada Bay and its rivers; alteration of the natural flow of Godavari River and obstructing freshwater discharge into the estuary and mangroves; cattle grazing inside mangroves; overfishing and overexploitation of mangrove forests by villagers for timber, fuel wood and boat manufacture. It is estimated that 30-40% of the

degradation of mangrove forests has taken place in the last decade due to agriculture, aquaculture and deforestation, and oil and pesticide pollution.

The direct drivers of habitat loss in EGREE are (i) changes in Land Use/Land Cover, (ii) overexploitation and consumption of coastal and marine resources and (iii) pollution from industries, aquaculture, and urban agglomerations (Kakinada, Andhra Pradesh, and Yanam, Pondicherry). The indirect drivers of ecosystem change relate to demographic pressures that are exacerbated by challenges in governance and economic constraints faced by the local population. One of the key governance issues pertain to the Forest Department responsible for management of CWLS. It is severely short of frontline staff and requires personnel with advanced training to face the impacts of climate change in future.

The current report presents the outcome of the two years of the study. This report is divided into different chapters, each pertaining to the different components of the study. In addition, an entire chapter focusing solely on climatic change, the latest projections of Inter-Governmental Panel of Climate Change and potential impacts have also been included. Methodologies and results for each component have been included separately in the respective section.

PART - 1

DISTRIBUTION PATTERNS OF FLORA AND FAUNA



CHAPTER 1

Study of Mangroves and its associates

Mangroves are salt-tolerant coastal forests that are mostly distributed along river banks, lagoons, or estuaries in tropical and sub-tropical coasts. They have special adaptations to survive in the saline, waterlogged conditions of an estuary or lagoon. Some of the adaptations include presence of aerial roots, viviparous reproduction, tidal dispersal of propagules, active secretion of salt by special cells or glands, etc (Alongi, 2002). The term 'mangrove' is used to denote the ecosystem as well as the various plant species specialized to live in such brackish environment (Tomlinson, 1986).

Just like the highly productive estuaries, mangrove forests also fulfill many important functions and provide a wide range of services at the local and national level. Apart from providing livelihood to local communities, mangroves also play an important role in the aquaculture industry. Because of its high economic return, shrimp farming is being promoted to boost the national economy and alleviate poverty in several countries including India. Mangroves also offer a source of timber and fuelwood, providing subsistence for local populations. The dense root network of mangroves traps the sediments and silt coming with the tidal cycle that in turn helps in stabilizing the coast and prevent erosion. They also act as natural defense against coastal floods, storm surges, cyclones and tsunami.

Notwithstanding the different roles and services provided by this unique ecosystem it is being destroyed at an alarming rate across the world. Already 20-35% of mangroves have been lost globally making them the most threatened ecosystems in the world. A study published in 2007 even suggests that given the current rate of loss in mangrove cover, they will be functionally non-existent in 100 years. In India itself, which has the fourth largest mangrove cover in the world, 40% declines had been observed by the Government of India in 1987 (Govt. of India (1987) Mangrove in India. Status Report,

Ministry of Environment & Forest, Govt. of India, pp. 1-150). Given their important role in subsistence of the local communities and as natural coastal defense, loss of mangrove cover will render coastal regions, particularly in India to serious damages due to sea level rise and other impacts of climate change.

Previous studies in Godavari mangroves

Species composition and list of species has been reported from Godavari by Venkateshwarlu (1944), Mathuda (1957), Rao (1959), Sidhu (1963), Chapman (1974), Blasco (1975), Reddi (1982), Lakshman (1984), Venkanna (1988), Umamahshwara Rao and Narasimha Rao (1988). Benerji (1957) identified five distinct zones in Coringa mangroves based on tidal indulation, Rao (1959) divided the entire Godavari deltaic mangroves into three major zones like Northern pure dense mangrove zone, the Southern open stunted mixed mangrove zone and high lying isolated blank zones. He pointed that differences in tide table, soil texture, rhythmic tide table, salinity and excessive silt deposition of Godavari is chiefly responsible for distribution of mangrove species.

According to Mathuda (1959), dense and tall trees of *Avicennia officinalis*, *Excoecaria agallocha* and *Lumnitzera racemosa* constituted nearly 90% of the population of the Godavari mangrove wetlands in 1950s, but now they constitute only 37% of the population. On the other hand, bushes of *Suaeda maritime* and *S. monica* constitute nearly 40% of the population. These two species are halophytes but not true mangrove species and they can tolerate salinity as high as 100 ppt.

According to Sidhu (1963), forest communities of Godavari mangroves falls into three heads like Tidal Evergreen, Tidal Semi-evergreen and Tidal deciduous, besides with herbaceous halophytic communities with saline blanks. He further classified the tidal evergreen as Pure *Avicennia* community, Mixed *Avicennia* community, *Avicennia-*

Aegiceras mixed community, *Lumnitzera* community, *Lumnitzera-Scyphiphora* community. In tidal semi-evergreen and deciduous there are *Exocoecaria-Avicennia* community, *Exocoecaria* community and *Clerodendron inerme* community. The halophytes are classified into mixed *Suaeda* community and *Salicornia brachiata* community. Coming to the saline blanks, there were formed after the planned felling of mangroves in 1935, these blanks under a process of stratification and hardening of deposited clay are dominated by *Suaeda* sps and *Aeluropus repens*. He mentioned that the development of these communities is greatly influenced by biotic factors and edaphic factors. After heavily felling of 1935, *Aegiceras majus* and *Ceripos candollena* was formed as mixed communities, but already because of adequate undergrowth of *Avicennia* seedlings thriving under the shelter of *Aegiceros* and *Ceripos*, tend to grow and formed the forest in low lying deltaic regions. Towards the back waters, where water is highly saline, *Avicennia* is dominated while towards the land, where water is less saline *Exocoecaria agallocha* is dominated. He identified 26 species of mangroves from Godavari Delta.

Rao and Rao (1992) found out that there is a positive relationship between fine particles and plant abundance. The landward zones showed low density of mangrove distribution because of low lying areas which are formerly mangrove swamps but lost their contact with salt water due to the seaward extension of fresh water zone and the areas which are closer to the water are flooded by high tides Vadlapudi (1999) carried out change analysis on mangroves of Godavari using IRS 1B LISS II data and observed that during a span of one year period (1994- 1995), the spread of aquaculture has caused destruction of mangrove up to 22.69 ha.

Raju J. S. S. N (2003) by continuous phase-wise observations on *Xylocarpus* species for two years (2000-02) in Pandi, Pora, Kothapalem, Masanitippa and \ Ratikaluva areas of the EGREE mangrove forests revealed new distributional record. *X. mekongensis* is more

frequent whereas *X. granatum* is rare. Their simultaneous occurrence was not recorded earlier.

V. Selvam (2003) pointed out that by measuring the growth of the sand spit with the available map prepared in 1789, it has been estimated that previously the mangrove was at about 6 km inside the present shoreline. This is an indication for expansion of the mangrove into the sea, a characteristic feature of the river dominated mangrove wetland.

Ramasubhramanian et al. (2006) analyzed the remote sensing images of 1986 and 2001 and reported that the changes in the vegetation are due to forest restoration and natural regeneration. According to the changes in mangrove vegetation between 1975 and 1986, the southern bank of Godavari River (Nilarevu River) in Rathikaluva RF has eroded because of floods during the southwest monsoon. Furthermore, because the Nilarevu River is getting wider from 1986 to 1998, the erosion of mangroves along the southern bank of Nilarevu River increased further. The main species which are present here are *Rhizophora apiculata*, *R. mucronata*, *Xylocarpus molluccensis*, *Brugiera gymnorrhiza*, *Avicennia marina*, *A. officinalis* and *Excoecaria agallocha*. *Tamanx trollpii*, a mangrove associate, is recorded in this RF along with *Thespesia populneoides*. *Hibiscus tiliaceus*, *Clerodendron inerme*, *Suaeda* spp. and *Jalicornia brachiata* occur in degraded areas. The course of the river has changed too, resulting in further mangrove erosion.

According to C. Sudhakar Reddy et.al from 1977 to 1988, the mangrove vegetation cover had a negative change and lost about 24.6 km², which was mostly recovered during the next period (1988-2000), giving a total balance of 185.2 km² from 1988 to 2000. In the last period (2000-2005) there was gain with an area of 0.9km², but over the entire three decade period the net change was negative, which was qualified as 8.8km². The increase in the mangrove was due to accretion and restoration. In any case, it was not possible to analyze the change in species composition.

B. Satyanarayana (2006) based by multivariate analysis on mangrove tree density and basal area measurements in Coringa, revealed 6 different floristic groups. While Group-1 and Group 2 characterized by a combination of *Sonneratia apetala* and *S. caseolari*, *Avicennia alba*, reflected conditions typical of low-lying swamps, Group-3, consisting of *Xylocarpus mekongensis*, *Rhizophora mucronata*, *R. apiculata* and *Bruguiera gymnorrhiza*, was found close to the sea where high saline conditions prevailed. Group-4 species, *Avicennia marina*, *A. officinalis* and *Excoecaria agallocha*, represented widespread distribution. Group-5 consisted of *Lumnitzera racemosa*, *Ceriops decandra* and *Aegiceras corniculatum* which occurred at sites not very far from the influence of Gautami-Godavari estuary, suggestive of their preference to low salinity regimes.

Finally, Group-6 typically represented by *Bruguiera cylindrica* was seen interiorally at sites under the direct influence of Bay waters. Moreover, the mangrove formations are particularly susceptible to natural geo-morphological and climatic perturbations, which can regulate the extent and structure of mangrove forests and may mask the local importance of spatial or temporal variation in salinity by limiting distribution or abundance of individual species. Recent work suggests that establishment/growth of mangroves (particularly seedlings) could be influenced by several abiotic and biotic factors such as light availability, soil condition, tidal current, salinity, animal predation, propagule size and dispersal, intra- and interspecies competition etc.

Satapathy (2007) by using satellite sensor data detected the changes in the mangrove cover for a period of 12 years (1992–2004). It was found that an area of about 1,250 ha of mangroves was destroyed by anthropogenic interference like aquaculture, and tree felling etc. By taking this as an advantage, spectral data was utilized for clear demarcation of mangroves from nearby paddy fields and other vegetation. Ecological parameters like mud-flats/ swamps, mangrove cover alterations, and biodiversity

status are studied in detail for a period of 12 years. The increase in mangrove front towards coast was delineated using remote sensing data.

According to Narasimha Rao GM and Reddi BN (2013) the population structure of the mangroves and associated mangroves in Godavari estuary reveals that the abundance of typical mangrove species is less in the Godavari estuary than other halophytes or associated mangrove species. Due to topographical changes, aqua cultural activities and over exploitation of mangrove species for various purposes may leads to formation of abundant halophytic vegetation and other associated mangrove species in the Godavari estuary.

Methodology

To determine the vegetation structure and composition of the mangroves quadrat method was used.

Thirty-five *1km X 1km* grids have been selected based on natural/ artificially planted vegetation following initial surveys. Selection of these sites was done within undisturbed tracts and care was taken that it would be logistically feasible for frequent monitoring in future. In each grid, *10m X 10m* 5 sub-plots are laid which have been marked on all four corners (Plate 5).

After marking them, some basic data are collected which includes species identification, number of individuals, height and DBH or diameter of the trunk at breast height (usually at 1.37 m above the ground), phenology status, live or dead status, number of seedlings, as well as some environmental factors such as canopy cover, compaction of ground and salinity.



Figure 9: Marking of quadrates for studying the composition of mangroves species

Results and Discussion

Three rounds of vegetation sampling in 125 plots of 100 square meters were sampled thrice during the period from 2014 to 2015. Thirty-five species of mangroves were recorded in the Coringa WLS belonging to 17 families. Avicenniaceae seems to be the most dominant family followed by Euphorbiaceae and Rhizophoraceae.

The relative density, relative dominance and relative frequency of individual species are given below in the Table 3.

Table 3: Mangroves species with their relative dominance, relative density, and relative frequency

S.No.	Species	Relative density (%)	Relative frequency (%)	Relative dominance (%)
1	<i>Avicennia officinalis</i>	10.46	20.60	39.89
2	<i>Avicennia marina</i>	41.16	26.58	49.67
3	<i>Avicennia alba</i>	1.23	1.00	5.47
4	<i>Rhizophora apiculata</i>	3.38	2.66	0.00
5	<i>Rhizophora mucronata</i>	0.44	0.66	0.00
6	<i>Bruguiera gymnorrhiza</i>	3.32	2.99	0.01
7	<i>Bruguiera cylindrica</i>	1.06	1.99	0.00
8	<i>Ceriops decandra</i>	11.11	10.96	0.05
9	<i>Lumnitzera racemosa</i>	3.69	3.32	0.00
10	<i>Scyphiphora hydrophyllacea</i>	0.44	0.66	0.00
11	<i>Aegiceras corniculatum</i>	6.67	9.30	0.02
12	<i>Sonneratia apetala</i>	0.58	1.99	0.00
13	<i>Sonneratia alba</i>	0.03	0.33	0.00
14	<i>Sonneratia caseolaris</i>	0.03	0.33	0.00
15	<i>Excoecaria agallocha</i>	16.34	16.28	4.90
16	<i>Xylocarpus molluccensis</i>	0.03	0.33	0.00

The overall density of trees in and around the sanctuary was calculated to be 2340 trees per hectare. The relative density of *Avicennia marina* was the highest followed by *Excoecaria agallocha*, *Ceriops decandra* and *A. officinalis*. The densities of these species varied habitat-wise. *A. marina* had the highest densities in Gaderu, Yedurlanka and the seaward side of the sanctuary. These sectors have relatively higher salinity values even

in the monsoon season. On the other hand, *A. officinalis* had higher density values in Matlapalem and Ramanapalem sectors where salinity values are relatively low during the monsoons. Similarly, *E. agallocha* also had high densities in the creeks with lower salinities.

The mangrove vegetation in and around the Sanctuary is mainly dominated by *Avicennia marina*, *Avicennia officinalis*, *Excoecaria agallocha* and *Ceriops decandra*. *C. decandra* is a Near Threatened species listed in the IUCN RedList. The IVI values of the true mangrove species are depicted in Figure 11 while values of relative density, relative frequency and relative dominance are listed in Table 3 and Figure 11.

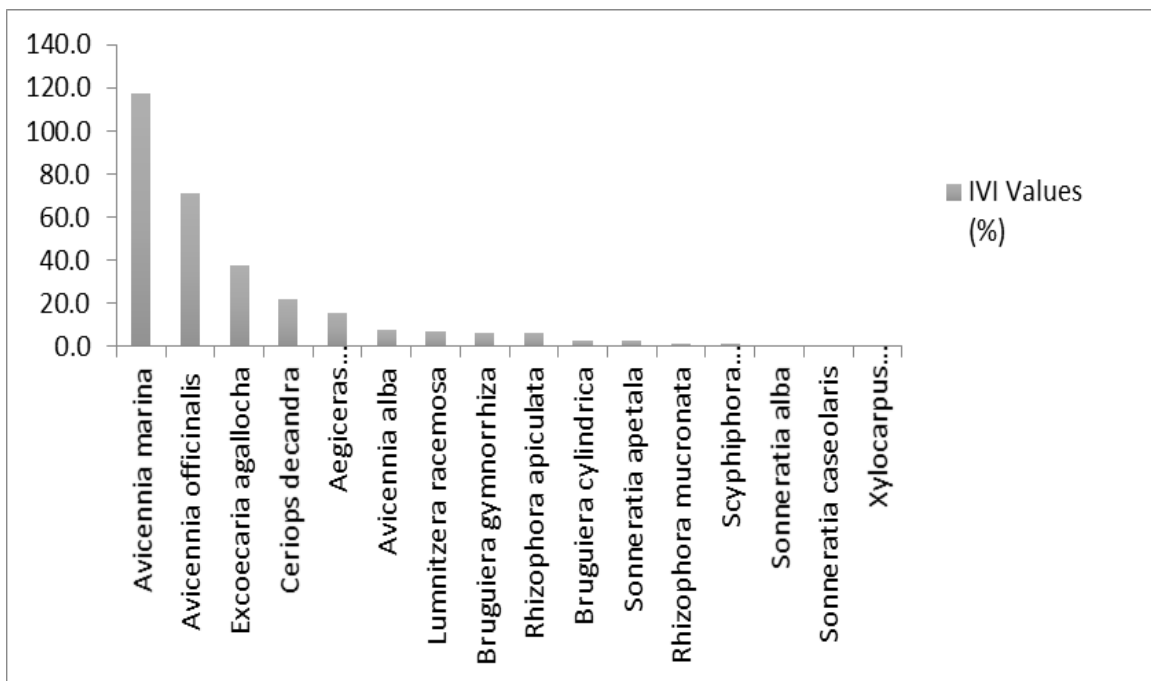


Figure 10: Graph showing IVI values of sixteen mangrove species

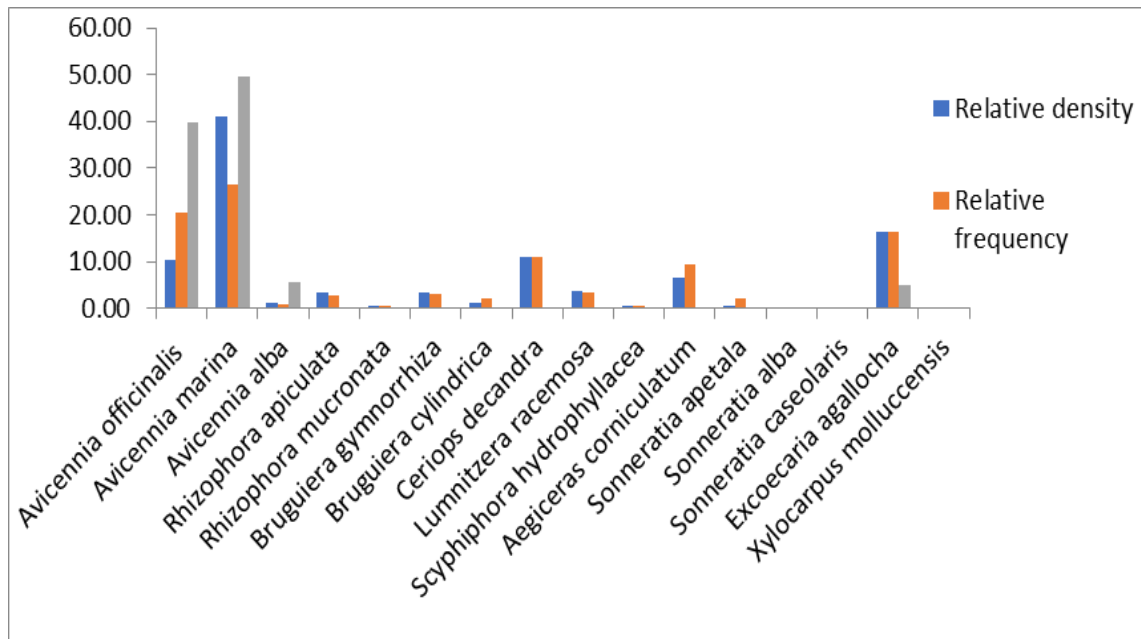


Figure 11: Comparison of Relative dominance, Relative density and Relative frequency in different families of mangroves present in Coringa

The IVI values also showed variations in different habitats. Figure 12 shows the distribution of the different species based on their IVI values in each habitat. Certain species such as *A. marina* and *A. officinalis* were dominant in all the five habitats that we surveyed while species such as *Avicennia alba*, *Rhizophora mucronata* and *Xylocarpus molluccensis* were mostly distributed in Gaderu sector.

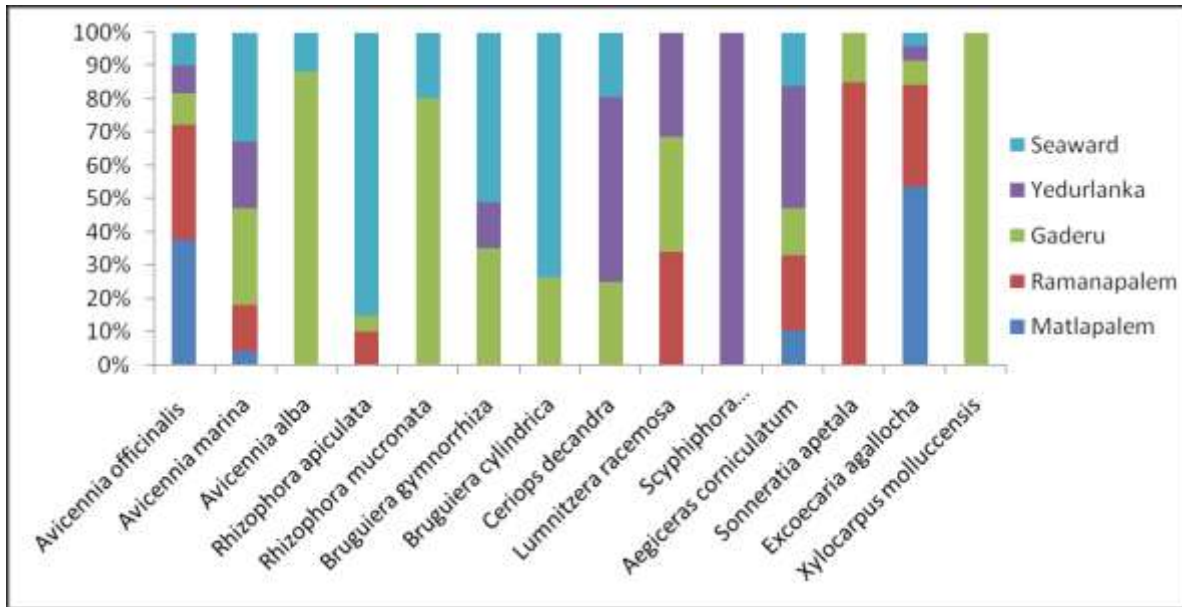


Figure 12: Graph showing IVI values of mangrove species in different sectors of Coringa Wildlife Sanctuary

Mangrove associates like *Acanthus ilicifolius*, *Derris trifoliata*, *Myriostachya whightiana*, *Caesalpinia crista*, *Ipomoea tuba*, *Hibiscus tiliaceus*, and *Thespesia poulneoides* were also commonly recorded along the creeks of the sanctuary. One important observation that we made is the extensive growth of *Caesalpinia crista* in the mangrove forests especially around aquaculture ponds. In certain areas, they had such extensive growth that it was not possible to enter the forest.

Flowering Seasons of Mangroves in Egree

Ceriops decandra, a Near Threatened species, has been observed to be flowering and fruiting throughout the year, while for the three *Avicennia* spp. flowering was observed between April and August. This data is important since the phenology pattern may change due to the rising ambient temperatures and other physiological changes due to climate change.



Figure 13: Flowers of different true mangroves in the EGREE landscape

Zonation pattern of mangroves in Coringa Wildlife Sanctuary

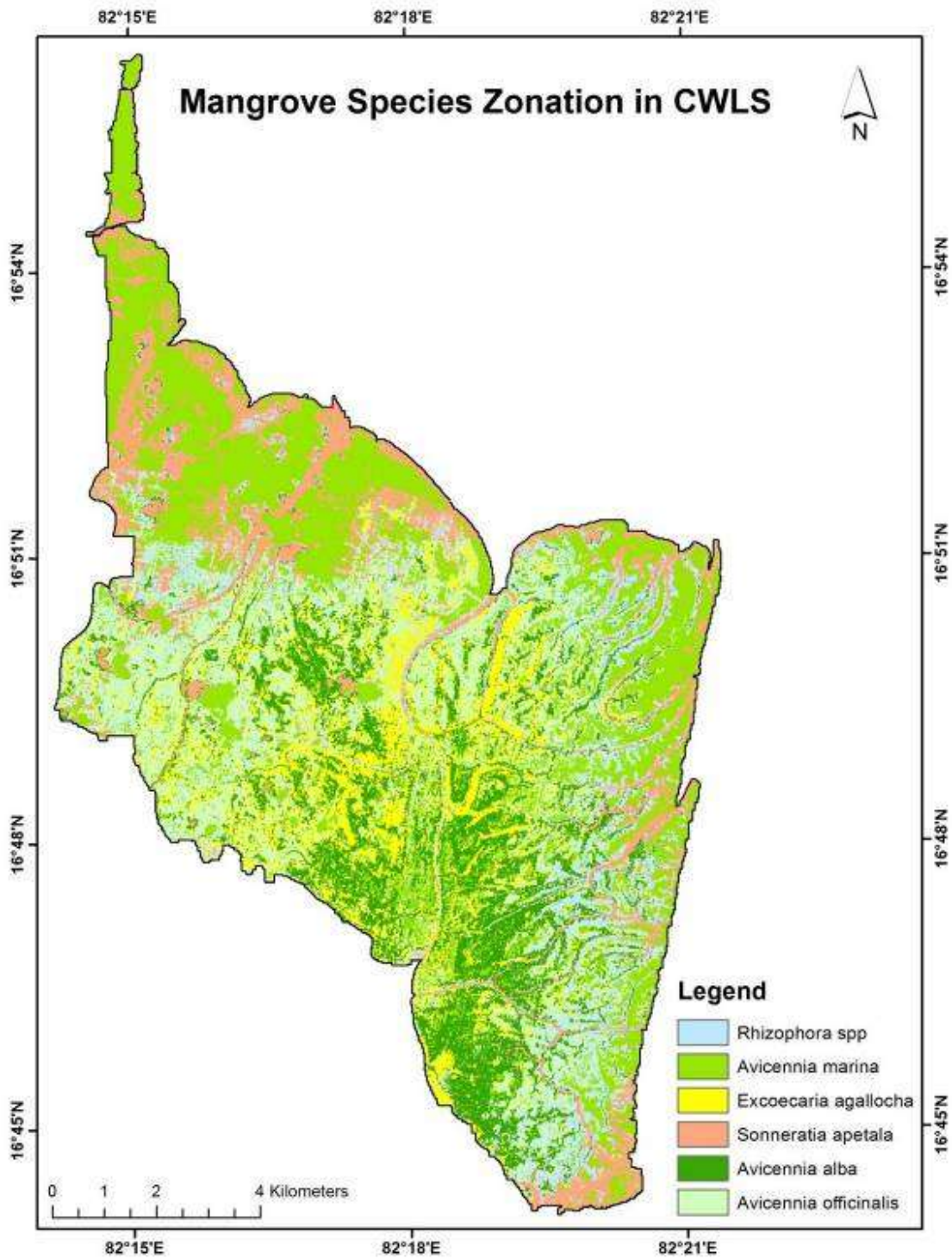


Figure 14. Map showing mangrove species distribution map

About 300 ground points were taken as reference points for the preparation of the Mangroves Species Zonation map (Figure 14) using the technique of Supervised Classification in ERDAS Imagine. The ground reference points were used for making signature file which then gave the above map showing the distribution of mangrove species in CWLS.

According to this analysis, *Avicennia marina* is the most dominant species in CWLS while *Rhizophora* sp. the least dominant. Species-wise mangrove cover is presented in Figure 15.

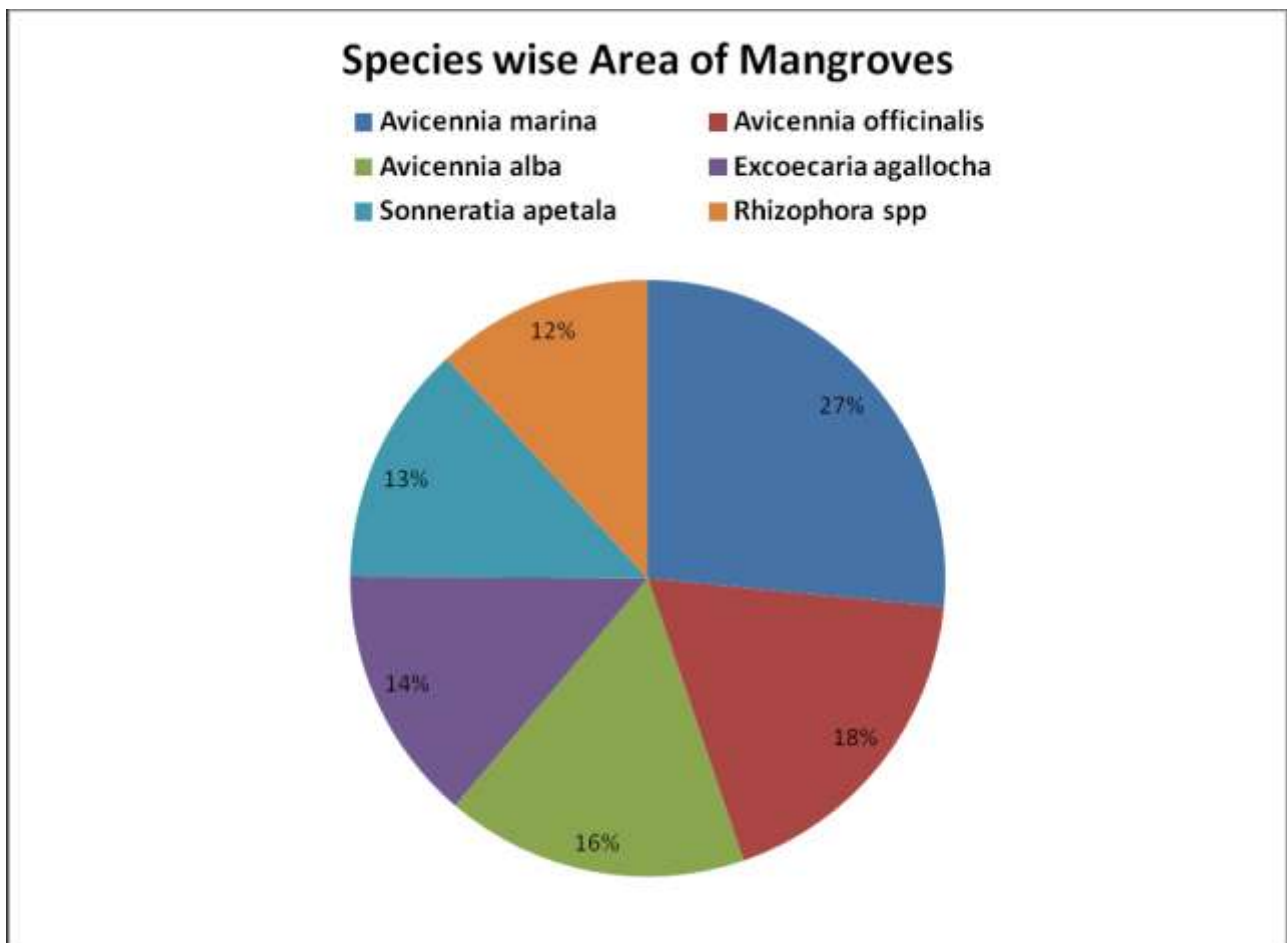


Figure 15. Area occupied by different mangrove species in CWLS



Figure 16: *Xylocarpus mollucenis* flowering in Coringa WLS



Figure 17: *Bruguiera gymnorrhiza* flower and propagule seen in Coringa WLS

Discussion

As per a study in 1959 (Mathuda), nearly 90% of the population of the Godavari mangrove wetlands in 1950s was constituted by *Avicennia officinalis*, *Excoecaria agallocha* and *Lumnitzera racemosa*. In contrast to this our study shows that the mangroves are now dominated by *Avicennia marina* followed by *Avicennia officinalis*, *Excoecaria agallocha* and *Ceriops decandra*. *Lumnitzera racemosa* is now limited to few patches in the forest now.

Dominance of *A. marina* in Coringa WLS could be an outcome of the plantation program carried out by the Forest Department every year. The species also has good recruitment inside the sanctuary. However, maintaining diversity is important for better structural resilience as well as to maintain the functional aspects of the forest. Basal area of *A. officinalis* is higher than *A. marina* in some parts of the sanctuary. Moreover, as per our observations the restored patches of the forests have a relatively open canopy than the natural patches. Such structural differences might give rise to different species assemblages in the two habitats.

At a landscape level, also the mangrove forests of EGREE have undergone changes through the past few decades. In the subsequent sections these changes will be discussed in more details. The potential impacts of climate change on these mangrove forests will also be discussed. Finally, in a later section we also show the different carbon sequestration potential of the different mangrove species in Coringa WLS.

Benthic macro-faunal community structure in the Godavari Coringa mangrove complex ecosystem

Godavari estuarine complex eco-region is a highly productive ecosystem which receives freshwater from Gautami-Godavari River in the western side and the transitional zone in upper northern side is covered by a shallow sand bar (Kakinada Bay) which ultimately connects into the Bay of Bengal and serves as the point for influx of coastal water. Between Godavari estuary and Kakinada Bay, the dense growth of mangroves (second largest mangrove region in the East coast of India after Sundarbasn) provide extensive amount of organic load which leads to high productivity (Satyanarayana et al., 2002; Raut et al., 2005).

Numerous studies have considered the ecological importance of the Godavari-Coringa mangrove complex (e.g. Tripathy et al., 2005; ICMAM report, 2001; Satyanarayana et al., 2002; Raut et al., 2005; Murty et al., 2011). In 1978, Godavari-Coringa mangrove complex was designated as a Marine Protected Area (MPA).

This region is also well known as an important coastal wetland ecosystem that performs magnitude of ecological functions including provision of habitat to different groups of organisms, food source for trophic level, spawning ground for rich fisheries, habitat for migratory birds and other associated fauna including those that live in the sediments (Murty et al., 2011). To date only a handful of studies have considered the benthic communities and their assemblages in Godavari-Coringa ecoregion (Radha Krishna and Ganapati, 1969; Kondalarao, 1983; Narasimham et al., 1984; Kondalarao and Ramana Murty, 1988; Vijayakumar et al., 1991; Rao et al., 2003; Raut et al., 2005).

Sampling and benthic faunal analyses

During the study period two years of sampling was done. In 2014, sediment samples were collected from four predefined stations [GOD 1 (567), GOD 2 (568), GOD 3 (569) and G1] in the Godavari- Coringa mangrove complex along with *in situ* measurement of hydrological parameters [e.g. temperature, dissolved oxygen (DO 6+ meter), salinity (hand held refractometer, Erma, Japan) and pH (pH meter)]. And in 2015, sediment samples were collected from eight stations including the above four stations from the study area. The locations of all the stations are detailed in Figure 18. At the time of sampling, duplicate sediment samples were collected from each station using a Ponar grab (biting area of 0.025m²). Immediately after the grab was hauled to the deck, two sub-samples were collected for downstream analyses (enumeration of benthic fauna and sediment granulometry).

Rose Bengal solution (1 g in 1 litre distilled water) was added to collected sediment sub-samples and subsequently fixed with 4% buffered formalin (Heip et al. 1985). Replicate sub-samples were subsequently processed separately in the laboratory at IISER Kolkata and data were pooled for analyses. For macrofauna extraction, sediments (50 gms; wet weight) were washed through with mesh size of 0.5 mm sieve (Sommerfield and Warwick, 1996).

After sieving, all organisms were carefully separated. Collected organisms (e.g. small gastropods) were sorted and enumerated under a zoom stereomicroscope (ZEISS - StemiDV4). All taxa were segregated into different groups and then identified to species, generic or other higher levels based on standard taxonomic keys (e.g. Polychaeta: Fauvel, 1953, Day, 1967; Mollusca: Subba Rao et al., 1991).



Figure 18. Locations of stations sampled in the Godavari - Coringa mangrove complex in 2014 and 2015

Results and Discussion

In 2014, both air and water temperatures were found to be highest in mud flat station (GOD 1- 567) followed by mixing zone station (GOD 4 - G1) and lowest in mangrove stations (GOD 3 - 569 and GOD 2 - 568). Variations in temperature within the study region may due to time of sampling during that day. Salinity values were comparatively low, because sampling was undertaken during late monsoon period (26th October 2014) (Table 1).

Dissolved oxygen concentration of surface water was higher in mangrove sites (GOD 3 & GOD 2), low at mixing zone (GOD 4) and intermediate at mud flat station (GOD 1) (Table 1). The pH of studied stations was generally alkaline in nature (Table 1). The transparency of the water column as indicated by Secchi depth showed variability between the stations. All the measured hydrological parameters have been detailed in Table 1. In October 2015, the measured *in situ* environmental parameters showed patterns congruent observed in previous year with an increasing trend for stations near

the shore. In general, the salinity was found to be very low although majority of the stations showing value above zero. High freshwater flow can have altered the salinity gradient across the sampling stations since it is well known that mean annual freshwater discharge from Gautami Godavari River into the Bay of Bengal is generally high (Raut et al. 2005).

The pH of the surface water was found to be stable across all the studied stations and dissolved oxygen concentration showed trends like previous year. All the measured hydrological parameters have been detailed in Table 4.

Table 4. Measured *in situ* hydrological parameters of studied stations located in the Godavari - Coringa mangrove complex ecoregion in the month of October 2014.

Stations	GOD 1 (567)	GOD 2 (568)	GOD 3 (569)	GOD 4 (G1)
Air temperature (°C)	35.7	28	28.3	31.3
Water temperature (°C)	31.4	28.4	28.6	29.3
Salinity	0	0	2	4
Surface water Dissolved Oxygen (mg/l)	3.21	3.67	5.18	2.96
pH	8.66	8.33	8.2	8.2
Secchi depth (cm)	51	57	67	60

Table 5. Measured *in situ* hydrological parameters of studied stations located in the Godavari - Coringa mangrove complex eco region in the month of October 2015

Stations	GOD 1 (567)	GOD 2 (568)	GOD 3 (569)	GOD 4 (G1)	GOD 5 (514)	GOD 6 (517)	GOD 7 (520)	GOD8 (618)
Air Temperature (°C)	35	34.5	34.8	34.8	33	32.9	35	35
Water Temperature (°C)	32.3	32	32.3	32.5	31.5	31	31.4	32.1
Salinity	2	3.5	3	3	0	2	0	4
Surface water Dissolved Oxygen (mg/l)	5.42	5.49	5.89	5.84	5.62	5.72	5.61	5.68
pH	8.1	8.1	8.2	8.2	8.5	8.2	8.1	8.1
Secchi depth (cm)	40	50	54	70	60	76	50	62

In October of 2014, a total of 153 macrofaunal organisms were encountered from the studied stations and these organisms represented five major groups such as Gastropods, Bivalves, Polychaetes Amphipods and Tanaids. The studied sites were mainly dominated by Gastropods in terms of abundance (58 individuals/50 gm) while in terms of species composition polychaetes dominated the study sites (8 species). Along spatial scale, both macrofauna abundance and species diversity were highest in mangrove sites (GOD 2 & GOD 3) followed by mixing zone (GOD 4) and mudflat (GOD 1). Polychaete abundance were homogeneous across all the sites while *Capitella* sp. and *Lumbrinereis* sp. were restricted to mangrove sites and *Prinospio* sp. was found only in mixed zone.

Table 6. Numerical abundance of encountered macrofaunal groups in studied stations of Godavari – Coringa mangrove complex in collected samples of October 2014.

Macrofaunal species	GOD 1 (567)	GOD 2 (568)	GOD 3 (569)	GOD 4 (N1)
Polychaetes				
<i>Nephtys sp.</i>	2	1	4	3
<i>Nereis sp.</i>	4	1	2	5
<i>Diapatra neapolitana</i>	1	4	2	0
<i>Lumbrinereis sp.</i>	0	0	1	0
<i>Prinospio pinnata</i>	1	0	0	1
<i>Prinospio sp.</i>	3	0	0	0
<i>Polydora sp.</i>	0	0	2	1
<i>Capitella sp.</i>	0	1	2	0
Gastropods				
<i>Nassarius stolatus</i>	2	2	1	2
<i>Nassarius sp.</i>	5	0	3	2
<i>Cerithideopsilla cingulata</i>	3	8	6	11
<i>Umbonium vestiarium</i>	2	4	2	5
Bivalves				
<i>Meretrix casta</i>	0	0	3	3
<i>Modoilus moduloides</i>	0	2	0	1
<i>Macoma sp.</i>	1	0	0	1
<i>Tegillarca granosa</i>	0	2	2	0
Amphipods				
<i>Eurythoe sp.</i>	1	12	8	0
<i>Gammarous sp.</i>	1	7	5	2
Tanaids				
<i>Apseudes sp.</i>	0	2	1	0

Among Gastropods, four species were recorded from the studied stations in October 2014 whereas bivalve species like *Tegillarca granosa* was found to be restricted only in

mangrove sites and *Macoma* sp. was found in both mixed zone and mud flat. Crustacean abundance was high in stations located near mangroves; amphipods and species of tanaids such as *Aapseudes* sp. were found to be limited to sites near mangroves. In October of 2015, 351 specimens were sorted out from the sieved sediments and represented by four benthic macrofauna groups (polychaetes, gastropods, bivalves, and crustaceans - amphipods, tanaids, shrimp larvae and crab). Polychaetes were predominated (77.5%) across the study region, followed by gastropods (13.7%), crustaceans (6.6%) and bivalves (2.3%) while taxa composition showed dominance for polychaete (16 taxa), followed by crustaceans (8 taxa), gastropods (6 taxa) and bivalves (3 taxa) (see Fig 19).

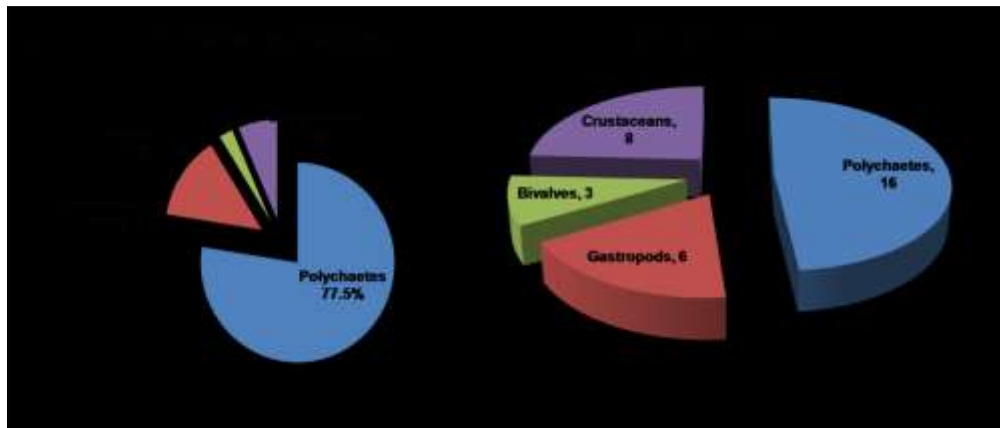


Figure 19. Numerical abundance of benthic macro-faunas and taxa level composition in collected sediments from October 2015 in Godavari – Coringa mangrove complex.

Spatially, benthic macrofauna showed maximum abundance in estuarine based stations (GOD 4, GOD 5 and GOD 6), followed by mangrove associated stations (GOD 1, GOD 2 and GOD 7) and near to the sea shore stations (GOD 3 and GOD 8). Polychaetes were found across all the stations with higher abundance and diversity, while crustaceans were absent in GOD 3 and GOD 5; similarly, gastropods were absent in GOD 1, GOD 3 and GOD 6. However, bivalves were present only in GOD 2, GOD 7 and GOD 8. In this

study, GOD 3, a station located near to the shore was found to be represented only by polychaetes while other macrofauna groups were absent.

Table 7. Benthic macrofauna numerical abundance and their taxa composition in collected samples of October 2015.

Stations	Polychaetes		Gastropods		Bivalves		Crustaceans	
	Abundance	Taxa	Abundance	Taxa	Abundance	Taxa	Abundance	Taxa
GOD 1 (567)	80	13	0	0	0	0	7	4
GOD 2 (568)	11	7	4	3	1	1	6	6
GOD 3 (569)	69	12	0	0	0	0	0	0
GOD 4 (G1)	10	7	7	3	0	0	4	3
GOD 5 (514)	8	5	1	1	0	0	0	0
GOD 6 (517)	29	12	0	0	0	0	1	1
GOD 7 (520)	36	12	12	6	3	2	4	3
GOD 8 (618)	29	11	24	5	4	3	1	1

In analyzed sediments of October 2015, the polychaete genus *Nephtys* was the most dominant (90 individuals; represented by 3 species), followed by *Diapatra* (47 individuals; represented by 3 species), *Polydora* (38 individuals; represented by 1 species) and abundance was found to be low least abundance was found indicator

genera *Capitella* (13 individuals with 2 species). However, *Prinospio* sp. 1 was restricted to mangrove stations and genus like *Nephtys* and *Diapatra* were highly abundant in estuarine stations. In gastropods, *Cerithideopsilla* genera were dominant followed by *Umbonium*, whereas bivalves and crustaceans were found throughout although their abundance was very low. The observed homogeneous pattern of polychaetes distribution in 2014 and 2015 could be attributed to the nature of sediment (medium – fine sand by observation) in the Godavari Coringa study region and such type of sediment texture is usually ideal for infaunal species (Alongi and Christoffersen, 1992).

However, the presence of genus *Capitella* indicates the possibility of high organic load as reported in other ecosystems (Alongi, 1990) and in earlier studies that focused on this ecosystem (Raut et al., 2005). Similarly, the presence of genus *Prinospio* in the station which is in close proximity to mixing zone indicates that the turbidity of water column is generally high as reported in other studies (e.g. Manokaran et al., 2014). Filter feeding bivalve species such as *Tegillarca granosa* is found in mangrove such as Godavari Coringa region 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 (medium sand by observation) and high amount of food deposits (Dittmann, 2002; Raut et al., 2005)

In 2014, the Shannon-Wiener diversity ($H'(\log^e)$) did not vary significantly; stations which were close by were found to have comparable values (e.g. GOD 2 & GOD 4). Similar trends were also observed following other univariate analyses [e.g. Pielou's evenness (J'), Simpson dominance ($1-\Lambda$)] except for Margalef's species richness (d) which showed low value in case of station GOD 2 (Table 8).

Table 8. Univariate measures based on generated macrofaunal dataset in Godavari – Coringa mangrove complex (October 2014)

Sampling stations	S	N	d	J'	H'(log ^e)	1-Lambda'
GOD 1 (567)	12	26	3.376	0.9344	2.322	0.9231
GOD 2 (568)	12	46	2.873	0.8697	2.161	0.8734
GOD 3 (569)	15	44	3.7	0.9283	2.514	0.9249
GOD 4 (G1)	12	37	3.046	0.8743	2.172	0.8739

In case of 2015, Shannon-Wiener diversity (H') showed high value in case of station GOD 7, while other stations did not exhibit any significant variation; Margalef's species richness (d) values were found to be higher in mangrove associated stations. Other univariate analyses such as Pielou's evenness (J'), Simpson dominance (1-Lambda') did not exhibit any significant differences between sampling stations (Table 5). Overall, the H' values were found to be consistent for stations sampled in 2014 and 2015 possibly indicating that the ecosystem level disturbance was not pronounced.

Table 9. Univariate measures based on generated macrofaunal dataset in Godavari – Coringa mangrove complex (October 2015)

Sampling stations	GOD 1	GOD 2	GOD 3	GOD 4	GOD 5	GOD 6	GOD 7	GOD 8
S	17	17	12	13	6	13	23	20
N	17	32	20	35	19	27	35	7
d	4.607	5.491	5.708	4.767	4.087	3.34	6.459	2.542
J'	0.9924	0.9775	0.996	0.9587	0.9816	0.9738	0.99	0.985
H'	2.619	2.928	2.879	2.771	2.518	2.42	3.146	1.765
1-Lambda'	0.9842	0.9733	0.9936	0.9576	0.9668	0.9397	0.9836	0.9578

Since the number of stations sampled in October 2015 was higher, a non-metric multidimensional scaling (nMDS) approach was additionally undertaken to investigate if there was any relationship between the studied stations based on the generated benthic macrofauna dataset. The nMDS ordination plot clearly showed that benthic macrofauna community assemblages showed ~ 60% similarity within the estuarine stations, while mangrove associated stations (~ 50%) and shore stations were separated (only ~ 25%) because both abundance and taxa composition varied significantly. The observed variations in shore based stations could be related to habitat specification, for example, GOD 8 was near to mud flat while GOD 3 close to the mangrove plants.

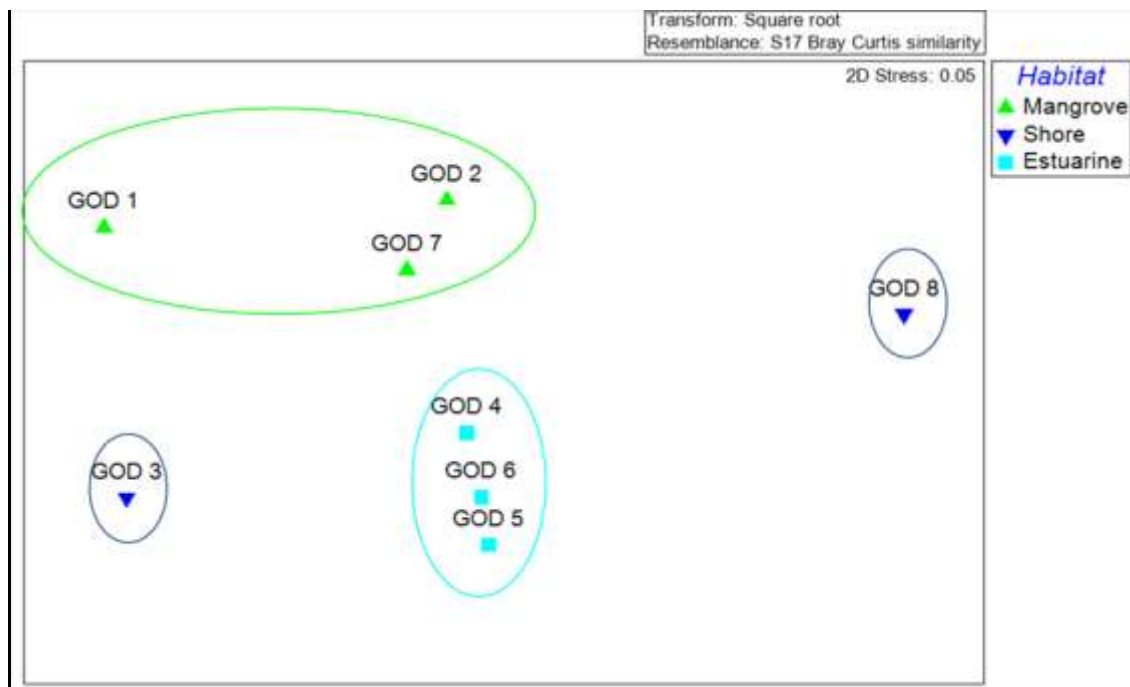


Figure 20: nMDS ordination plot for benthic macrofauna communities in studied stations of October 2015 across Godavari - Coringa mangrove complex

Although, the study has been undertaken for only two time point nevertheless a general picture of benthic macrofaunal community structure across spatial scales has started to emerge for Godavari-Coringa mangrove ecoregion. 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.



Figure 21: Sampling of benthic communities in Godavari Estuary

Figure 22: Different benthic communities seen in Godavari Estuary



Diapatra neapolitana



Nereis sp.



Prionospio sp.



Capitella sp.



Nassarius sp.



Cerithideopsilla cingulata



Umbonium vestiarium



Meretrix casta



Tegillarca granosa



Macoma sp.

Gammarus sp.

Aapseudes sp.

CHAPTER

3

Study on Mangrove Associated Molluscans in Coringa Wildlife Sanctuary

Introduction

Mollusca are the largest marine phylum, comprising about 23% of all the named marine organisms (Chapman 2009). These invertebrates first appeared in the Cambrian period, approximately 500 million years ago and are thriving well having been adapted to a range of living conditions from rocky shores, deep oceans, estuaries, lagoons as well as deep sea vents etc. This group contains diverse organisms such as bivalves, snails, slugs, octopuses, squids etc. In the tropical seas around the globe, they occupy every trophic level, ranging from primary producers to top level carnivores (Mohamed 2012).

India has around 5,070 species of Mollusca of which 3,370 species are from marine environment (Venkataraman and Wafer, 2005). Due to the increasing threats to marine biodiversity and over exploitation of shells, many of the marine species have been included in the Wildlife (Protection) Act (WPA), 1972. 24 species of marine mollusks of India have been included under Schedule I and IV of WPA (Ramakrishna & Dey 2003). Most of these mollusks listed in WPA of India have very high international and national market demand. Moreover, due to the lack of awareness and inadequate law enforcement most of the molluscans are still collected and sold illegally (John et al. 2012).

Mangrove-associated molluscans

Mangroves forests are considered as evolutionary hotspots where terrestrial species have re-adapted to marine life, and marine species have undergone the transition to terrestrial species. These forests comprise mostly of salt tolerant trees which evolved from rainforest trees over 50 million years ago (Duke 1995; Ellison et al. 1999) and are unique in their adaptation to the distinct environmental requirements of the intertidal habitat (Tomlinson 1986). Estuaries provide valuable resources like fishes, bivalves, crabs, shrimps, etc. Thus, it plays a pivotal role in rural livelihood and constitute as an important socio-economic entity (Boominathan et al. 2008).

Molluscs especially gastropods are one of the most prominent taxa in the mangrove forests. The unique characteristics of a mangrove ecosystem lead to an assemblage quite different from the adjacent coastal ecosystems such as the sandy beaches and intertidal rocky shores. Potamididae (commonly known as mudwhelks or horn snails), a family of gastropod is known to be closely associated with mangrove and similar soft substrate habitats. Studies based on fossil records also suggest that these gastropods have developed adaptive features which are closely associated with mangroves (Reid et al., 2008).

The soft muddy substrate and array of microhabitat features in mangrove ecosystems provides ideal conditions for high abundance of gastropod diversity. At same time mollusks also play important role in the ecosystem functioning of the mangrove forests. Along with decapod crustaceans they play the crucial role of degradation of organic detritus and nutrient recycling. They are also an integral part of the complex food web in mangroves, occupying different levels as prey, predator, herbivore, detritivore, and filter feeder (Cannicci et al. 2008). Gastropods and bivalves associated with mangroves and estuaries also have very high economic value as food and in lime and cement industries.

Due to their physiology, Gastropods and Bivalves can act as good bio-indicators for environmental changes or anthropogenic disturbances. Majority of bivalves such as oysters and clams are filter feeders; therefore, they tend to accumulate contaminants and trace metals from the water in their bodies. At the same time, they are also vulnerable to small disturbances in their habitats making them good bio-indicators. Similarly, numerous studies have found negative impacts of heavy metals and organochloride pesticides on the physiology of gastropods (Ubrihien, 2012; Bu-Olahyan and Thomas, 2001; Kesavan et al. 2009; Bryan et al. 1983; Shanmugan et al. 2007; Mohamed and Ahmed, 2006).

Knowing their importance, mangrove mollusks have been studied by different scientist throughout India. Stoliczka (1869), Neville (1880, 1884), Preston (1915) & Annandale & Prasad (1921) reported several species in Gangetic delta; Ganapati and Rao (1959) reported 11 species from the Godavari estuary; Radhakrishna and Janakiram (1975) 9 species from Krishna estuary; SubbaRao and Mookherjee (1975) 20 species from Sundarbans and 9 species from Mahanadi estuary; Murthy and Balaparameswara (1977) 10 species from mangrove swamp of Machlipatnam, Andhra Pradesh; Pillai and Appukuttan (1980) 6 species from the mangroves of Palk Bay and Gulf of Mannar; Kasinathan and Shanmugan (1985) reported 10 species from the Pichavaram mangrove

and Das and Dev Roy (1989) reported 100 species from mangrove areas of Andaman and Nicobar Islands.

Zoological survey of India has reported around 357 species of marine mollusks from Andhra Pradesh of which 2 belong to Polyplacophora, 200 to Gastropoda, 6 to Cephalopoda, 146 to Bivalvia and 3 to Scaphopoda. Some of the important studies in Andhra Pradesh were done by Nagabhushanam (1955, 1960) who recorded 23 wood boring species from Visakhapatnam harbor, and Rajagopal and Mookherjee (1978, 1982) and Mookherjee (1985) who reported 9 and 8 species of molluscs respectively from Andhra Pradesh during their work on marine mollusks of Coromandel Coast. Subba Rao *et al.* (1991) recorded 69 species of molluscs from the state in their report of marine molluscs from Orissa coast. Surya Rao and Subba Rao (1991) reported the occurrence of 13 species from Andhra Pradesh during their study of molluscan fauna of Lakshadweep. Subba Rao *et al.* (1992) recorded 41 species of marine and estuarine species from the state of Andhra Pradesh during their work on estuarine and marine mollusks of West Bengal. Subba Rao and Dey (2000) listed 43 species of marine molluscs from Andhra Pradesh in their Catalogue of Marine Molluscs of Andaman and Nicobar Islands.

Additionally, malacological studies of the Godavari estuary have been done in past with notable contributions from some of the following people, Alagarwamy and Narasimham (1968), Jones and Alagarwamy (1968) and Narasimham (1969), Radhakrishna & Janakiraman (1975) & Radhakrishna & Ganapati (1969) in relation to Godavari mangroves and the Kakinada Bay.

As evident from the above discussion number of studies have been done on the malacofauna of the Godavari mangroves. The aim of this study is to update the checklist of molluscans from the estuary, assess their status and finally to collect

baseline data on the ecology of the gastropods and bivalves occurring inside mangroves of the Coringa Wildlife Sanctuary.

Following are the objectives of our study on molluscans:

1. To update the checklists of molluscans found in East Godavari estuary and its associated mangroves and
2. To study the assemblage patterns of mangrove-associated gastropods and bivalves in the natural and planted stands of mangrove inside Coringa WLS.

Methodology

Study area for this objective is inside Coringa Wildlife Sanctuary. Coringa WLS had a long history of felling until 1978 when it was declared as a Protected Area. Due to poor regeneration of the mangroves the Forest Department started artificial regeneration of *Avicennia marina* inside the Sanctuary in 1987. As per the Management Plan of the Sanctuary till 2012 around 1005 hectares have been replanted by pure stands of *Avicennia marina*.

A total 23 random plots of 10x10 m² were laid along the banks of the three main creeks Tulabaghya, Coringa and Gaderu creeks inside the sanctuary, based on the natural and planted stands. In Tulabaghya creek, 8 plots were laid out of which 2 were in natural stands and 6 in planted. Similarly, in Coringa creek 5 plots in natural and 4 in planted. In Gaderu creek 2 natural and 4 planted plots were laid. In each of these plots 3-5 circular quadrates of 1m² diameter were laid. Therefore, 30 quadrates of 1m² each were laid in natural stands and 42 quadrates laid in planted stands; this amounts to a total of 72 quadrates and an effective sampling area of 72m². Apart from these, three plots were also laid near abandoned aquaculture ponds with a total of 19 quadrates.

In each of the quadrates, the number of species and individuals were noted down. For this study, we have only concentrated on the epifaunal and arboreal molluscs. Molluscs which were encountered in the plot are handpicked and identified using following references (Deepak A), after identification they were released back to their normal place. Some habitat features such as predominant vegetation, canopy cover and ground cover were also noted down. Shannon's Diversity Index (H'), species richness, evenness and density of each species were calculated for each quadrat. Species diversity and density of different species were used for comparison between molluscan assemblages of natural and planted stands. Moreover, some of the opportunistic sightings of the molluscs outside the plots were also recorded.

The species richness and abundance were very low in aquaculture ponds; therefore, only natural and plantations plots were used for analysis. For statistical analyses, appropriate parametric and non-parametric tests were conducted. To assess patterns in the species assemblage Cluster Analysis using Ward's method was conducted followed by SIMPER analysis to detect those species contributing most to the differences between the natural and planted habitats. All tests were done using statistical software Past ver. 2.17.

Results

Species abundance and density

16 molluscan species were recorded during this study, out of which 15 were gastropods and only 1 bivalve (*Meretrix meretrix*) was recorded. *Cerethidea cingulata* (1004 individuals) and *Assimonia nitida* (633 individuals) were the two most abundant gastropods. However, the relative frequency of these two species was very low. Instead *Cerethidea obtusa* and *Telescopium telescopium* were the two most frequent species. Ellobiidae was the dominant family with 6 species belonging to it followed by Potamididae with 3 species. But latter was the more abundant family with a total of 1146 individuals. However, with the opportunistic sightings in the mangrove areas,

overall 34 species of molluscan species are identified with 14 families (Appendix I) out of which 28 are gastropods and 6 are bivalves.

The overall density of molluscans recorded in this study was 22.4 indi./m². Surprisingly the gastropod density was highest in the abandoned aquaculture ponds (72.4/m²) compared to the natural (16.5/m²) and planted plots (3.8/m²). Among the species, *Cerithidium cingulata* had the highest overall density (11/m²) 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 *Assimonia nitida* had the highest density (5.9/m²) followed by *Cerithidium obtusa* (3.6/m²); in the plantation plots *Pythia plicata* (1.31/m²) and *Melampus sinaporensis* (0.9/m²) had the highest densities.

Species richness, Species diversity and evenness

The species richness (Margalef's species richness index) in the study area ranged from 0 to 1.243 and the species diversity (Shannon diversity index) from 0 to 1.197 which evidently are very low. The mean species richness, mean species diversity and evenness was highest for natural plots followed by the abandoned aquaculture ponds and then by plantation plots. In Table No.10, a summary of species richness, species diversity and evenness has been given.

Table 10. Summary of species richness, species diversity and evenness.

Habitat type	Sampling plots	Mean Species richness	Mean Species diversity	Mean species evenness
Natural	27	0.55	0.563	0.330
Restored	26	0.10	0.100	0.069
Abandoned	10	0.13	0.187	0.107

aqua ponds				
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To study the differences between the different habitats statistical analyses were performed. As mentioned before, abandoned aquaculture ponds were not included in the any analyses since in most plots species richness was zero. To compare the species richness between the natural and plantation plots, non-parametric test Mann-Whitney U-test was performed which resulted in highly significant differences between the two habitats ($p=4.30E-06$). Similarly, the same test was performed to analyze differences in species diversity and again highly significant differences were found ($p=3.96E-06$).

Differences in Species Assemblage

To check whether the species assemblages differed between the natural and planted habitats, Cluster Analysis using Ward's method was done. This resulted in more or less two distinct assemblages of Natural and Planted sites. SIMPER test was performed to analyze the differences between the two clusters. The test revealed that more than 75% of the differences were due to three species- *Assimonia nitida*, *Cerithidium obtusa* and *Neritica violacea* which had higher abundances in natural plots. Table No.11 summarizes the results of this test.

Table 11. Results of SIMPER test showing the most important species between natural and restored plots

Taxon	Av. dissim	Contrib. %	Cumulative %	Mean abund. (Natural)	Mean abund. (Restored)
<i>Assimonia nitida</i>	32.67	33.82	33.82	8.13	0.184
<i>Cerithidea obtusa</i>	31.29	32.4	66.22	5.22	0.163
<i>Neritica violacea</i>	8.768	9.079	75.3	2.04	0.347
<i>Cerithidea cingulata</i>	8.149	8.438	83.74	3.35	0

<i>Melampus sincaporensis</i>	3.722	3.854	87.59	0	1.57
<i>Telescopium telescopium</i>	3.612	3.741	91.33	0.565	0.184
<i>Pythia plicata</i>	3.36	3.479	94.81	0.0435	1.18
<i>Cassidula nucleus</i>	2.187	2.264	97.08	0	0.571
<i>Ellobium auris judae</i>	1.692	1.752	98.83	0.0435	0.204
<i>Meretrix meretrix</i>	0.6446	0.6675	99.5	0	0.163
<i>Littoraria scabra</i>	0.486	0.5032	100	0.087	0

Following the SIMPER test, linear regression was conducted between the three-important species identified and canopy cover and ground cover. Though significant correlations were found between each pair but mostly were weak correlations.

Abundance of *Assimonia nitida* and *Neritica violacea* ($r= 0.46$ and 0.53 respectively) were moderately correlated to canopy cover whereas *Assimonia nitida* was negatively correlated to ground cover ($r= 0.52$).

Discussion

When compared to other mangrove forests in India (Kesavan et al., Kesavan et al. 2009; Boominathan et al. 2012, Kurhe et al. 2009; Suresh et al. 2012 etc.), the number of species (N=16) recorded in this study is relatively similar or higher. But species diversity is low as compared to similar studies done in other countries (Yolanda et al. 2015; Dissanayeka and Chandrasekhara 2014; Ashton et al. 2003 etc.). Even in the natural stands of mangroves which are relatively mature and older than the planted ones, the mean species diversity of gastropods is 0.562 ± 0.06 which is very low. Low species diversity is also explained by dominance of just few species in few sites.

In a similar study on macrobenthic community in Qatar, species richness of crabs and mollusks were lower in the planted mangrove patches of *Avicennia marina* than the

natural mangroves (Al-Khayat and Jones 1999). On the contrary, a study on degraded and restored mangrove forest in Thailand did not reveal significant differences in molluscan assemblages but lowest species diversity was recorded in a highly degraded tin mining site (Macintosh et al. 2003). The species composition of the mollusks in the mature mangrove sites differed from the younger restored sites.

In this study, significant differences were found in the assemblage structure of gastropods in natural and restored sites where the species richness and species diversity of the natural sites were higher than the latter. The mean total density of gastropods was also higher in natural sites than the planted ones. Surprisingly the highest mean density was recorded in abandoned aquaculture ponds mainly due to the high densities of *Cerithidea cingulata* and *Assimonia nitida*. However, in case of these ponds only 4 species were recorded with very high dominance of just 2 species suggesting a highly stressed environment.

The species composition of gastropods was dominated by Ellobidae followed by Potamididae families. Species belonging to Ellobidae family were recorded both in the natural as well as in planted sites but had relatively higher densities in the latter. This contrasts with the study on the Thailand mangroves referred above which found Ellobidae to be dominant in mature forests. Ellobidae are pulmonates or air-breathing gastropods which move up and down the mangrove floor with the high and low tides. During the study, we noted that the restored sites were situated relatively higher than the natural sites and thus were not much affected by the rising tides. This might explain the relative dominance of Ellobidae as compared to the mangrove-dependent Potamididae which had higher densities in the natural sites.

The Cluster Analysis also divided the gastropod assemblage into two main clusters, 'Natural' and 'Planted' which differed by around 97% (SIMPER analysis). The Natural cluster is composed of mainly natural plots except two restored plots from the Tulabaghya creek. Possibly due to good canopy cover recorded in these two sites, the

assemblage is like those of natural plots. In majority of the restored plots no canopy cover was recorded due to lower heights of the trees of *Avicennia marina* and dominance of *Suaeda* spp. whereas in most of the natural plots, canopy cover of more than 75% was recorded with relatively low ground cover. Therefore, canopy cover might be playing an important role in determining the gastropod assemblage in the naturally growing *Avicennia* sites of the Sanctuary.

From this study, it is evident that the restored patches of mangroves inside Coringa WLS are still at the seral stages of succession due to which the associated macrofauna (in these case gastropods) differ significantly between the two habitats. There could be several reasons for this but difference in species richness and average heights of trees of the mangrove species seem to be important factors. *Avicennia marina* followed by *Excoecaria agallocha* has been recorded in the restored sites but these sites are dominated by *Suaeda* spp. and have almost no canopy cover. Evidently soil moisture has also been observed to be lower in the restored sites than the natural ones.



Figure 23: *Cerethidea obtusa* feeding on detritus of tidal creeks of Coringa WLS



Figure 24: *Littoraria scabra* seen in Coringa WLS



Figure 25: *Pythua plicata* seen in Coringa WLS



Figure 26: *Ellobium aurisjudae* seen hanging on *Avicennia marina* in Coringa WLS

Study on the Ichthyofaunal diversity in Godavari estuary

The role of estuaries as important habitats for fishes has been well studied in the past (Laegdsgaard and Johnson, 1995; Kathiresan and Bingham, 2001; Blaber, 2007). The high productivity of estuaries and high input of nutrients makes it a rich feeding ground for various marine fish species. For some diadromous species, it provides a gradual transition state which makes it easier for the fishes to migrate into varying salinities.

However, the most important role among all has been recognized to be that of a nursery ground for fishes (Blaber, 1980; Bell *et al.*, 1984; Robertson and Duke, 1987; Laegdsgaard and Johnson, 1995). As part of the *Coastal Ecosystem Mosaic* (Sheaves, 2009) estuaries act as crucial link between the freshwater and marine habitats of fishes.

India with a vast coastline lies in the Indo-West Pacific zoogeographical region, which is the center of origin for majority of tropical shore fauna (Matthew, 1915; Briggs, 1966). Studies on various Indian estuaries point towards the immense diversity of fish fauna and as expected species richness is very high, particularly in estuaries belonging to eastern coast.

Comparing the different studies on fish richness of estuaries belonging to the two coasts of India, it is seen that richness in eastern coast is higher than the west coast (Table 12). This could be explained by various geographical features of the two coastlines which are distinct from each other.

Table 12. Number of fish species recorded from different estuaries of Indian coast

Name of estuary	Number of species recorded	Coast where it lies	Reference
Pichavaram mangroves, Tamil Nadu	195	Eastern	Krishnamurthy and Jeyaseelan, 1981
Chilika Lake, Odisha	152	Eastern	Jones and Sunjansingani, 1954
Adyar estuary, Tamil Nadu	128	Eastern	Ramanujam et al., 2014
Sharavathi estuary, Karnataka	29	Western	Bhat et al., 2014
Aghanashani estuary, Karnataka	80	Western	Ramchandra et al., 2013
Gangavali estuary, Karnataka	55	Western	Ramchandra et al., 2013

Whereas the presence of a contiguous mountainous range breaks the western coast- the Western Ghats, it is not so in case of the eastern coast. Therefore, the continental shelf is wider in eastern coast of India and hence estuaries in this part are bigger and more diverse in habitats. Another factor is the shallowness of the Bay of Bengal, particularly in the northern part which might also contribute to higher species diversity to the eastern estuaries of India. However, it is just a hypothesis and not based on any empirical data, which is a huge gap as very few comprehensive studies exist on fish diversity of estuarine ecosystems in India.

Despite the obvious differences among the estuaries of the Indian studies cited above, making any inference from them would be futile as the time span and the sampling designs are not similar between the studies. In case of India, studies mainly focus on presence/absence of different species in discrete estuaries or a part of the coast (such as those of Krishnamurthy and Jeyaseelan, 1981; Ramchandra et al., 2013; Bhat et al., 2014). There are rarely any studies which focus on the spatio-temporal variability of fish assemblages or their relationship with the different environmental factors in an estuary. Only recent studies have begun to address this gap (Biswas et al., 2014). Another challenge in comparing different studies in India is the lack of a uniform sampling design. Most studies, even now focus on collections from the landing centers or local fish markets, which might give highly biased results as major landing centers include commercial catches from inshore, coastal as well as off-shore fishing grounds in addition to the use of wide variety of fishing gears and fishing crafts by the fishermen.

CURRENT STATUS OF ICHTHYOFAUNA OF EAST GODAVARI ESTUARY

Several studies have been conducted on the ichthyofaunal diversity of Godavari estuary. Krishnamurthy et al. (1984) reported 223 species from Godavari estuary, including 16 coral species. In another survey of the Gauthami Godavari and Vasistha Godavari by Zoological Survey of India, Krishnan and Mishra (2001) updated the list to around 312 species, containing both freshwater as well as marine species. Subsequently there have been other surveys too which have added to the list of fish species of the region.

Aim of the present study is not just inventorization of the fish species but more importantly to study their community ecology and role of key environmental factors in their distribution. Such study is highly important for assessing the vulnerability of the ecosystem as well as the region's fishery sector to potential threats posed by climate change and other anthropogenic factors.



Figure 27: Sampling of Ichthyofauna in creeks of Coringa WLS



Figure 28: Tuna fish in the market near Kakinada

With the above context, the current study is aimed to assess the vulnerability of the aquatic ecosystem in EGREE to threats produced by climate change as well as other anthropogenic activities in the region.

Methodology

Under the aquatic component, data on ichthyofauna and associated environmental parameters were collected from February 2014 to March 2016 with an aim to set a baseline dataset on the number of species and their distribution patterns. This baseline data will then be used to predict any changes in distribution patterns of the important species. Based on the seasonal discharge of the Godavari River the study period has been divided into three seasons i.e. Dry season (February to April), Pre-monsoon (May to July) and Post-monsoon (December to February).

A systematic approach is being followed for studying the ichthyofauna of the Gowthami estuary system wherein currently 47 grids (1km x 1km grids) have been selected. These grids span across the entire Gowthami Godavari estuary, including main channels of Gaderu, Matlapalem and Ramanapalem, Giriyampeta creek, the main channel of Nilarevu River as well as the mouth of Nilarevu River and Kakinada Bay. Sampling was done at mid-point of each grid using locally-available trammel nets during low tide. At each site, the net was kept for duration of 1-hour after which names of each species along with their length-weight measurements were noted down. Salinity and depth were also noted down at each site before keeping the net. Samples of unidentified species are preserved in 10% formalin and taken to base camp for identification.

In addition to this, fish diversity in the various fish markets as well as landing centers were also monitored regularly.

For analysis, Shannon Diversity Index (H') (Shannon and Wiener, 1949) was calculated for the different habitats:

$$H' = -\sum (n_i/N)\ln(n_i/N)$$

where, n_i = No. of individuals of i^{th} species

N = Total no. of individuals of all species

Catch per Unit Effort or CPUE is an indirect way of measuring relative abundance of fish stocks in a defined period in a habitat. Higher CPUE possibly indicates higher abundance of fish stocks and *vice versa*. For the present study, it was calculated as:

$$\text{CPUE} = \text{Catch}/\text{Effort}$$

where, 'Catch' is the total number of individuals caught in a single sample and 'Effort' is the total number of boat hours (1 hour during low tide) and number of gears (3 nets) used.

In addition, length-weight relationships for the most abundant species have also been calculated using following formula:

$$W = a L^b$$

Where, W - is weight (g), L - is total length or standard length (cm), 'a' and 'b' are constants with b usually being closer to 3.

To get a straight-line regression equation, the above formula is log transformed as follows:

$$\text{Log } W = \text{Log } a + b \text{ Log } L$$

Results

Environmental Parameters

Depth

Depth in the estuary ranged 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 ($p > 0.05$). This trend was also observed when the habitats were compared with each other with the depths being lower in rainy and summer seasons

than winter seasons. Again, the statistical analysis did not reveal any significant differences between the habitats.

Salinity

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 having lower salinity values. Salinity ranged from 0 ppt to 34 ppt. As expected, in rainy season the salinity values were lowest in every habitat due to increased discharge of the river and flushing of the entire estuary.

Though the overall salinity did not show significant seasonal differences ($p > 0.05$) but highly significant differences were observed in salinity values between the habitats ($p < 0.01$). In case of Matlapalem and Ramanapalem creeks the values were mostly lower than 10 ppt whereas in case of other habitats, including Nilarevu River (the main channel of Godavari River), the salinity values were higher, usually more than 15 ppt. This indicates that except for Matlapalem and Ramanapalem creeks, influence of sea water is high in other habitats. Matlapalem creek for most part of winter and rainy seasons experienced salinities closer to freshwater while in the sites in Nilarevu River located farther from sea, the salinity in rainy season decreased considerably from summer season.

Water temperature

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 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.

pH

The pH values across the estuary ranged between 7 and 10 with the highest mean value recorded during the summer season in Matlapalem 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. In rainy season, pair-wise comparisons revealed high differences between most habitats.

Species checklist

During this study, we prepared a checklist of the fish species recorded from markets, landing centers, fishermen's catch and our own sampling in Godavari estuary. Our records were compared with previous checklists and a comprehensive checklist of 382 species belonging to 98 families and 25 orders have been prepared. Out of these 382 species, around 150 species (including opportunistic sightings) have been recorded from the Godavari estuary. During the long-term study in Godavari estuary 113 species have been recorded from the Godavari estuary.

Species richness

For analyzing species richness, Margalef's species richness index were used which varied from 0 to 4.654. The overall mean species richness was highest in the rainy season, yet there were no significant differences between the three seasons.

In case of habitats Kakinada Bay had the highest mean species richness. There were significant differences observed between the habitats in each season with the difference

being particularly significant in the winter season. However, when individual sampling sites were compared seasonally in each habitat, except for Giriyampeta creek no significant differences were observed in species richness within the habitats.

In Giriyampeta creek also, the species richness was widely different in winters from that in summers and rainy seasons since in 3 out of 6 sampling sites no species were recorded in winter season. Moreover, species richness in Giriyampeta creek was also different from that in Nilarevu River with which it has a direct connection.

Species diversity

Like species richness, species diversity also showed similar patterns. There were no differences in species diversity between the three seasons but on comparison of the different habitats with each other marked differences were found, particularly between the Giriyampeta creek and Nilarevu River. Similarly, within Giriyampeta creek the species diversity varied between the sampling sites during winter season.

Fish Catch

The total catch for the entire sampling period spanning 1 year is 1768 individuals with an overall average catch of 15.4 individuals per fishing effort of 1 motor boat and 1 trammel net. Average catch in winter season is higher than summer and rainy seasons but the differences were not significant, nor were any significant differences found within and between habitats.

Changes in average catch, even though not significant, can reveal important information about movement of fishes across the estuary. In Kakinada Bay, particularly the average catch was very high in winters (72.4), became half in summers (34.6) and further decreased in rainy season (13.4). On the contrary, in Giriyampeta creek the highest average catch was recorded in summers and lowest in winters.

Species abundance

Leiognathus equulus, *Mystus gulio*, *Tetraodon fluviatilis* and *Dendrophysa russelli* are the four most abundant species in the estuary out of which *M. gulio* and *D. russelli* have high commercial values too. In case of *L. equulus*, the relative abundance was highest in winter season while for *M. gulio* abundance was highest in summer season. Like the average catch, species abundance also did not differ significantly between seasons or within habitats but it differed significantly between habitats during the winter and summer months.

Species composition

Results of CCA show that the most important parameter structuring the estuary as well as the species is salinity. Axis 1 was responsible for most variations and salinity had highest loadings in Axis 1 for all three seasons. Second most important parameter was water temperature since it had highest loading in Axis 2 in both winter and rainy seasons. In summers, depth was the second most important parameter.

Most of the variations between the habitats and species were explained by salinity with the influence of salinity strongest in summer months. A strong gradient in the sampling points can be observed across the estuary; the sites in Kakinada Bay had highest salinities followed by Giriampeta, Gaderu creek and Nilarevu River while on the other end of spectrum are Ramanapalem and Matlapalem creeks with low salinity values. Even within these 2 creeks a gradient has been observed in salinity from north to south direction. However, both these habitats also segregate to opposite quadrates in winter season mainly due to salinity which is also indicated by the ANOVA results.

In case of species assemblage too the Ramanapalem and Matlapalem creeks show a distinct assemblage than the other 4 habitats. *Mystus gulio* and *Oreochromis mossambicus* (an exotic species) are found mainly in the mangrove-lined creeks of Ramanapalem and

Matlapalem while species such as *Leiognathus equuluus* and *Tetraodon fluviatilis* preferred habitats with relatively higher salinities.

These CCA plots also indicate potential movement of fishes between the different habitats of the estuary. In case of a commercially important species *Mugil cephalus*, the plot shows a clear pattern of its distribution across the year. In winters, the Nilarevu River seems to be the most preferred habitat for the species while in summers it's more abundant in Ramanapalem and Matlapalem creeks.

The results of SIMPER show that the 4 most abundant species are also responsible for 65.9 % variations within assemblages of the five habitats. The SIMPER results also clearly show the affinity of *Mystus gulio* to the mangrove-lined creeks in the estuary.

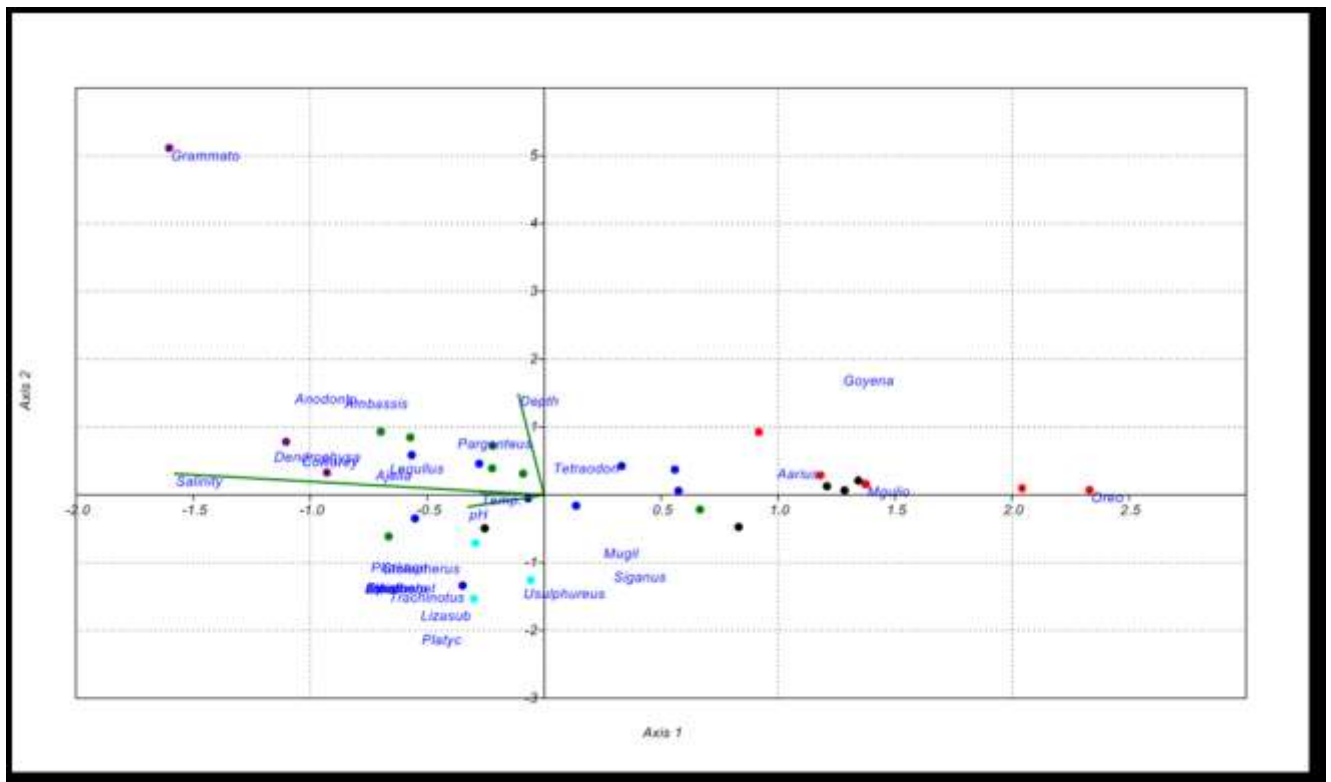


Figure 29: CCA Plot for Summer season

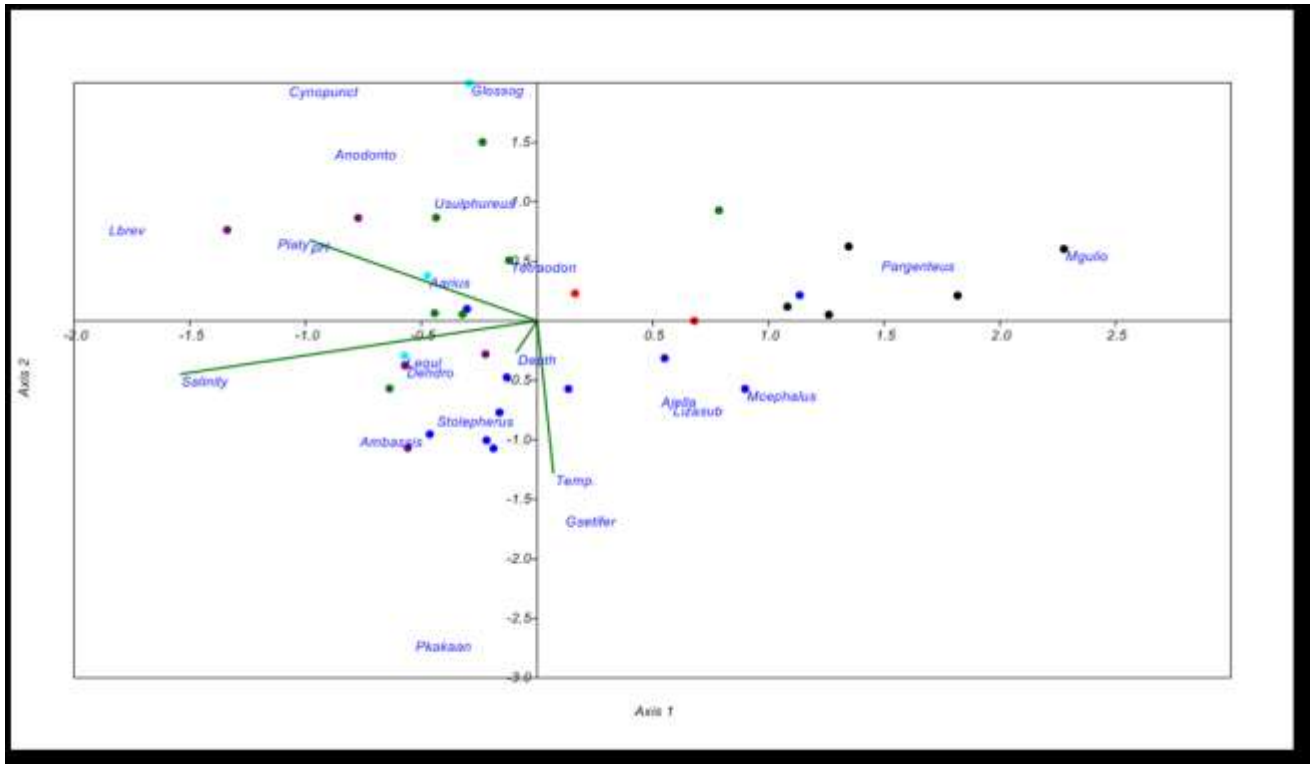


Figure 30: CCA Plot for Rainy Season

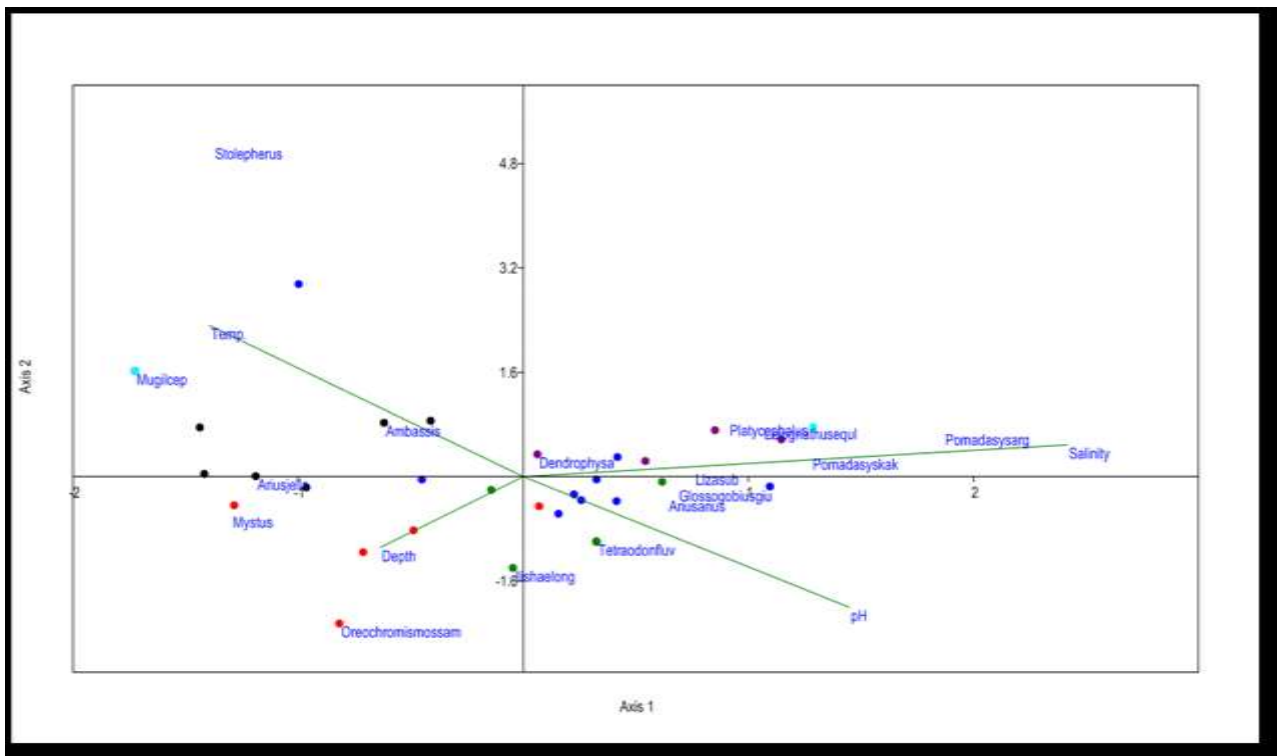


Figure 31: CCA Plot for winter

Table 13: Results of SIMPER Analysis

Taxon	Av. dissi m	Contri b. %	Cumulati ve %	Mean abun d. 1	Mean abun d. 2	Mean abun d. 3	Mean abun d. 4	Mean abun d. 5	Mean abun d. 6
Mystus	16.3	19.52	19.52	14.2	4.6	0.727	1.33	0	0
Dendro	15.6	18.68	38.2	1.5	1.6	3.64	1.83	1.5	8.8
T.fluviatil is	12.97	15.53	53.73	1.33	4.4	4	5.83	0	0
L.equluus	10.17	12.18	65.92	0.167	0	0.455	0.667	2	40
Mugil	7.499	8.982	74.9	4.67	0.4	1.64	0.5	1.5	0.4
A.arius	6.943	8.315	83.21	0.5	2.2	4.18	0.167	0.25	2.2
Oreochro mis	6.011	7.199	90.41	2.67	3.4	0	0	0	0
Lizasub	3.847	4.607	95.02	0.167	2	1.36	0.167	0	0.2
P.argenteu s	2.872	3.44	98.46	0.667	0.2	0.182	0.667	0.25	6.4
G.oiyena	1.288	1.543	100	0	0.8	0.090 9	0	0	1.4

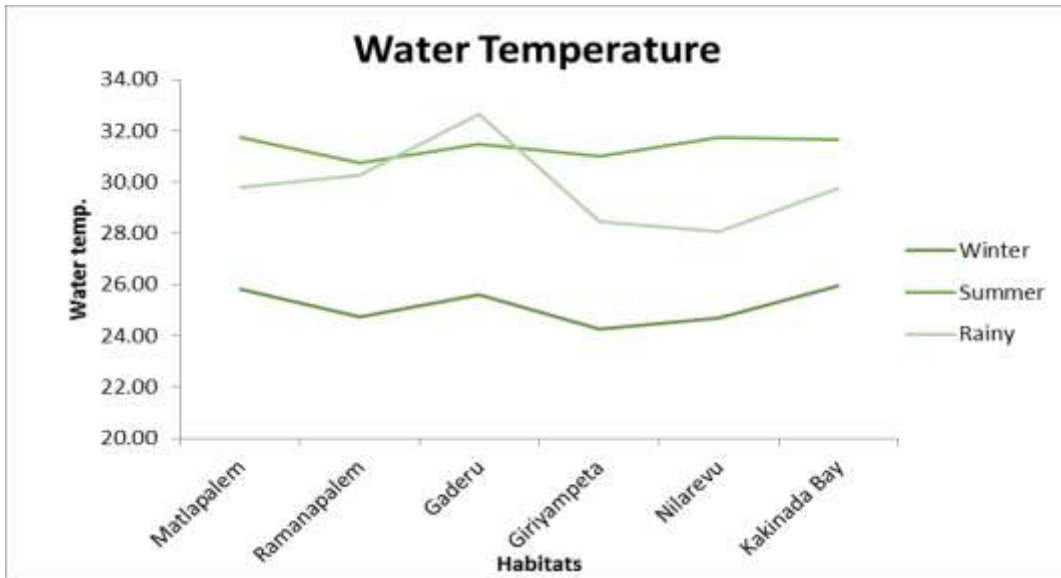


Figure 32: Water temperature of the 6 creeks of Coringa WLS

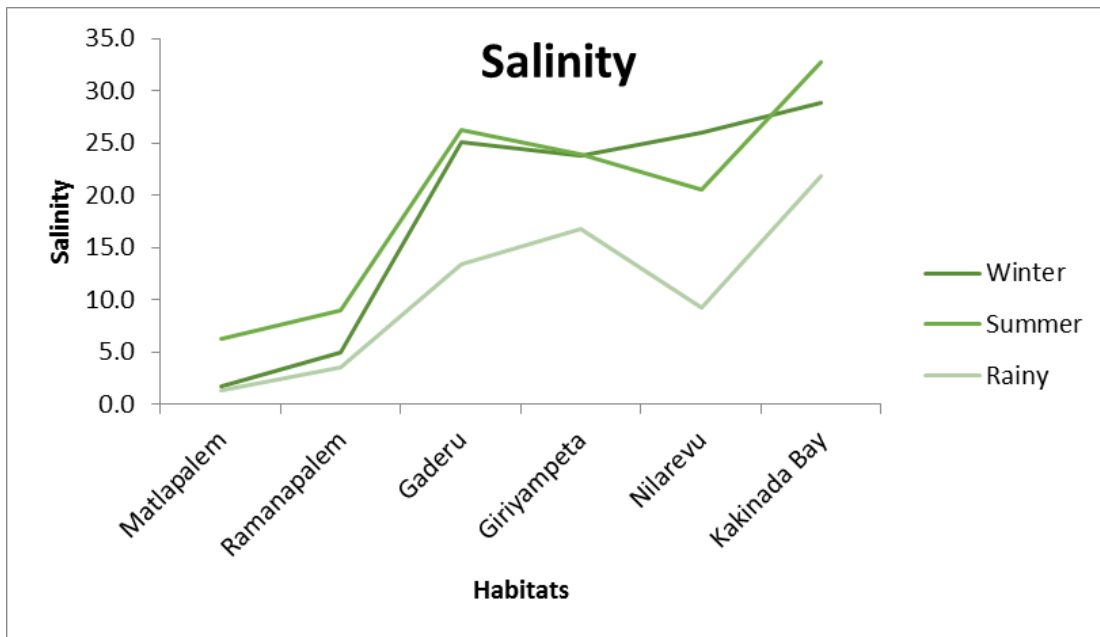


Figure 33: Salinity of the 6 creeks of Coringa WLS

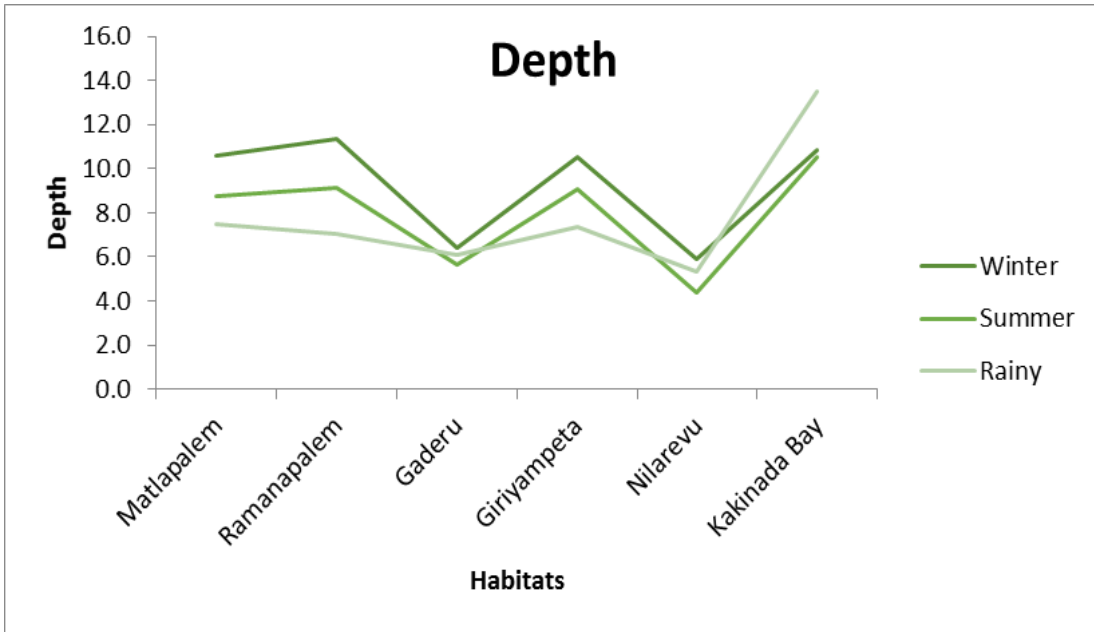


Figure 34: Depth of the 6 creeks of Coringa WLS

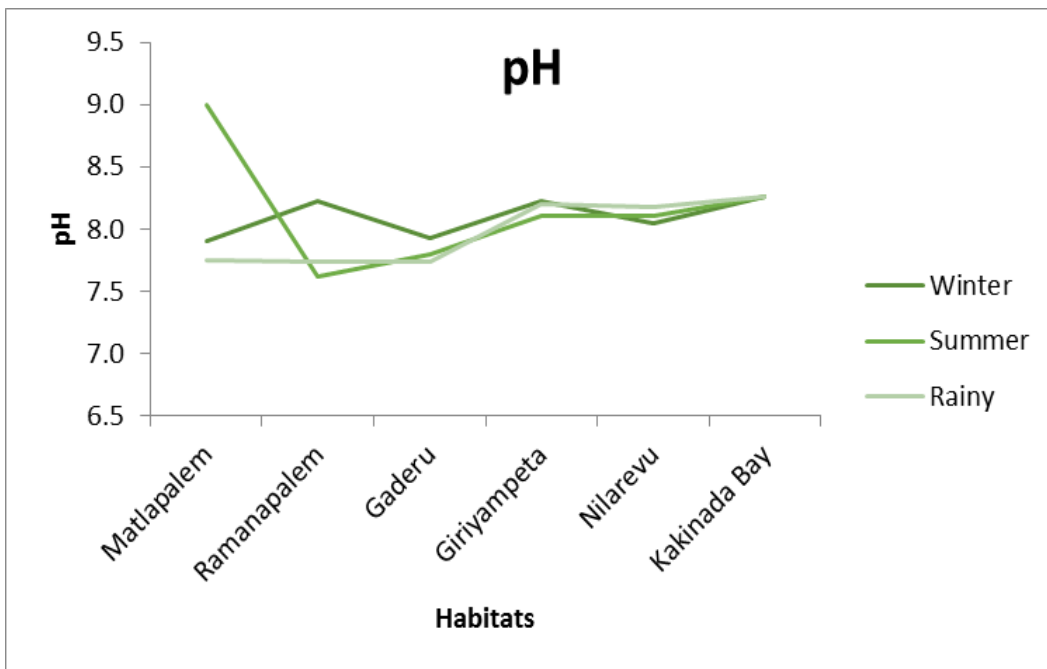


Figure 35: pH of the 6 creeks of Coringa WLS

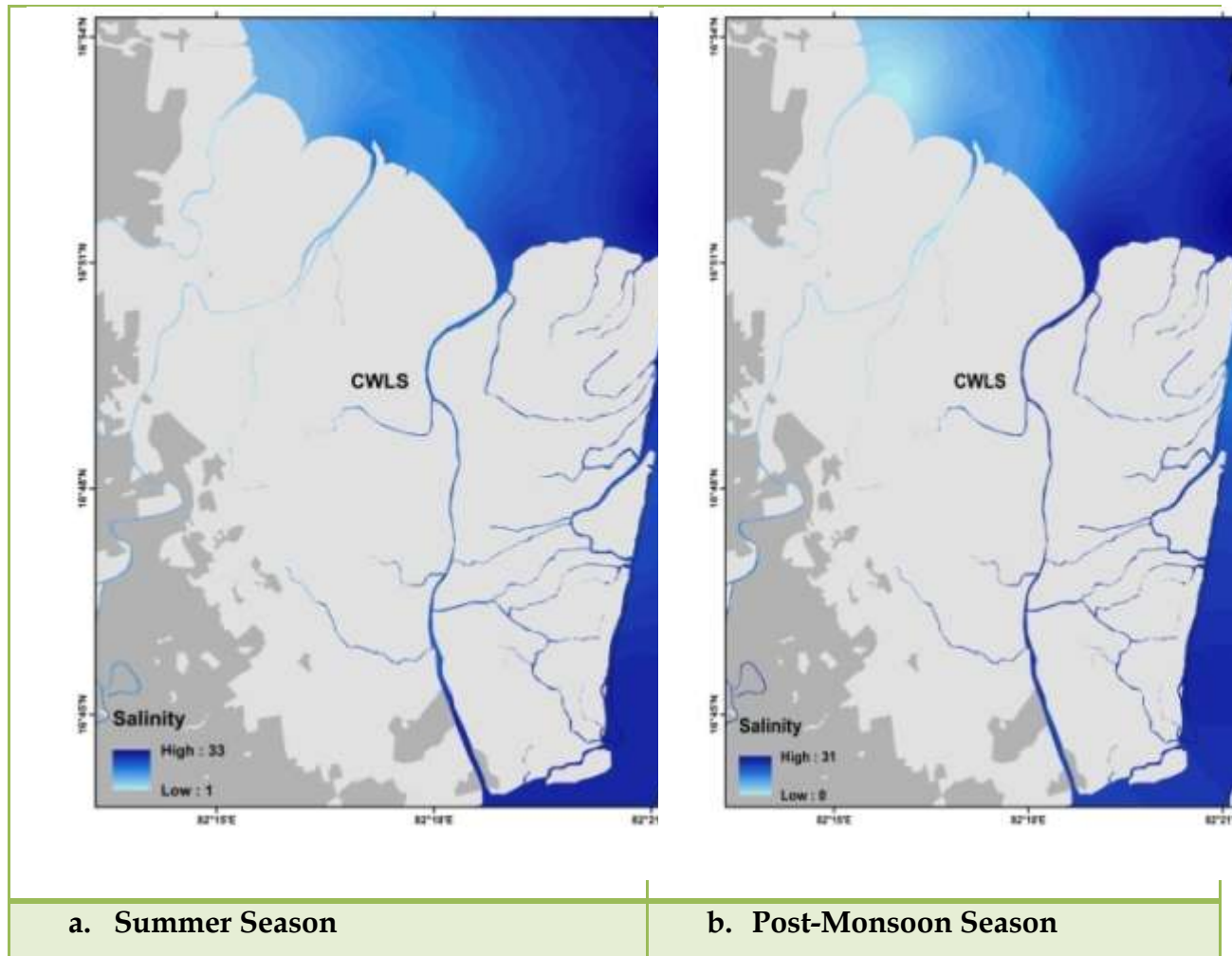


Figure 36. Salinity Distribution in Coringa Wildlife Sanctuary for two seasons (2014-15)

Discussion

The results of this study on fish assemblage pattern of the Godavari Estuary in EGREE shows that salinity and water temperature are important factors that affect the distribution of fishes. As is clear from the Figure there is a gradient of salinity in the creeks of Coringa Wildlife Sanctuary which also varies seasonally.

In summers, there is a strong gradient of salinity in Matlapalem and Tulabagya creeks, with the northern parts having high salinity due to connection with the bay while in post-monsoon season both these creeks have low salinity levels due to the high

discharge of freshwater during the rainy season. The influence of Godavari River is therefore higher in these two creeks. On the contrary in the Gaderu creek, the salinity levels are towards higher range even in the post-monsoon season, indicating the high influence of sea.

This difference in salinity values among these three creeks as well as among the three seasons also lead to differences in the fish assemblage. Species such as *Mystus gulio* and *Mugil cephalus* were mainly found in Matlapalem and Tulabagya creeks, which have lower salinity values. On the other hand, *Arius arius*, *Dendrophysa russelli* and *Platycephalus indicus* were distributed mainly in the habitats with high salinity values. Some of these species also showed variations in their distribution across the three seasons which can be explained by the changes in salinity values as well as possible migration or movement for spawning. In case of *Mystus gulio*, the major spawning period in the mangroves were identified to be in the summer season or the pre-monsoon season when high abundance of the species was noted in the creeks with developed reproductive organs.

Platycephalus indicus is a Near Threatened species that was recorded during this study. The main distribution of this species was identified in the main channel of Godavari, i.e. Nilarevu River. Juveniles of another threatened species, *Epinephelus malabaricus* (Endangered) were also recorded twice from the mangrove-lined creeks of Coringa Wildlife Sanctuary. However, we also recorded the presence of an exotic species *Oreochromis mossambicus* in the Matlapalem and Tulabagya creeks of the sanctuary. Although our study suggests that this species prefers lower salinity values but its relatively higher abundance is a cause for concern. It is among the ten most important or dominant fish species in the estuary.

Mystus gulio, *Dendrophysa russelli*, *Tetraodon fluviatilis*, *Leiognathus equluus*, *Mugil cephalus* and *Arius arius* were the most important species in the estuary. Except for *T. fluviatilis* and *L. equluus*, other species have high commercial values for the local subsistence

fishermen in the region. But the non-commercial species such as *T. fluviatilis* (pufferfish species) still play very important ecological role in the mangrove ecosystem of Coringa. A study on a pufferfish species in a mangrove forest of Brazil showed that by feeding on barnacles it regulates their growth on stilt roots of the *Rhizophora mangle* (Krumme *et al.* 2007). Along with the barnacles, fiddler crabs were another important food source for these pufferfishes; the latter predated on these crabs which again show the ecological importance of pufferfishes in mangrove ecosystems.

The fish catch in the estuary was dominated by juveniles. Therefore, it either acts as a nursery for the estuarine and marine species or it could also suggest a high fishing pressure. The important habitats that have been identified from this study are the mangrove-lined creeks of Matlapalem and Tulabagya, the Kakinada Bay and the Nilarevu River and its mouth. For the different migratory fish species, Kakinada Bay and Nilarevu River act as connecting link between sea and the Godavari River. The shads and eels are important migratory species present in the estuary but high fishing pressure especially during their migratory season are big threats for these species.

Climate change is a big threat for the fish community of this estuary, especially for those species distributed in the mangrove-lined creeks of Matlapalem and Tulabagya. Since salinity and water temperature have been identified as major factors for the fish community, any changes in them due to sea-level rise and increase in sea surface temperatures will impact the fishes. Changes in the fish community such as range extension or contraction, decrease in abundance or decrease in catch can all have negative impacts on the local subsistence fisheries of EGREE.

Study on the Avifaunal diversity in Godavari estuary

Introduction

Biodiversity is the term which reflects the totality of genes, species, and ecosystems of a region. But the occurrence of a variety of organisms reflects the biological diversity of that expanse. Species are distinct units of diversity with each having a specific role in an ecosystem (Trivedi, 1999). More than 9702 avian species belonging to more than 1800 genera are present throughout the world (Sibley and Monroe, 1990). Of which, approximately 1300 species of birds have been reported from India (Manakadan and Pittie, 2001).

Estuary is a place where the sea reaches a river basin as far as the upper limit of tidal rise (Fairbridge 1980) and are one of the most biologically productive and threatened ecosystems (Kennish, 2002). Because it is one of the most productive biomes on the planet Earth, it supports important biogeochemical processes (Day et al. 1989; Constanza et al. 1993, 1997). Coastal ecosystems which include estuaries and associated habitats have been extensively used for commercial and developmental purposes (DeLuca et al., 2008). These various types of anthropogenic disturbances have severely affected the bird populations and their habitats throughout the world (Kennish, 2002).

Due to their high productivity, the coastal ecosystems around the world have been used by human settlements since many years which lead to strong negative impacts biotic communities (Hilbert, 2006; Lotze et al., 2006). And in many parts of the world human induced activities around estuaries had a significant effect on the bird communities, their behavior and finally on their existence (Jayathilake et.al 2015). Many waterbirds mostly rely on estuarine wetlands during breeding, migrating, and wintering periods,

so the loss or degradation of estuarine wetlands can be harmful to such species (Howe et al. 1989; Goss-Custard et al. 1995; Weber et al. 1999).

Birds are generally regarded as secondary consumers in the trophic level of estuaries. Most of the birds found in the estuaries have adopted their food searching behavior to suit the tidal and seasonal rhythms of their preferred prey. Moreover, the bill-length of particular species of birds is found to be suited to particular organisms of prey organisms. These birds mostly can be found feeding on the rich inter-tidal populations of annelids, crustaceans and molluscans which are exposed during the low tides (Donald S McLusky 1981).

For the birds, species richness and relative abundance depends mostly upon habitat requirements like size of the habitat, water level and quality, availability and distribution of food resources, presence of suitable roosting sites (Wiens 1989). However, any changes in the habitat might lead to changes in the bird species composition (Garcia et al, 1997, Caziani and Derlindan 2000).

Some of the earlier analyses on coastal shorebird assemblages indicated that date, tide and weather are the most variations in species richness and abundance (Burger 1984). Impact of abiotic factors varied among habitats, tides influenced communities at both freshwater and estuarine sites (Burger 1984). In many estuaries throughout the world large numbers of migrating and wintering shorebirds arrive (Senner and Howe 1984, Myers et al. 1987) have tidal regimes that result in relatively predictable temporal patterns of food availability (Burger 1984).

Studies on avifauna in Andhra Pradesh have a long history dating back to 1839, when T.C. Jerdon started working on the birds of the Madras Presidency. After a long gap of 30 years, Ball (1877) worked in Kondakarla and the surrounding areas of the Visakhapatnam district. Some more noteworthy observations were made by Abdulali (1945,1953), Krishna Raju and Justus (1971), Krishna Raju and Price (1973), and Majumdar (1984).

However, till date no detailed studies have been done to examine the species richness and ecology of avifaunal communities in Godavari delta. Except a few studies on species diversity such as that of Rao *et al.* (1996) who listed 236 bird species, and more recently by Sathiyaselvam and Sreedhar (2015), there are no major studies on avifauna in this poorly studied ecosystem. So, the main objective of this particular study is to determine the bird species diversity and feeding guilds across different habitats in Godavari Basin, Andhra Pradesh.

Study area

Andhra Pradesh has a coastline of about 972 kms on its eastern side and many mighty rivers like Godavari, Krishna and Pennar joins the sea, thus forming a huge mangrove forest complex. Godavari basin is located between 16°30'-17°00' N and 82°10' - 80°23'E and extends over an area of 316 km² giving rise to a complex of coastal and estuarine ecosystems.

Due to the timely inflow of freshwater and sea water Godavari delta is characterized by different types of habitats like mangrove and riparian forests, riverine sandbars, open mud flats and lagoons. Since Godavari delta is a river dominated estuary which experiences huge amount of sediment influx each year, many sand splits form mainly at the river mouth, noteworthy mention is a 16-km long sand split popularly known as Hope Island. It forms at the river mouth and extends northwards bordering the mangroves of CoringaWLS finally enclosing a lagoon called Kakinada Bay.

The estuary also has few patches of mudflats located in the southern and western parts of Kakinada Bay as well as in the southern parts of the delta near Yetimoga and Masanitippa villages. All these habitats possess unique geographical and ecological features giving rise to distinct avifaunal assemblages. For this study, we have selected all these habitat types across the delta to study both habitat (spatial) and seasonal (temporal) differences in avifaunal diversity in EGREE.

Methodology

Our study was conducted in 53 transects covering all the important habitats like mangroves, open mudflats, lagoon, sandbars and abandoned aqua culture ponds. We used the variable radius point count method (Sutherland, 2006) to document the bird species richness and abundance in randomly chosen transects spreading across various habitats. At every point, we waited for about 10 minutes to watch for birds and the number of points was usually three to eight. With two observers, mostly we have recorded the birds in each transect with the help of 10 * 50 Nikon binoculars (Nikon, Inc.) and took photographs using Canon SX50 camera (Canon, Inc.) to aid with further identification. Most of transects were conducted either during the morning hours between 07:00–09:00 or during the evening hours between 16:00–18:00, when there is maximum bird activity. We have also recorded various habitat details like open, closed canopy, salt blanks, plantations and anthropogenic disturbances like tree felling, grazing, aquaculture, sand mining and hunting wherever we saw in the transects. In addition to this systematic study, we also recorded opportunistic sightings of bird species.

The residential status of the birds was reported and categorized as “winter visitor”, “summer visitor”, “resident”, and “passage visitor” (Grimmett & Inskipp 1999). The birds that were encountered regularly in the study area were placed under the category “residential”; birds encountered only in winter and summer seasons were placed, respectively, under “winter visitor” and “summer visitor”; and birds that were encountered only once or twice during the study period were considered “passage visitor.”

Results

During the study period, 242 avian species belonging to 47 families were identified, which also included opportunistic sightings (see Appendix I). 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). In case of 29.7% of the bird families only one species was recorded. Additionally, based on available literature and our observations around 59% of the recorded species were residents, 36% were winter migrants, 2.8% were local migrants and 2% were passage migrants.

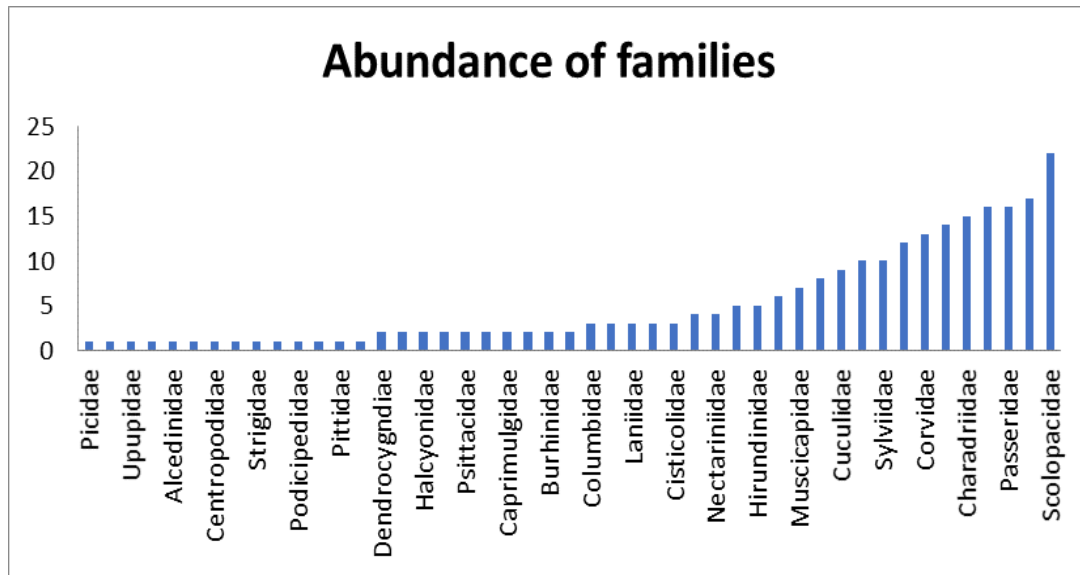


Figure 37: Graph showing relative abundance of different avifaunal families in Godavari delta

Lesser Sand Plover *Charadrius mongolus* was the most abundant species recorded during the entire 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. Black tailed godwit *Limosa limosa*, Black headed gull *Larus ridibundus*, Brown headed gull *Larus brunnicephalus*, Northern pintail *Anas acuta*, Little stint *Calidris minuta*, Common Red shank *Tringato tanus* and Asian open-bill *Anastomosos citans* are the other important species recorded in terms of their abundances.

Relative abundances of species varied seasonally with the highest abundances recorded during the winter months. Brown headed Gull *Larus brunni cephalus* was the most abundant during summers, Lesser Sand Plover *Charadrius mongolus* during rainy season and Black Tailed Godwit *Limosa limosa* during winter season.

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 lagoon, sandbars as well as winter migrants dominated abandoned ponds mostly waders.

Another interesting observation from the mangroves was on Brahminy Kite *Haliastur indus*, a commonly occurring species in coastal areas of India. It was recorded to be abundant in mangroves but in other habitats it constituted less than 1% of the total abundance, which is an indication of its dependence on mangrove forests. They were also rarely recorded from the fringes of the sanctuary dominated by human habitations where Black Kites *Milvus migrans* seem to replace them as top predators.

The bird communities of the mudflats were dominated by Black headed gull *Larus ridibundus* and Brown headed gull *Larus brunni cephalus*, while in the lagoon Black tailed Godwits *Limosa limosa* were the most abundant. They flock in huge numbers to this region during the winter season. Around 250 individuals of this winter migrant were recorded in a single opportunistic sighting from a fish sampling point near Yetimoga village. During our survey 180 was the highest number recorded at once near the same location.

Sandbars also saw good congregations of winter migrants such as Northern pintail *Anas acuta* (total of 120 indi. recorded in winters) and Ruddy shelduck *Tadorna ferruginea* (n=70 indi.). During this study, we also recorded flocks of Indian Skimmer *Rynchops albicollis* at the sandbars near Yanam city (Malla *et al.*, 2015). We had several opportunistic sightings of this species later, in one such sighting around 150 birds were recorded. In addition, a big congregation of Bar headed geese *Anser indicus* (between 80-

100 individuals) was also recorded from the sandbars in Kotipalli in January 2015. These observations show the important contribution made by these sandbars towards the rich bird assemblage of the Godavari delta.

We also studied few abandoned aquaculture ponds present adjoining the Coringa WLS, mainly to determine their role in shaping the avifaunal community of the study area. Though the overall abundance was lowest in these habitats but nevertheless they formed important alternate sites for several migrating birds such as Black tailed godwit *Limosa limosa*, Black winged stilts *Himantopus himantopus*, Lesser Sand plover *Charadrius mongolus* and Kentish Plover *Charadrius alexandrinus*.

Opportunistic sightings of several threatened species were also made such as Curlew Sandpiper *Calidris ferruginea*, Black-headed Ibis *Threskiornis melanocephalus* etc. Certain areas such as those near the Industrial zone at Kakinada Beach (included as abandoned aquaculture in this study) are very good sites for winter migrants as well as some local migrant species such as Spot-billed pelican *Pelecanus philippensis*, Open bill storks *Anastomus citans* and Painted storks *Mycteria leucocephalus*. Abandoned aquaculture ponds near Giriampeta village are also good alternate habitats for winter waders.

Spatial and Temporal variations in the structure of species assemblage

To study the patterns in species assemblage across the different habitats, Shannon's Index of Species Diversity, Margalef's Species Richness, and Simpson's Evenness Index were calculated for different habitats across the three seasons. The mean species richness was highest in the mangroves (Margalef's richness index $R_1=7.1$) followed by the lagoon and sandbars (Margalef's richness index $R_1 = 3.7$ each) and 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 for the mangroves (Shanon diversity index $N_1=3.2$, Simpson's Evenness Index $1-D=0.95$) (See table no.14). Since sampling efforts varied for the different habitats, inter-habitat comparisons were

not possible. So, only the seasonal changes in species diversity and species richness were statistically analyzed for each habitat.

Habitat types	Species diversity				Species richness				Species evenness			
	Summer	Rainy	Winter	Mean	Summer	Rainy	Winter	Mean	Summer	Rainy	Winter	Mean
Mangrove	7.067	6.718	7.459	7.08	3.216	3.26	3.207	3.23	0.9468	0.9563	0.9359	0.95
Mudflat	2.316	2.671	3.661	2.88	1.611	2.011	2.537	2.05	0.7175	0.797	0.8971	0.80
Lagoon	3.045	2.941	5.301	3.76	2.11	2.04	2.692	2.28	0.8344	0.818	0.8844	0.85
Sandbars	3.27	3.052	4.692	3.67	1.759	1.926	2.606	2.10	0.7085	0.7734	0.8972	0.79
Aquaponds	1.883	2.256	3.722	2.62	1.644	1.916	2.653	2.07	0.7408	0.8265	0.9136	0.83

Table 14: Species diversity, richness, and evenness across different habitats in three seasons

In the mangroves, most of which lie inside the Coringa WLS, highest mean species richness (Margelefs species richness value=7.5) was recorded during winter months and the lowest (Margelefs species richness value=6.7) during the rainy season. Quite opposite to this, species diversity as well as evenness in the mangroves was highest in the rainy season (Shanon diversity index $N_1=3.26$, Simpson's Evenness Index $1-D=0.96$) but lowest in the winters (Shanon diversity index $N_1=3.21$, Simpson's Evenness Index $1-D=0.94$). As per the results of our statistical analyses, highly significant seasonal

differences were observed in species richness (ANOVA, $p=2.71 \times 10^{-8}$) and species diversity (ANOVA, $p=4.74 \times 10^{-6}$) in the mangroves.

In other habitats, too significant differences were found in species richness between the three seasons. But, there were no significant differences in species diversity for other habitats except for mangroves and the lagoon. When the data from all the five habitats were pooled and analyzed for overall seasonal differences in species diversity, highly significant differences were noted especially in the winter season (Kruskal wallis test $p=1.01 \times 10^{-9}$) bird assemblage possibly due to advent of large number of winter migrants. Similar was the case for species richness, with the highest number of species recorded in the winter season.

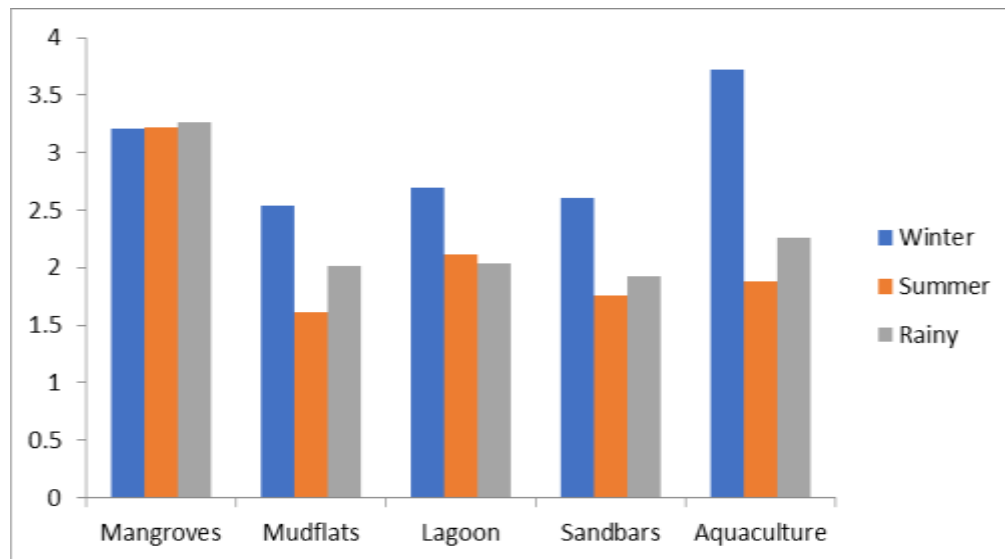


Figure 38: Graph showing Species Diversity across various habitats in three seasons

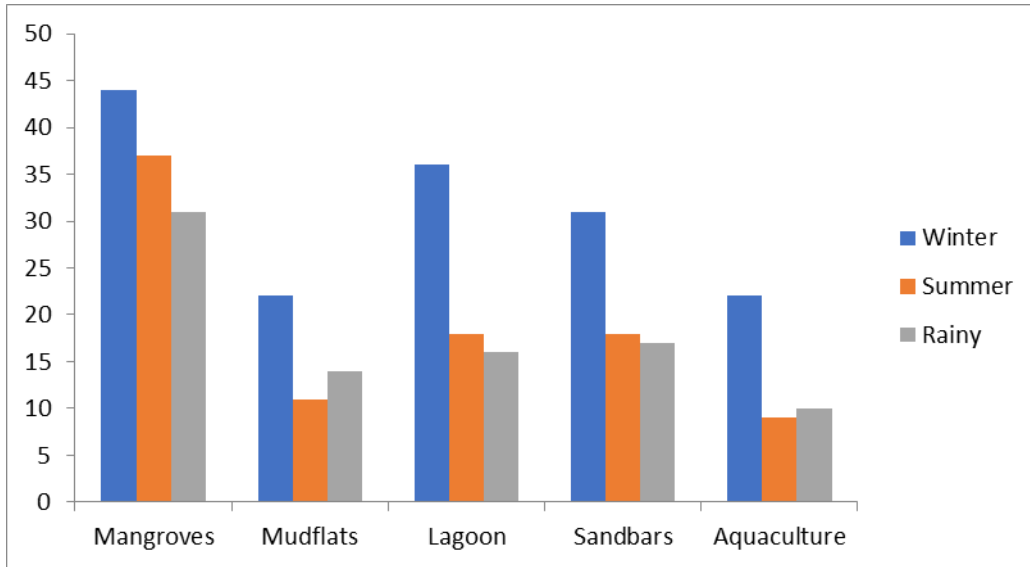


Figure 39: Graph showing Species richness across various habitats in three seasons

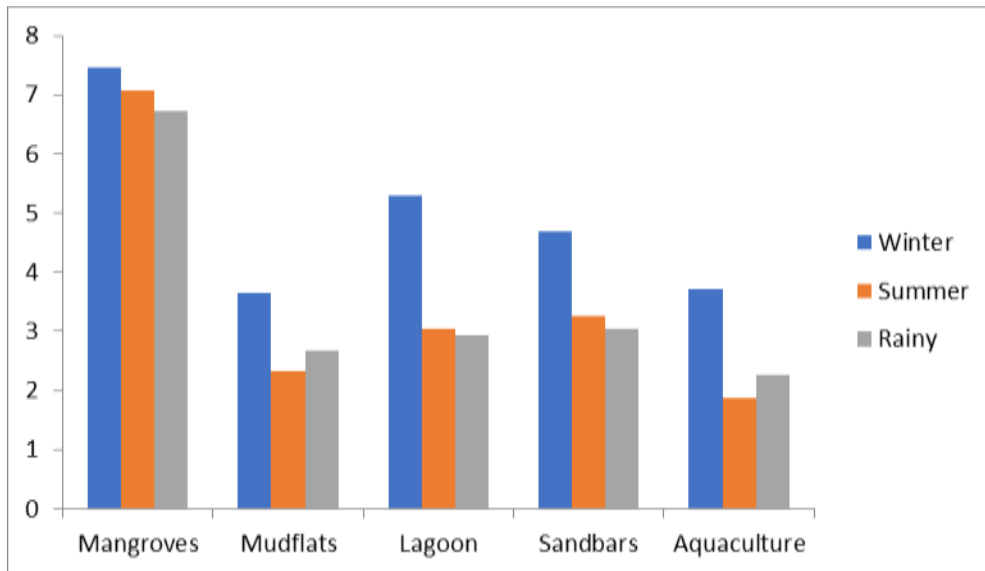


Figure 40: Graph showing Margalef's index across different habitats in three seasons

Feeding guilds in different habitats

To study the functional groups and composition of feeding guild in the bird communities based on habitats we divided the 242 species into 7 feeding guilds viz. Insectivore, Carnivore, Grainivore, Frugivore, Nectarivore, Herbivore and Omnivore. The results showed that Insectivore was the most dominant group of birds as compared to other feeding guilds in all habitat types. Around 36% were Insectivorous, 31% omnivorous and 23% were carnivorous whereas Herbivores and Nectarivores constituted less than 2.5% of all the species (Figure 41).

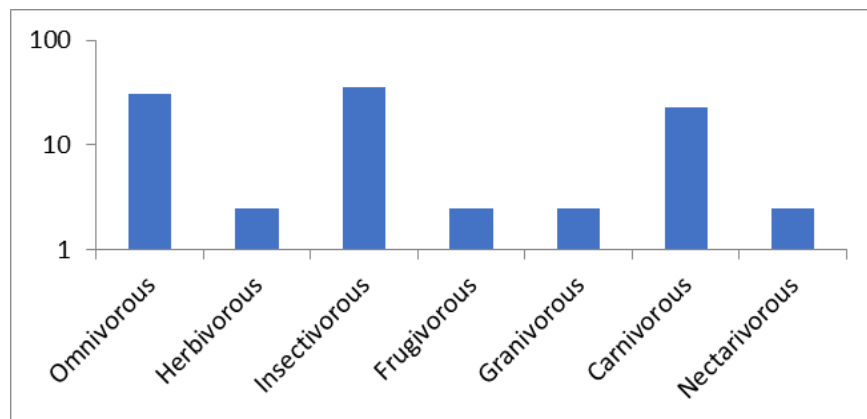


Figure 41: Graph showing Feeding guilds of different avifauna

Subsequently, we also studied the distribution of these 7 feeding guilds across the 5 habitats and found that except mudflats and abandoned aqua ponds, in all other habitats. Carnivores were the most dominant groups followed by Insectivores and Omnivores. In the hot months of summer season Carnivores, Insectivores and Omnivores were the only guilds observed in the lagoon and sandbars while in aqua ponds they were the only guilds observed throughout the year. Only 3 species belonged to the feeding guild of Herbivores (all were duck species) which were recorded during the season of winter in lagoon and sandbars.

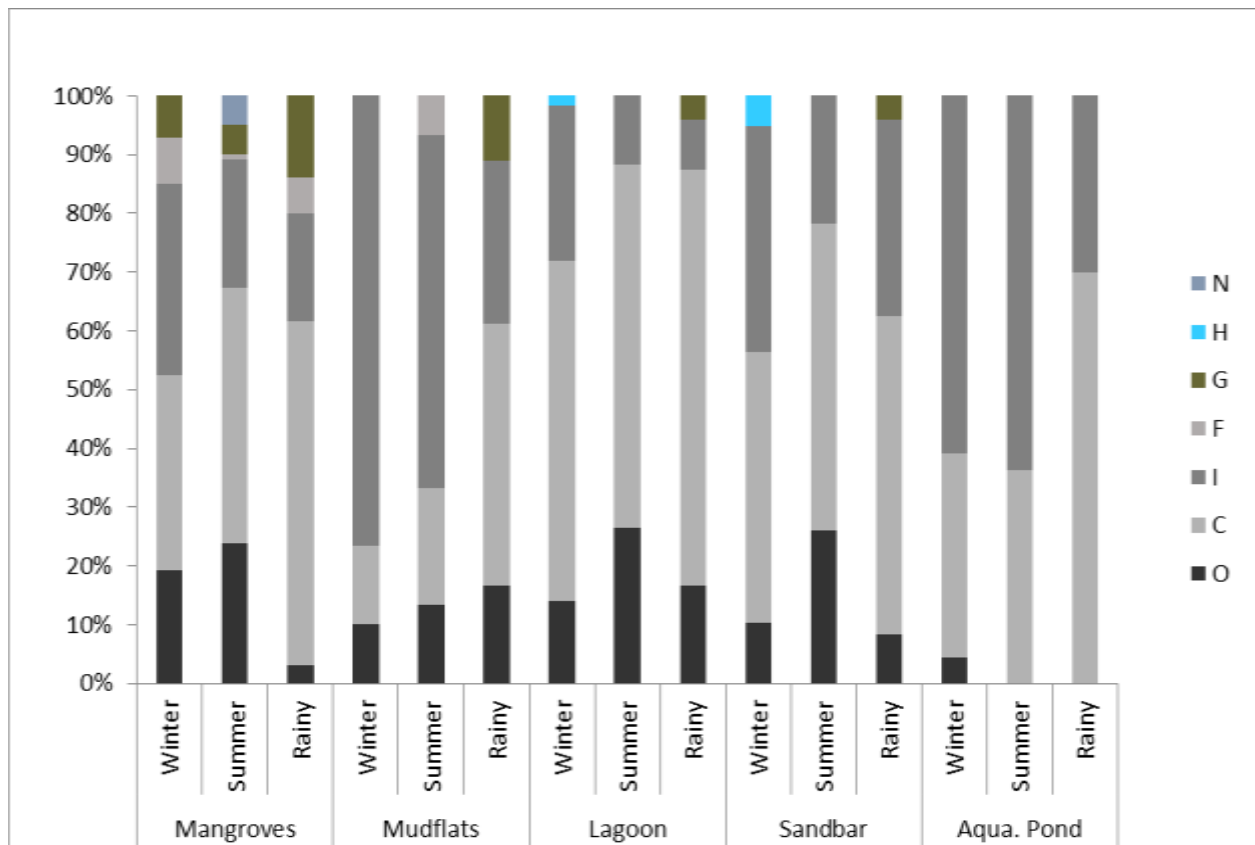


Figure 42: Graph showing seasonal difference in feeding guilds of birds across different habitats (N-Nectarivores, H-Herbivores, G-Granivores, F-Frugivores, I-Insectivores, C-Carnivores, O-Omnivores)

On pooling the data from all the habitats an overall comparison of each functional guild was done between the three seasons using appropriate statistical tests. While the differences in the Insectivore and Omnivore assemblages were found to be highly significant, in case of Carnivores it was not so and it was the dominant guild in all the three seasons. The number of insectivorous birds increased drastically from summer to winters, which was also proven by the statistical analysis. However, in case of omnivorous species significant differences were observed in the rainy season assemblage as the least number of omnivores were recorded in this season. The numbers of insectivorous and carnivorous species were also the least during rainy season but these differences were not so significant.

Habitat types	Seasons	Mangroves	Mudflats	Lagoon	Sandbar	Abandoned Aqua. Pond
Omnivore	W	1.08	0.60	0.75	0.67	0.33
	R	0.08	0.60	0.33	0.33	0.00
	S	0.96	0.40	0.75	1.00	0.00
	Average	0.71	0.53	0.61	0.67	0.11
Carnivore	W	1.88	0.80	3.08	3.00	2.67
	R	1.52	1.60	1.42	2.17	2.33
	S	1.76	0.60	1.75	2.00	1.33
	Average	1.72	1.00	2.08	2.39	2.11
Insectivore	W	1.84	4.60	1.42	2.50	4.67
	R	0.48	1.00	0.17	1.33	1.00
	S	0.88	1.80	0.33	0.83	2.33
	Average	1.07	2.47	0.64	1.56	2.67
Frugivore	W	0.44	0.00	0.00	0.00	0.00
	R	0.16	0.00	0.00	0.00	0.00
	S	0.04	0.20	0.00	0.00	0.00
	Average	0.21	0.07	0.00	0.00	0.00

Grainivore	W	0.40	0.00	0.00	0.00	0.00
	R	0.36	0.40	0.08	0.17	0.00
	S	0.20	0.00	0.00	0.00	0.00
	Average	0.32	0.13	0.03	0.06	0.00
Herbivore	W	0.00	0.00	0.08	0.33	0.00
	R	0.00	0.00	0.00	0.00	0.00
	S	0.00	0.00	0.00	0.00	0.00
	Average	0.00	0.00	0.03	0.11	0.00
Nectarivore	W	0.00	0.00	0.00	0.00	0.00
	R	0.00	0.00	0.00	0.00	0.00
	S	0.00	0.20	0.00	0.00	0.00
	Average	0.00	0.07	0.00	0.00	0.00

Table 15: Seasonal difference in feeding guilds of birds across different habitats (W- Winter, R-Rainy, and S-Summer)

Conservation Status

We recorded 12 globally threatened species out of which two are vulnerable Indian Skimmer *Rynchops albicollis* and Woolly-necked Stork *Ciconia episcopus*, one endangered Black bellied Tern *Sterna acuticauda* and nine Near threatened species Painted stork *Myteria leucocephala*, Spot billed pelican *Pelecanus pelecanus*, Black headed ibis *Threskiornis melanocephalus*, Oriental darter *Anhinga melanogaster*, Pallid harrier *Circus macrourus*, Eurasian curlew *Numeniusarquata*, Black tailed godwit *Limosalimosa*, Alexandrine parakeet *Pssitaculaeupatria*, Ferruginous Pochard *Aythyanyroca*.

Discussion

Godavari delta along with Coringa Wildlife Sanctuary and adjoining wetlands have been recognized as an Important Bird and Biodiversity Area as it is an important stop-over point for the south-bound migrating birds in the Central Asian Flyway. Since several years there have been demands to declare this region as a Ramsar site (Imran and Rahmani, 2004 and 2008) due to the immense diversity of waterbirds found here as well as the increasing threats due to rapid economic growth in the surrounding coastal cities. Several studies and surveys have been done on the avifaunal diversity of this region (Rao et al. 1996, Islam and Rahmani, 2008 etc.). The most recent report lists around 264 species of birds from the area (Sathiyaselvam and Sreedhar, 2015).

The results of our study also confirm to these earlier findings which show the dominance of waders in this region. Like the earlier studies our study also recorded Lesser Sand Plover as one of the most abundant species across all the habitats. Our study revealed Sandbars and the Lagoon as important habitats especially during the winter season since it may provide shelter, abundant food, and safe roosting sites for different groups of birds. Interestingly, the advent of this species in this region starts from the rainy season and the highest abundance in sandbars and lagoon was recorded in this season only. By the winter season, the species starts spreading to other habitats such as the mangroves and mudflats indicated by the rise in abundance. Surprisingly we recorded low abundance of Lesser Sand Plover from the mudflats which could be either due to the area of mudflats being small compared to other estuaries in east coast or due to some unknown sampling error.

One can determine the importance of these habitats for foraging of different types of bird species. We observed that most of the ducks and geese used open water bodies near sandbars on the Gowthami- Godavari River. These deep water bodies have plenty of vegetation on which they feed. Bitterns, herons, whimbrels, water cock, water hens are mostly seen feeding and hiding themselves in thick mangrove patches of the

Coringa WLS. The mangroves and its waters support them with plenty of vertebrates like fish and invertebrates like insects and gastropods.

Three species of Kingfishers were recorded in the study area, of which Black capped kingfisher is a migratory species. These birds are mainly seen in mangroves and near abandoned aqua-culture ponds mostly feeding on reptiles, fish etc. Moreover, the mangroves provide shelter for them during heavy rains.

During the winters in the mudflats, lagoons, and abandoned aqua-culture ponds, plovers, snipes, and sandpipers can be seen wading and searching for small insects and molluscans in the wet muddy substratum. The main reason for the difference in habitat preference by bird species could be due to different vegetation types (Weller, 1978) and abundant food resources (Puttick 1984) and because of natural predators which affect the bird's distribution across different habitats.

This study shows that Godavari delta and its different types of habitats are very rich in supporting diverse avifauna. Most of the habitats support them with plenty of food resources and provide optimal combination of resources that allows them to fulfill their biological needs like food, shelter, protection, from natural calamities. Since it also proved from this study that these habitats are very good in terms of bird diversities, there is an urgent need to protect them in addition to Coringa WLS.

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 be developed further in the future.

This study thus highlights the role of these different habitats in shaping the overall avifaunal community of the East Godavari River Estuary, which is an important part of the Central Asian Flyway. We also observed several threats during our surveys such as sand mining, dredging, water pollution by oil refineries and fertilizer companies along the river and creeks. Recently due to the bifurcation of the Andhra Pradesh state, Godavari delta is experiencing rapid industrial growth and is turning into one of the

mega districts in the state. In future, the construction of Polavaram Dam will also lead to decline in sediment flow to the downstream riverine habitats which might have severe consequences. Therefore, proper mitigation plans must be taken beforehand by the policy makers.



Figure 43: Black tailed godwits feeding on rich resources of the mudflats in Kakinada Bay near Yetimoga



Figure 44: Indian skimmer seen on the banks of Godavari River, near Yanam

Study of terrestrial mammals in Coringa Wildlife Sanctuary

Introduction

Coringa Wildlife Sanctuary and its surrounding areas, around 14 species of mammals belonging to 6 orders and 10 families have been recorded. Of these 14 species, *Prionailurus viverrinus*, *Delphinus delphis*, *Susa chinensis*, *Stenella longirostris*, *Tursiops truncatus* are listed in Schedule-I of Indian Wildlife Protection Act 1972, whereas *Macaca mulatta*, *Macaca radiata*, *Felis chaus*, *Paradoxurus hermaphrodites*, *Herpestes edwardsii*, *Canis aureus*, *Lutrogale perspicillata* are listed in Schedule-II. Further, *Prionailurus viverrinus* is listed as Endangered category in IUCN Red list, while the *Lutrogale perspicillata* is listed as Vulnerable.

Carnivore Study

Many species of terrestrial mammals live in close association with rivers and estuaries, often as feeding grounds and frequently using them as a place of safety and as a means of escape from predators. Precise knowledge of habitat requirements is of paramount importance for conservation of such species which have unique behavior and adaptations due to their dynamic habitat. No single factor could be identified as responsible for their decline (Maran and Henttonen, 1995). The main reason, therefore, for the carnivore study in EGREE is to gain greater knowledge on their habitat utilization, feeding ecology, threats and adaptive capacity, and their conservation status.

Methodology

Habitat Utilization of Carnivores

Two hundred and ten (210) Grids (1km X 1km) covering 210 km² of the study area were surveyed for recording the habitat utilization of carnivore species through indirect evidences like pug marks, scats, scraps, rake and vocalization and camera trapping. For better understanding on the habitat utilization of these carnivores in the EGREE landscape, six different habitats like mangroves, aqua-culture ponds, villages, agriculture, mudflats, and sandbars were thoroughly surveyed. For the surveys, only the three major carnivore species- Fishing cat *Prionailurus viverrinus*, Smooth coated otter *Lutrogale perspicillata* and Golden Jackal *Canisaureus* have been selected because of their good presence in all the six habitat types. Analysis: Nai'Ve estimate was used to calculate the overall carnivore presence with respect to their habitat utilization in EGREE.

Results and Discussion

Most of the carnivore signs were found in 83 grids out of the 210 grids selected. Throughout the survey, it was found that most of these carnivores preferred mangrove habitat, followed by aquaculture ponds and villages (Table 4 and Figure 14). Moreover, it has been found that the carnivores' presence in other habitats like mudflats and sandbars was very low. These results indicate that all these carnivore species are highly dependent on the mangrove forests as they provide abundant supply of food as well as relatively lower disturbance levels. However, presence of smooth-coated otters (and occasionally of fishing cats) was found very close to the aquaponds and villages, making them highly vulnerable to human-animal conflict in such areas.

Fishing cat *Prionailurus viverrinus* is one of the medium sized cats which inhabit wetlands and marshy areas across its home range. Much of its ecology is unknown till date. This large stocky powerful cat is olive-gray in colour, patterned with rows of parallel solid black spots that often form stripes along the spine. The tail is very short,

less than half of the body length (Nowell and Jackson 1996, Macdonald and Loveridge, 2010). This cat is built bulky and has immense power as miniature jaguar (Brander, 1923). These cats are adapted with wetlands and occur in coastal and inland wetlands, near rivers and streams, in marsh areas, reed beds, tidal creeks, and mangrove forests (Nowell and Jackson, 1996; IUCN, 2011).

Table 16. Occupancy of different habitats by carnivores in EGREE landscape

SL. No	Mangrove	Aquaponds	Villages	Agriculture	Mudflat	Sandbar	Total
No of 1*1km grids surveyed	70	43	25	41	24	7	210
Grid cells with carnivore presence	46	12	14	9	0	2	83
Probability of site detection	0.65	0.28	0.56	0.22	0	0.28	0.39

The fishing cat is well adapted for catching fish, its primary prey (Bhattacharyya 1989; Mukherjee 1989; Haque and Vijayan, 1993). It has a deep-chested body, with short legs and tail, and small close-set ears. Like the flat-headed cat, its front feet are partially webbed, and its claw tips protrude from their sheaths even when retracted, thus giving a signature track imprint (Sunquist and Sunquist, 2002). It is a strong swimmer and can cover long distances under water (Roberts, 1977).

Fishing cats are strongly associated with wetland. They are typically found in swamps and marshy areas, oxbow lakes, reed beds, tidal creeks, and mangrove areas. Along watercourses they have been recorded at elevations up to 1525 m, but most records are from lowland areas (Nowell and Jackson, 1996). Presently the fishing cat is classified as an endangered species by the IUCN Red List because of severe population declines reported throughout much of its range over the last decade (IUCN, 2011). In India, the fishing cat is distributed from the foothills of the Himalaya, Central India, and Eastern and Western coastal areas (Pocock, 1939, Nowell and Jackson, 1996, Kolipaka, 2006, Mukherjee et. al., 2012). Fishing cats are believed to be solitary and mostly nocturnal (Nowell and Jackson, 1996).

One of the major threats to fishing cat population is wetland destruction. Moreover 50% of the Asian wetlands are in moderate to high degree of threat (Scott and Poole, 1989). The rapid changes in the Godavari mangroves due to encroachment of aquaculture ponds, shipping industries, oil refineries are the immediate threats to fishing cat population. These mangroves are of global importance and with proper management we can safeguard the survival of not only Fishing Cat but also another mangrove dependent mammal found in the area, the Smooth Coated Otter.

Population Estimation of Fishing Cat

Several factors affect the population density of carnivores, including prey availability (Carbone and Gittleman, 2002), inter-specific competition (Creel and Creel, 1996) and

hunting by humans (Inskip and Zimmermann, 2009). Data on the numerical response of different species to habitat degradation by livestock and hunting by humans are scarce, particularly for small- and medium-sized felids. Hence accurate and unbiased estimates of population size are desirable for species conservation and management (Silveira et al., 2003). Census tools must therefore be accurate, reliable, cost-effective, and reasonably easy to apply (Jackson et al., 2006). Assessing accurate estimates of population density is one of the major goals for wildlife management, especially for those species that are difficult to observe directly owing to their behavior and the ecological conditions of their habitat.



Figure 45: Fishing cat hunting in the creeks of Coringa WLS

However, for small elusive felids, such as fishing cat, such practices of estimation are really being challenging. Estimates based on track observations are failure prone and unreliable, while radio-telemetry is costly and constrained to a small number of individuals (Karanth 1999). To estimate the density of fishing cat, we used the method

described in Karanth and Nichols (1998), which makes use of standard camera-trapping and capture– mark–recapture population models (Otis et al., 1978; Silver et al., 2004). Karanth (1995) in most of his study used an application with the natural variation in fur markings for identifying secretive mammals. Camera trapping in combination with capture-recapture (CR) statistical modeling (non-spatial (Otis et al., 1978, Karanth and Nichols, 1998) and spatially explicit capture-recapture (SECR; Efford 2004, Royle and Young, 2008)) has been successfully used to reliably estimate densities for nocturnal, elusive felids with distinct coat patterns, such as tigers, leopards, jaguars, ocelots etc.

SECR (Spatially Explicit Capture and Recapture) density estimation technique is one of the most widely used robust tools to deal with low sample size. These models first determine an individual's activity centre by using the spatial location of captures and then estimate the density of these activity centres across a precisely defined polygon containing the trap array (Gardner et al., 2009, Royle et al., 2009b), thereby avoiding the issue of estimating the effective area sampled (Sollmann et al., 2011). In addition, SECR methods also deal with uncertain edge effects and spatially heterogeneous detection probability caused by movement in conventional animal trapping (Efford, 2004, Borchers and Efford, 2008). Fishing cat populations are very scarce and highly fragmented in the Godavari Delta and therefore conservation measures should focus on the best ecological information, particularly in an accurate assessment of population numbers.

The aim of the present study was to assess the population size of fishing cat through established procedures for capture-recapture analyses of a closed population by using camera-trapping in place of traps and the individual variation in coat coloration and markings of the fishing cat to recognize 'recaptures' in photographs.

Methodology

A preliminary survey of the study area, based on the collection of fishing cat signs (e.g. scats, footprints, trails etc) was conducted to find the best place to set camera traps. Fifteen digital camera traps (Cuddle back Ambush Flash) with passive infrared motion/heat sensors were deployed systematically covering the entire mangrove area in 198 trap stations (Figure 15), in pairs, to obtain photographs of both sides of the fishing cats, allowing better identification of each individual. Camera traps were placed at 15-25 cm above ground attached to a tree trunk at 3-5 m from a trail or point where animal movement might be expected.

Camera traps were set with a delay time of 5 sec. between successive photos. The whole camera trapping period lasted continuously from December 2014 to August 2015, but it was arranged in 20 consecutive sessions, each one lasting 12-14 days and the trap stations were checked at least once a week. We have not used any attractants or baits were used to avoid differential responses according to sex, age, and status.



Figure 46. Map showing the camera trap locations for studying the activity patterns of Fishing cat

Analysis

To distinguish individuals, we considered number, shape, dimension and position of stripes, bands and spots on the trunk and limbs, number and shape of the rings on the tail, as well as the dimension of its black tip; the observation of unequivocal body signs such as scars on face, lips and ears was also useful in individuals identification.

Non-Spatial Density Estimation

Non-spatial estimation of abundance (N) and capture probability (p) was done using full closed CR model in program CAPTURE[39]. The software program CAPTURE is mainly used to generate population estimate based on capture-recapture models under the assumption of a closed population where immigration, emigration, births and deaths did not affect the estimate. Capture-recaptures models differ in their assumption about capture probabilities, in particular individually heterogeneity (M_h) assumes that each individual had its own probability of being captured independently of time and behavior, time model (M_t) accounts for variation in capture probabilities across occasions, behavior model (M_b) considers a differential response (trap-happy or trap-avoid) if the individual has been previously captured and finally, capture probabilities are assumed to be constant (M_0) respect to time and individuals. In addition, CAPTURE allows estimation under 4 more models that combine the sources of variation cited above (M_{bh} , M_{th} , M_{tb} , M_{tbh}). To estimate the effective sampled area where the population size (N) was estimated, we measured the mean maximum distance covered by all individuals photographed at two or more locations during the survey period as a proxy for home-range diameter (Karanth & Nichols, 2002). We used half the mean maximum distance (w) to buffer each camera trap location (following Silver et al., 2004). Animals whose home ranges overlap the buffered area at least partially have a capture probability greater than zero. We divided the population size estimate by the effective sampled area to estimate population density (individuals/ km²).

Spatially Explicit Density Estimation

Considering the fact that space and movement have no explicit manifestation in classical MMDM based CR models (Royle et al. 2009a), we tried to address this issue through SECR models. A usual framework for developing spatial models is based on point process models (Efford, 2004, Borchers and Efford 2008; Royle and Young, 2008), which assume that each individual i in the population has a fixed point associated with it considered as its centre of activity s_i (two-dimensional coordinate representing a point in space about which its movements are concentrated).

SECR models hence operate as generalised linear models with random effects (i.e. GLMMs) with many unknown variables (random effects) in the model (Royle et al., 2009a; Sollmann et al., 2011) particularly the activity centres of each individual (s_i) and the number of such activity centres (i.e. the population size N). We used two different calculation techniques to estimate SECR density of leopard cat. The maximum likelihood-based method using program DENSITY4.4.1.2 (Efford, 2007) which directly estimates density by fitting spatial detection functions to CR data from arrays of passive detectors such as camera traps (Efford, 2004). Here, the probability density functions for detections of animals based on distance from activity centres are modelled using hazard rate, half-normal or exponential detection functions (Efford et al., 2008). These models can be considered as mixture models where the mixture is over the distribution of animal locations, and the estimators are based on the marginal distribution acquired by integrating the joint likelihood over the distribution of unobserved locations (Borchers and Efford, 2008).

Results

Results from camera trapping shows an abundance of 75.0 ± 7.7 (SE) (62.8 – 94.3), with 107 captures of 54 different individual cats. 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, selected based on minimum AICc value, described the detection function with a hazard rate function. The density estimate was 0.53 ± 0.94 (SE)/km². Pictures of camera trap photographs are given in Figure 16ab.

Activity Patterns of Fishing Cat

Here, we describe a method to estimate activity level from camera trap data collected at locations that were random with respect to the animal activity schedule. The main purpose of camera trapping is to study the activity patterns of the fishing cats and to know their ecology in detail. After thorough examination of the study area, camera traps were deployed in the mangrove forests to study and know the behavior of fishing cat for a period of one year from January 2014 to January 2015. Daily activity patterns of fishing cats are presented in Figure 17.

Cuddle back camera traps were used for sampling, with 2-8GB memory cards for image storage. All these cameras are 24 hrs active, with 5 seconds time delay in photo capturing. Since the main food resource of fishing cats are fishes for which they come to the banks daily, most of the camera traps were deployed in the trails adjoining the channels and creeks to get the maximum probability of capturing them.

Upon locating the best trail with maximum animal movements (depending on the signs), the camera traps were deployed around trees at an interval of every 300m and at a height of 2-3 m. For each site, the GPS location was noted down. The cameras were deployed for around 10 days between the full moon and new moon, based on postulation that the tidal variations during this period might have some influence on the behavior of fishing cat hunting in the creeks.

Salient features of Camera trapping of fishing cat

- Camera trapping which was done in 10-15 days interval gave us an insight into the behavior of fishing cat to tidal activity of the creeks.
- Distance between the two camera traps were maintained at 300m interval, so that the time spent during the fishing hours can be sorted out.
- Camera traps were deployed in a closed system for maximum activity pattern observation.
- For further genetic analysis, we have collected all fresh feces and stored in zip-lock covers and dried with silica gel. Later on, the DNA of a subsample of each one of these scats will be extracted and amplified by PCR. The species will be identified using a sequence based analysis of the 16s rRNA mitochondrial gene (Johnson and O'Brien, 1997).
- With the closed system of camera trapping we found that male territories are overlapping with several female territories.

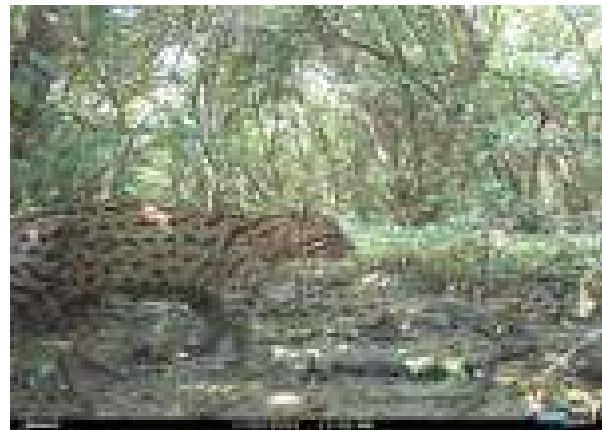


Figure 47. Fishing cat pictures captured through camera traps.

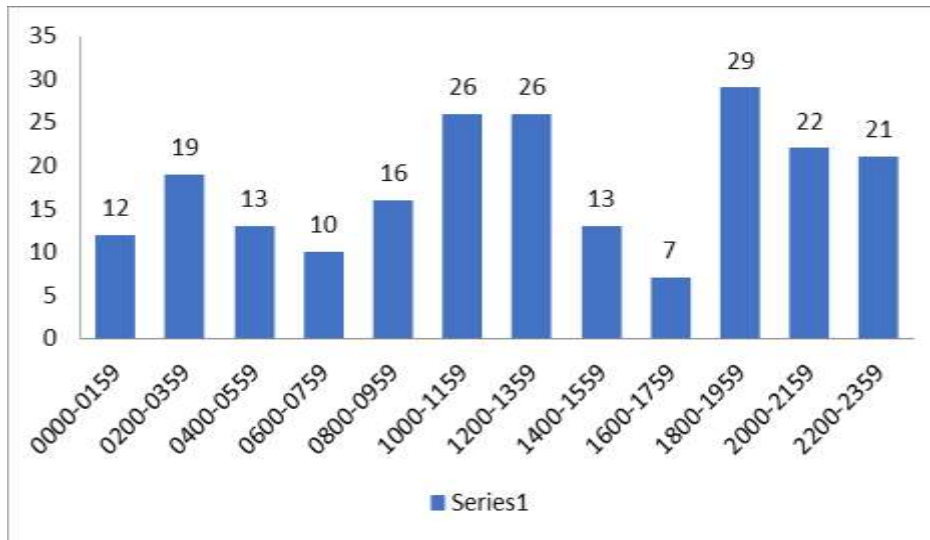


Figure 48. Graph showing daily activity pattern of Fishing Cat in Coringa WLS

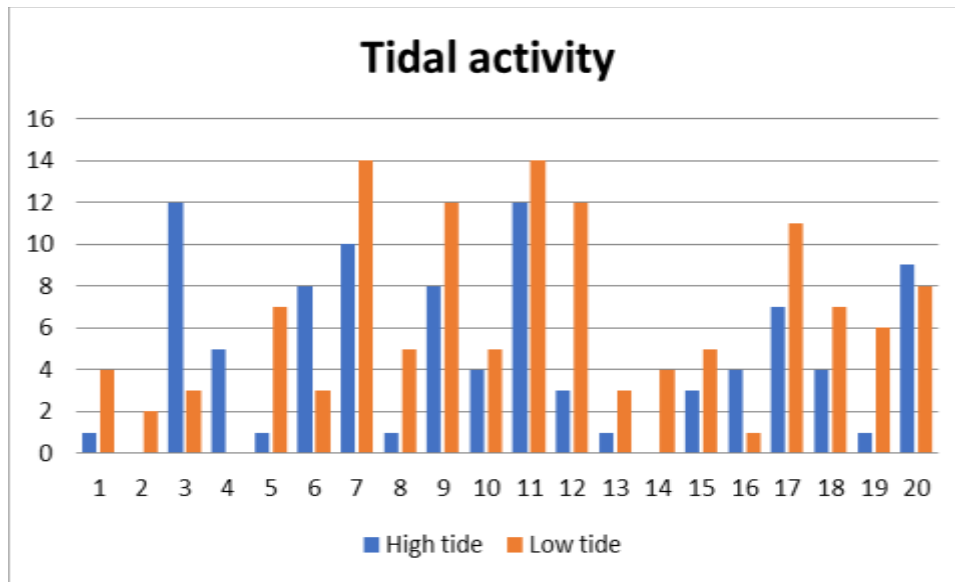


Figure 49. Graph showing fishing cat activity with respect to tidal activity in the creeks of Coringa WLS

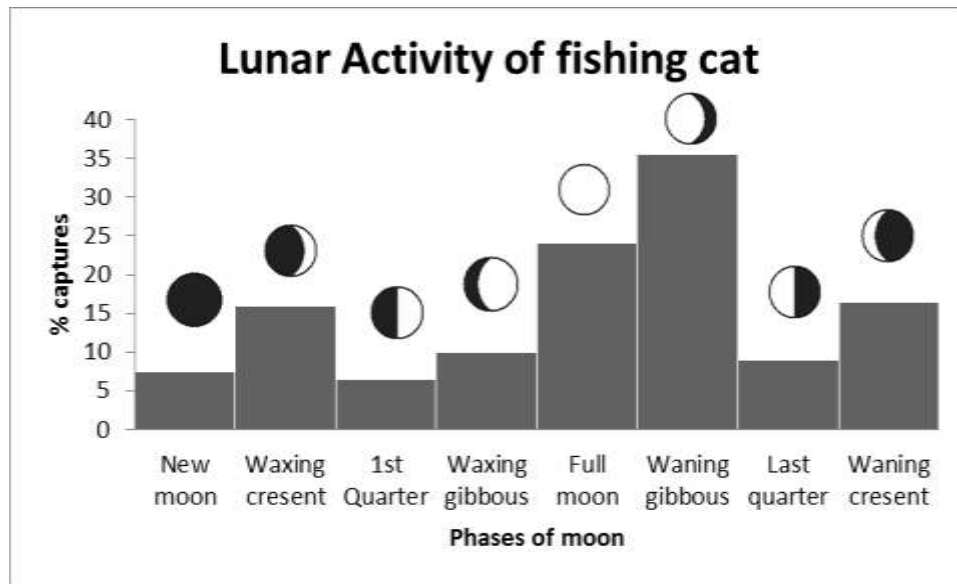


Figure 50. Graph showing fishing cat activity with respect to lunar phases in Coringa WLS

Fishing cats were more active during low tides (65%) than high tides (35%) (Figure 18). When compared with the lunar phases, activity was more during waning gibbous (35.5% captures) and full moon (24% captures) respectively (Figure 19). 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 (Figure 51). Moreover, positive signs of fishing cat were present near to the intact mangrove cover. These results show that Coringa wildlife sanctuary seems to be holding higher densities of fishing cat population.

This study also indicates that the likelihood of occurrence of fishing cat increases with intact mangrove cover when compared to the varying degrees of human-modified habitats present across the delta like oil refineries, aquaculture ponds etc., giving an utmost importance to mangroves for the survival of the fishing cat.

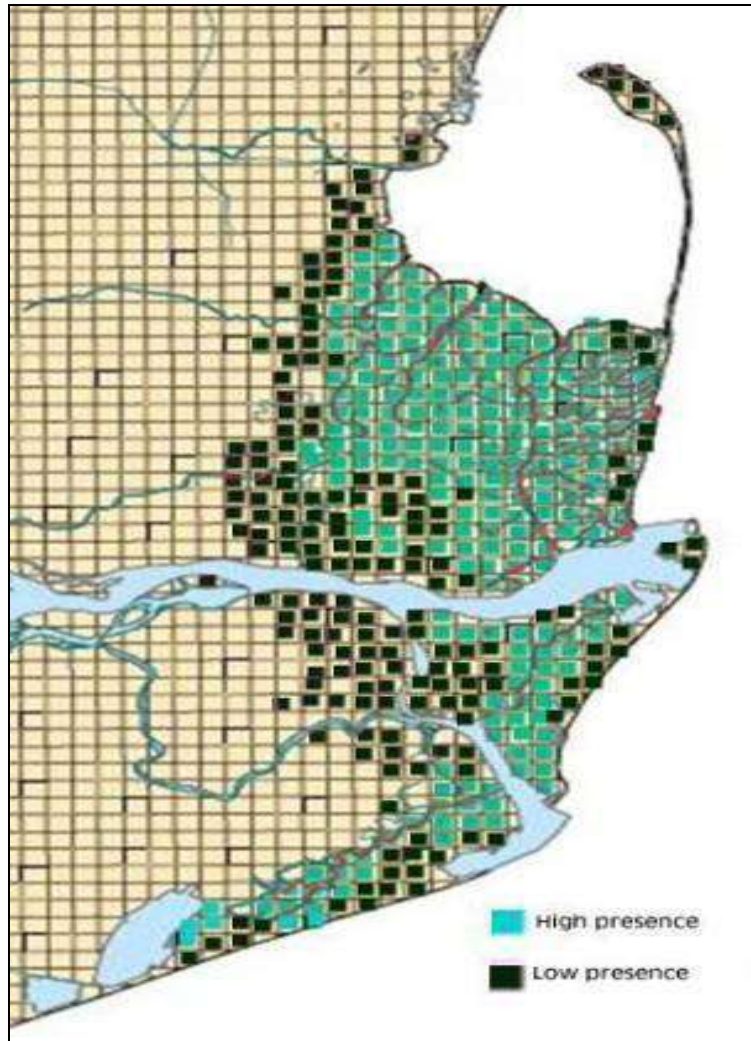


Figure 51. Fishing cat presence in Coringa and camera trap images

Conclusion

The present study has given some promising insights into the behavior of these elusive small cats. The study also shows how the mangrove forests of this region are highly important for the survival of this species. In mangrove forests of other parts of the country or the world these cats have suffered huge population decreases due to habitat loss or competition from other top predators. But the Godavari mangroves provide a relatively safer habitat for these cats and lower degree of competition from another

predator's. However, the tough nature of mangroves provides a big challenge for assessing and monitoring their population status. A proposal for telemetry study has been submitted which will give detailed information about the behavior of the species along with crucial information on its home range and territory.

Ecology and Conservation of Otters

Otters are members of weasel family, *Mustelidae* that comprises 67 species (Ewer. 1973), and is one of the largest families of order *Carnivora*. Mustelids are small to medium sized carnivores with characteristic short legs and long bodies. Most Mustelids feed on vertebrates with few species of *Otters* as exception which feed on invertebrates. Otters come under the sub-family *Lutrinae* out of five sub families of Mustelids. Otters occur in all continents except Australia and Antarctica.

The first recognizable fossil of aquatic Otter lived 30 million years ago and therefore, had long time to adapt to an aquatic way of life (Channin, 1986). Presently, 13 species of Otters exist in the world and all of them seek food from water. Although Otters are well designed for life in water, they have no unique adaptations to cope up with this way of life such as no modified breathing structure to breathe underwater; hence Otters are considered as semi- aquatic mammals.

Otters have a streamlines body and webbed feet that makes them efficient swimmers. The hair of otter's interlock among themselves and trap air between them thus helping in thermoregulation as they lack blubber unlike other aquatic mammals. Also, the long stiff hairs (vibrissae) that located on the sides of mouth of Otters assist in hunting prey even in murky waters (Mason and Macdonald, 1983; Channin, 1986). These adaptations make Otters excellent predators in water. In India three species of Otters occur namely the most widely distributed Smooth Coated Otter *Lutrogale perspicillata*, the Eurasian

Otter *Lutra lutra* and Asian small clawed Otter *Aonyx cinerea*. In EGREE presence of smooth coated otters has been reported.



Figure 51. Otters basking on a grass and *Suaeda* patch in Coringa wildlife sanctuary.

Methodology

The study area was intensively explored for presence of Smooth coated otter signs that include paw prints and spraints. The effect of high tide and low tide cycle in the study area and its influence on boat movements and Otter signs visibility were also observed during this survey. A sample questionnaire survey was conducted in the villages bordering the sanctuary to know their responses and to finalize the questionnaire. Based on this survey, sampling design for otter distribution study was finalized.

Extensive signs surveys were carried in the study area along the banks of the creeks starting from villages and ending at mouth of the river. Belt transects of 600 metres long and 10 metres width were laid along the banks with 1 km interval all along the selected creeks. Size and location of belt transects were decided based on reconnaissance survey.

The number of signs encountered in each transect were noted (Jeffress et.al., 2010). Any spraints encountered during the survey were collected. Habitat variables that are thought to be affecting otter presence in the study area were measured based on the literature and direct observation. Habitat variables measured in each transect were

- (i) Dominant tree species
- (ii) Width of the creek
- (iii) Depth of the creek
- (iv) Percentage bank vegetation and type.
- (v) Number of open grass patches
- (vi) Number of *Suaeda maritima* patches
- (vii) Distance from village
- (viii) Disturbance
- (ix) Number of channels present in the 600m stretch

The above variables other than (v), (vi), (vii) were found to be effecting otter presence from previous studies. Since the study area is a mangrove habitat there are no rocky structures or sandy substrates where otters were found to be defecating and grooming respectively from previous studies. Otters were observed to be grooming, basking and defecating on open grass and *Suaeda maritima* patches during the study period and the fishermen were also found to observe otters basking on these patches. Moreover, out of 81 spraints only 5 spraints were found on non-grass location. The reason for this could be the fact that otters mark their territories using their spraints and grass and *Suaeda maritima* patches are few areas in the study are which does not get inundated even during high tide so they remain dry.

Prior the sign survey the probability of finding signs with increasing distance from banks was measured wherever the signs were found. Most of the otter signs were observed from 4m and in rare occasions till 6m. So the plot size of 600 x 10m was selected for the study. This was also evident from several studies (Kruuk and Conroy,

1987; Hussain and Choudhury, 1997). A sign survivorship survey was done to know how much time it takes for a sign disappear or loose shape so that it can no longer be identified. For this signs at different distances from land were marked and were observed every day for presence and absence. This was done because of the highly dynamic nature of mangrove ecosystem where high tide and low tide effect varies with the distance from sea and the size of the creek. This in turn can affect the survival of signs. This can cause underestimation of the signs in areas where they quickly disappear. (Mathewson et.al., 2008; Weckerly et.al., 2000)

Spraints were collected during the intensive signs surveys and once a sprainting location was identified the sight was revisited frequently to collect spraints. A spraint was defined as the collection of all faecal matters of an otter group deposited on one communal sprainting site. Only fresh spraints were collected since there is risk of losing some faecal matter with time. Further, it was found that fishing cat, dogs and birds feeding some foods items from the spraints. Fresh spraints were identified by their Greyish black colour, moisture content and typical Smooth coated otter spraint odour. These spraints were collected in zip-lock bags for further analysis. A total of 81 spraints were collected during the study period.

The collected spraints were soaked in detergent solution on the same day for 6 hours and transferred to iron sieve with mesh size 1mm and washed thoroughly under tap water. The spraints were then dried under shade and stored in zip-lock bags for further analysis.

The present study was mainly focused on the amount of fish that otters could take from fish farms, therefore, a reference sample of fish scales of all the five carps namely *Catla catla*, *Labeorohita*, *Cirrhinus mrigala*, *Cyprinus carpio* and *Ctenopharyngodon idella* cultivated in the farms were collected and preserved for identification. Further, 11 more fish species that were commonly found during fish sampling were also selected and

their reference fish scale samples were preserved for future identification. Total body length and weight of the fish specimens from which scales were collected were also measured to estimate the body size of fish. The scales were stored in glycerine when collected and then soaked for 12 hours in luke warm water for the scales to soften. This was done because the scales tend to curl during storage. Then the scales were mounted on slide using DPX mount and covered with a cover slip. Identification of the items in the spraint was done using a hand lens with spraint placed in Petridish. The Scales, bones and other body parts were separated using forceps and needle. The venation pattern of the scales was used to identify fish from the spraint. Catfishes were identified by their sharp lateral spines. Crab and prawn remains were identified using colour and shape of the exoskeleton. Crabs and prawns were not identified to genus level. Also, effort was not made to identify size class of the fish.

The prey categories for each spraint were noted and the number of occurrences of a prey category in each spraint was expressed as proportion of the total number of occurrences of all prey categories in a sample, so that the sum of frequencies would be 100 (Melquist and Hornocker, 1983, Hussain and Choudhury, 1998, Pardini, 1998). In this method, the proportion of each prey item was estimated visually. Then each prey item was given a score from 1-10, so that the total for one spraint is 10. The score for each category was multiplied by the dry weight of the spraint and the resulting figures were summed for each category and expressed as a percentage (Wise et.al., 1981; Hussain and Choudhury, 1997).

The amount of prey available could only be done in the natural system i.e., creeks as it was possible to know the available fish from aquaculture farms. Gill nets were used for fish sampling to measure the relative abundance of different fish specie sand also abundance for different creeks. The gill nets were placed from one end of the creek t othe other end during the low tide for one hour and fish caught in the nets were identified and noted with habitat variables. Cast nets were no used as the water is

continuously flowing inwards or outwards. Crabs and prawns were not sampled as they were not under the study objective and, they form a minor part of Smooth coated otter diet (Hussain and Choudhury, 1997; Anoop and Hussain, 2004)

Ivlev's index was tried to calculate the otters prey fish use and their availability. Score bulk estimate of fish from the spraints that have been collected exclusively from the mangroves areas was considered as use and their relative abundances were considered as their availability for otters to feed. The Ivlev's electivity (selection index) describes a predator's preference for prey. It scales from -1 to 1; where -1 indicates total avoidance of a prey; 0 indicates that a prey is taken in proportion to its abundance in the ecosystem. It is defined as: $E_i = (r_i - P_i) / (r_i + P_i)$ where, i is the relative abundance of a prey in a predator's diet and P_i is the prey's relative abundance in the ecosystem.

As this study focuses on identifying the level of interaction between Otters and Aquaculture farms, knowing the perception of people mainly aquaculture farm owners and workers becomes important. For this a semi-structured questionnaire survey was carried out for the aquaculture farm owner and workers about their perception on whether otters are feeding extensively on cultured fishes and if they are causing any economic loss along with methods they follow to tackle this if they are any. A total of 8 villages have Aquaculture farms bordering the study area. In each village, the number of people cultivating fish or prawn was first enquired and then 10 to 50 percent of the population that is into aquaculture were interviewed. The number of people in aquaculture varied from 3 people to nearly 100 people depending on village. A total of 53 respondents were interviewed during the study period.

Analysis

Ordinal regression was used to find the relationship between otter signs intensity with their habitat variables. All the variables were 'Z' standardized before analysis. The signs were grouped as no signs, low signs and medium to high signs based on the median

number and range (Sokal and Rolf, 1995). The data was analysed using SPSS 22.0. Graphs for this were also done using the same software.

Ivlev's index was used to measure use vs availability in the natural system. This could not be done for aquaculture farms because it would require data from every farm owner and is not reliable.

Program 'R' was used to run Generalised Linear Models with Poisson distribution to identify the attitude of farmers with different income levels and education status with their responses that are important for conservation (Sokal and Rohlf, 1995). Clustered columns and scatter plots were used to show percentage of particular response in the population. Graphs for this were generated using Microsoft Excel 2013.

Results

The total number of prey items found in a spraint was varied from 1 to 11 revealing the diverse range of food preference of Otter in the study area (Figure 52). However, most of the spraints contained 5-7 prey species. Frequency of occurrence of all food items found in the spraints was calculated. Of the all food items, fish was found in almost all spraints (98.6%). As per the score bulk estimates, fish was again dominated in all spraints (99.6%) with respect to their relative quantity found in all spraints collected in the field. Therefore, this result is once again confirmed that the most preferred food of Smooth coated otter is fish that was earlier support by Hussain and Choudhury (1997) and Anoop and Hussain (2004).

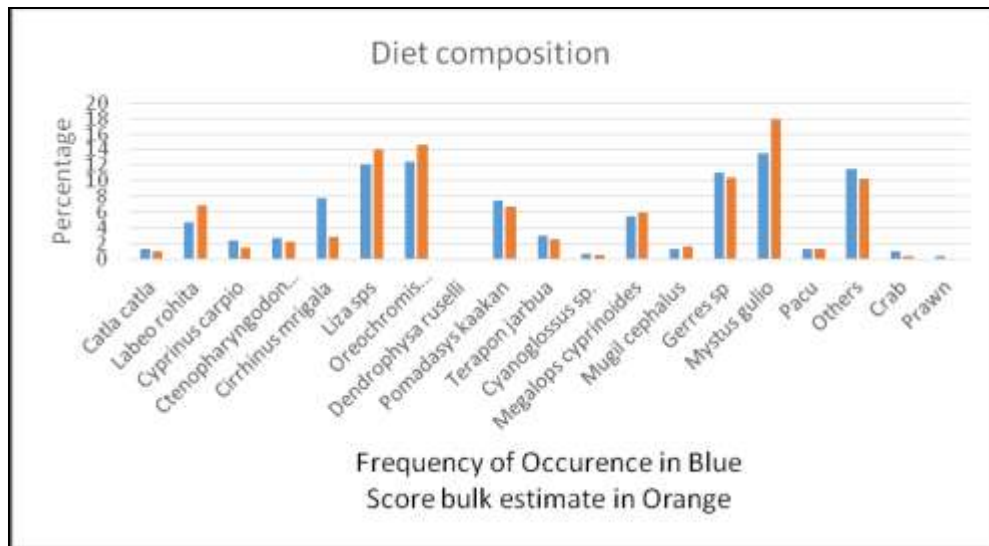


Figure 52. Diet composition of different species of fish for two different methods

Mystus gulio (long whiskers catfish) found to be the major prey of otter in the Coringa WLS, constituting 17.8% of weight of all food items found in the spraints and this fish was also eaten by many otters (found in 13.4% of spraints). *M. gulio* was also the most common fishes of the Sanctuary. *M. gulio* followed by *Oreochromis mossambicus* (Tilapia) constituting 14.6% of weight of all food items found in the spraints (score bulk estimate) and 12.4% for frequency of occurrence method. *Gerrres sps* and *Liza tade* constituted 10.3% for score bulk estimate and 11.1% for frequency of occurrence and 13.9% and 12.1% for score bulk estimate and 11.9% for frequency of occurrence respectively. *Dendrophysa russelli* was never encountered. Pacu a native to South American river system was encountered with 1% constitution for both the methods (Figure 52).

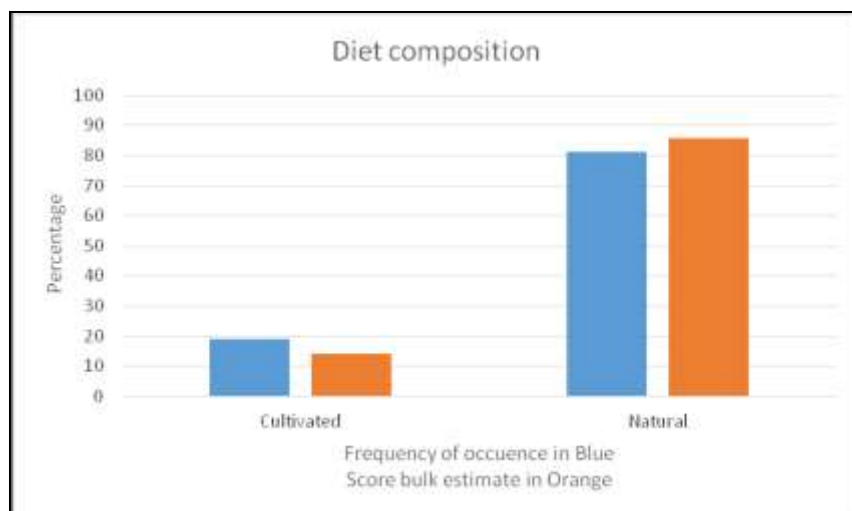


Figure 53. Diet composition of fish from aquaculture farms and from mangroves for two different methods

All five major aquaculture species of fish were found in the spraints of Otter. Of the five species, *Labeo rohita* was most preferred farm fish of otter and this species was most preferred for fish farming. *L. rohita* 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. Other three cultivated species constituted 1 to 2.2 percent in both score bulk estimate and frequency of occurrence method. In overall, the aqua farm fishes constituted only the 14.4% of weight of total foods items found in the spraints of otter. Of the total spraints collected, only 17.8% of spraints contained the aquafarm fishes and remaining 82.2 % otter spraints did not have aqua farms fishes and these otters were seeming to be eaten only the wild fishes (Figure 53).

The ivlev's index did not seem to give appropriate results as the biomass of prey consumed could not estimate in the wild. But, in the case *Dendrophysa ruselli* the index gave a value of -1 showing that otters completely avoided this species, as it was not found in the diet but found in creeks. The ivlev's index was negative for all species showing the avoidance even for *Mystus gulio* which has the major share in otter diet. So

the index values were not reliable in this study due to inherent problems in fish sampling.

Prior to finalizing the area of the sampling plot, the distributions of otter signs from the either banks of creek towards mangroves were studied. A total of 19 such surveys were carried out indifferent parts of the sanctuary. It was found that almost all otter signs largely foot prints were found within 5m from the banks of creeks (Figure 54). Only two signs were found at 6 m distance. Based on this observation, the effective sampling plot size was decided as 600 X 10 m along either bank of creeks.



Figure 54. Encounter rate of signs with increasing distance

The of otter signs such as paw-prints and spraints found in each sampling plots were related with following different habitat variables to understand the habitat selection of otter in the study area using the scatter plots. The habitat variables are;

- (i) Width of the creek
- (ii) Depth of the creek
- (iii) Bank vegetation cover in percentage and type.
- (iv) Number of open grass and mud patches
- (v) Number of *Suaeda maritima* patches

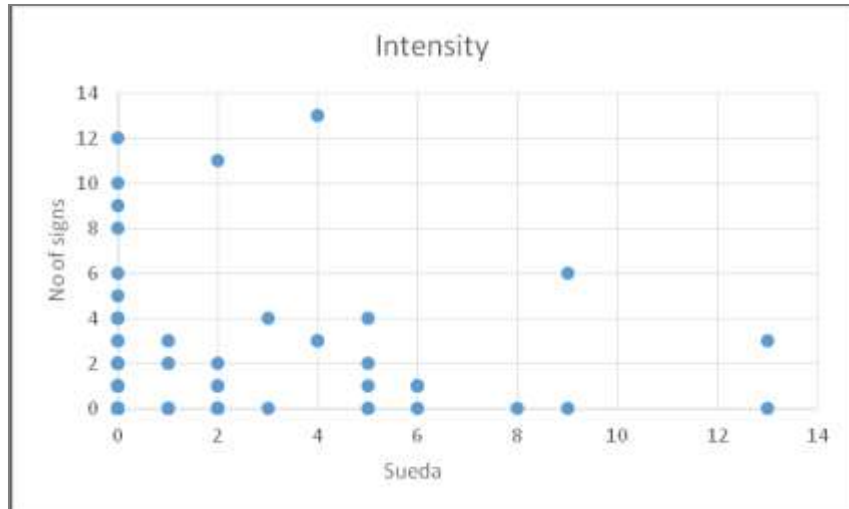


Figure 56. Effect of Suaeda on sign intensity

Similarly Otters were observed to be basking and grooming on open mud patches. But no significant relationship was observed from scatter plot between intensity of signs and open mud patches (Figure 57).

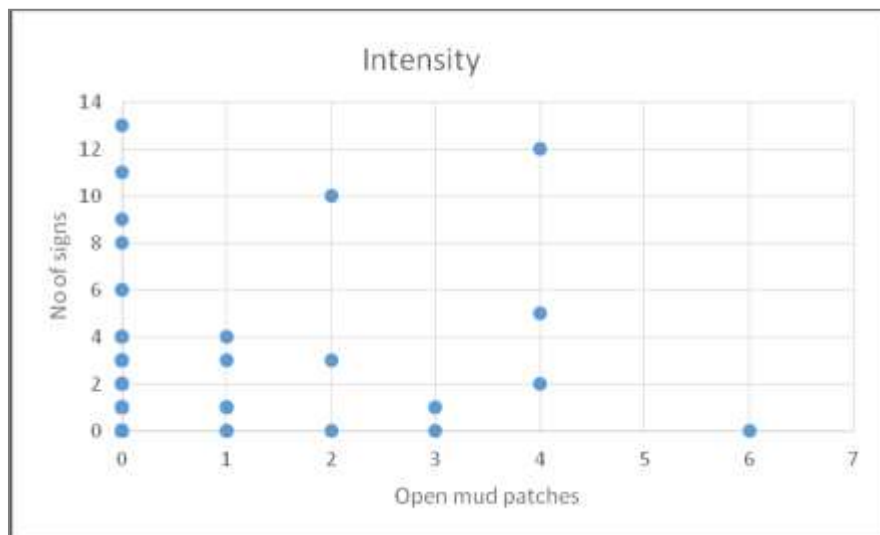


Figure 57. Effect of open mud patches on sign intensity

Maximum intensity of 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 (Figure 58).

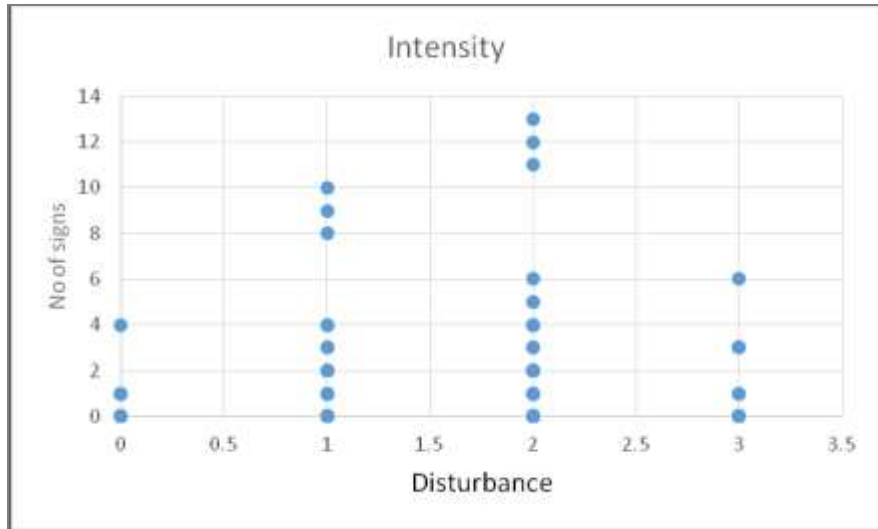


Figure 60. Effect of disturbance on sign intensity

Distance from mouth of the river changes many other factors like width, salinity, depth, species diversity etc. Otter sign intensity increased with increasing distance from mouth of the river or the closer to land the more intensity (Figure 61). Otter sign intensity was less very close to village because of dominance of *Caesalpinia crista* along the banks. *Caesalpinia crista* is a thorny and dense bushy tree where sign survey could not be done efficiently due to which signs were not detected efficiently.

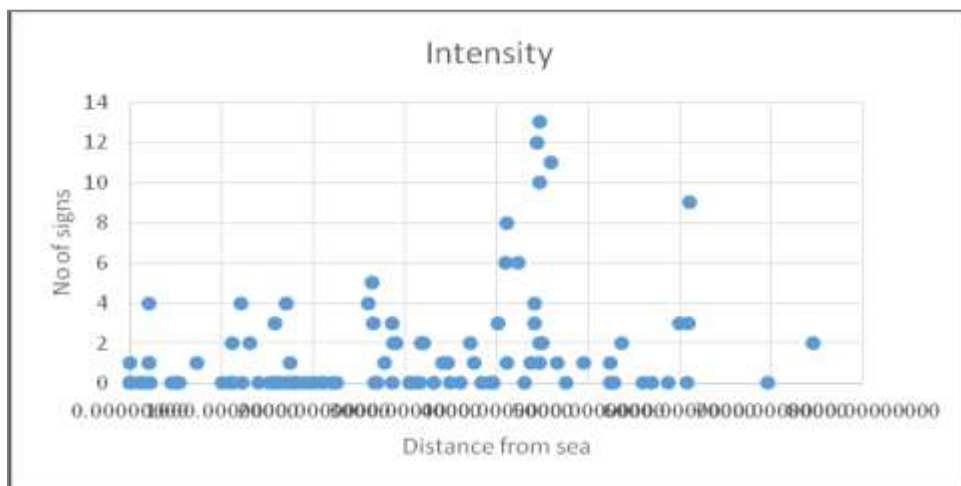


Figure 61. Effect of distance from sea on sign intensity

Intensity of signs increased with decreased bank vegetation. This could be due to presence of *Acanthus* as bank vegetation in many plots and as *Acanthus* is thorny and dense, the bank may be inaccessible for Otters (Figure 62).

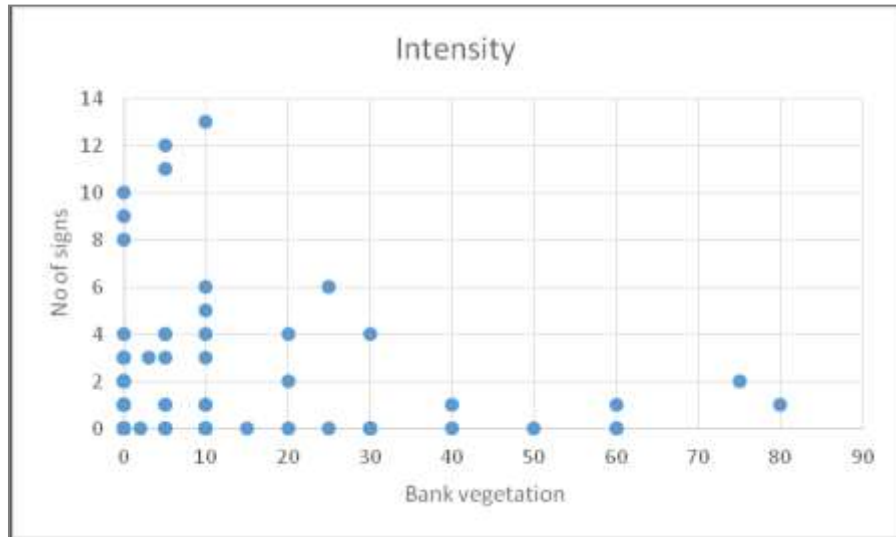


Figure 62. Effect of bank vegetation on sign intensity

The number of channels shows only marginal effect on intensity of signs with highest number of signs when the number of channels was from 2 to 5 (Figure 63).

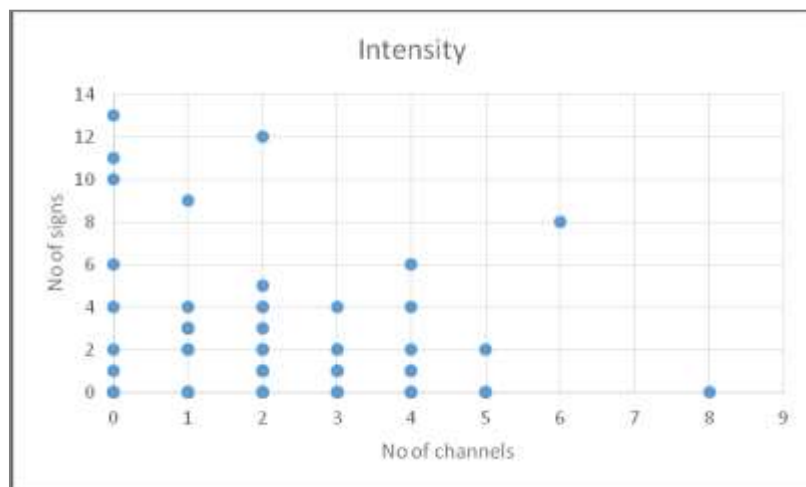


Figure 63. Effect of number of Channels on sign intensity

Otter seems to be concentrated more towards villages where the entire resources essential for Otters are present. One of the most abundant fish *Tilapia (Oreochromis 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.

Shelter for Otters are Holts in which has to protect Otter from its threats where it can reproduce and perform other important activities (Kruuk 2003). So, a place which remains sturdy and dry even during high tide time and during rainy season would be ideal to make a Holt. Because finding such place is difficult to search in a mangrove habitat only one Otter Holt was found during the study period and that place turned out to be below pumping station of a Prawn culture farm near the border of village. The Holt was identified by heavy sprainting activity near the Holt and inside the Holt and high intensity of pugmarks (Mason and Macdonald, 1983; Channin, 1988; Kruuk, 1995). The fishermen and farm owner around the Holt were aware of Otters holting there. Also, many villagers said that Otters frequently make Holt in pumping stations of Aquaculture farms and in *Caesalpinia crista* patches. *Caesalpinia crista* is a thorny creeper that dominates the vegetation near the villages along the banks. Due to its dense thorny nature, usually no one enters these patches. Due to this *Caesalpinia crista* could be providing refuge for Otters from human threat.

Otters are air breathing mammals which need to surface for time to time during hunting for their oxygen requirement (Mason and Macdonald1983). Due to this constraint Otters usually prefer hunting in shallow waters which are 2-3 metres deep. In a study on Coastal Otters in Scotland, it was observed that most successful dives were on an average 36 percent shorter than unsuccessful dives (Kruuk and Hewson, 1978). So, it is unlikely that Otters hunt at depths higher than 4 m. In the study area depth, higher than 4m exists near the mouth of the rivers where the wave action is also high

and the Otter has to negotiate with the wave action for hunting. So, it is unlikely that Otters prefer habitat near mouth of the river with higher depths. In contrast creeks near villages have a depth ranging from 1.5 to 3 metres and as earlier mentioned food resources are abundant near villages.

Width and depth are positively correlated in the study area; the creeks near villages have a width of 20 to 40 metres where high intensity of Otter signs is found. This could be because of depth and other factors rather than width itself. This is evident from the fact that Otter signs were comparatively lesser in creeks of less than 15 metre width which are usually far from villages. So, depth is another important factor that makes Otter choose habitat near villages.

Otters require substrates for performing grooming, basking and sprainting activities (Dubuc et.al., 1990; Prenda and Granado-Lorencio, 1996; Shenoy et.al., 2006). Grooming and basking are two essential activities than maintain body temperature of Otters. In the present study area Otters were many times observed to be basking and grooming in open grass and *Suaeda maritima* patches which remain dry even during high tide and provide roughage required for grooming. The fishermen also know that Otters bask in grass and *Suaeda maritima* patches. Otters mark their territories using spraints. Grass patches are few places in the study area which remain dry and open so for an Otter to select a sprainting site that remains dry and visible for other otter's grass patches are great option. This was evident from in the study area as only 5 spraints out of 81 spraints were collected from non-grass substrate. In one occasion where no grass patches were present nearby spraint was observed on an *Avicinnia officinalis* tree as the land gets inundated during high tide so there is threat of spraints getting washed away. This behaviour is observed in Smooth Coated Otter for the first time and is known from other otter species Hairy nosed otter (*Lutra sumatrana*) from South East Asia (Kanchanska, 2001).

The ordinal regression model did not show any significance of both grass and *Suaeda* patches, this could be because there are many grass and Suaeda patches far away from villages but no otter signs were found near these plots. So, it can be concluded that grass and Suaeda patches play an important role in otter activities and distribution provided they are near to land.

Open mud patches are the areas where sighting an Otter sign is easy, also the absence of thorny *Acanthus* and other pneumatophores give otter an ease in movement. These could be reasons for positive effect of mud patches on Otter distribution.

From the above resources that Otter is utilising in the study area it is evident that distance from land affects every resource in the study area. This is because with increasing distance from land the species composition, salinity, water flow, habitat type and many other factors change in a mangrove ecosystem thus forming a zonation. In the present study, the resources that are essential for survival of Otters are concentrated towards villages. So naturally Otters are utilising habitat near villages and this is not because of aquaculture farms being present near villages but various other factors are contributing to their presence near villages.

So, they are coming in direct conflict with the farm owners due to other factors. Therefore, distance from sea or village could be the most important factor contributing to Otter distribution in the study area.

Questionnaire Surveys

A questionnaire survey was carried out with aim of understanding their traditional ecological knowledge of otters as well as their perspectives towards otters. This survey was conducted targeting only the men in the age group of 20 to 70 years, as they are

involved in the management of fish farm farms in the region. The respondents were divided into five age classes of 20-29, 30-39, 40-49, 50-59 and 60-69 (Figure 64).

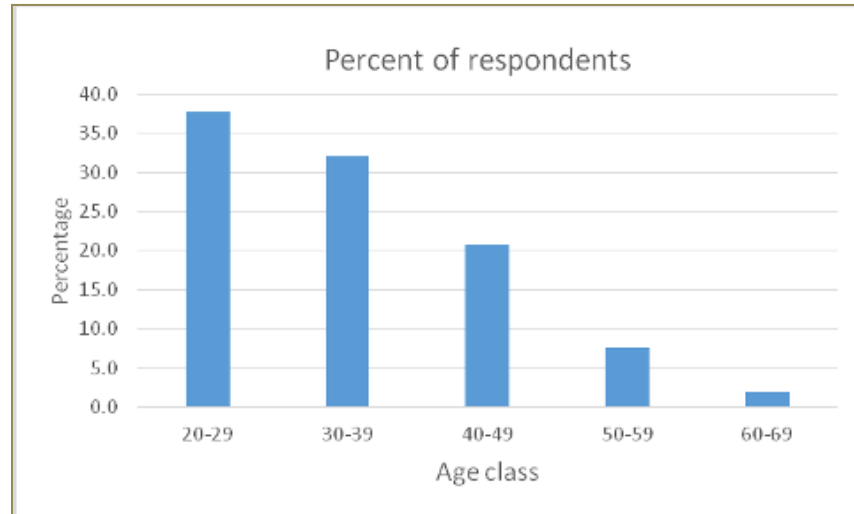


Figure 64. Age class of respondents

About 38% of respondents were from the age class of 20-29 and the percentage of respondents decreased with increasing age classes. Least representations from 60-69 age class with only 1.9%. This could be due to the fact that the maintenance of aquaculture farm requires more dynamic and physical hard working young people. It was found that about 90% of the respondents had aquaculture as their primary occupation with minor secondary occupations largely related to agriculture and other works. This indicates that their higher level of dependence on aquaculture (Figure 65).

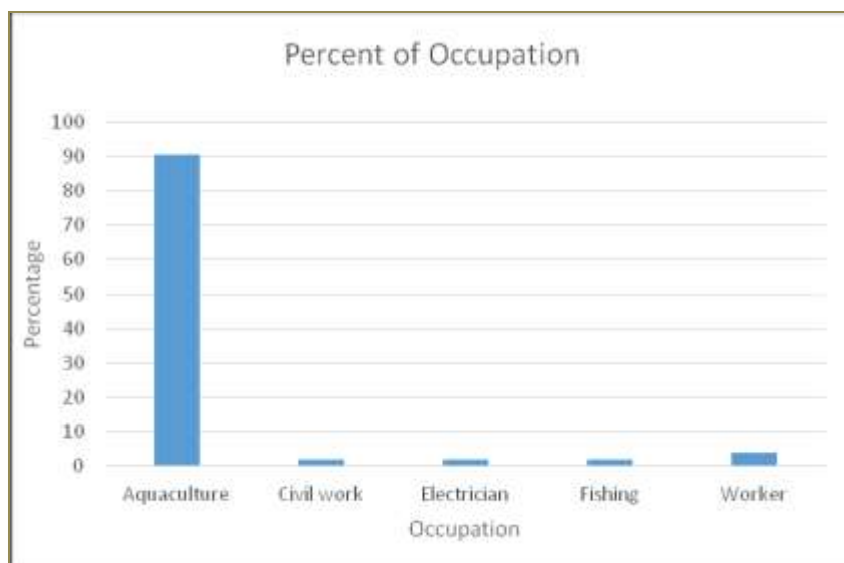


Figure 65. Major occupations of respondents

A total of eight species of fishes and prawns were cultivated in the fish farms around the Coringa Wildlife Sanctuary. They are: *Labeo rohita*, *Catla catla*, *Liptopinnaeus vannamei* or White shrimp, Grass carp, Tiger prawn, Chinese carp, Mrigal and Scampi. *Labeo rohita*, *Catla catla*, White shrimp, Grass carp and Tiger prawn were preferred most by the farmers and these species were cultivated in poly culture aqua farms. Prawns were mostly cultivated in monoculture (Figure 66). However, these species that have been cultivated in the farms were not found in the mangroves of study area.

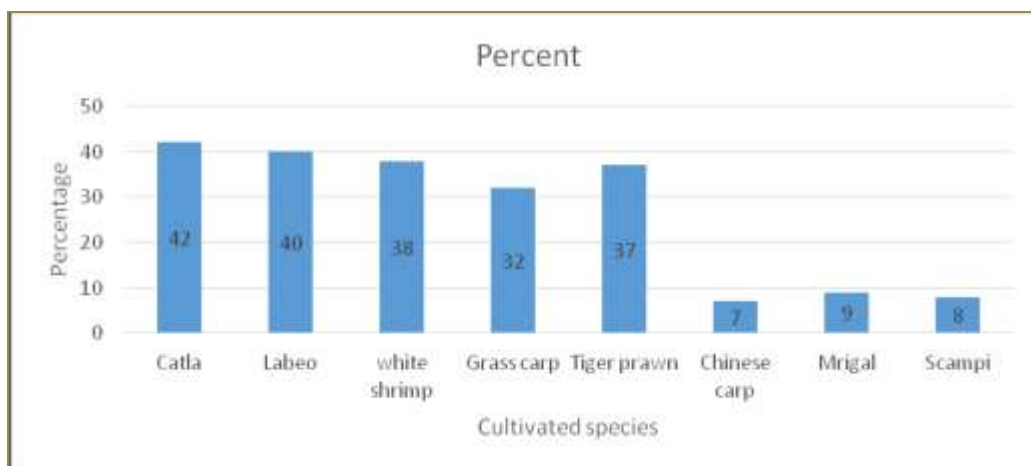


Figure 66. Percentage of fish species in aquaculture farms.

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 (Figure 67).

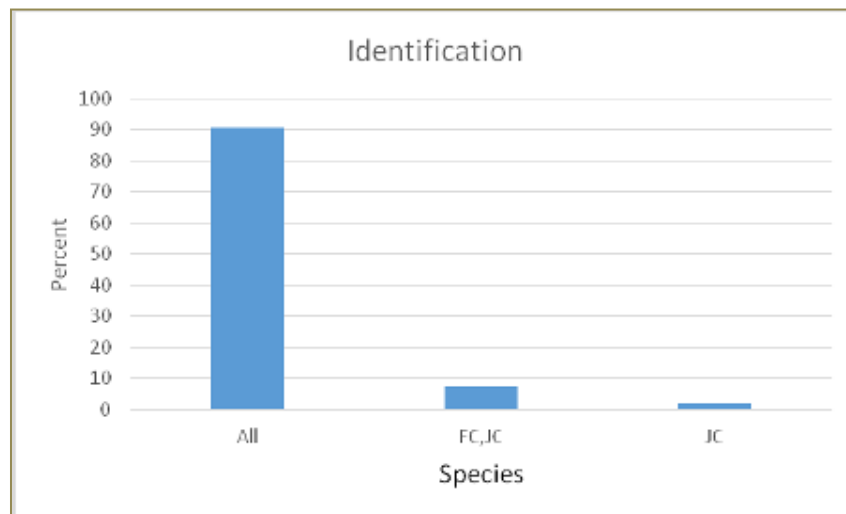


Figure 67. Percent of respondents who could identify Otter

About 60% of the respondents felt that all three species such as otters, fishing cat and jackals visit aqua farms and feed farms 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 none of these animals visit their farms (Figure 68).

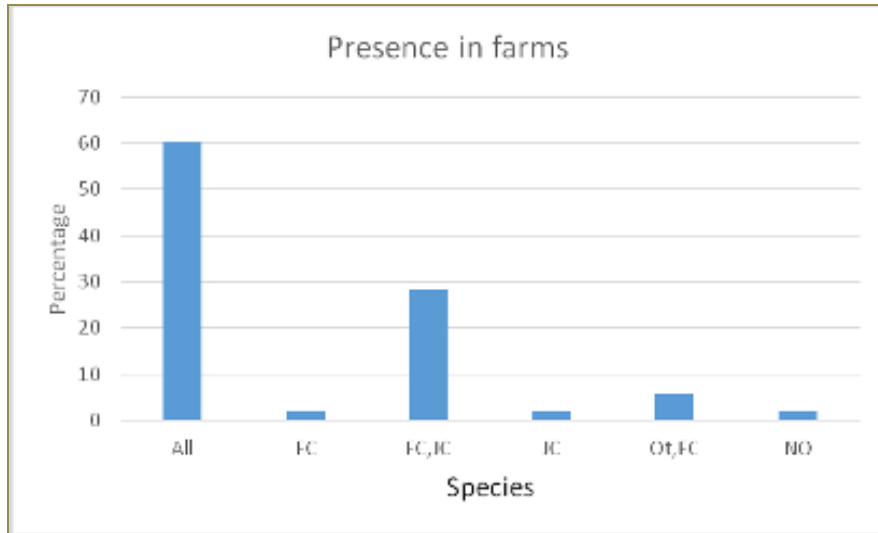


Figure 68. percent of aquaculture with otter visits.

Based on interview survey, about 79% of the respondents felt that Otters visit their farms at night that confirms the nocturnal behaviour of Otters around human habitation, which is supported by previous studies (Figure 69).

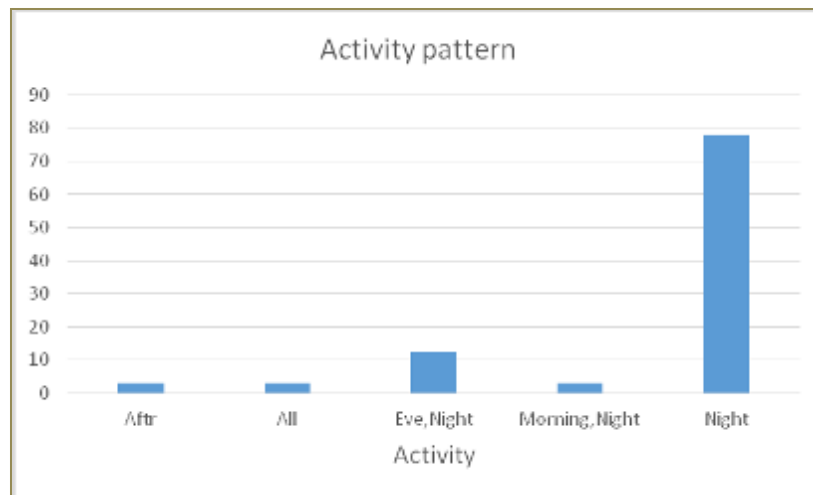


Figure 69. Activity patterns of Otters near farms

About 75% of the respondents believed that otters were high threat to aquaculture when compared to fishing cat and jackals. This is due to their behaviour of feeding in groups, whereas fishing cats and jackals visit aquaculture ponds solitarily (Figure 70)

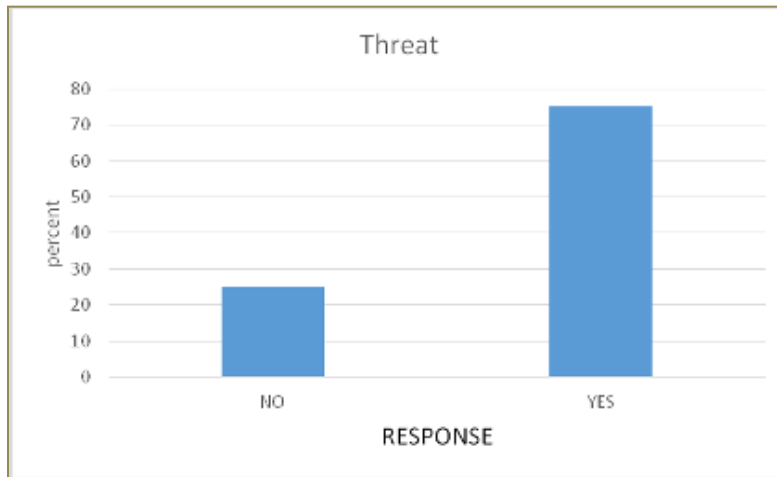


Figure 70. Percent of respondents who consider otters as threat to fish

Nearly 11% of respondents felt that Otters have caused an income loss of 1-5% followed by 9% of respondents who claimed a loss of 10-30%. Few farmers (2%) felt that Otters cause nearly 30-50% of loss (Figure 71). However, about 29% of the respondents did not know how much income loss Otters were causing but they felt that Otters are significant threat to their farms.

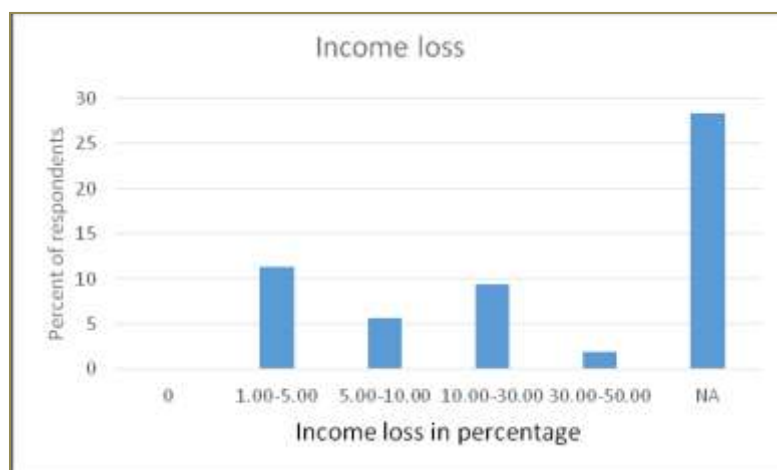


Figure 71. Percent of income loss caused by Otter as perceived by owners.

The respondents were asked about their response if an otter was found injured or dead due to their protective measure. In response, about 65% of people informed that they normally leave the otter without touching it. However, the rest of the respondents admitted that they either eat the meat or sell to someone who eats the same (Figure 72).

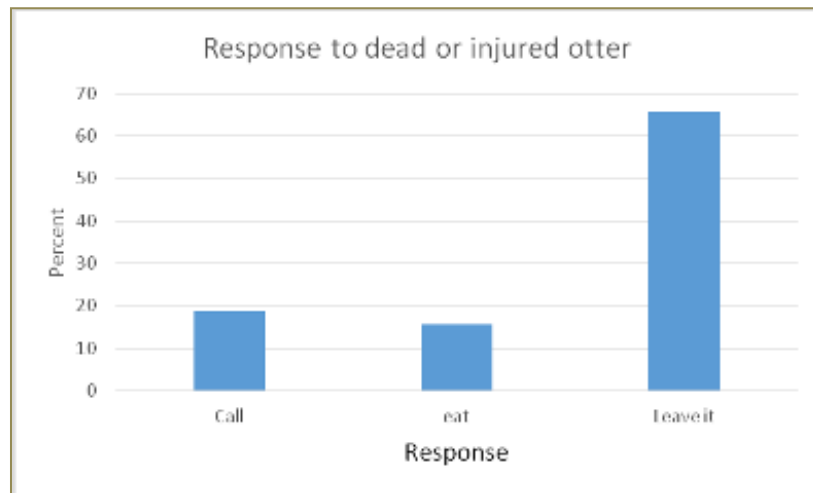


Figure 72. Response to injured or dead otter near farms

Nearly 65% of the respondents felt that there was a decline in the sightings of otters and they have also believed that the population had been declined in the region. However, in contrast, about 13% of them felt that there was an increase in Otter population over years and most of these respondents who have also believed that high loss of income due to otter's visits to their aqua farms (Figure 73).

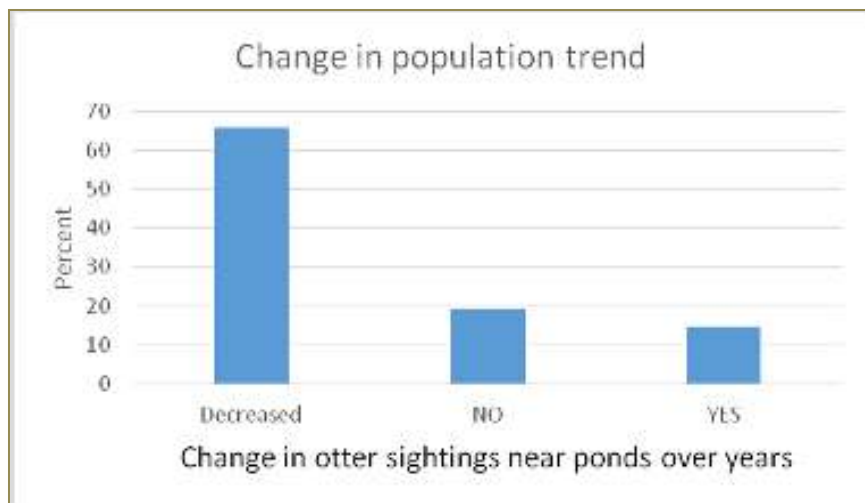


Figure 73. Observations on otter population by respondents

About 60% of the respondents knew that Otter is a protected species under a law but 30% of them did not know whether it is protected or not and rest 10% did not know whether Otter is protected or not (Figure 43). However, the level of awareness about otters and other protected species have been enhanced in the recent past due to various awareness programmes organized by the EGREE (East Godavari river estuarine ecosystem) Foundation.

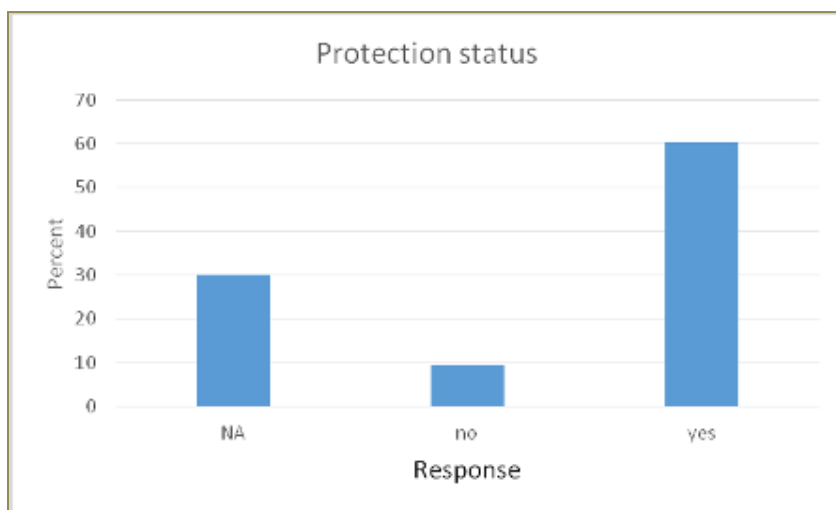


Figure 74. Awareness of respondents to protection status of otter

Most of the farm owners admitted that they always scare and chase away otters when they enter into their farms. Though only 11% of them opted for killing does not mean that people have a positive attitude towards Otter (Figure 75). This is since killing an Otter is difficult as they are very fast and are known to attack on humans when approached closely.

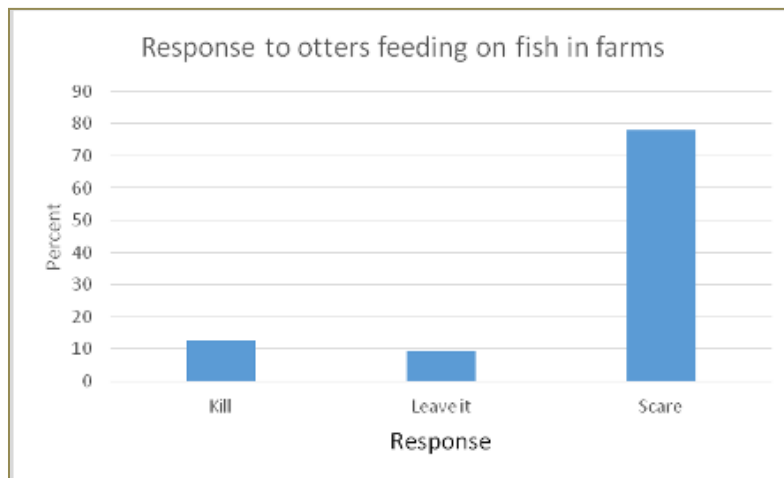


Figure 75. Response when Otter feeds in farms

Smooth coated Otter being a plain's otter is able to adapt to diverse aquatic habitats with wide geographic distribution (Pocock, 1943). They are found in semi arid region of North-Western region of India and Deccan plateau in India in varied aquatic habitats. From large rivers, rice fields to mangroves, Smooth coated Otter is found to utilise a variety of resources (Prater 1971; Hussain 1997; Foster-Turly, 1992).

Smooth coated Otters were found to be more abundant in mangroves than rain forest Rivers in Kaula Gula, Malaysia (Shariff, 1984). The present study is carried out in a mangrove habitat. Mangrove habitats are known for their high diversity, complex species interaction along with high level of productivity. Mangroves also serve as mating ground for many aquatic species both vertebrates and invertebrates and are also feeding grounds for many marine organisms (Vancucci, 2001).

With such diverse and productive ecosystem as habitat Smooth Coated Otter expected to depend on wide range of resources for their survival. The present study emphasizes on the understanding resource selection by Smooth Coated Otter and also assessing the level of threat and conservation measures to be taken for its long-term survival in an area where humans directly compete with Otters for food and also cultivate Otter food. For any Hetero troph availability and distribution of food is most essential resource. Smooth coated otter being a piscivorous carnivore with high energy requirement the distribution, abundance of fish which the Otter can predate on is essential (Mason and Macdonald, 1983; Pardini, 1998). Shelter is another essential resource for any animal and Otters live in dens called Holts which are made very near to the feeding range. Smooth coated otter is a semi aquatic animal with adaptations to maintain their body temperature in water. Basking and Grooming are two activities that assist them in keeping their adaptations in condition. So, sites for basking and grooming that are near Holts within foraging range are the resources that are essential for Otter survival.

The present study area is a mangrove ecosystem known for its high diversity of fishes. During the fish sampling 93 species of fish were found and the number could be much higher since sampling was not done in narrow creeks and all fishes do not get caught in gill nets. This study area contains highest diversity of fishes in comparison to other diet studies of Smooth Coated Otter in India which are in fresh water system (Hussain and Choudhury, 1997; Anoop and Hussain, 2004). Also unlike river systems or other fresh water ecosystems Otters have to deal with many problems in a mangrove habitat. The effect of tidal cycle is very prominent in mangrove habitat where organisms must adapt and deal with ever changing water level, speed, and salinity. In Coringa wildlife Sanctuary semi diurnal tidal cycle occur with two high tides and two low tides each with 6-hour duration in a day. Thus, the direction of water flow changes every 6 hours and swimming is efficient in the direction of water flow. So, Otters have to swim in the

direction of water flow to conserve energy, so they are limited to certain direction of movement for conserving energy.

In a mangrove habitat presence of rocky structures in which Otters are known to make Holts (Mason and Macdonald, 1983; Hussain and Choudhury, 1997) is very rare. Also, the roots of trees do not protrude out creating a hollow space unlike trees in terrestrial system where otters make Holts. Due to the nature of soil the roots are deeply embedded in the soil with no space. Due to this finding, a suitable place for holting is a challenge in such habitat. Mangrove habitat does not usually contain sandy substratum for grooming and basking of Otters. Due to these factors, the resources that Otters select in mangroves are expected to be different from a fresh water system.

Along with these difficulties the most possible threat comes from deforestation of mangroves for creating aquaculture farms where fish are stocked at high density. Aquaculture farms form the boundary of the sanctuary towards land. According to Resource dispersion hypothesis animals tend to select those areas where resources are concentrated. So, there is high chance that Otters select areas closer to villages. Incidentally the rocky structures, sandy substrates and other resources are concentrated towards villages. Due to this combined factors Otters are frequently sighted near aquaculture farms and many times feed on fish from these farms thus coming into direct conflict with people. As Otter is considered as vermin and its meat is considered to be containing medicinal values in the present area Otters face everyday challenge for their survival.

As expected cultivated fish species were found in the spraints of otters and most of the spraints were found near villages. But cultivated species did not form a major part of Otter diet. 18% of Otter diet was from five cultivated species. Major part of Otter diet consisted of *Mystus gulio* and *Oreochromis mossambicus* with 17% and 15% followed by *Liza tade* with 14%. Whether this 18% is high or negligible portion depends on the

perception of the person. *Mystus gulio*, *Oreochromis mossambicus* and *Liza tade* are some of the most abundant fishes sampled. This indicates that Smooth Coated Otter is an opportunistic feeder which is also evident from studies in Chambal River of central India and Periyar River in Western Ghats (Hussain and Choudhury, 1997; Anoop and Hussain, 2004). Tilapia (*Oreochromis mossambicus*) is an invasive species in many parts of the world and occurs in both fresh water and estuarine ecosystem.

The present study area also has Tilapia with high abundance and Otter is feeding on it to high extent. Also, Tilapia is usually found near grass banks which are more towards villages or along aquaculture farms and many times fishermen were observed to catch Tilapia with bare hand from their nest. This indicates the easiness which one can hunt Tilapia. For a predator like Otter a prey that can be easily caught is preferred.

Tilapia is known to compete with native fishes for resources, as Otter is feeding on Tilapia to a huge extent it is helping the native fish fauna by controlling Tilapia population. Tilapia was also abundant in man modified ecosystem of Periyar reservoir and nearly 51% of Otter diet composed of Tilapia (Anoop and Hussain, 2004). *Mystus gulio* is a slow swimming catfish which is also present in high abundance in sanctuary and this fish consisted major part of Otter diet. This could be due to wide range of salinity tolerance of the fish so it could be having wide range of distribution in the sanctuary. *Liza tade* is a mullet species and mullets are known to move in schools so it would be easy for an Otter to hunt mullets.

Labeo rohita commonly called Rohu was highest in the diet of Otter of all five-cultivated species followed by *Cirrhinus mrigala* both are column feeder. *Cyprinus carpio* and *Catla catla* consisted only 1-2% of otter diet. Grass carp is not stocked at high densities unlike other fish, usually 100 fish for acre in comparison to 800 -1000 fish for other species. So, Grass carp being less abundant was found in negligible amounts in diet.

Another invasive species the South American **Pacu** was found once in otter diet. Pacu was seen frequently in the fish market and the fishermen said that they occasionally get this fish in nets and also informed that some farms stock them in minor quantities. Though Pacu was not captured during fish sampling the reference sample of scale was obtained from fish market.

As Pacu was found only once in diet in negligible amounts it can be concluded that it is not abundant in both natural water and fish farms. These findings indicate that Otters in the study area are opportunistic rather than targeting a particular species of fish and are also opportunistically feeding on fish from aquaculture farms.

The presence of such huge number of aquaculture farm owners is due to a government initiative in early 1990's to decrease the dependence of fishermen on fishing and increasing their livelihood. During that period and also when Reliance Industries setup an oil refinery and rig near the sanctuary around 2004 huge amount of mangrove forest on which local people were depending was lost. To compensate this local were given nearly 5 acres of land in and around mangrove for aquaculture and they were trained in culturing fishes and prawns. Though many of them cultivated initially but later on due to losses some people sold their farms to others or give their farms for lease. Many rice fields around the sanctuary were also converted into aquaculture farms due to high profits. As of today, the entire sanctuary is bordered by aquaculture farms near villages. This also caused threat to Otters as they feed on these fishes the farms owners started treating Otters as vermin.

From the questionnaire survey, it is evident that most of the aquaculture farm owners know that Otters feeding on fish from their farms. Other mammals fishing cat *Prionailurus vivverinuis* and Golden jackal *Canis aureus* feed in aquaculture farms. But the other mammals are not regarded as threat by the farm owners because Otters enter into the farms and feed in groups. Moreover, Otters have the habit of defecating near

their feeding sites and defecate in a group. This makes the farm owners aware that Otters are feeding and the huge piles of spraints also make them think that each Otter feeding on large amount of fish (Rosas-Ribeiro et.al., 2012).

Whereas the worker or owners come to know about other mammals feeding in their farms only when they see them as they do not defecate near farms and their faecal matter can be confused with dog.

During the study period Otters were also observed to be feeding on fish caught in gill nets laid by fishermen. Filaments of gill nets were also found in the 15 Otter spraints during diet analysis. Thus, they face the wrath of fishermen also. In farms cultivating *Liptopinaeus vannamei* it has been observed that the farms owners deploy live wire at knee height around the farms during night time. This is majorly targeted to prevent thieves and other people but Otters also become victims of the live wire many times.

When an Otter dies under such circumstances some of the respondents said that they would eat it indicating no regret from the farm owners. Also, many respondents who knew that Otter is a protected species and causing harm to it would cause legal action wanted to kill Otter if it enters their farm.

These respondents who had a negative attitude towards Otters are those people who have narrow range of income and did not even complete primary education. Since these people cannot afford to lose even small portion of their income they were against Otters. Education plays an important role in knowing and understanding things which gives awareness about our surroundings. As these many of them are illiterates and people with education below primary level they were not aware of the importance of conservation of other species.

Otter diet consisted of about 18% of fish from farms during 3-month period. Now whether this is a negligible amount or high amount depends on the person looking at it. A conservationist or a farm owner with high income may say that this is negligible; however, the answer from a poor fish farmer would be entirely different.

CONSERVATION MEASURES FOR OTTERS:

From the above inferences, the best way for Otter conservation in the study area for long term survival is by changing the perspective of the farm owners and fishermen towards Otters and mainly those whose income level is low and who are less educated. This can be done by seeing that the next generation gets educated till at least high school level and by improving the lifestyle of the fishermen and farm owners by providing additional livelihood. During the questionnaire survey major portion of respondents felt that there has been steady decline in Otter population over years due to various reasons one of them being death of Otters due to farms. So, convincing the farm owners to not to use live wire and employ other means of protection is necessary for the survival of otters. By decreasing the fishing pressure in the sanctuary, the prey available for Otters also increasing which may decrease their dependence on aquaculture farms.

Coringa Wildlife sanctuary is one of the few places where Otters and Fishing cats are present in India. Promoting ecotourism and involving fishermen and farm owners with the tourism can change their perspective towards Otters and may be towards entire sanctuary as seen in the case of Periyar tiger reserve (Anoop, 2001).

PART -2

**ASSESSING THE IMPACT OF CLIMATE
CHANGE**



CLIMATE CHANGE: PROJECTIONS AND IMPLICATIONS

Changing climate is not a new phenomenon for Earth as it periodically undergoes a cycle of glacial advance followed by global meltdown. In the last 6,50,000 years there have been seven cycles of glacial advance and retreat, with the abrupt end of the last ice age about 7,000 years ago marking the beginning of human civilization. Therefore, global climate can obviously vary naturally due to inherent climatic variations as well as external forcings such as volcanic activities. However, the current global warming event, though natural but the high rate of warming is unprecedented in the history of earth. Experts and scientists across the world now attribute unequivocally this to anthropogenic factors which modify the atmosphere and natural systems.

The role of anthropogenic activities in the current phase of climate change is clearly highlighted by United Nations Framework Convention on Climate Change (UNFCCC), in its Article 1, where it defines climate change as: *“a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.”*

Similarly, 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”.*

The main evidence for a changing climate comes from the rising atmospheric and sea-surface temperatures. 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 (Figure 76). On one hand, the past three decades have been warmer than each preceding one; on the other hand, the 10 warmest years have

occurred since 2000, with 2014 being the warmest year since 1880. Similarly, evidences suggest that the sea-surface temperatures are also rising along with increase in extreme weather events, rise in sea-level and glacier meltdown. The rate at which these atmospheric variables are changing, climate change is bound to have serious impacts on natural as well as human systems across the Earth.

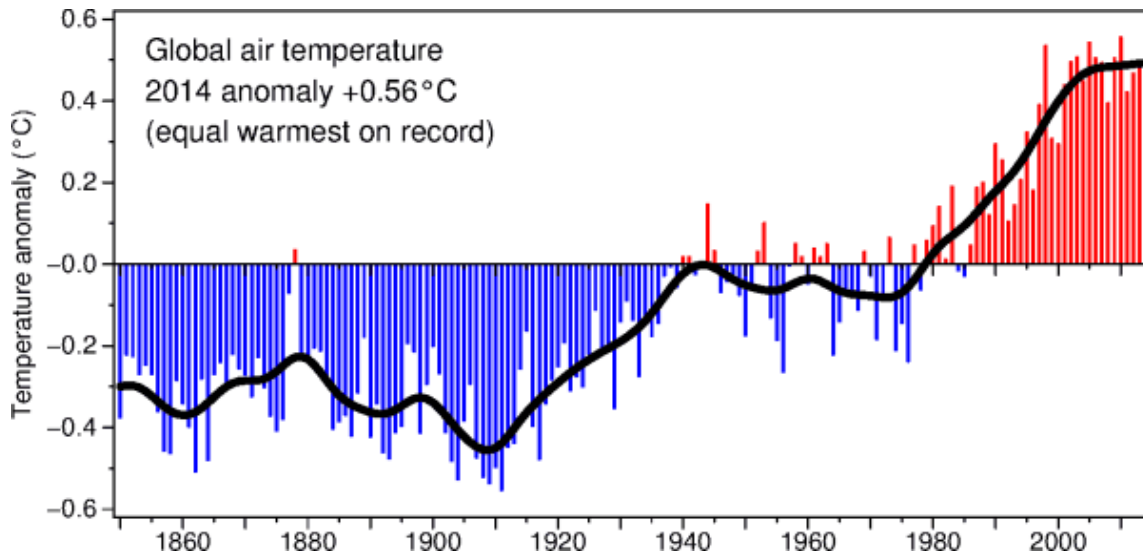


Figure 76: Observed global air temperature anomalies, combined for the land and ocean, from 1850 to 2012 (Source: CRU)

Greenhouse Gas Emissions

The solar cycle and the processes which maintain radiative balance between incoming solar short-wave radiation (SWR) and outgoing long-wave radiation (LWR) is depicted in Figure 78. The two main ways which can bring changes in this balance are natural fluctuations in solar output (solar cycle), or by changes in the emission/absorption of the SWR and LWR from the troposphere. It is a known fact now that excessive release of greenhouse gases and aerosols due to human activities is the main cause for the current trend in global warming. Carbon dioxide concentrations in the atmosphere

since pre-industrial times have increased from 280 parts per million to nearly 400 parts per million and half of its emissions have occurred in the last 40 years (IPCC 2014a). As per its fifth report, IPCC attributes around 78% of anthropogenic CO₂ emissions to fossil fuel combustion and industrial processes. This is worrisome as even though the world is trying to limit the use of coal and oil but we are still heavily dependent on them for our economic growth.

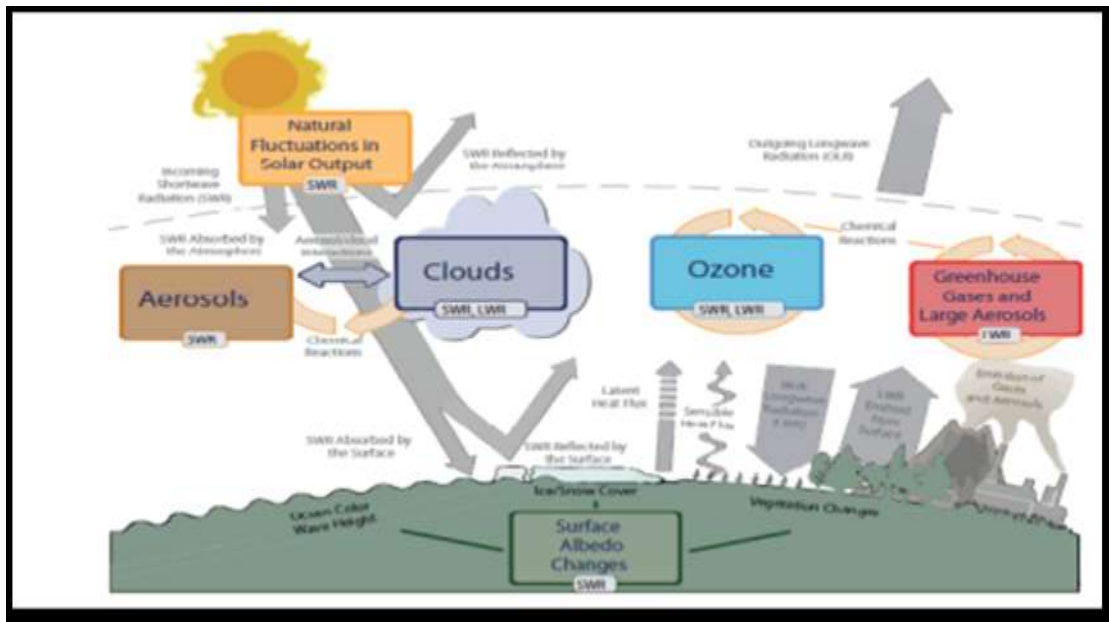


Figure 78. Main drivers of climate change. (Source: IPCC Fifth Assessment Report, WGI)

Not only CO₂ but concentrations of other greenhouse gases have also increased in the past four decades (Figure 8), most of which is during the period between 2000 and 2010. Anthropogenic changes in GHGs (e.g., CO₂, CH₄, N₂O, O₃, CFCs) and aerosols tend to absorb outgoing LWR and re-emit less energy at a lower temperature. This traps the radiations in the earth's atmosphere and thus leads to increased temperatures. Changes in the surface albedo due to loss in vegetation or land surface properties or ice cover and ocean colour also contribute to increased temperatures.

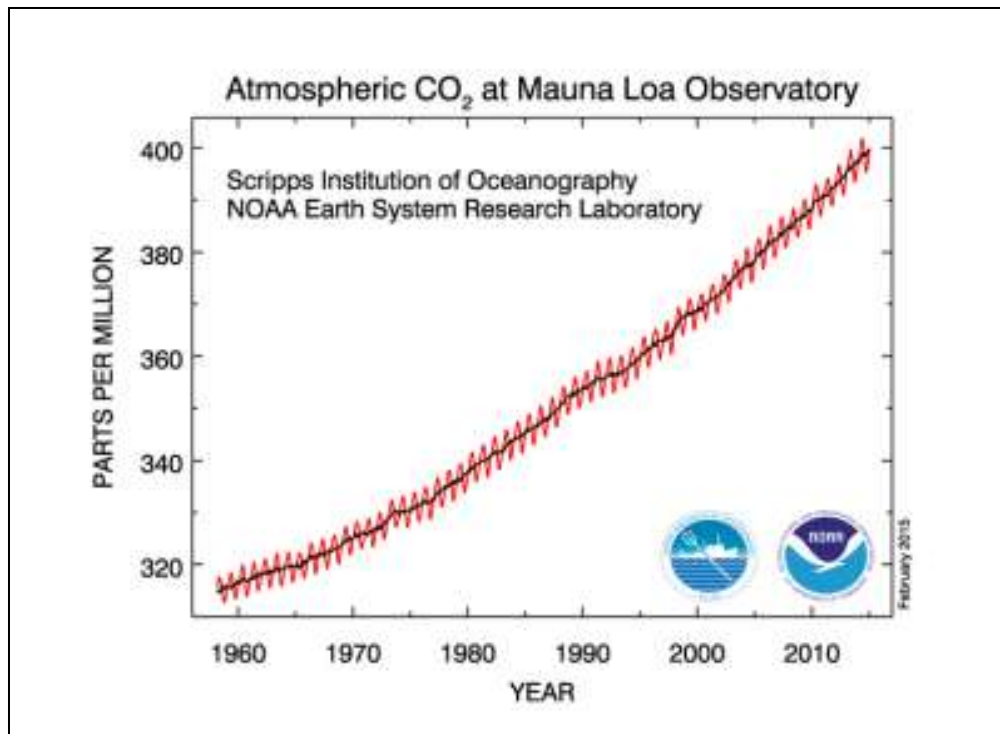


Figure 79. Atmospheric carbon dioxide from 1958-2014. The red curve shows the monthly average. The black curve has been adjusted to take the seasonal changes in CO₂ concentration into account. (Source: Dr. Pieter Tans, NOAA/ESRL (<http://www.esrl.noaa.gov/gmd/ccgg/trends/>) and Dr. Ralph Keeling, Scripps Institution of Oceanography (scrippsco2.ucsd.edu/).

Global Climate Change: Projections based on IPCC AR5

The most recent IPCC report, i.e. the Fifth Report also known as AR5 was released in 2014. It incorporates recent findings and higher confidence in future projections of the various climate change indicators and their impacts.

A summary of the observations in AR5 are given below:

- **Carbon and other GHGs:**
 1. The atmospheric concentrations of the greenhouse gases carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O) have all increased since

1750 due to human activity. In 2011 the concentrations of these greenhouse gases exceeded the pre-industrial levels by about 40%, 150%, and 20% respectively. The present concentration of CO₂ recorded in Mauna Loa observatory as on February 2016 is 404 ppm (www.esrl.noaa.gov/gmd/ccgg/trends/). For CH₄ the current concentrations recorded as on December 2015 is 1843.2 ppb (www.esrl.noaa.gov/gmd/ccgg/trends-ch4/).

2. From 1750 to 2011, anthropogenic sources (fossil fuel combustion, cement production and land use changes) have released an average of 555 GtC into the atmosphere.
 3. Out of this 555 GtC, 28% have been absorbed by oceans while 29% by natural terrestrial ecosystems. The rest of the emissions have accumulated in the atmosphere.
- **Atmosphere and temperature:**
 1. Since 1850, each of the three decades has been warmer than the previous.
 2. Almost all the regions across the world have experienced rise in surface temperatures. The global average temperatures have increased by 0.85 C (land and ocean surface temperatures combined).
 3. In mid latitudes particularly, precipitation has increased since 1951.
 4. The number of extreme climatic events has increased since 1951. For example, frequency of heat wave events has increased in large parts of Europe, Asia, and Africa. The frequency of heavy precipitation events has also likely increased in the world.
 - **Oceans and sea level rise:**
 1. Oceans have warmed since 1971 specifically their upper surface. The upper 75 m of the ocean warmed by 0.11°C per decade between 1971 and 2010. Observations also suggest a warming in the deeper layers with the largest warming observed in Southern Ocean below 3000m.

2. Regional differences in ocean salinity also indicate towards changes in evaporation and precipitation due to climate change. Areas with high salinity have experienced further increases in salinity whereas those with lower salinity have become fresher indicating increased precipitation.
3. Ice sheets in Greenland and Antarctic are decreasing and the glaciers around the world are shrinking. This with thermal expansion of oceans is leading to rise in sea levels. The global mean sea level has risen by 0.19 m between 1901 and 2010. The period over 1993 and 2010 experienced the highest rise in mean sea level (0.32 m yr⁻¹).

To predict the future impacts of climate change, different sets of scenarios are considered. These scenarios or climate model simulations consider the historical trends, status and future projections of many factors such as projected rise in GHGs, rise in surface temperatures, changes in energy generation and land-use patterns, population growth, economic development, etc. IPCC mainly uses future projections of GHG levels and consequent radiative forcing to predict changes in various drivers of climate change. In AR5, IPCC introduced a set of four new scenarios known as Representative Concentration Pathways (RCP) for the end of 21st century (2081-2100) about the period of 1986-2005. The four RCPs (RCP 2.6, 4.5, 6.0 and 8.5) and respective projections are given in table 17.

		2046-2065	2065-2100
	Scenario	Mean	Mean
Global mean surface temperature change	RCP 2.6	1	1
	RCP4.5	1.4	1.8
	RCP6.0	1.3	2.2
	RCP8.5	2	3.7
Global mean sea level rise	RCP 2.6	0.24	0.4
	RCP4.5	0.26	0.47
	RCP6.0	0.25	0.48
	RCP8.5	0.30	0.63

Table 17: Table showing mean projections of the four RCP's

Future projections based on these 4 RCPs are:

1. Except for RCP2.6, the global mean surface temperatures will likely exceed by 1.5°C in the 21st century in all other scenarios when compared to the base period (1986-2005). In case of the last two scenarios the temperatures will increase by more than 2°C.
2. It is almost certain that the frequency of hot events will increase along with the frequency and timescale of heat waves over most land area. On other hand number of cold temperature extremes will decrease.
3. The mean precipitation will likely increase in mid-latitude and subtropical wet regions, while it will decrease in mid-latitude and subtropical dry regions. Extreme precipitation events have been projected to increase in frequency as well as intensity in most of the mid-latitudes and tropical regions.
4. Monsoon systems have been projected to widen over more area as well as lengthen in duration. A likely decrease in monsoon winds will occur but the precipitation will intensify.

5. In case of oceans, the global warming will continue to heat the upper surfaces more than deeper ones but strongest warming has been predicted in tropical and sub tropical (Northern Hemisphere) regions. Best estimates of ocean warming in the top one hundred meters are about 0.6°C (RCP2.6) to 2.0°C (RCP8.5), and about 0.3°C (RCP2.6) to 0.6°C (RCP8.5) at a depth of about 1000 m by the end of the 21st century.
6. By the end of 21st century, probability of almost all regions (95% of the oceans and 70% of coastal areas) experiencing sea level rise is high but will vary place to place. As per the four RCPs the projected global mean sea level rise for 2081–2100 relative to 1986–2005 will likely be in the ranges of 0.26 to 0.55 m for RCP2.6, 0.32 to 0.63 m for RCP4.5, 0.33 to 0.63 m for RCP6.0, and 0.45 to 0.82 m for RCP8.5.
7. Ocean acidification will increase globally with a decline of ocean pH in the range of 0.06 to 0.07 for RCP2.6, 0.14 to 0.15 for RCP4.5, 0.20 to 0.21 for RCP6.0 and 0.30 to 0.32 for RCP8.5.

Projections for India

Though CO₂ emissions of India are only about 4% of total global emissions but due to its proximity to the equator and huge disparity among its population the country is highly vulnerable to the impacts of climate change. 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 and monthly Indian summer temperatures will reach about 5°C above the 1951–80 baselines by 2100 in the multi-model mean.

The warming will occur uniformly across the South Asian region but in case of local inter-annual variations, coastal regions might experience higher warming, especially in the southwest. In case of a projected rise in temperatures by 4°C, the west coast and

southern India, as well as Bhutan and northern Bangladesh might shift to new climatic regimes, with the monthly temperature distribution moving towards warmer values. Similarly, the models project considerable rise in sea level in the South Asian region (Figure 9). 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. These projections in sea level rise can be higher/lower at local scales depending on topography and bathymetry of the coast and other natural or human-induced factors.

Rising temperatures will eventually lead to increase in global mean precipitation which has also been predicted by the various climate models. Similar predictions of enhanced precipitation have been made for South Asia particularly northwest coast to the southeast coast of peninsular India, which might experience ~30% increase in annual mean rainfall. Generally, models also have projected an increase in the Indian monsoon rainfall under future emission scenarios of greenhouse gases and aerosols but with significant degree of uncertainty. Models also project significant increases in inter-annual and intra-seasonal variability in the south-west monsoons (Endo et al., 2012; Sabade, Kulkarni, and Kripalani, 2010; Turner and Annamalai, 2012; Kumar et al., 2010). Major proportion of India's economy is intricately linked to the South-West Monsoons which is very important for agriculture and water supply. Therefore, any variability in the monsoon system increases the region's risk of flooding and droughts which in turn might have negative repercussions on country's economic growth.

Impacts of climate change

Based on the Fifth Assessment Report of IPCC, a summary of the potential impacts of a changing climate is presented below:

1. Hydrological systems are being altered due to changes in precipitation and/or melting snow and ice which in turn are affecting the quantity as well as quality of water resources. Extreme events of floods, flash floods and droughts are increasing in intensity as well as frequency.

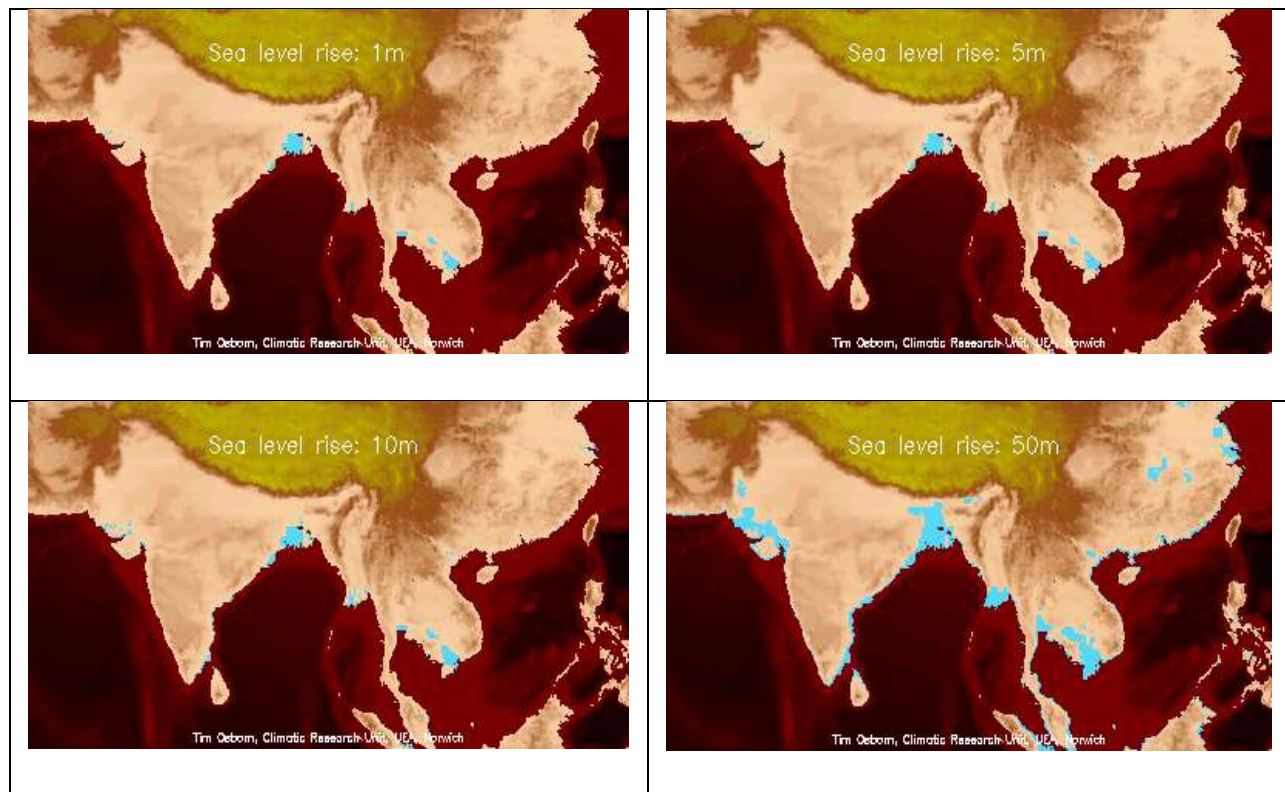


Figure 80: Predictions of complete submergence under different scenario of sea-level rise in South Asia. These maps show regions which are highly vulnerable to inundations for an average sea level of 1m, 5m, 10m or 50m. The blue colour represents those regions whose average elevation is within 10m (or 20m, 30m, etc.) of the current sea level.

2. Many terrestrial, freshwater, and marine species have shifted their geographic ranges, seasonal activities, migration patterns, abundances, and species interactions in response to ongoing climate change. A large fraction of both terrestrial and freshwater species faces increased extinction risk under projected

climate change during and beyond the 21st century, especially as climate change interacts with other stressors, such as habitat modification, over-exploitation, pollution, and invasive species.

3. Due to sea level rise projected throughout the 21st century and beyond, coastal systems and low-lying areas will increasingly experience adverse impacts such as submergence, coastal flooding, and coastal erosion.
4. Due to projected climate change by the mid 21st century and beyond, global marine-species redistribution and marine-biodiversity reduction in sensitive regions will challenge the sustained provision of fisheries productivity and other ecosystem services.
5. Ocean acidification poses substantial risks to marine ecosystems, especially polar ecosystems, and coral reefs, associated with impacts on the physiology, behavior, and population dynamics of individual species from phytoplankton to animals. Highly calcified mollusks, echinoderms, and reef-building corals are more sensitive than crustaceans and fishes, with potentially detrimental consequences for fisheries and livelihoods.
6. For the major crops (wheat, rice, and maize) in tropical and temperate regions, climate change without adaptation is projected to negatively impact production for local temperature increases of 2°C or more above late-20th century levels, although individual locations may benefit. Climate change has already negatively affected wheat and maize yields globally, particularly for many regions.
7. Heat stress, extreme precipitation, inland and coastal flooding, landslides, air pollution, drought, and water scarcity pose risks in urban areas for people, assets, economies, and ecosystems. Risks are amplified for those lacking essential infrastructure and services or living in poor-quality housing and exposed areas.
8. Throughout the 21st century, climate-change impacts are projected to slow down economic growth, make poverty reduction more difficult, further erode food

security, and prolong existing and create new poverty traps, the latter particularly in urban areas and emerging hotspots of hunger.

9. Climate-change impacts are expected to exacerbate poverty in most developing countries and create new poverty pockets in countries with increasing inequality, in both developed and developing countries.

Impacts from recent climate-related extremes, such as heat waves, droughts, floods, cyclones, and wildfires, reveal significant vulnerability and exposure of some ecosystems and many human systems to current climate variability. Impacts of such climate-related extremes include alteration of ecosystems, disruption of food production and water supply, damage to infrastructure and settlements, morbidity and mortality, and consequences for mental health and human well-being.

Table 17: Main climate-related drivers for coastal systems, their trends due to climate change and their main physical and ecosystem effects (Source: IPCC Fifth Assessment Report)

Climate related driver	Physical/chemical effects	Trends	Projections	Progress since AR4
Sea level	Submergence, flood damage, erosion, saltwater intrusion, rising water tables/ impeded drainage, wetland loss (and changes)	Global mean sea level very likely increase	Global mean sea level very likely increase	Improved confidence in contributions to observed sea level.
Storms tropical	Storm surges and storm waves, coastal	TCs, low confidence in	TC's likely decrease to no	Lowering of confidence of

<p>cyclones(TCs), ex tropical storms(eTCs)</p>	<p>flooding, erosion, salt water intrusion, rising water tables, impeded drainage, wetland loss (and changes). Coastal infrastructure damage and flood defense failure</p>	<p>trends in frequency & intensity due to limitations in observations & regional viability. eTCs, likely poleward movement of circulation features but low confidence in intensity changes</p>	<p>change in frequency, likely increase in the most intense TC's eTCs high confidence that reduction of eTCs will be small globally. Low confidence in changes in intensity</p>	<p>observed trends in TCS & ETCs.</p>
<p>Winds</p>	<p>Wind waves, storm surges, coastal currents, land coastal infrastructure damage</p>	<p>Low confidence in trends in mean & extreme wind speeds</p>	<p>Low confidence in projected mean wind speeds likely increase in TC extreme wind speeds</p>	<p>Winds not specifically addressed</p>

Waves	Coastal erosion, overtopping and coastal flooding	Likely positive trends high altitudes	Low confidence for projections overall but medium confidence	Large increase in no. of wave projection studies.
Extreme sea levels	Coastal flooding erosion and salt water intrusion	High confidence of increase due to global mean sea level rise	High confidence of increase due to global mean sea level rise, low confidence of changes due to storm changes	Local subsidence is an important contribution to regional sea level rise in many locations
Sea surface temperature (SST)	Changes to stratification and circulation, reduced incidence of sea ice at higher altitudes, increased coral bleaching and mortality poleward species migration, increased algal	High confidence that coastal SST increase is higher than global SST increase	High confidence that coastal SSTs will increase with projected temperature increase	Emerging information on coastal change in SSTs

	blooms			
Freshwater input	Altered flood risk in coastal lowlands, altered water quality/salinity, altered fluvial sediment supply, altered circulation and nutrient supply	Medium confidence in a net declining trend in annual volume of freshwater input	Medium confidence for general increase in high latitudes & wet tropics & decrease in other tropical regions	Emerging information on freshwater input
Ocean acidity	Increased CO ₂ fertilization, decreased sea water pH and carbonate ion concentration (or ocean acidification)	High confidence of overall increase with high local & regional variability	High confidence of increase at unprecedented rates but with local & regional variability	Coastal ocean acidification not specifically addressed. Considerable progress made in chemical projections & biological impacts

Source: SAEX= IPCC 2012, Special report on Managing the Risks of Extreme Events & Disasters to Advance Climate Change Adaptations

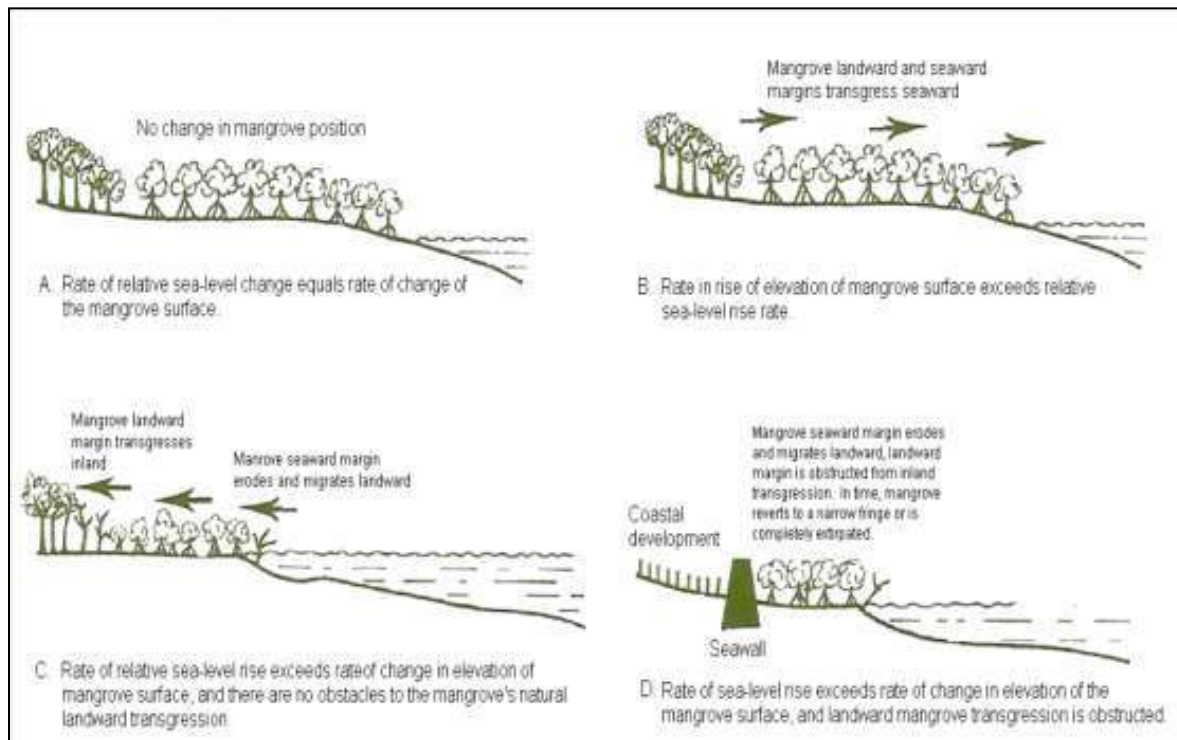


Figure 81. Mangrove response to relative sea-level rise under four different scenarios (adapted from Kennedy et al., 2002)

Potential Impacts on the Mangrove Forests

Mangroves occupy an intertidal habitat, and are extensively developed on shorelines such as deltas, where sediment supply determines their ability to keep up with sea level rise. Direct climate change impacts of rise in temperatures on these mangrove ecosystems are likely to be less significant than the devastating effects of associated sea level rise.

1. **Rise in sea surface temperatures:** mangroves are distributed in tropical and sub-tropical regions. Therefore, some believe that direct impacts of rise in temperatures will not be significant on mangroves (Field 1995). However, temperatures above 35°C might negatively affect root structure and recruitment. Some studies also show cessation of photosynthesis at leaf temperatures between 38°C and 40°C. Some studies also suggest a decrease in species diversity of mangrove forests in higher temperatures (Saintilan *et al.*). Flowering and fruiting patterns might change which again will bring changes in the species composition (Field 1995; Gilman *et al.* 2007). With increasing atmospheric and sea surface temperatures, it has been postulated that mangroves tend to migrate polewards but they still might be limited by extreme cold events in higher latitudes (McLeod *et al.* 2006).
2. **Increased CO₂ concentrations in atmosphere:** CO₂ is often considered to be an important factor for growth of plants, so increase in CO₂ concentrations would result in increased productivity and hence improved growth. This effect would be more pronounced in C-3 plants which are less efficient in fixing carbon than the C-4 species. Mangroves being C-3 plants, increase in CO₂ will enhance their growth and decrease water loss (UNEP 1994). However, it is not as simple since this effect of enhanced CO₂ will only be effective when other essential factors such as salinity, temperature, hydrological regime etc. are not limiting (Field 1995). Ball *et al.* (1997) in their study showed that growth rates of two mangroves *Rhizophora stylosa* and *Rhizophora apiculata* increased with increased levels of CO₂ but only in low salinity levels. There was no effect in higher salinity levels.
3. **Changes in precipitation:** IPCC projects an increase in rainfall in wet sub tropical and tropical regions but depending on the location the pattern might vary. In regions with decrease in precipitation mangrove productivity, growth and recruitment rates might decrease, and the species composition might change with salt tolerant species proliferating than the freshwater ones (Ellison 2000, 2004). Increased rainfall would lead to opposite, i.e. enhanced growth of

mangroves and higher species diversity (Field 1995) but they might displace adjoining habitats such as wetlands and saltmarshes (Duke et al. 1998; Harty 2004).

4. **Increased frequency and intensity of storms and cyclones:** Since mangroves are found along coasts they are always vulnerable to cyclones and storms. The recent projections indicate that in future the frequency and/or intensity of cyclones and storms will increase which might lead to mass mortalities of mangroves such as that in Caribbean forests in past 50 years or in Honduras (Cahoon *et al.* 2003). Storm surges, coastal flooding as well as high waves also add to the destruction (Ellison 2004).
5. **Rise in sea-level:** will have the most profound and direct impacts on mangrove forests. As the sea surface temperatures increase and the sea level rises, erosion of sediments will take place due to increased tidal flooding and sea shore erosion. The mangroves are resilient ecosystem and will tend to adapt to it by migrating towards the land by increased recruitment and vegetative reproduction (Semeniuk 1994). However, owing to the increasing land-use changes in the adjoining areas of the sanctuary and other factors, landward migration might be limited. In consequence, the mangroves might be reduced in area or the species composition might significantly change (Gilman *et al.* 2007). Increased salinity due to increased sea level, evaporation and reduced freshwater inflow might also affect the species composition, since species with higher tolerance will survive better than the ones with narrow tolerance range. Mangroves will also undergo physiological changes due to the increasing atmospheric temperatures, productivity might increase and the phenology pattern also might get altered.

Long-term, landscape-level response of mangroves and other tidal wetlands to relative sea-level rise is determined by:

- (a) The difference between the relative sea-level rise rate and the change in elevation of the mangrove surface

(b) The mangrove's physiographic setting (such as slope of the land on which the mangrove sites are situated, obstacles to landward migration, etc.) (Ellison and Stoddart 1991; Ellison 1993, 2000, and 2001; Woodroffe 1995; Alleng 1998; Lucas *et al.* 2002).

There could be three scenarios for mangroves' response to relative sea-level rise

i) When,

Relative rate of sea-level rise = rate of increase in elevation of mangrove surface.

If the rate of change in elevation of the mangrove surface (sediment accretion rate minus any sediment compaction) keeps pace with relative sea-level rise, the mangrove forests will be able to cope with the sea level rise and the mangrove margins will remain in the same location. Mangroves in Ganges delta (Blasco 1996), and in Jamaica (Alleng 1998) are two examples which have been documented to cope with rates of relative sea-level rise.

ii) When,

Relative rate of sea-level rise < rate of increase in mangrove surface.

If the rate of increase in elevation of the mangrove surface exceeds the relative sea-level rise rate, this will force the mangroves and their landward boundaries to migrate seaward, as has been observed in Fiji (Nunn 2000). Under these conditions, the mangroves may also expand laterally, displacing other coastal habitats.

iii) When,

Relative rate of sea-level rise > rate of increase in mangrove surface.

If the rate of change of the elevation of the mangrove surface is exceeded by the relative sea-level rise rate, the mangrove's seaward and landward margins will retreat landward, the mangrove species zones will migrate inland to maintain their preferred elevation as the seaward margin dies back, and tidal creeks will widen, with erosion

and slumping at their margins (Semeniuk 1980; Ellison 1993, 2000, 2001; Woodroffe 1995). In such a scenario, however, if the landward margins are already occupied or encroached upon by human infrastructure or activities, the mangroves might not be able to cope up with the rising sea level and might eventually undergo degradation and loss.

Studies (Ellison and Stoddart 1991) show that mangroves which have relatively large supplies of erogenous inorganic and organic sediment such as those in deltaic and estuarine regions can keep pace with a 4.5 mm/year relative sea-level rise rate. Based on Intergovernmental Panel on Climate Change (2001b) projections of global sea-level rise, there will be an annual rise of between 0.8 mm and 8.0 mm from 1990 to 2100, indicating that, based on predicted general rates of mangrove accretion, such mangroves could experience serious problems due to rising sea level, and low island mangroves may already be under stress.

Potential Impacts on the Estuary and Kakinada Bay

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. Increased sea level might lead to changes in the stratification regime of the estuary, sediment redistribution, tidal range etc. (Anthony *et al.* 2009). Shoreline erosion might increase due to extreme weather events such as cyclones, leading to increased flushing and rise in salinity as well as. Increased water temperature may affect the primary productivity of the estuarine flora and the various biological processes such as reproduction, metabolic activities etc. of the aquatic fauna. This might change the species assemblages and decrease richness. Increasing acidification might have dramatic effects on calcifying organisms of the estuary such as oysters and clams which also have high commercial value for the local communities. Range extensions of many

fish species are already being reported, with a general tendency to migrate to higher latitudes (Perry *et al.* 2005).

Potential Impacts of Climate Change on the estuarine aquatic fauna

Sea levels have risen by 0.1-0.3 m over the past century because of the rising global temperature (Wigley and Raper 1987; Liu 2000; IPCC 2001). Various models now predict an increase ranging from 0.3 to 5.0 m, possibly inundating almost 1 million km² of coastal land (Klige 1990; Daniels *et al.* 1993; Liu 2000). This rise is occurring at a faster rate than plants can colonize and establish wetland habitat (Daniels *et al.* 1993; Stevenson *et al.* 2002). Therefore, many tidal wetlands, estuaries, mangroves, and other shallow-water habitats may be lost if climate change continues at the predicted rates.

Extremes in environmental factors, such as elevated water temperature or salinity, low dissolved oxygen, and low pH can be devastating for the fishes (Moyle and Cech 2004), which can affect their foraging, growth, and fecundity, alter metamorphosis, and affect endocrine homeostasis and migratory behavior (Barton and Barton 1987; Donaldson 1990; Pörtner *et al.* 2001). Because many native organisms currently live near their tolerance limits, estuarine and coastal ecosystems will likely exhibit responses earlier to regional changes, including native species loss and exotic species increases (Kennedy 1990; Carlton 1996).

Estuarine species occur in a highly dynamic system that varies daily and seasonally and thus are generally able to tolerate wide fluctuations in the environmental parameters. Mostly the resident fishes are euryhaline which can tolerate wide range of salinities. However, it is the marine and freshwater migrants and stragglers that might be affected the most. Marine stragglers may increase in abundance in case of reduced freshwater input and rise in salinity, whereas freshwater stragglers will be negatively impacted. Similarly, distribution of freshwater migrants under future

climate-change scenarios is likely to depend on the amount of freshwater flow into the estuary.

In case of East Godavari Estuary, during the south-west monsoons, estuary is flushed out by the huge discharge of freshwater from the river. This is the time when salinities are less throughout the estuary and migratory species such as *Tenuulosa ilisha* resume their journey upstream. In coming years, the amount of freshwater flow might decrease considerably due to construction of a multi-purpose project across the Godavari River, near Polavaram. This would further exacerbate the potential impacts of global warming on such vulnerable species. Reduced freshwater input especially during the monsoons may mean that deoxygenated water of the estuary is not replaced with 'fresh' marine water, thereby providing poor conditions for feeding and spawning (Nicholson *et al.* 2008; Sakabe and Lyle 2010).

Rise in water temperatures will have less influence on estuarine fishes than salinity or freshwater flow, and will affect tropical and temperate species differently, depending on whether they are at extremes of their distribution and temperature tolerance. Range expansions or contractions of fish species have been predicted for some species that are at the southern or northern boundaries of their geographic range (Last *et al.* 2011). Species near the upper limits of thermal tolerance will show impaired growth, foraging, immune competence, and competitiveness (Portner and Farrell 2008). The eggs, larvae and spawning adults of several species have narrow thermal windows due to developmental constraints (Najjar *et al.* 2010; Pörtner and Peck 2010) and any negative impacts on these life stages will affect the recruitment success of such species.

Another climate-related driver which might bring about changes in the estuarine community structure is increasing concentration of dissolved CO₂, which in turn will lower the pH and make the estuary more acidic. The seawater is supersaturated

with calcium carbonate, or in other words there are abundant building blocks for calcifying organisms to build their skeletons and shells. However, continued ocean acidification will render many parts of the ocean to become under-saturated with these minerals, which will likely affect the ability of such species to produce and maintain their shells.

Fishes also possess calcium-carbonate otoliths that aid them in balancing and hearing. Though several studies suggest that fishes may be able to regulate the acid-base balance and thereby be less affected by enhanced CO₂ concentrations (Munday *et al.* 2009c), elevated CO₂ may still negatively affect sensory ability and behavior of the fishes (Munday *et al.* 2009b, 2010; Dixon *et al.* 2010). Reduced pH can have indirect effects on estuarine fish through the effects on their prey which most often are invertebrates with calcified structures such as crustaceans and molluscs.

Threats to the Fishery Sector

As per FAO's report "The State of World Fisheries and Aquaculture" (2012), global fish production has grown dramatically in last five decades, with an average growth rate of 3.2% per year in the period 1961–2009. Per-capita food production also increased from an average of 9.9 kg (live weight equivalent) in the 1960s to 18.4 kg in 2009. However, if we look at, the world's marine fisheries, it increased markedly from 16.8 million tonnes in 1950 to 86.4 million tonnes in 1996, and then declined before stabilizing at about 80 million tonnes. In 2010, the global recorded production was 77.4 million tonnes. Most of the stocks of the top ten species, which account in total for about 30 percent of world marine capture fisheries production, are fully exploited and have no potential for increase in production. However, three FAO regions which have shown increases in marine fishery production are Western Central Pacific (Area 71), Eastern (Area 57) and Western (Area 51) Indian Ocean.

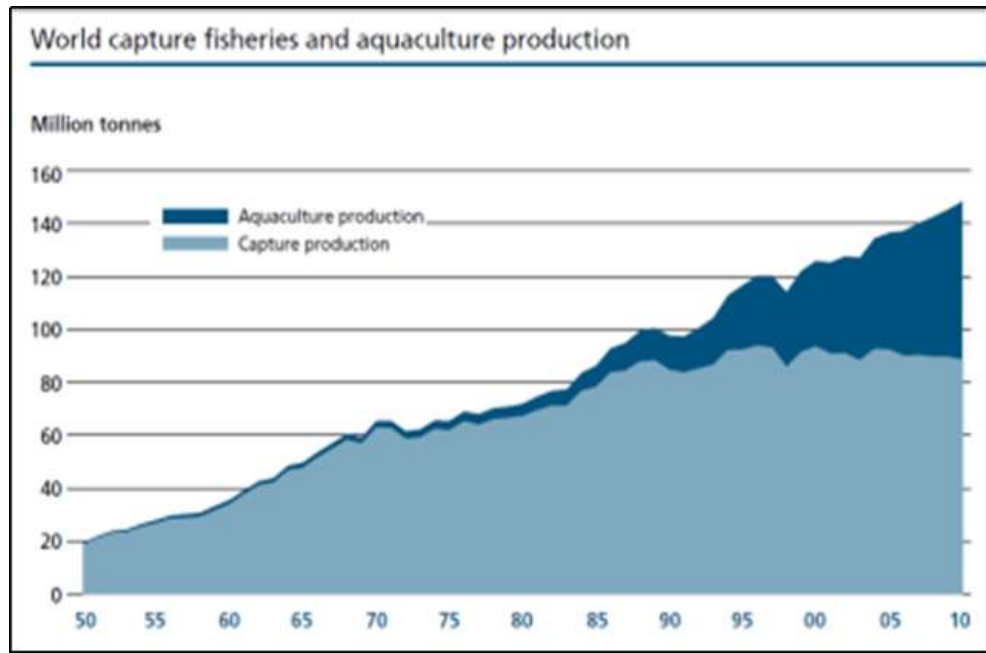


Figure 82. Global fish production in last five decades

To evaluate the status of marine fisheries in India, Bhathal (2005) reconstructed the annual catch data over a period of 1950 to 2000. It was found that though marine fish catches increased gradually from 0.6 tonnes in 1950 to 3.3 million tonnes in 2000, but the Mean Trophic Level (MTL) of landings pointed towards the 'fishing down' phenomenon across the country. 'Fishing down' means the tendency for these fisheries to rely increasingly on small fishes and invertebrates placed lower in the food webs, due to increased scarcity of large, high trophic-level predatory fish. This, as per the author is alarming as it might mean the end to expansion phase of the marine fishery in India.

The above situation might be worsened by the impacts of global warming (Table shows impacts of climate change on aquaculture industry). Rising temperatures might bring about physiological changes in fishes which in turn will affect their behavior and recruitment success. Stenothermic species, with low temperature tolerances, will be the most affected. As mentioned earlier these changes would lead to range extensions or poleward migrations of those stocks living at the edges of

their range. These responses will be most rapid for highly mobile pelagic species (Harley *et al.* 2006) as has already been demonstrated by tuna (which is a major component in the fishery industry of Kakinada too) in the tropical Pacific in response to ENSO variability (Lehodey *et al.* 1997).

Similarly, species with shorter life spans and rapid turnover rates such as planktons, squid and small pelagic fishes also are most likely to experience drastic changes. This might lead to earlier spring plankton blooms (Mackas, Goldblatt and Lewis 1998; Edwards and Richardson 2004) for some species or might change species composition as the development times for different species of marine communities are altered. Changes in net primary production will also have serious impacts on the entire marine food web. Recent studies suggest that though global net primary production (NPP) will decrease with changing climate, the changes could vary region-wise. Lower latitudes will suffer reduction in NPP because of reduced vertical mixing and replenishment of nutrients (Sarmiento *et al.*, 2004) and changes in circulation and direct human impacts (Cruz *et al.*, 2007). Cheung *et al.* (2008), using a somewhat different approach based on observed current geographic ranges, trophic levels, primary production, and fish catch, found a significant relationship between primary production and fisheries catch, with a high probability of shifts in locations of maximum catches.

The fishery and the aquaculture industry are not only highly vulnerable to the impacts of climate change but are already under tremendous pressure due to over-exploitation and ever-increasing demands. As discussed above 'fishing-down' is the norm in almost every fishing region of the world. Any negative impacts can bring serious repercussions for the millions of people engaged in the two sectors. It is estimated that around 660-820 million people (10-12% of global population) are directly or indirectly dependent on fisheries and aquaculture for their livelihoods, out of which 54.8 million people were engaged in the primary sector of fish production in 2010.

Drivers of change	Impacts on culture systems	Operational impacts
Sea surface temperature changes	Increase in harmful algal blooms Decreased dissolved O ₂ Increased disease and parasites Longer growing seasons Changes in locations and ranges of suitable species Reduced winter natural mortality Enhanced growth and food conversion rates Competition, parasitism and predation from altered local ecosystems, competitors, and exotic species	Changes in infrastructure and operation costs Increased fouling, pests, nuisance species and predators Expanded geographic ranges for species Changes in production levels
Changes in other oceanographic variables	Decreased flushing rates and food availability to shellfish Changes in abundance of species used for food and fishmeal	Accumulation of wastes under nets Increased operating costs
Sea level rise	Loss of areas for aquaculture Loss of areas providing physical protection Greater flooding risks Salt intrusions into groundwater	Infrastructure damage Change in aquaculture zoning Increased insurance costs Reduced freshwater availability
Increased storm activity	Larger waves Higher storm surges Flooding from precipitation Salinity changes Structure damage	Loss of stock Facility damage Higher costs for designing new facilities Increased insurance costs
Drought and water stress	Salinity changes Reduced water quality Increased diseases Uncertain water supplies	Loss of stock Facility damage Conflicts with outer water users Reduced production capacity Change in cultured species

Potential Impacts on the Local Communities

As per the latest reports of IPCC (2014b), people living in the low-lying coastal regions in Asia are the most susceptible to global warming. Sea level rise will directly impact the communities living closer to the coast with tidal flooding and erosion. Since a major part of the population in this region is dependent on fisheries, global warming will have

negative implications for such communities. Most of them are subsistence or artisanal fishermen, fishing mainly in shallow waters of the Bay or the creeks.

Increasing sea level and the changing biotic community might lead to decline in exploitable fish stocks (Roessig *et al.* 2004). Such coastal communities will also become more vulnerable to diseases as well as damage from extreme weather events such as cyclones. The agricultural sector might also face losses due to reduced crop yields, increased incidence of diseases etc. In a study, wherein an agro-economic model was applied across India, it was found that increased GHGs and aerosols, increased temperatures and reducing radiation have lead to decrease in rice harvest growth (Auffhammer *et al.* 2006)

Inputs from India's Climate Change Document

There is now concrete evidence that the on-going climatic change is irreversibly affecting natural species across the globe (Parmesan and Yohe 2003). Among the predicted changes, climate change is expected to induce diverse functional (e.g., phenology, physiology) and structural (e.g., changes in species distribution, range contractions, poleward movements) ecological responses among organisms (Parmesan 2006). The biodiversity in aquatic environments is declining faster than the terrestrial environments (Casselman, 2002) and this problem is particularly acute in streams and small ponds and lakes (Jackson and Mandrak, 2002).

Climate is a key determinant of the structure and functioning of ecosystems, patterns of species distribution and dispersal. The energy flow influenced by climate is directly related to the productivity and ecological processes operating within a system, although ecosystem responses to climate change are complex and varied. Regional species pool and species life history strategies vary significantly across larger landscapes.

Conservation biologists have long argued for maintaining balance of nature, while ecologists signaled cascading negative effects if the complex relationships between the

ecological pyramid and food chain are disturbed or weakened, but these concerns largely emanated from excessive exploitation and disturbance to natural setting by humans. Also, there are certain natural disturbances such as drought, earth quake, fire and flood that potentially modify or change system configuration and course of the ecological processes.

Ecologists and conservationists perceive the disturbances (both natural and human induced) to offer positive and negative feed-back depending on the scale and extent of impacts. Some regards moderate level of disturbance to reinvigorate the system functions, thereby, facilitating viability of the system. However, rapid change in climatic factors in the recent years and the projection showing unprecedented scale of effect is a shocking revelation (IPCC, 2001) and has invoked greater concern among the world communities.

Species distribution range and their abundances and ecological dynamics are already responding to climate shifts, and local extinctions have taken place across the world. Tree-line advancement has been observed in high mountains, and similarly, species boundaries are expected to change, particularly in the transition zones or ecotones. It is also believed that climate change would increase net productivity, thus, causing super abundance of some species including invasive species and creating chaotic species interactions. Despite skeptics treating climate change effect as a case of over-reaction, climate change is termed as the single most challenge to human society in the current century. The Intergovernmental Panel on Climate Change (IPCC) summarizes the linkages between climate change and biodiversity that “Changes in biodiversity and the changes in ecosystem functioning associated with them may affect biological productivity. These changes may affect critical goods and services upon which human societies depend. They may also affect the total sequestration of carbon in ocean and terrestrial ecosystems which can affect the global carbon cycle and concentration of GHG in the atmosphere.

OBSERVATIONS ON THREATS AND THEIR IMPACTS ON EGREE

Context of the Present Study

Numerous chemical as well as physical factors play crucial roles to shape these complex and dynamic ecosystems. Slightest changes in any of these factors might lead to a domino-effect on the entire estuarine system. Among the various factors effecting mangrove ecosystems, sea-level change has been certainly identified as the major outcome of global warming. However, the impact of climate change on EGREE is not very well studied.

EGREE is 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 in export of marine fishes. 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. Any oil spills or accidents such as the recent one in Sunderbans would be devastating for the aquatic biota of EGREE. Numerous other industries line the coast which possibly also contributes towards polluting the waters.

Therefore, in this scenario wherein the ecosystem is already under so much pressure from various anthropogenic disturbances, deciphering the specific impacts of climate change would be very difficult. For e.g. not only rising sea level but reduction in annual freshwater flows due to damming or excessive extraction of water in the upstream regions will also lead to rise in salinity.

Elliot and Quintino in 2007 identified this ambiguity and proposed the Estuarine Quality Paradox, which they described as *“that the dominant estuarine faunal and floral community is adapted to and reflects high spatial and temporal variability in naturally highly stressed areas but that it (the community) has features very like those found in anthropogenically-stressed areas thus making it difficult to detect anthropogenically-induced stress in estuaries. Furthermore, as estuaries are naturally organically-rich areas then the biota has similarities to anthropogenically-organic rich areas”*. This becomes pertinent in our study area too which is experiencing high rate of industrial development.

Even though 235.7 sq.kms of mangroves have been declared as Coringa Wildlife Sanctuary and numerous other policies exist to protect EGREE, the region is still undergoing rapid changes and destruction. The region will experience profound changes in natural as well as human-modified ecosystems due to the impacts of climate change. Unsustainable resource extraction and land-use changes will just exacerbate the negative impacts and will decrease the resilience and adaptive capacity of the region. Maintaining the extent and ecosystem functionality of this estuary and its mangrove forests is, therefore, crucial as a strategy to address climate change and its impacts on the region.

In this chapter, the major threats to EGREE and its associated biodiversity have been identified and discussed. For this purpose, the land use/land cover patterns and changes were analyzed, the detailed methodology is described below. Further the results and observations linking to changes due to climate change are highlighted at the end.

Land Use/Land Cover of EGREE

Land-cover refers to the physical characteristics of earth's surface, captured in the distribution of vegetation, water, soil, and other physical features of the land, including

those created solely by human activities e.g., settlements. Land-use refers to the way in which land is being used by humans and their habitats, usually with focus on the functional role of land for economic activities. The spatial configuration of land use determines many ecological and socio-economical processes (Lambin et al, 2001, Verburg et al., 2004).

Land use affects land cover and changes in land cover land use. Globally, land cover today is altered principally by direct human use: by agriculture and livestock grazing, forest harvesting and management and urban & sub-urban construction and development. Land cover can also be altered by natural events such as weather, flooding, forest fire, climate fluctuations and ecosystem dynamics. There are also incidental impacts on land cover from other human activities such as forest and lakes damaged by acid rain from fossil fuel combustion and crops near cities damaged by tropospheric ozone resulting from automobile exhaust (Meyer, 1995).

In some instances, land use land cover change may result in environmental, social, and economic impacts of greater damage than benefit to the area (Moshen A, 1999). Hence, to use land optimally it is not only necessary to have the information on existing land use, land cover but also the capability to monitor the dynamics of land use resulting out of both changing demands or increasing population and forces of nature acting to change the landscape.

Land-use/Land-cover (LULC) change information has an important role to play at local and regional as well as at macro level planning. Often, the planning and management actions are ineffective or hampered due to insufficient information on rates of land-cover/land-use change. The land-cover changes occur naturally in a progressive and gradual way, however sometimes it may be rapid and abrupt due to anthropogenic activities. A comparison of remotely-sensed data at different time interval helps in analyzing the rate of changes as well as identifying the causal factors or drivers of changes. Hence it has a significant role in regional planning at different spatial and

temporal scales. Therefore, Remote Sensing along with the spatial and temporal analysis technologies namely Geographic Information System (GIS) and Global Positioning System (GPS) help in maintaining up-to-date land-use dynamics information for sound planning and cost-effective management decisions (Ramachandra and Kumar, 2004).

Methodology

1. Land Cover Map For EGREE

Cloud free scenes from LISS I and LISS III sensors of IRS 1A/B/C/D, P6 and Resourcesat I and II were chosen. Some digitised data were also collected from the Andhra Pradesh Forest Department. The GIS Cell of APFD shared the following shape files: EGREE Roads, EGREE Villages, EGREE Mandals, and EGREE Revenue Villages.

Toposheet Maps corresponding to 65K04, 65L01, 65L02, 65L03, 65L05 and 65L06 were purchased from the Survey of India, Dehradun.

The month for all the LISS scenes was kept constant at February-March as these months have the least cloud cover over the landscape, hence the images are cloud free. For the year 2013, image from the month of April had to be selected because of cloud cover in February and March.

An image from November 2013 was also selected for comparing the seasonal changes in reflectance of the vegetation in the region. As a first step for finding land cover changes, all the images need to be classified with supervised classification method. For the supervised classification method, signature reflectance values for the different vegetation and land cover types need to be ascertained by collecting the GPS locations for every land use type on the ground.

Before starting collection of GPS locations, a Land Use Map was prepared based on unsupervised classification to point out the areas where discrete land use types could not be assigned due to mixed reflectance and averaged pixel values. This Land Use Map

based on Unsupervised Classification was used (Figure 84) for the first phase (March-April 2014) of field surveys for collecting GPS locations of different land use types. The months for ground truth locations were synchronised with the months to which the data belongs. The Land Use Map presently being used for the field survey is based on the satellite image of April 2013. Hence, the field surveys are being carried out during the March-April.

Ground truth data collection was carried out during the month of April based on the classified image of April 2013 covering different land-use areas, classified by unsupervised way of classification. Points for ground data collection were chosen based on the areas with high pixel mixing. Locations in the map where land use class allotment was ambiguous were visited.

Before the beginning of field work, some thematic maps were also prepared for generating a better knowledge of the region.



Figure 83. Map showing Grids covered during Ground Truthing – Ist Phase

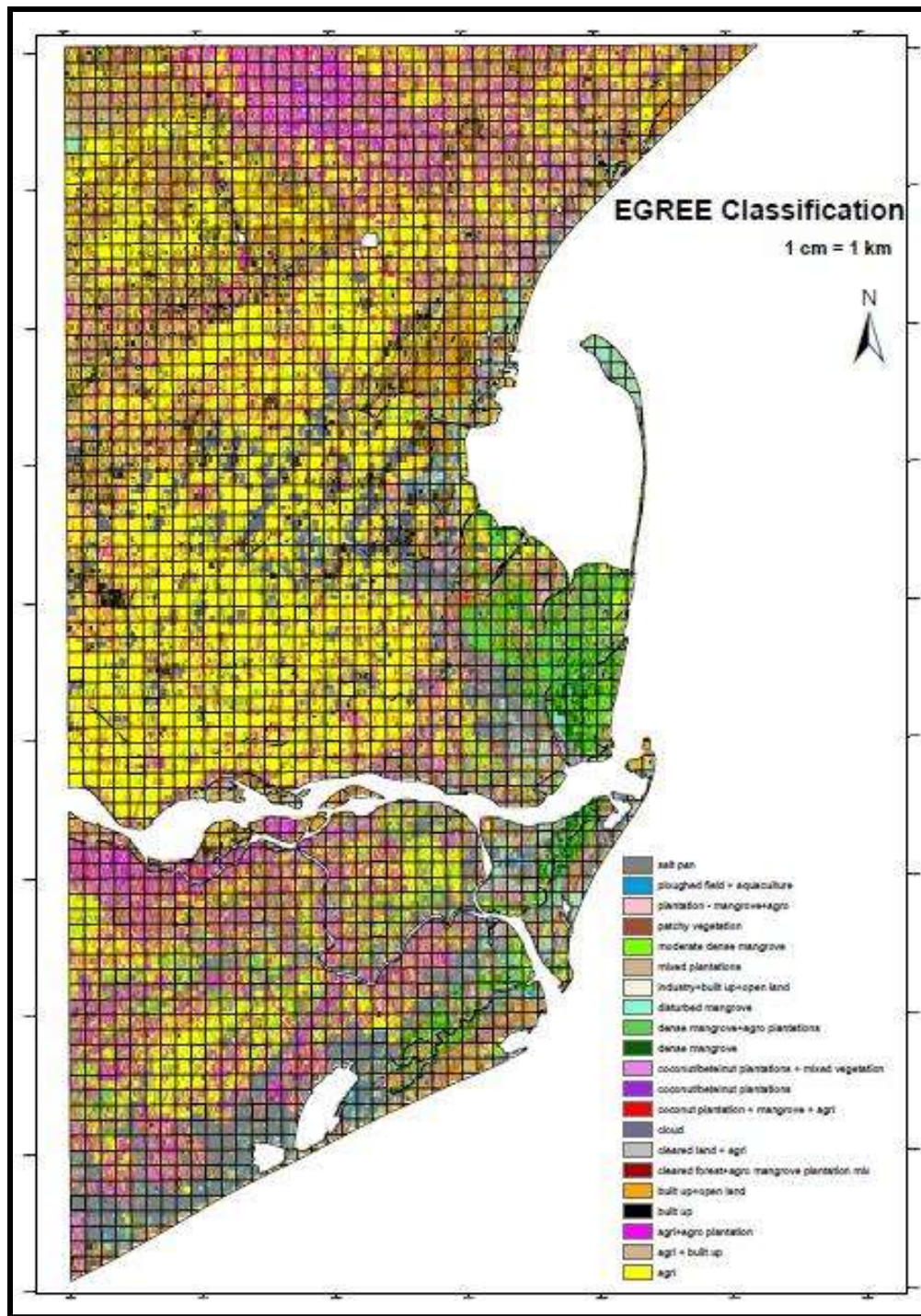


Figure 84. Map showing Land Use Land Cover Map of EGREE based on unsupervised classification



Salt Pan



Coconut Plantations



Mud Flats



Mangroves



Agricultural Fields



Grazing Land

Figure 85. Various Land Use types in the Landscape

Based on the ground truth data, the image was classified again by supervised way of classification (Figure 86). Google earth was also used during the process. Finally, a Land Use/Land Cover classification map was prepared for EGREE.

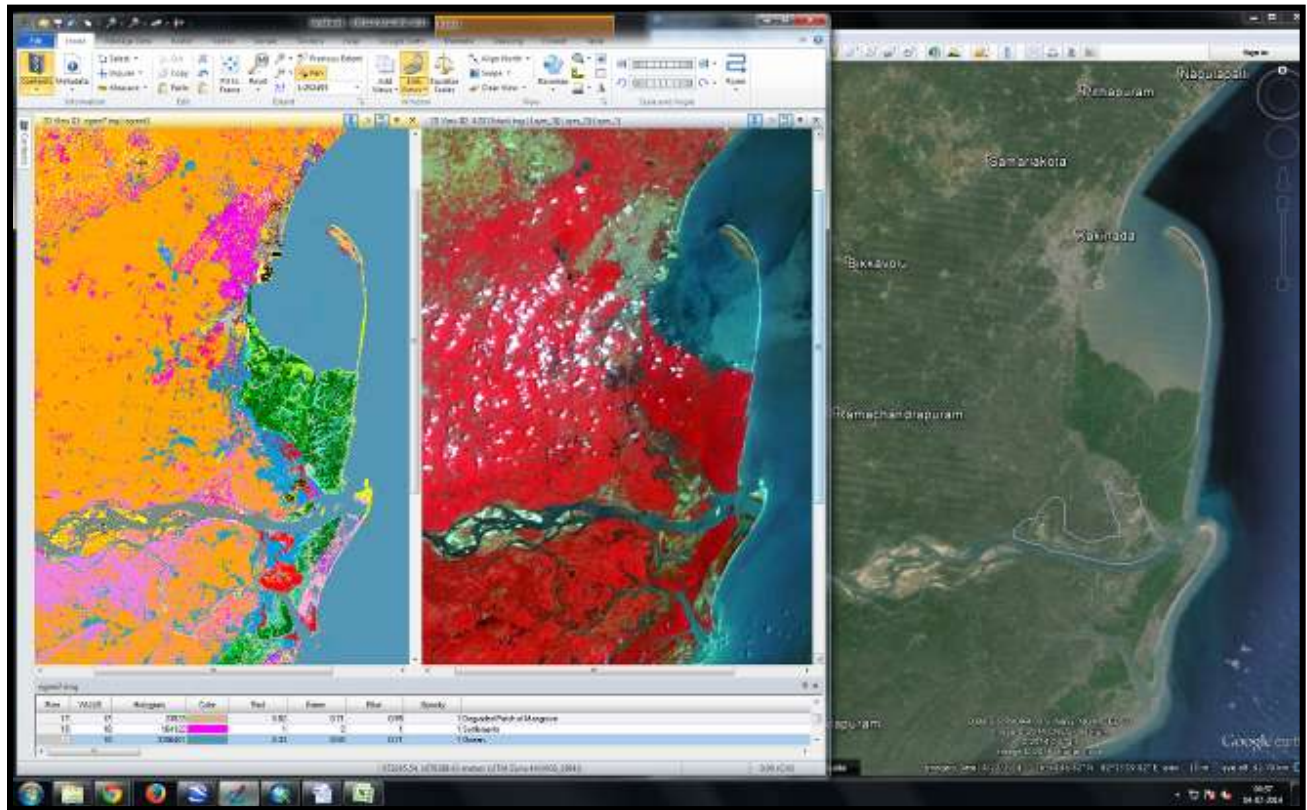


Figure 86. Supervised Classification Process

2. Land Use Land Cover Change Analysis for EGREE

Several procedures of land cover change detection using digital data have been proposed which could aid in updating resource inventories. These methods include comparison of land cover classifications, multi-date classification, image differencing, ratioing, vegetation index differencing, principal components analysis and change vector analysis. Digital change detection approaches may be broadly characterized by (1) the data transformation procedure (if any) and (2) analysis techniques used to delineate areas of significant alterations (Singh, 1989).

There are two basic approaches for change detection; (1) comparative analysis of independently produced classifications for different dates and (2) simultaneous analysis of multi-temporal data. It may be mentioned here that accurate spatial registration of the two images is essential for most change detection methods. This necessitates the use of geometric rectification algorithms that register the images to each other or to a standard map projection (Singh, 1989).

The classification of the older satellite images is in process. Ample time and effort has been invested in outlining a holistic and error minimizing, as well as time effective method for the common classification of all the images.

Coming to change detection in land use/cover, the methodology for classification of each image was reviewed since the process of supervised classification was met with several challenges. The challenges were met majorly because of similar values of spectral reflectance among certain land cover types. The following picture (Figure 86) depicts the major land cover types which showed pixel mixing.

Faced with the above classification issues, it was decided to change the classification methodology from supervised classification to “Visual Interpretation” which involves manual digitization of each parcel of land use/cover. Since this is an intensive process and requires greater input in terms of time and effort, at present we have been able to digitize only two images, temporally spaced between 5 years (2010 to 2015; Figure 67,68 & 69). However, this method has given extremely reliable results, and the results may be stated with a greater confidence than could be said while using the previous method. It may also be noted at this point that, all the previous studies carried out in this region by other investigators, have adopted the method of supervised or unsupervised classification, and our study may contribute in way of a methodological advancement with special relation to our study area.

For our analysis, we have maintained some criteria while selecting the satellite images:

- ✓ Low tide during the time of satellite passes in all imageries. This would help us in eliminating error in shift of shoreline which may appear to be artificially shifting due to tidal silt.
- ✓ Cloud free sky in all images.
- ✓ Even though, the months of September-October are usually selected for remote sensing analysis purpose, as the vegetation (including agriculture fields) is completely covered with green and it makes identification of vegetated and non-vegetated areas easy, in our case we chose the dry months, as the monsoon months were completely covered with cloud.

Land Use Land Cover of EGREE

The land use land cover map (see Figure 64) provides the latest figures for the status of mangroves and the surrounding land use types in the EGREE landscape. It is important to have figures demonstrating the extent of the ecologically critical and vulnerable areas as it contributes to collective long-term monitoring of the area. As can be seen from the map, the EGREE landscape is dominated by agriculture, covering about 1364 km². The agricultural fields are well interspersed with Coconut Plantations, which cover 212 km² area in the landscape. The total mangrove cover in the East Godavari district, as in April 2013 has been calculated to be 195.3 Km².

Mangrove cover in EGREE

Based on our analysis, we have found the total mangrove cover in the East Godavari district to be 195.3 Km² as opposed to 197 Km² in 2001 (Ramasubramaniam et al., 2006) indicating that there has been a loss of about 1.7 Km² of Mangrove area in the East Godavari District. However, there has been a considerable recovery of the degraded mangrove patches too. Ramasubramaniam et al. (2006) categorized 33 Km² of mangrove area as degraded in their study, while in the present study only 18 Km² was

found to be under the degraded category, thus implying recovery of 15 Km² of degraded mangroves.

This may be attributed to the Mangrove sapling plantation program carried out yearly by the Andhra Pradesh Forest Department. Another latest study puts the area of CWLS to be 118 km² (Murty et al., 2011) but by 2013 around 2.4 Km² of Mangrove area were lost.

Comparison of the present study result with the result provided by Ramasubramaniam et al. (2001) shows a loss of 1.7 Km² area of mangrove in the entire EGREE landscape; while comparison with the results of Murty et al. (2011) shows a loss of 2.4 Km² of Mangrove areas within CWLS itself.

This irregularity in the data may be explained by a possible increase in the mangrove area in the southern part of the Gautami Godavari River, which lies outside the CWLS boundary, hence compensating against the decreasing area inside CWLS. The decrease in Mangrove area inside CWLS may be because of degradation and/or sea level rise.

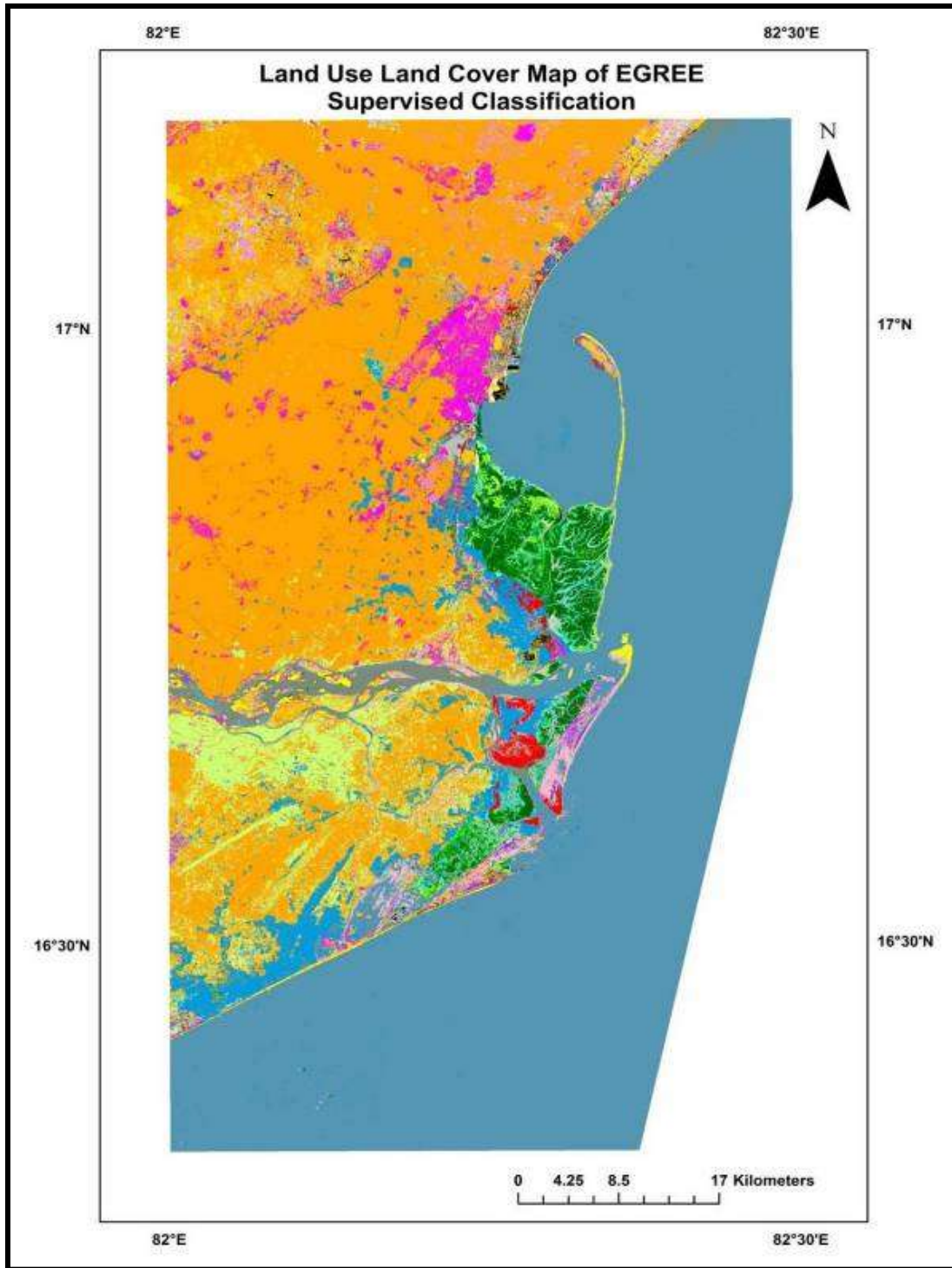


Figure 87. Map showing Land Use Land Cover classification of the EGREE region.



Table 18. Area covered under each land class

CLASS_NAME	Area (sq.km)
Agriculture - Kharif	986.70
Aquaculture Pond	145.60
Built up - Industry	9.97
Casaurina Plantations	10.53
Clearance+Plantation	11.70
Coconut Plantation	203.48
Degraded Patch of Mangrove	18.44

Fallow Land - Open	50.93
Fallow land with Coconut plantations	78.65
Healthy Mangrove	31.79
Healthy Mangrove - Plantation	31.55
Less Dense Mangrove	10.81
Mangrove Lake	21.14
Mangrove Patch at risk	20.09
Mangrove Swamp	11.90
Mix Vegetation	27.59
Moderately Dense Mangrove	13.51
Moderately Healthy Plantation	15.61
Open Mangrove	24.28
Plantations	51.23
Prosopis	19.54
Salt Pan	18.32
Sand Bar	22.50
Settlements	105.18
Tidal Swamp	29.33

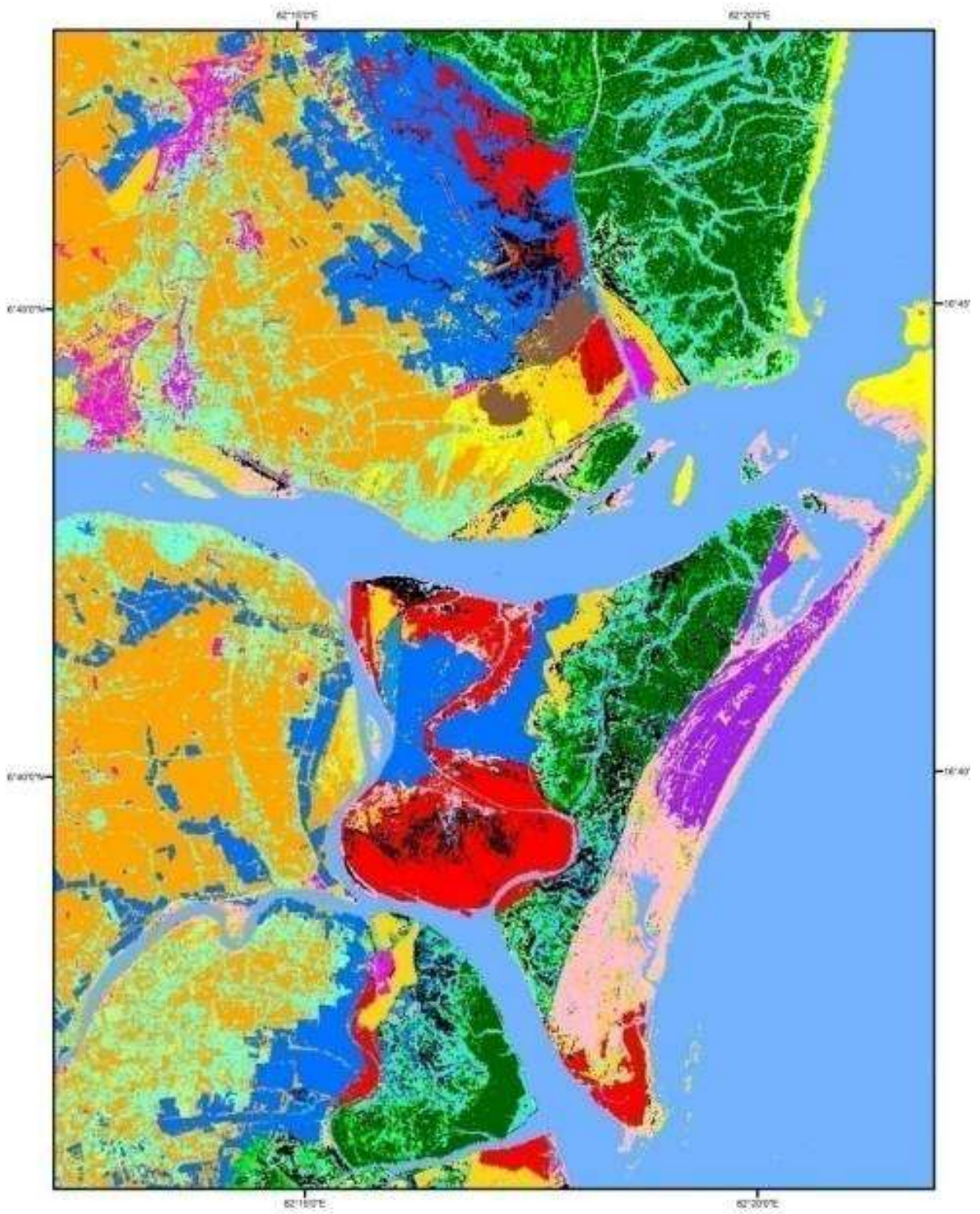


Figure 88. Map showing vulnerable areas of mangrove

Aquaculture Ponds are spread over 120.5 Km² and Salt Pans occupy 2.59 Km². Another category which has been marked in red color in the map, shows those areas of mangrove which are at risk of conversion to another land use type. Because of their proximity with aquaculture ponds, it is highly probable that these mangroves will get reclaimed into Aqua ponds. About 18 Km² of mangrove patches are at risk of reclamation.

Though the comparisons among the results of the different studies show some irregularity, 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. This process of degradation of mangroves easily leads to conversion of the mangrove to other land use types. The drying up of the mangroves which lie in the fringes of the CWLS may also be attributed to climate change and needs to be further investigated.

LAND USE CHANGE

Change refers to the alteration of the structure and function of the land use mosaic over time, caused by changes in the distribution of the population and changes in the biophysical conditions (e.g. climate change or soil degradation) (Verburg et al., 1998). The rapidity and extent of human alterations of the land surface are effervescent (Turner et al., 1990; Lambin et al., 1999, Lambin et al., 2001). *“Land-use-change patterns are the result of the complex interaction between the human and the physical environment”* (Verburg et al., 2004). Over the last couple of decades changes in land cover and land use have been recognized as important environmental changes around the globe (Turner, 2002; Ramankutty et al., 2005).

Land-use and land-cover changes are so enveloping the whole globe and significantly alter key aspects of Earth System functioning. They directly impact biotic diversity worldwide (Sala et al., 2000, Lambin et al., 2001); are the primary source of soil

degradation (Tolba et al., 1992, Lambin et al., 2001); and, by altering ecosystem services, affect the ability of biological systems to support human needs (Vitousek et al., 1997, Lambin et al., 2001). Such changes also determine the vulnerability of places and people to climatic, economic, or socio-political perturbations (Kasperson et al., 1995, Lambin et al., 2001). Ramankutty and Foley (1999) estimated that the global expansion of croplands since 1850 has used up almost 6 million km² of forests and woodlands and 4.7 million km² of savannas/grasslands/steppes and on the other hand, 1.5 and 0.6 million km² of cropland have been abandoned.

Land cover change has always played a central role in land change science (Turner et al., 2007; Verburg, 2009). This has been possible, thanks to the extensive data availability through remote sensing techniques (Verburg, 2009). Advances in remote sensing and land inventory techniques make it possible to “assess current land resources, identify ongoing land cover change processes and identify hot-spots of change” (Herold, 2006). Lambin (2000), observes that different modeling approaches are appropriate in tackling the question of intensification at different locations. One could anticipate using different modeling tools (or a different mix of these tools) to develop landscape scale models that take account of decision-making processes (Lambin, 2000). As also mentioned earlier, better data alone are not sufficient for improved models or projections (Lambin et al., 2001). There must be a hypothetical and proven logical link between changes and their causes (data used).

CHANGE DETECTION

The maps produced by ‘visual interpretation’ and the major findings from a post classification comparison of the two images are given under.

A first look at the figure depicting changes in land use patterns from 2010 to 2015 reveals a lot of information regarding the changes taken place in the landscape in past 5 years. The biggest change has been the spread of aquaculture ponds which expanded

from little more than 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 majority of the aquaculture ponds in this region are located just adjacent to the mangrove forests and other coastal wetlands and the increase also has been in these aqua ponds.

At a closer look, 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.

As discussed in the previous chapter, if the sediment accretion rate is lower than the rising sea level the mangroves will tend to move landwards 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.

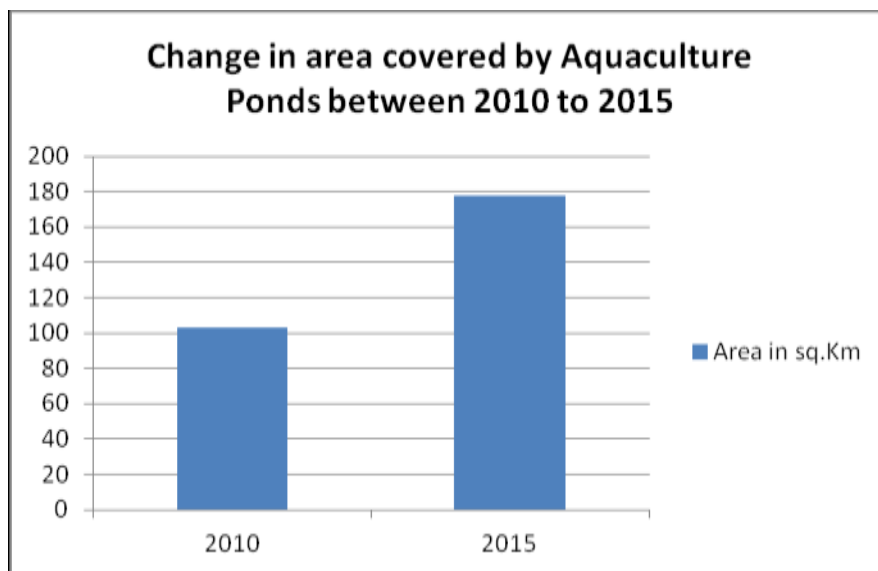


Figure 89. Graph showing change in aquaculture pond area over last 5 years

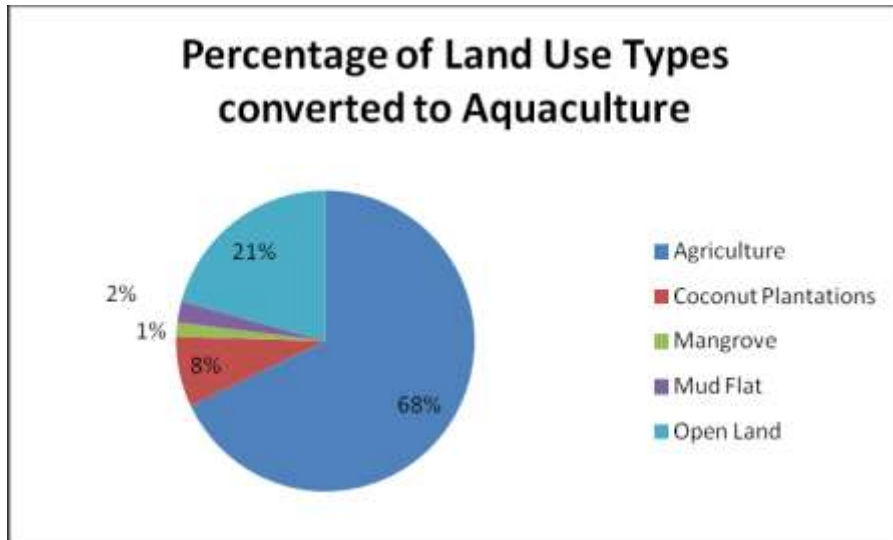


Figure 90. Pie chart showing percentage of land converted for aquaculture

On the contrary, casuarina plantations have led to conversion of 51% of mudflats and 29% of mangroves, particularly in the southern parts of the landscape where protection of mangroves is less. A rise of 22% in coastal casuarina and coconut plantations within 5 years has been noted.

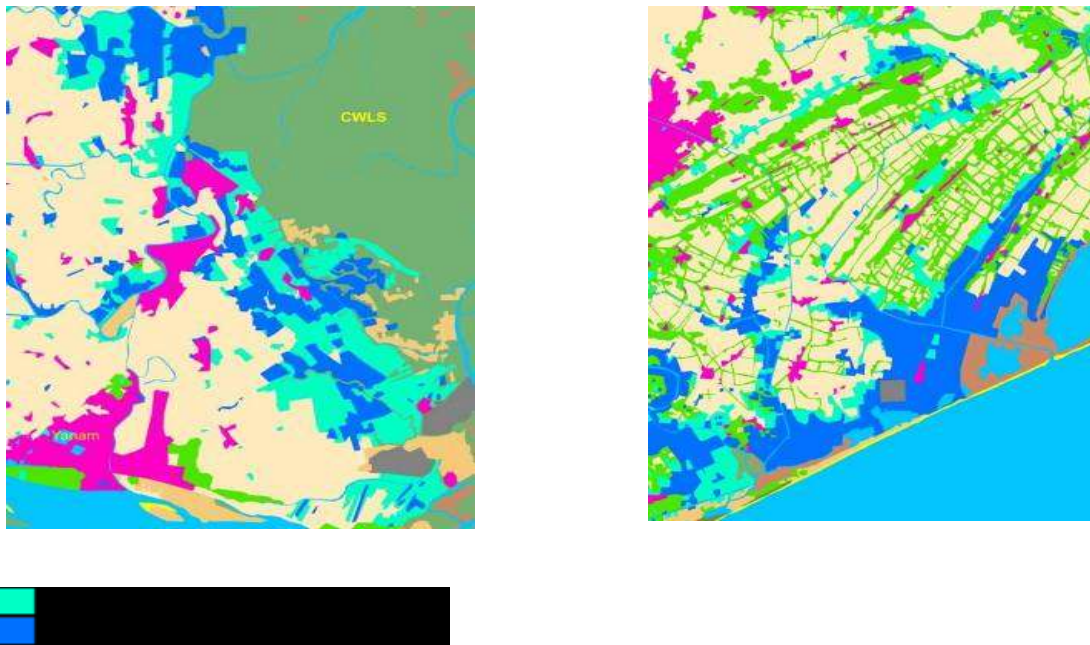


Figure 91. Change in the aquaculture ponds around the CWLS between 2010 and 2015.

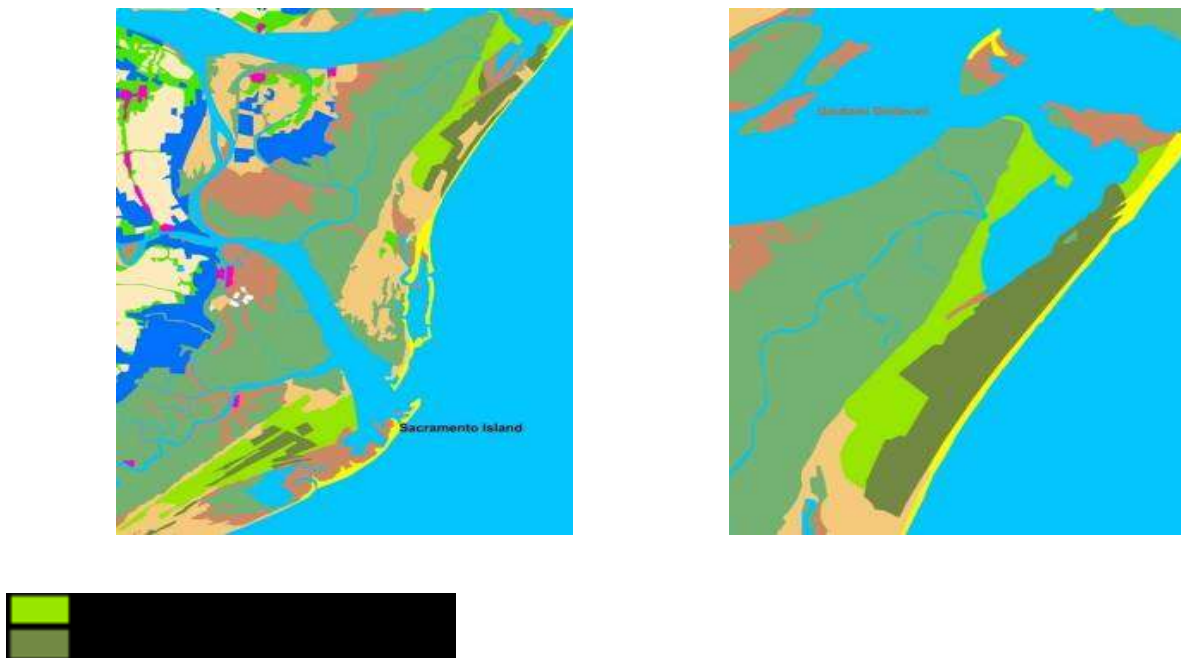


Figure 92. Change in the plantation (casairina & coconut) around the CWLS between 2010 and 2015.

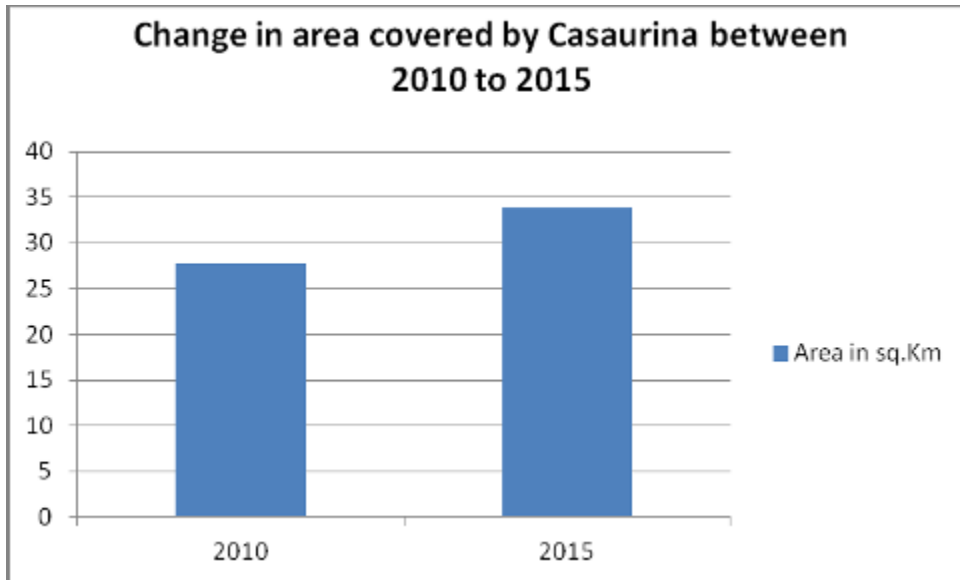


Figure 93. Graph showing change in area covered by Casaurina over last 5 years

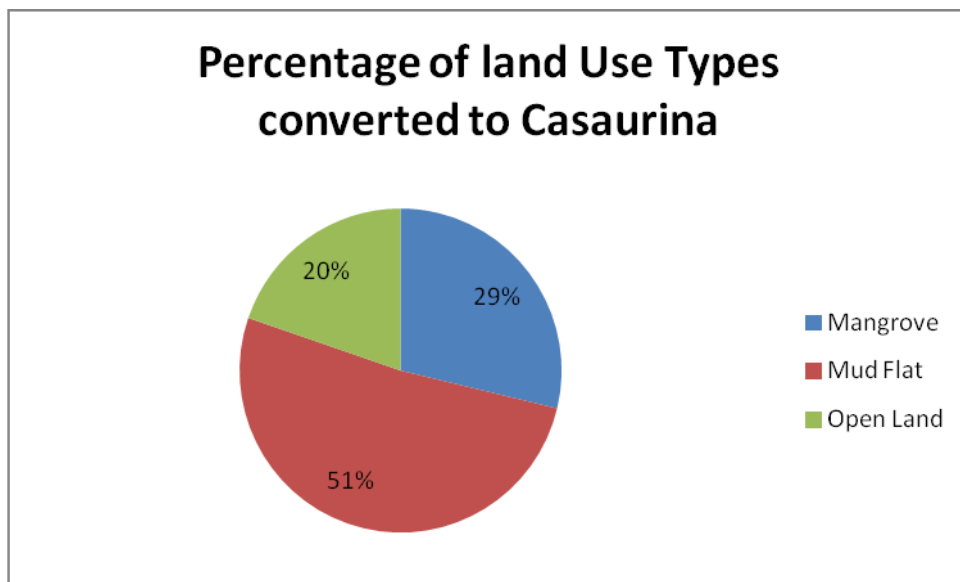


Figure 94. Percentage of land converted for Casuarinas plantations over last 5 years

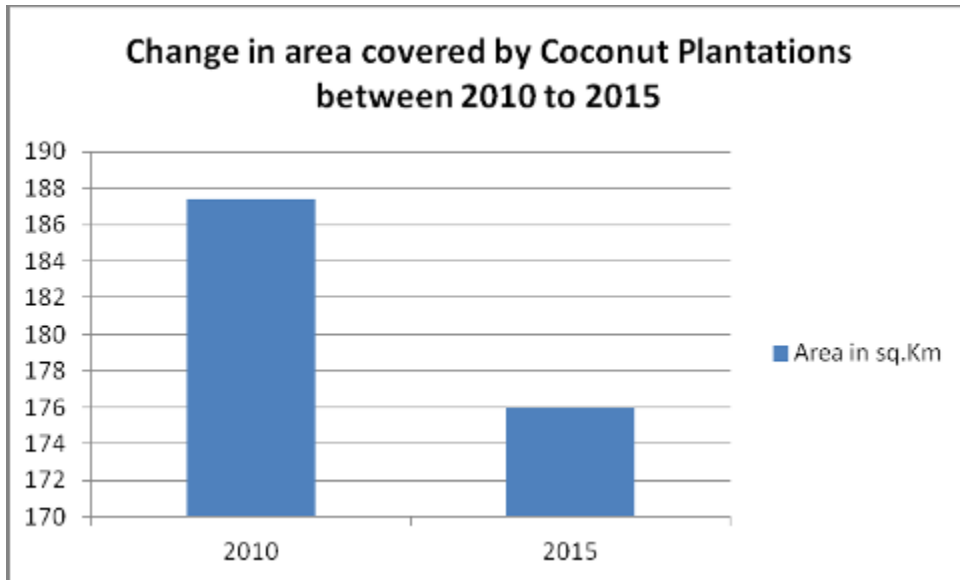


Figure 95. Change in area covered by Coconut plantations over last 5 years

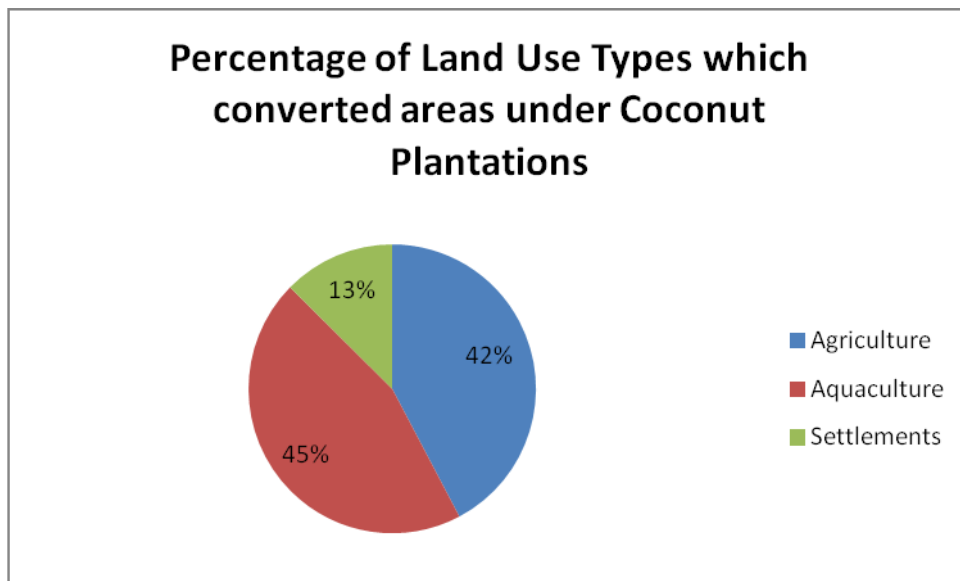


Figure 96. Percentage of land converted for Coconut plantations over last 5 years

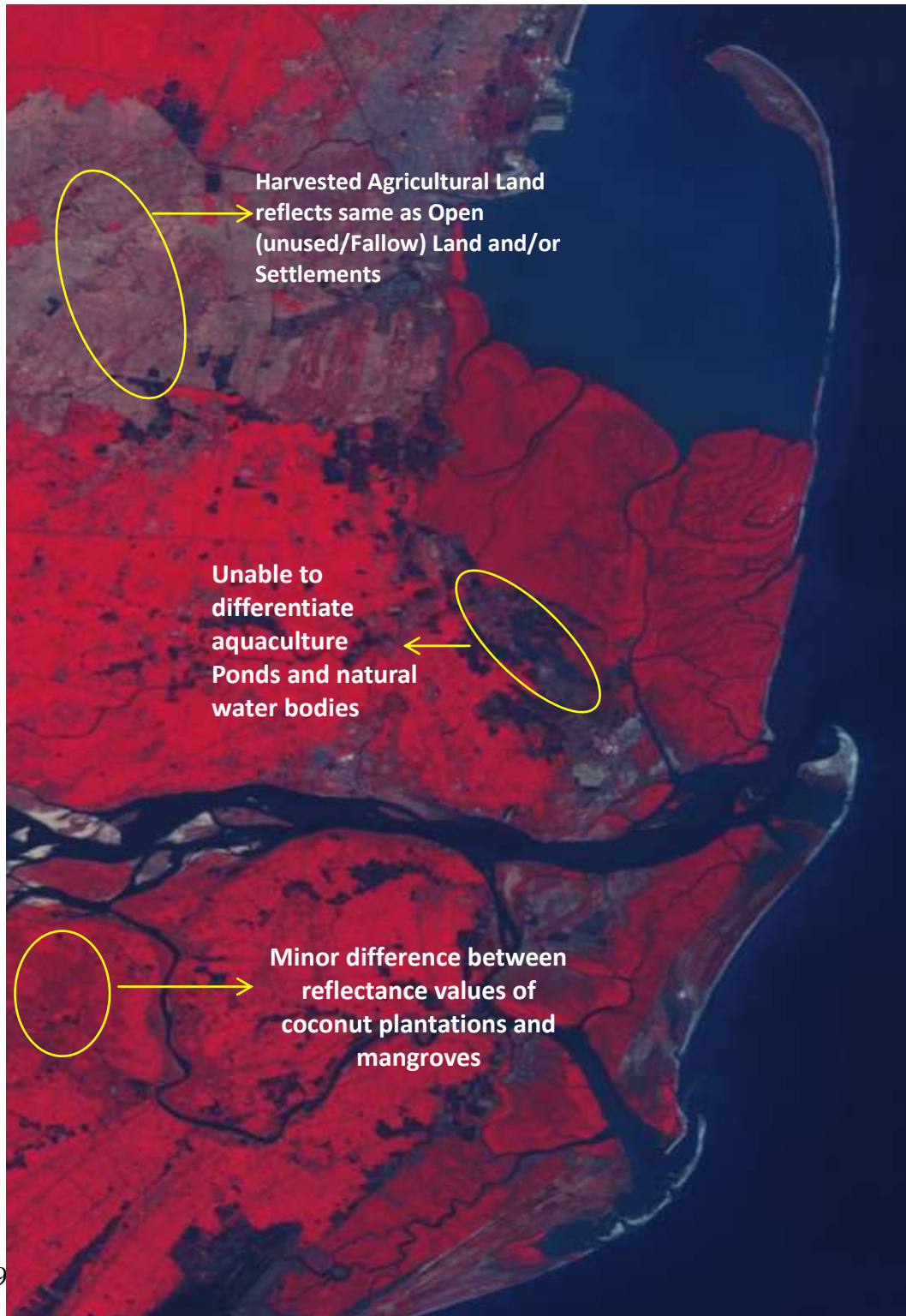


Figure 9

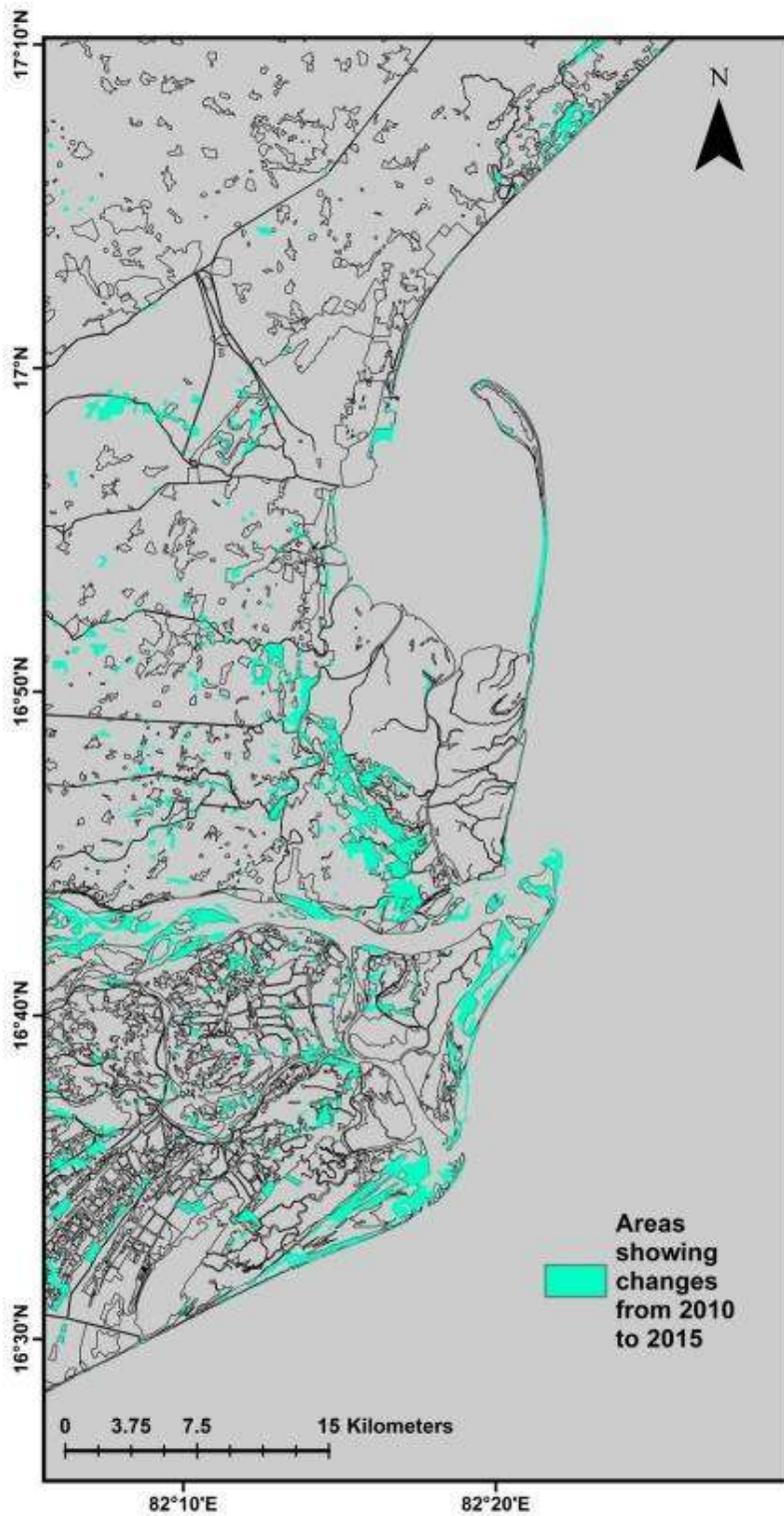


Figure 98. Map showing areas that showed changes in LULC between 2010 to 2015

Changes in Land cover which were driven by economic developmental activities were also observed (Figure 97 & 98). 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'.

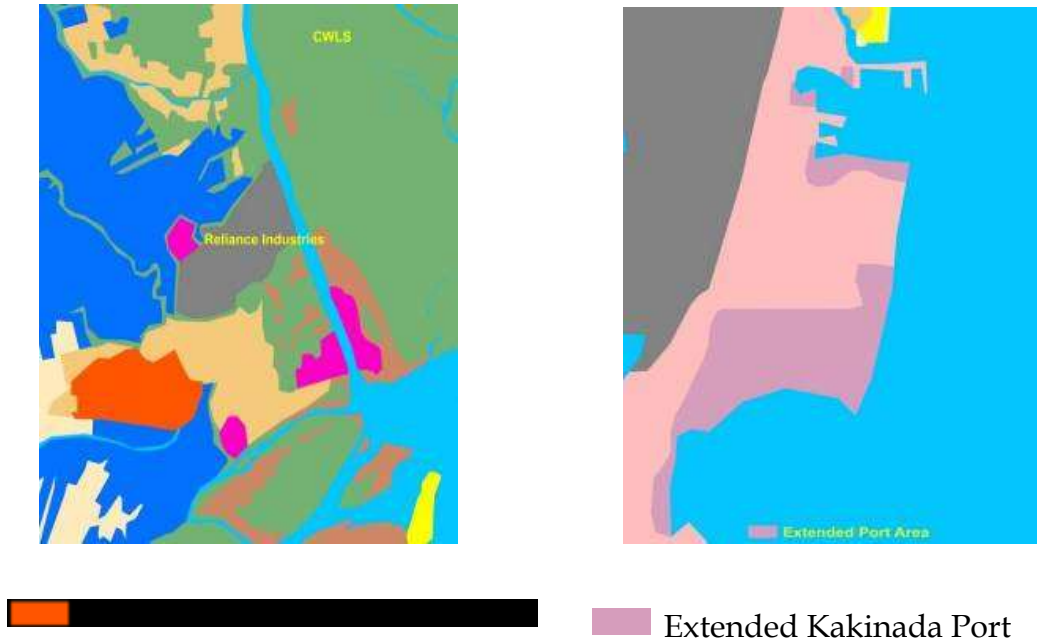


Figure 99. Change driven by economic developmental activities around the CWLS between 2010 and 2015.

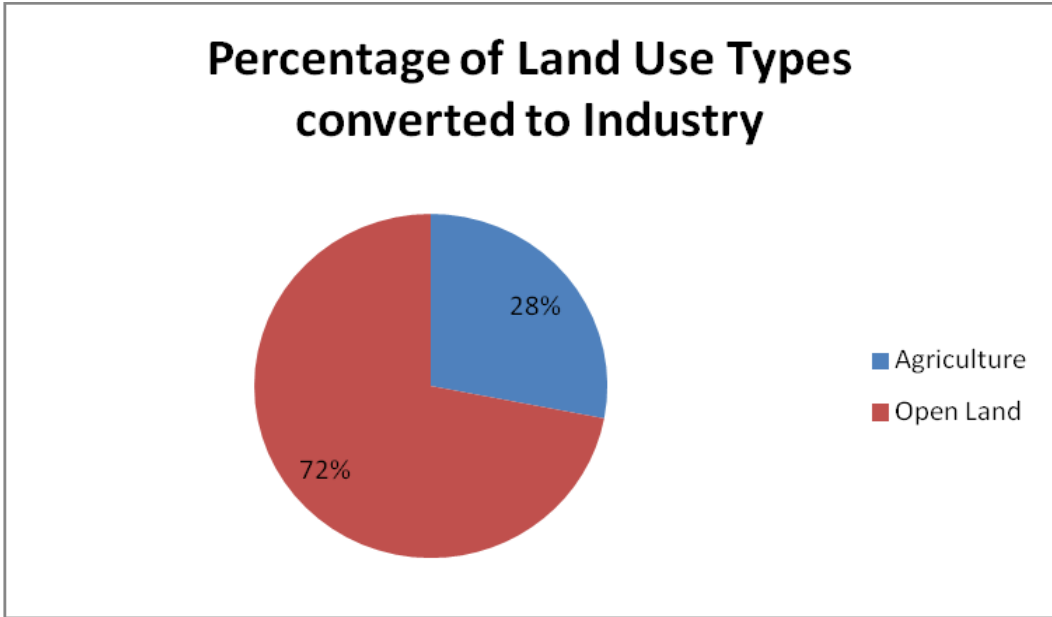
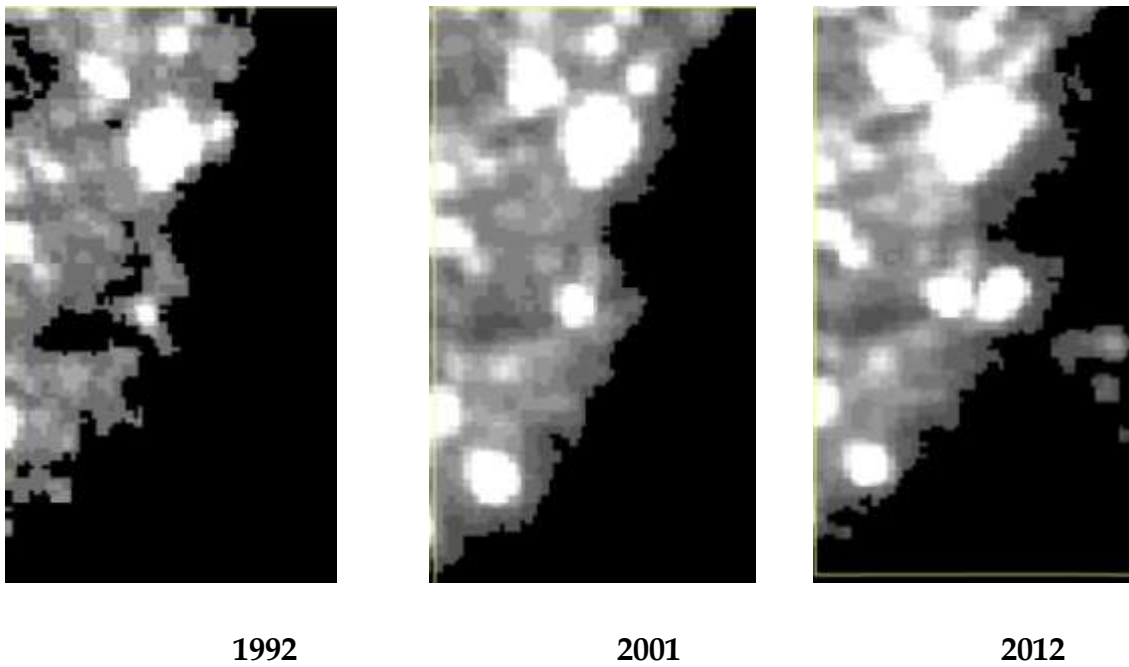


Figure 100. Percentage of land converted for developmental activities over last 5 years

Night Light reflectance data from NOAA was also used to assess the built-up area coverage over the EGREE landscape. It is assumed that as the built-up area coverage increases, the night light captured by the satellite would also increase.



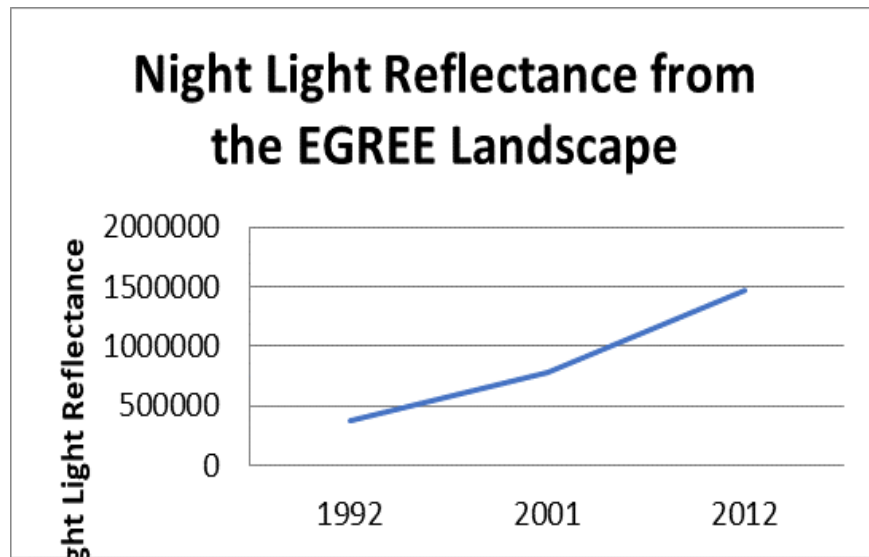


Figure 101: Graph showing the trend of rising night light areas

As is visible from the images of the night light data of the three years and as evident from the above graph, it can be safely said that the EGREE landscape has been experiencing a major increase in its night light reflectance. The increase is almost of about 300% (288%), i.e. the night light reflectance has increased three folds between 1992 and 2012.

The night light increase is a direct indication of the increase in the built-up areas on the landscape. In the last image, it may be noticed that a patch of night light has been reflecting from the bay area as well. It may be from the hope island and from the vessels which remain lighted throughout the night. So much of lighting in the night time may pose threat to the turtle nesting.

Climate change in EGREE

In the context of EGREE, there has been no systematic scientific work/documentation with respect to the impact of climate change on the estuary or the mangroves. However, the table below indicates the relevance of different weather phenomena to the various aspects of this important ecosystem.

Indicators - Weather/ Seasons	Relevance to CWLS: H/M/L/N A	Comment	Evidence/ Source	Confidence: H/M/L/NA
Precipitation	H	Main parameter for mangrove distribution and species assemblage.		H
Temperature	H	Temperature variations through seasons act as cues for flowering or fruiting in mangrove plants		H
Wind	M	The region is prone to strong winds and annual cyclones		M
Fog days	L	Insignificant	----	H
Humidity	L	Wetland areas have higher humidity in their related	Quantitative analysis of impact on	L

Indicators - Weather/ Seasons	Relevance to CWLS: H/M/L/N A	Comment	Evidence/ Source	Confidence: H/M/L/NA
		atmosphere	atmospheric humidity of wetland ecosystems with MODIS (Pong <i>et.al.</i>)	
Pollution levels (air/water)	H	Bird behaviour, breeding are known to be adversely affected by pollution. Aquatic animals are affected due to water pollution	Murlidharan (1993), Vijayan et al., (2006), MoEF report etc.	H

Observations on changes due to climate change in EGREE

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 some scientific literature which indicates changes in temperatures and sea level rise in the region.

Since our study period is very less for any climate change study, these observations cannot be implied to be direct evidences of climate change. Yet they provide firm

indication that the landscape of EGREE is indeed changing and impacts of such changes would be profound. Therefore, whether the reasons are climate change or any other phenomenon, mitigation and adaptive measures are important for the region.

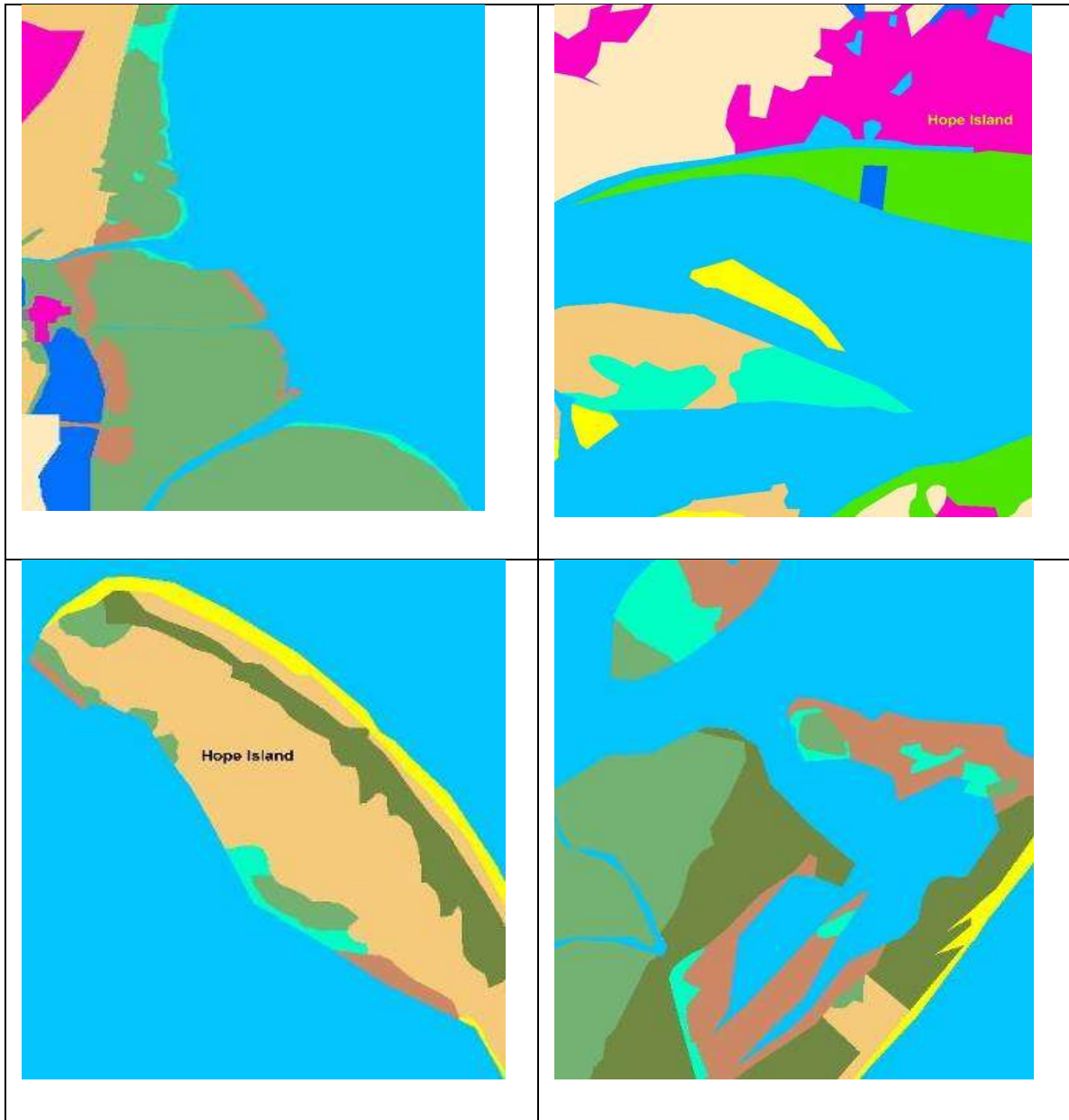
1. Changes in mangroves of CWLS

Some positive changes have been noted while analyzing the changes in the mangroves. About 2 sq.km of mangroves have stabilized on mud flats in the shore, which is a positive change (Figure 80). Recruitment seems to be high in the intertidal creeks inside CWLS. As per the locals several smaller creeks which existed few years ago are blocked; some smaller creeks which were used as navigation channels between the three bigger subtidal creeks inside the sanctuary are now completely closed.

In contrast to above, observations have been recorded in the seaward side of the Coringa WLS (Plate 4), where most of the sand is getting deposited on the mangroves and a landward movement of mangroves has been noted. Shoreline changes and accretion in Kakinada bay is due to sediment deposit from the Gaderu and Corangi rivers, especially during the high river discharge during the south-west monsoon season. Generally, these sediments are deposited up to 300 meters towards the bay. Likewise, gradual erosion has been observed from the tip of Hope Island up to the Nilarevu river mouth. At several places on this side mangrove tree diebacks as well as ingress of sand into the mangrove forests have been observed.

When comparing the data of 1950's it was observed that most of the mangroves here were dominated by 90% of *Avicennia officinalis*, which reduced to around 39% (Mathuda 1959). Moreover, the mangroves here are highly influence by silt discharge. 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 (Rao and Rao 1992).



Newly Formed Mangroves

Figure 102. Newly developed mangrove area around the CWLS between 2010 and 2015.



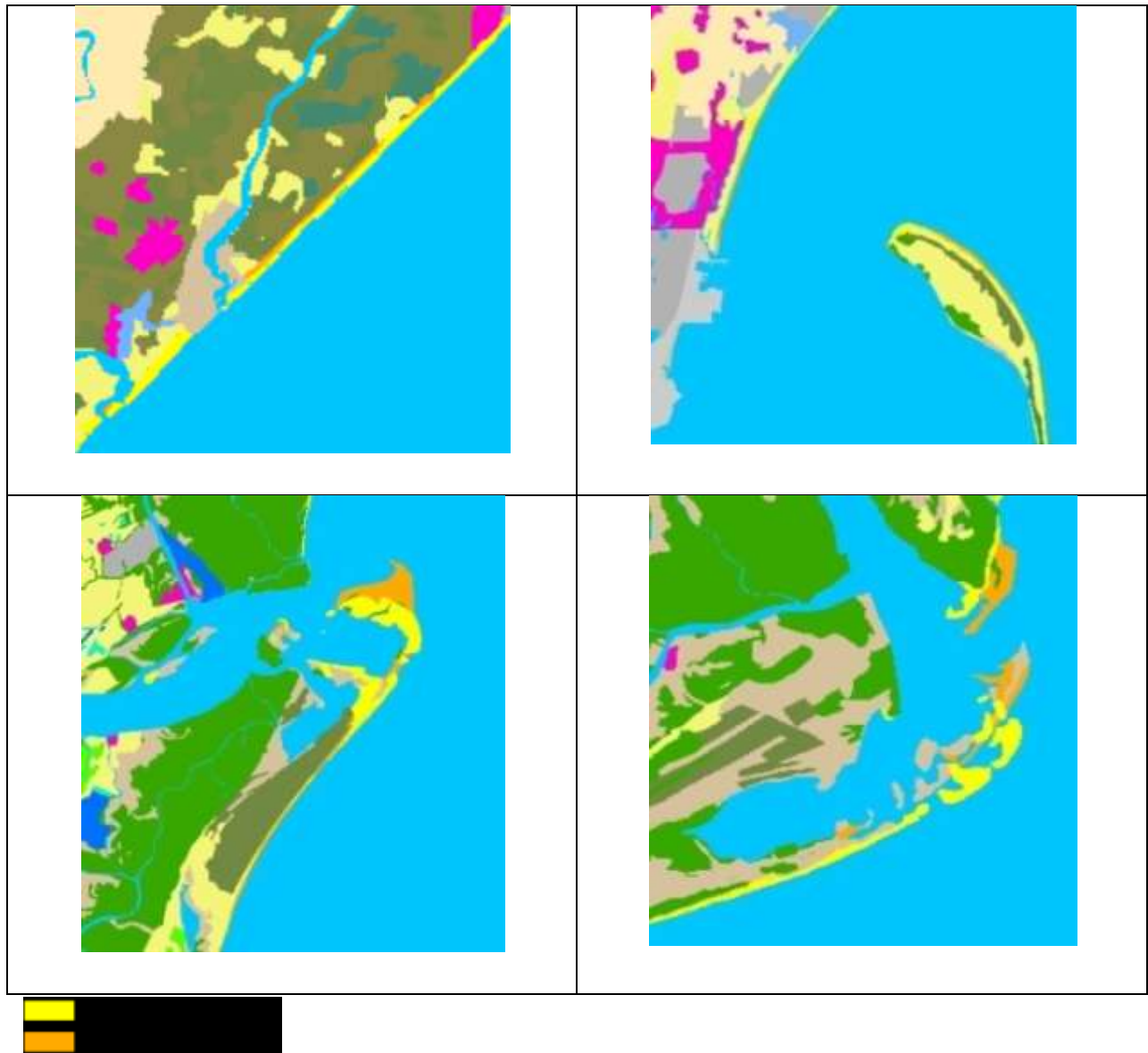
Figure 103: Shoreline changes seen in the eastern side of the Coringa Wildlife Sanctuary.

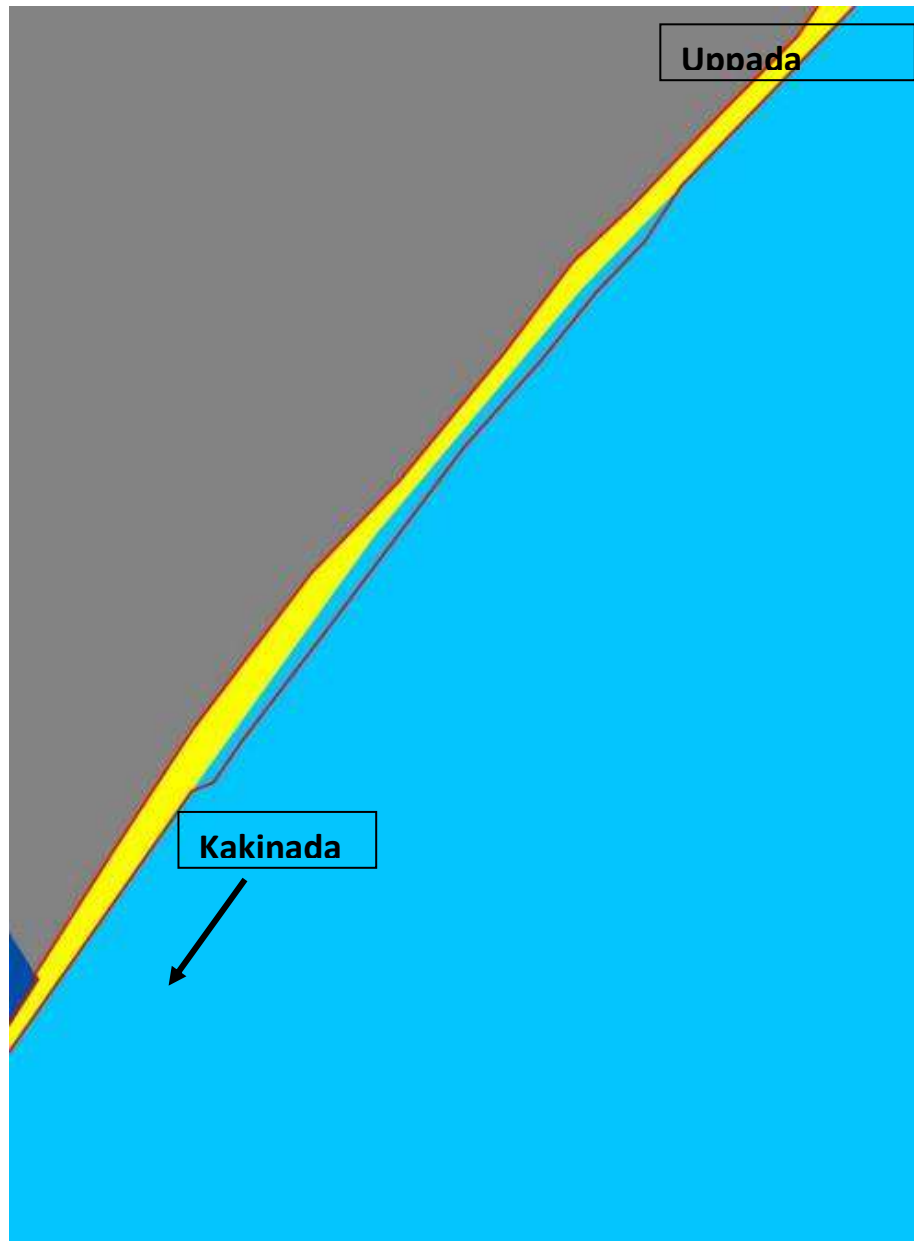


Figure 104: Mouth of the Pillarava kaluva in Coringa WLS

2. Changes in shoreline

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 (Figure 105 a,b,c,d). Though it may be due to erosion by wave action, sea level rise due to climate change also has a role. Barring few areas where new accretions have been observed, most of the shoreline particularly along CWLS, Hope Island and Sacramento Islands have been retreated.

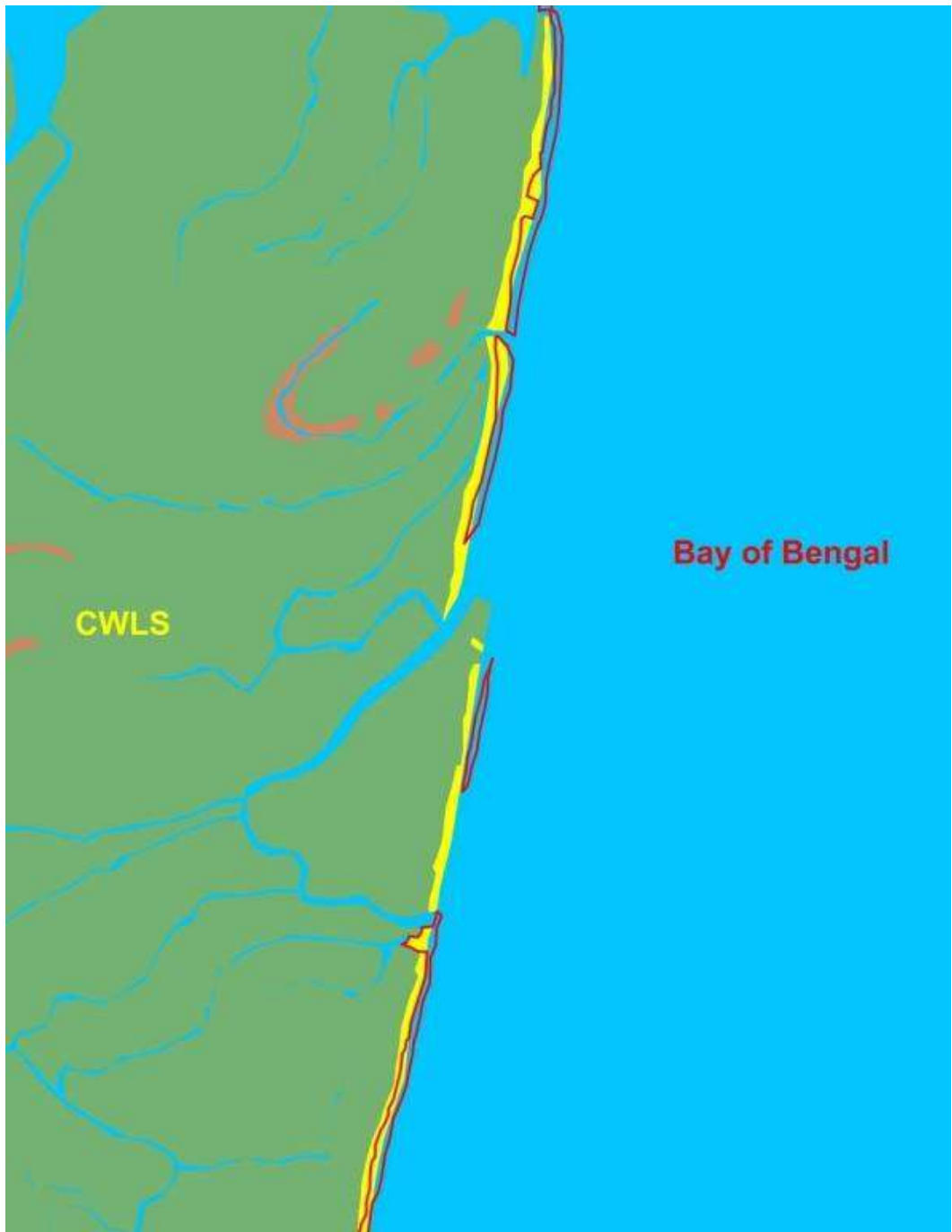




 Shoreline in 2010

 Shoreline in 2015

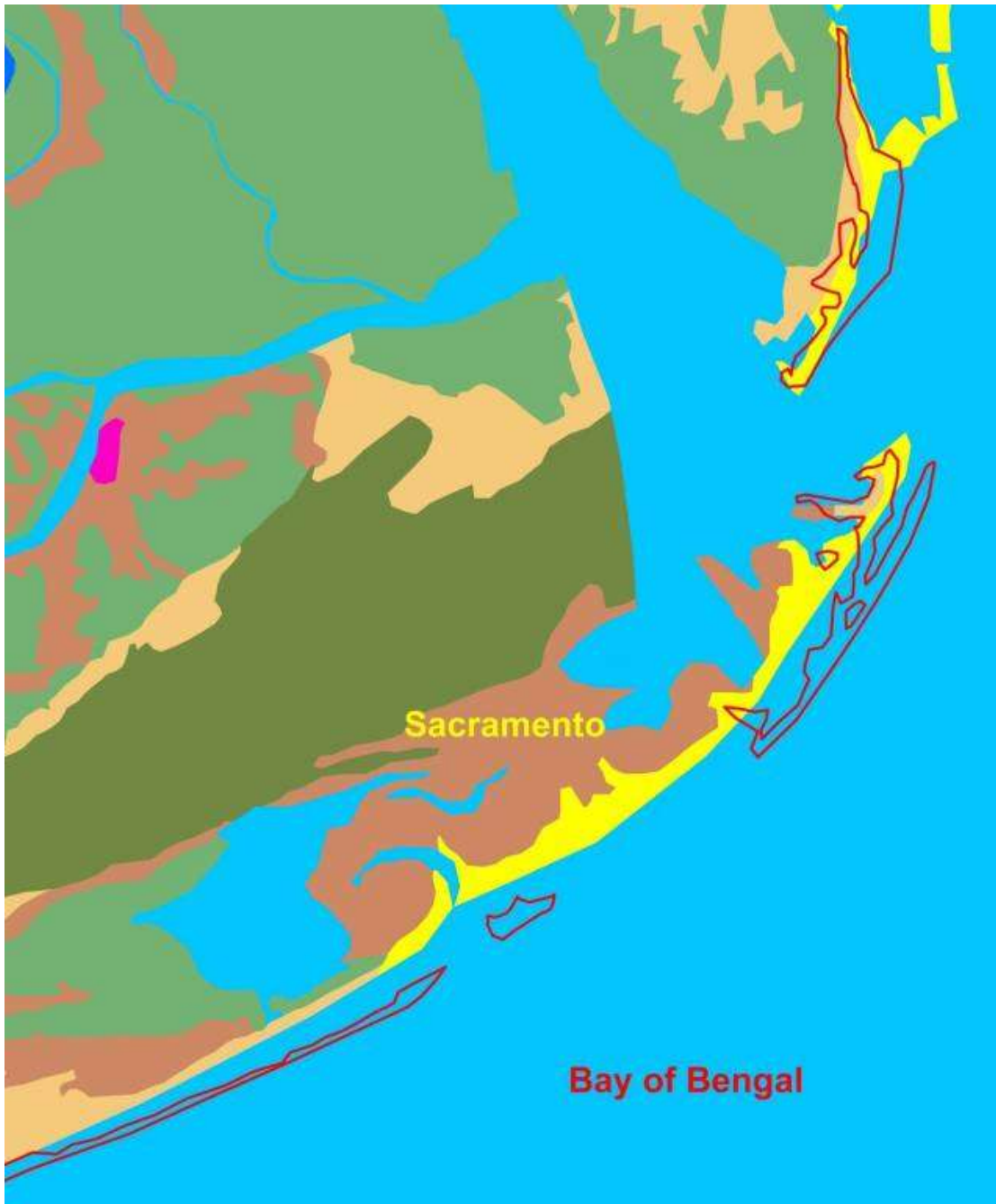
Figure 105a. Change in shoreline shift near Uppada village.



 Shoreline in 2010

 Shoreline in 2015

Figure 105b. Change in shoreline shift along the CWLS.



 Shoreline in 2010

 Shoreline in 2015

Figure 105c. Change in shoreline shift along Sacramento beach area.



Figure 105d. Change in shoreline shift along Hope island.

Trends in temperature and rainfall

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.

Trends in sea surface temperature and cyclone

In a review article by Mishra (2014), he analyzed the data of 122 years of tropical cyclones in India from 1891 to 2013. The results show that Bay of Bengal is a hotspot for cyclones in India and that the frequency and intensity of cyclones is increasing. Particularly in the east coast, i.e. 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 coast of Andhra Pradesh apparently has higher temperatures throughout the year.

Trends in sea level rise

Fang and Zhang (2015) analyzed sea level trends among three oceans, Pacific, Indian and Atlantic Oceans. Their study revealed that the mean sea level rise (MSLR) in Indian Ocean at 4.06 mm yr^{-1} is the highest among the three oceans. In another study on sea level rise in Indian coastal areas, it was found that the northern and eastern coasts of Bay of Bengal are experiencing the highest MSLR at 5 mm yr^{-1} or more.

The nearest tide gauge station to EGREE is Visakhapatnam which has recorded the net rate of MSLR at 0.69 mm yr⁻¹ for the period 1937-2000 while a 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. As per the previous study 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.

Predicting IULC in EGREE by 2030

Driving factors of change

The identified driving factors of change in LULC were tested for correlation among them. Initially mean precipitation data for all the months were used for analysis. But the precipitation layers showed correlation, hence finally precipitation for May and November were only chosen. The correlation matrix was prepared again and now no correlation among variables was observed (Table.19).

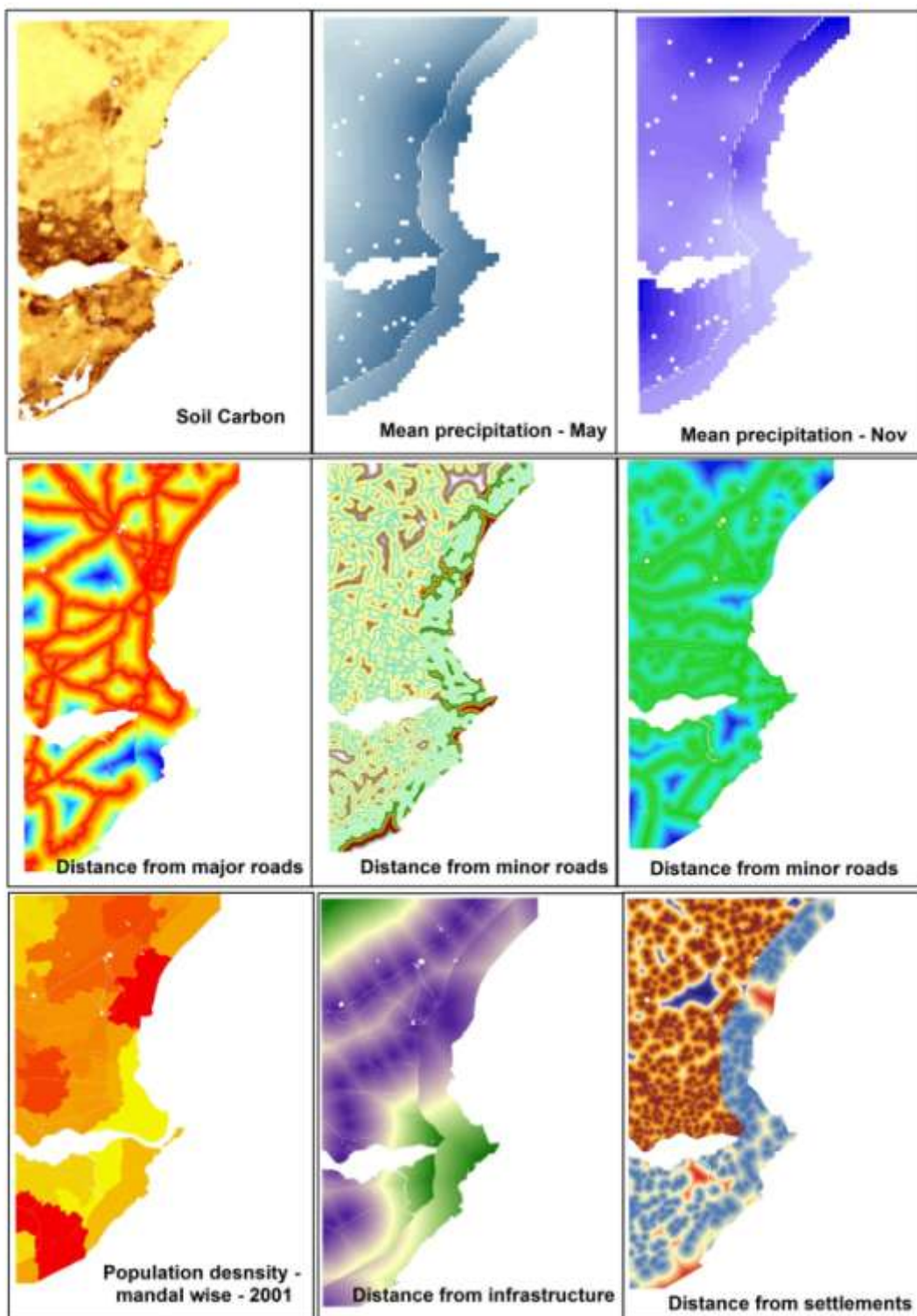


Figure 106: Driving factor maps

Table 19: Correlation matrix of the independent variables

Layer	1	2	3	4	5	6	7	8	9	10
8										
1	1.00000	1.00000	-0.53604	0.08560	0.19539	0.02167	0.32624	-0.01146	0.00676	
0.53033										
2	1.00000	1.00000	-0.53604	0.08560	0.19539	0.02167	0.32624	-0.01146	0.00676	
0.53033										
3	-0.53604	-0.53604	1.00000	0.05261	-0.00664	0.12920	-0.10156	-0.10331	-0.04620	-
0.22907										
4	0.08560	0.08560	0.05261	1.00000	0.02502	0.24722	0.19344	0.24700	0.01556	
0.01382										
5	0.19539	0.19539	-0.00664	0.02502	1.00000	-0.02747	0.06277	-0.18525	-0.57094	
0.04486										
6	0.02167	0.02167	0.12920	0.24722	-0.02747	1.00000	0.06228	0.08808	0.02250	
0.04234										
7	0.32624	0.32624	-0.10156	0.19344	0.06277	0.06228	1.00000	-0.11236	-0.00957	
0.08307										
8	-0.01146	-0.01146	-0.10331	0.24700	-0.18525	0.08808	-0.11236	1.00000	0.09105	
0.07853										
9	0.00676	0.00676	-0.04620	0.01556	-0.57094	0.02250	-0.00957	0.09105	1.00000	
0.22354										
10	0.53033	0.53033	-0.22907	0.01382	0.04486	0.04234	0.08307	0.07853	0.22354	
1.00000										

Mutli-Regression analysis

The different land use categories which were expected to change from one land sue to another were tested for their dependence on the independent variables through multi regression analysis (Table.20).

Table 20: Multi-regression analysis of dependent variables with independent variables

Dependent variable Vs independent variables	Agriculture	Aquaculture	Built up	Open Land	Coconut Plantations
Dist from major road	-0.427	0.011	0.00059	0.005	0.03
Dist from minor road	-0.45	0.056	0.048	0.0007	-0.354
Dist from settlements	-0.0023	0.014	0.08	0.001	
Dist from infrastructure			0.027	0.008	
Dist from aquaculture		0.466			
Dist from forest edge		0.257			
Dist from canal	0.428	0.003			
Population density					
precipitation - may	0.253				0.22
precipitation - november	1.17				
Soil Carbon	0.341	0.003			0.56

Model Validation

The following ROC values were achieved for the respective models and area subsets:

Table 21: ROC values for each subset

Subset	MLP	MARKOV without MCE	MARKOV with MCE
Near Shore ecosystem	0.926	0.933	0.938
Agricultural ecosystem	0.878	0.886	0.896
Agro-plantation ecosystem	0.63	0.628	0.665

Based on Table.21, the best fit model was used for modeling final prediction maps for each area subset.

Prediction mapping

Using the trained models, 2015 LULC layer was used for predicting the 2029 LULC map.

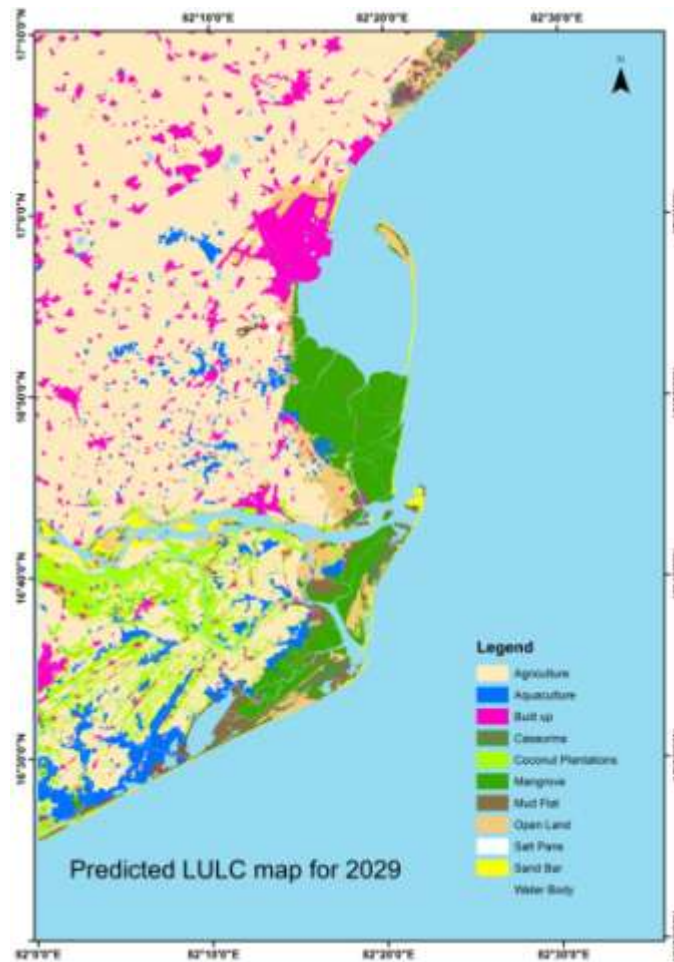


Figure 107: Predicted LULC map for 2029

Conclusion

Land use/land cover mapping forms an important and indispensable aspect of any ecological study for better spatial planning, development, and nature conservation. Through this study, clear demarcation has been made on the status of the mangrove cover and the adjoining land use types in the landscape. 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. Later, these degraded mangroves became more vulnerable for conversion to other land use types.

This study found that all degraded mangroves around the Coringa Wildlife Sanctuary are vulnerable for encroachment and conversion to other land-use types, therefore, it is recommended to restore these mangroves as early as possible and annex as an Eco-Sensitive Zone of the Sanctuary. The information generated is expected to be baseline for the long-term monitoring of this seascape/landscape for future planning in this region. This study also revealed that the visual interpretation technique for mapping of coastal landscapes would be better to understand the land use pattern more accurately, which would ultimately help for the long-term conservation planning of threatened mangrove habitats.

This study provides an up to date information on the changes in the vegetation/land use types in the landscape. The annual rate of loss of mangrove cover (-0.22%) reported in this study is comparable to the loss reported by Vadlapudi (2003), who also adopted visual interpretation technique for image classification. Results in the present study showed that, about 40% of mangroves lost were outside protected area. It is evident from this study, that the spread of aquaculture and built up areas in the landscape has increased vastly over the years, with increasing intensity in the recent past. Both

aquaculture and built up spaces have compromised on agriculture land. From the field surveys, it can be predicted that the built-up spaces in the landscape would see a rise in coming years. A significant area of mangroves outside the protected area would also converted to aquaculture ponds if corrective measures are not taken now.

Intensification of aquaculture ponds in the landscape is expected to have detrimental effects on the stability of the ecosystems in the landscape as intense aquaculture is expected to affect both soil and water salinity regime as well as the livelihood pattern. Therefore, the remaining mangrove patches outside protected areas must be given consideration as they play a significant role in maintaining the salinity and moisture content of the soil and ground water. The information from this study is expected to provide the prevailing land use change pattern in the landscape and help in better management decisions. Since on screen visual interpretation was used for mapping in this study, it would be easy to update the vegetation/land use type for the future years. It would facilitate rapid monitoring of this dynamic landscape.

Based on the model performance for LULC prediction mapping it may be suggested that dividing the landscape into subsets of homogenous data and processing the subsets with relevant driving factors with respect to the subset not only makes the process simpler and easier but also gives more accurate results. Comparing the models that were used in the study, CA_Markov model performed better with transition potential prepared using the Multi-Criteria Evaluation (MCE) module which in turn uses the Analytical Hierarchy Process for weighting each driving factor. It may be said that the CA_Markov model in conjunction with MCE performed better when compared to the Multi-Layer Perceptron model as the former provides the scope for weighting the driving factors against each other and thus gives greater power to the modeler to rate the influence of each variable based on field knowledge.

As the predicted LULC map for 2029 shows, the remaining 18 Km² mangroves outside the protected area are expected to be converted to aquaculture or cleared for other land use purposes. At the same time, further increase (56%) in the built-up spaces may be

expected. Reduction in the natural ecosystem and increase in population may add to the existing pressures on the landscape. The sprawl of aquaculture ponds which have already caused increased salinity in the ground water and streams from the run off, will cause further rise in salinity. At the same time, failing crops due to saline soil, and reducing yield from estuarine fishing will encourage/force more farmers and fishermen to take up aquaculture, feeding the loop of sprawling aquaculture.

For maintaining the health and stability of the landscape, which comprises of dynamic ecosystems experiencing rapid changes, regular monitoring is necessary. Modeling scenarios and predicting possible LULC maps for future will act as warning and inform the policy makers and stake holders about the land use conversion potentials. Information on the transition potentials will provide significant clue about the detrimental effects of present activities in the landscape.

VULNERABILITY ASSESSMENT OF EGREE AND ITS BIODIVERSITY

IPCC in 2001 defines Vulnerability as “the extent to which a natural or social system is susceptible to sustaining damage from climate change. Vulnerability is a function of the sensitivity of a system to changes in climate (the degree to which a system will respond to a given change in climate, including beneficial and harmful effects) and of the adaptive capacity”.

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.

Wachenfeld et al. (2007) derives from the IPCC definition and gives following three components of Vulnerability: Exposure, sensitivity, and adaptive capacity. Lardy et al. 2012 have tried to explain the three terms which are discussed below:

- a) **Exposure:** When a system is affected by a certain disturbance or stress with high probability, the exposure of that system will be high to that disturbance. So in our study exposure can be the degree and nature of changes in the ecosystem due to such disturbances or stresses. It can be influenced by both climatic factors (GHG concentrations, temperature rise etc.) as well as non-climatic factors (land use changes, demography, economical factors etc.).
- b) **Sensitivity:** Sensitivity is the degree to which a system is affected, adversely or beneficially, by climatic stimuli. The sensitivity of a system becomes particularly important when substantial changes in the system arise for low levels of climatic

changes. Mostly they are more influenced by non-climatic stressors which increase sensitivity of a system to the effects of climate change.

- c) Adaptive capacity: It is the ability of the ecosystem to adjust to or mitigate the disturbances to decrease its vulnerability. In present scenario, mitigation mainly focuses on reducing the emissions of GHGs and increasing their sinks. On other hand adaptation mainly relies on the acceptance of the negative impacts of climate change and to reduce such impacts.

Lardy et al. (2012) believes that 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.

As discussed in Chapter 10, in a coastal ecosystem which is naturally so complex and dynamic various factors and externalities work synergistically to produce an impact. Therefore, in such a complex ecosystem it becomes extremely difficult to separate the changes and impacts due to climate change from those of other anthropogenic disturbances as well as natural variations. This issue has also been highlighted in the IPCC's AR5 where they accept the high uncertainties in predicting the impacts of climate change except for changes in species distribution (which is usually at a larger spatial scale) and melting of snowcap and glaciers.

In the following sections, therefore, the major threats apart from climate change are identified and listed out for 6 different groups of organisms found in EGREE. In next step, the relevant threats for each group of organisms are identified. These threats are then used to assess the vulnerability of each group. This exercise will not just help in identifying the most important threats to the flora and fauna of EGREE but also will help to understand to a certain extent the role of climate change in bringing changes in these groups.

Threats to EGREE

Based on the Land Use Land Cover map and Land Use change analysis complemented with our field survey, following threats have been identified which are or might have negative impacts on this estuarine ecosystem and its biodiversity:

1. Aquaculture pond proliferation around the mangrove forests with no buffer
2. Coastal development and urban sprawl
3. Unsustainable fishing practices, both inland and offshore
4. Over exploitation of resources such as fuel wood, crabs, shells etc.
5. Decrease in freshwater and sediment flow due to various reasons, most important being upstream barriers such as dams.
6. Water pollution
7. Cattle grazing inside the mangrove forests
8. Plantation of Casuarina and Coconut
9. Natural gas exploration and dredging activities inside as well as around the mangroves
10. Expansion of port and shipping activities
11. Invasion of exotic species both in mangrove forests and the aquatic habitats
12. Tourism
13. Natural calamities such as cyclones, storms, etc.
14. Mean sea level rise
15. Increase in surface temperatures
16. Increase in salinity
17. Increase in ocean acidification

Species Vulnerability Index

Six groups of organisms 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. The six groups of organisms are Mangroves, Mangrove-

associated molluscs, Commercial estuarine fishes, Sharks and Rays, Shorebirds, and Terrestrial mammals found in the mangroves of EGREE.

Vulnerability of EGREE to each threat was assessed using Species Vulnerability Index which is based on Wachenfeld *et al.* (2007). Wachenfeld *et al.* (2007) describe vulnerability as a function of three elements: exposure, sensitivity, and adaptability (including resistance and resilience). The method employed is a qualitative method to help in identifying the most serious and immediate threat 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.

For each threat, the group's Exposure and Sensitivity were assessed using four categories 'Very high', 'High', 'Moderate' and 'Low'. Subsequently, adaptive capacity of the group is then assessed for 2 situations- without any management interventions and with management interventions. Adaptability is categorized in three classes as 'Good', 'Moderate' and 'Poor'.

If the system is having high probability to get exposed to a threat coupled with high sensitivity and poor adaptability, such a threat will have serious implications on the system and hence needs immediate attention. But on other hand, the probability of exposure to a threat is low and sensitivity (if exposed) is high and the adaptive capacity is poor, such a threat will also increase the vulnerability of a system to negative impacts. Uncertainties in response of the ecosystem to a threat should also be treated seriously as they add to vulnerability of a system due to lack of knowledge.

Table 22: Vulnerability assessment of mangrove forests in EGREE

	Threats/pressures	Degree of Exposure	Sensitivity	Adaptive capacity-natural	Adaptive capacity-management	Residual vulnerability
1	Expansion of aquaculture ponds	V. High	V. High	Poor	Good	Very high
2	Timber collection	Moderate	Moderate	Moderate	Good	Moderate
3	Cattle grazing	Moderate	High-impacts recruitment and regenerative capacity	Moderate	Good	High
4	Sea-level rise	High	High	Poor - obstructions to landward migration	Moderate	Very high
5	Increase in salinity	Poor	Moderate	Poor	Moderate	Moderate
6	Decrease in freshwater/sediment flow	Poor, might increase in future due to Polavaram dam	High	Poor-because freshwater is essential for regeneration and recruitment of mangroves	Moderate-uncondition of minimum environmental flow from proposed dams	Moderate
7	Water pollution	High	Low (uncertain)	Moderate(uncertain)	Good	Moderate
8	Expansion of port and shipping activities	Low	Moderate	Poor	Good	Low

9	Natural gas exploration and dredging activities	High	Very high	Poor	Good	High
10	Coastal development	High	High	Poor	Good	Very high
11	Natural calamities such as cyclones, storms, etc.	High	Moderate	Moderate	Moderate	Moderate
12	Tourism	Low	Low	Good	Good	Low
13	Invasion of exotic/terrestrial vegetation	High	High	Moderate- depending on the condition of their habitat	Good	High

Table 23: Vulnerability assessment of malacofauna in EGREE

	Threats/pressures	Degree of Exposure	Sensitivity	Adaptive capacity-natural	Adaptive capacity-management	Residual vulnerability
1	Expansion of aquaculture ponds	Moderate	Moderate	Poor	Good	Moderate
2	Timber collection	Moderate	Moderate	Moderate	Good	Moderate
3	Cattle grazing	Low	Moderate	Moderate	Good	Low
4	Sea-level rise	High	Moderate	Poor - especially for mangrove-associated mollusks	Poor - especially for mangrove-associated mollusks	High
5	Increase in salinity					
6	Decrease in freshwater/sediment flow					
7	Water pollution	High	Very high	Poor	Good	High
8	Expansion of port and shipping activities	Moderate	Moderate	Poor	Good	Moderate
9	Natural gas exploration and dredging activities	Low - since these activities are located away from the good populations	Low	Good	Good	Low
10	Coastal development	High	High	Poor	Poor	Very high

11	Natural calamities such as cyclones, storms, etc.	Low	Moderate	Moderate	Good	Low
12	Tourism	Low	Low	Good	Good	Low
13	Shell collection	Very high	High	Poor - due to long-term exploitation without regulation	Moderate	Very high
14	By-catch	High	High	Poor - since there is no regulation on by-catch and benthic trawling	Moderate	Very high

Table 24: Vulnerability Assessment of Shorebirds in EGREE

	Threats/pressures	Degree of Exposure	Sensitivity	Adaptive capacity-natural	Adaptive capacity-management	Residual vulnerability
1	Expansion of aquaculture ponds	High	High	Moderate	Good - under proper management scenario, abandoned or temporary aquaculture ponds can acts as good alternate habitats/feeding grounds for waders, especially during the peak migratory season in winters.	Moderate
2	Timber collection	Low	Low	Good	Good	Low

3	Cattle grazing	Low	Low	Good	Good	Low
4	Sea-level rise	Very high	Very high	Poor	Poor	Very high
5	Increase in salinity	High	High - high salinity will bring changes in prey abundance	Moderate	Moderate	High
6	Decrease in freshwater/sediment flow	High	High	Poor	Moderate	High
7	Water pollution	Moderate	High	Poor	Moderate	High
8	Expansion of port and shipping activities	Moderate	Moderate	Poor	Moderate	Moderate
9	Natural gas exploration and dredging activities	High	High	Poor	Moderate	High
10	Coastal development	High	High	Poor	Poor	Very high
11	Natural calamities such as cyclones, storms, etc.	Moderate	Moderate	Moderate	Moderate	Moderate
12	Tourism	Low	Low	Moderate	Good	Low

13	Fishing pressure	Medium	Moderate	Moderate	Moderate	Low
			High - Since shell collection occurs near the best feeding grounds for waders in the			
14	Shell collection	Medium	estuary.	Moderate	Good	Moderate

Table 25: Vulnerability Assessment of Sharkes, Rays and Skates in EGREE

	Threats/pressures	Degree of Exposure	Sensitivity	Adaptive capacity-natural	Adaptive capacity-management	Residual vulnerability
1	Off-shore fishing	High - mainly for manta and mobula rays which are hunted for export to other countries	High - since all these species are threatened	Poor	Moderate - since the Ray populations take lot of time to recover.	Very high
2	Estuarine/coastal fishing	Moderate - but high for threatened species	High	Poor	Moderate	Moderate
3	By-catch	High	High	Poor	Moderate	Very high
4	Climate change	Very high	High	Poor	Poor	Very high
5	Water pollution	High	High	Poor	Moderate	High
6	Expansion of port and shipping activities	High	High	Poor	Moderate	High
7	Natural gas	High	High	Poor	Moderate	High

	exploration and dredging activities					
8	Coastal development	High	High	Poor	Moderate	High
9	Natural calamities such as cyclones, storms, etc.	Low	Low	Good	Good	Low
10	Tourism	Low	Low	Good	Good	Low
11	Decrease in freshwater/sediment flow	Moderate - might have indirect effects due to decrease in transport of nutrients from catchment areas	Moderate - only indirect effects	Moderate	Good	Moderate

Table 26: Vulnerability Assessment of Terrestrial Mammals in EGREE

	Threats/pressures	Degree of Exposure	Sensitivity	Adaptive capacity-natural	Adaptive capacity-management	Residual vulnerability
1	Aquaculture ponds	High	High	Moderate	Good	High
2	Habitat degradation and destruction	High	V.high	Poor (uncertain)	Good	Very high
5	Increase in salinity	High	Very high	Poor	Moderate	High
6	Decrease in freshwater/sediment flow	High	Very high	Poor	Moderate	High
7	Water pollution	Very high	Very high	Poor	Moderate	Very high
8	Expansion of port and shipping activities	Moderate	High	Moderate	Good	Moderate
9	Natural gas exploration and dredging activities	Moderate	High	Moderate	Good	Moderate
10	Coastal development	Very high	High	Poor	Good	High
11	Natural calamities such as cyclones, storms, etc.	Moderate	Moderate	Good	Good	Low
12	Tourism	Low	Moderate	Moderate	Good	Moderate

1						
3	Fishing pressure	High	High	Moderate	Good	High

Discussion

Expansion of aquaculture ponds is a major threat to the mangrove forests of EGREE, particularly for the patches that are outside the protected areas. The Land Use Land Change analysis also shows that several parts of mangroves are highly vulnerable to the expansion of aquaculture ponds around them. Therefore, for mangroves aquaculture ponds are presently a major threat along with coastal development and sea level rise.

Malacofauna such as gastropods and bivalves in the Kakinada Bay are important source of livelihood for number of people in the region. As it has been observed in the estuary, shell collection is commonly practiced inside the sanctuary often with no regulation. Available literature suggests that bivalves such as *Placuna placenta* which was once abundant in the bay have reduced in numbers due to over-exploitation. Gastropods and bivalves are also a major constituent of the by-catch that is generated due to benthic trawling practiced in Kakinada Bay. Over-exploitation and by-catch are the biggest threats to malacofauna in EGREE along with coastal development that leads to degradation of their habitats.

By-catch is also a major threat to elasmobranchs present in EGREE. A visit to the local fish markets or landing centers will reveal the large numbers of sharks and skates caught as by-catch in the region. Though a systematic evaluation of the catch of elasmobranchs could not be made during this project, sharks form an important part of the by-catch. The mobula and manta rays are targeted in the off-shore waters for their gill plates that are exported to other parts of the country and other countries.

Coastal development has been identified as a high-risk threat to many taxa in EGREE. Kakinada is an industrial port city that is under lot of pressure due to the need of increased economic development in the state. It is also being developed into a 'Smart City' by the central government which would attract more construction and industrialization in the region. However, there are no proper regulations to limit the impacts of coastal development on the fragile natural ecosystems of EGREE. Since the threat of climate change is real in the region, it is important to ensure the developmental activities do not compromise the various ecosystem services and goods provided by these natural ecosystems.

Since mangroves are among the best coastal defences, the mangroves around Coringa WLS must be declared either as the eco-sensitive zone of Coringa WLS or a conservation reserve so that the necessary management interventions can be made to restore and maintain these mangroves habitats. It is also suggested that both the banks of the river (with a width of 50 m) from the Polavaram dam site to the Godavari estuary be declared an ecosensitive zone. A green belt needs to be developed along the river using only native plants in this ecosensitive zone without disturbing its natural landscape.

Climate change adaptation and mitigation measures in EGREE

In its fifth assessment on climate change, IPCC confirmed that human-induced global warming is happening now and will have dramatic consequences for both natural and human systems. 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 CO₂. It was believed that mitigation would address the problem at the source, therefore it was accepted as the most efficient and cost-effective strategy (Fussler and Klein, 2006; Fussler, 2007). However the recent spate in extreme climatic events 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 as well as other climatic events across the world has brought forth the need to develop adaptive mechanisms as tools to tackle the impacts of climate change.

The definition of 'adaptation' and 'mitigation' by IPCC (2007) is given below:

Mitigation: An **anthropogenic** intervention to reduce the anthropogenic forcing of the **climate system**; it includes strategies to reduce **greenhouse gas sources** and emissions and enhancing **greenhouse gas sinks**.

Adaptation: Adjustment in natural or **human systems** in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Various types of adaptation can be distinguished, including anticipatory, autonomous, and planned adaptation:

Anticipatory adaptation – Adaptation that takes place before impacts of **climate**

change are observed. Also referred to as proactive adaptation.

Autonomous adaptation – Adaptation that does not constitute a conscious response to climatic stimuli but is triggered by ecological changes in natural systems and by market or **welfare** changes in **human systems**. Also referred to as spontaneous adaptation.

Planned adaptation – Adaptation that is the result of a deliberate policy decision, based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve a desired state.

The global debate regarding the reduction in emissions of greenhouse gases has led to skepticism about the efficacy of the global mitigation efforts (Pielke, 1998). It has also become clear now that even with great successes in reducing GHG emissions, climate change will continue and its impacts would still be felt (Martin *et al.* 2015). Moreover, adaptation measures can be easily implemented at a more local-scale with relatively rapid results, whereas mitigative measures require increased global cooperation and have multiple agencies and socio-economical systems involved. For a developing economy such as that of India, which has more than 1.2 billion people and whose economy is still largely dependent on agriculture, climate change will have severe consequences. Therefore, an integrated climate change policy is important with a balance between both mitigation and cost-effective adaptation measures.

This chapter mainly focuses on the importance of adaptation, the different approaches, and concepts of climate change adaptation. Finally based on literature survey, various adaptive measures relevant to coastal ecosystems will be discussed.

Three main approaches to climate change adaptation

As discussed by Martin *et al.* 2015, three main approaches have shaped the policies on climate change adaptations which are discussed below:

1. **Hazards Approach:** This approach focuses primarily on increased risk of atmospheric, geological, and other natural disasters, and response and recovery to such disasters. It emphasizes on preparation of social and natural systems to such rapid-onset natural events as opposed to slower-onset events, precisely due to which this approach has been criticized as it tends to portray these disasters to be caused by external forces with minimum or no role of the human systems (Dekens, 2007; Martin *et al.* 2015). It focuses more on disaster relief management which in recent times has progressed towards preventive and anticipatory measures (Wilkinson 2012).
2. **Vulnerability Approach:** This approach focuses on identifying and reducing the vulnerabilities of natural as well as human systems to climate change. Vulnerability which is the “*propensity or predisposition to be adversely affected*” can vary with different sites or situations. It not just relates to the risks from imbalance in natural systems or natural disasters but other factors such as demography, social issues, economic status etc. also adds to the vulnerability (Kozel *et al.* 2007). In an example cited by Martin *et al.* (2015) from South Asia (Moench and Dixit, 2004), the study showed that some prosperous farmers who were dependent on resources unavailable during droughts were more vulnerable than the low-income farmers who diversified their livelihood options and therefore were more adaptable to adverse impacts of droughts.
3. **Resilience Approach:** Resilience is defined by many as the capacity of a system to maintain or revert to a state of equilibrium following a shock or stressful event. It mainly derives from the field of ecology and builds on the previous two approaches to climate change adaptation. Instead of the victims-orientation of vulnerability approach it focuses on the inherent adaptive capacity of the various

systems (Martin et al. 2015). However as in case of hazards approach it may lead to short-sighted planning and policies which focus mainly on emergencies (Davouli 2012) but ignore the incremental risks. This led to the idea of evolutionary resilience which accepts the dynamism and complexities (Kinzing et al. 2006) inherent in the various natural and social systems and so leaves room for adapting to changing circumstances (Adger 2010; Davouli 2012, Shaw 2012).

In most cases, climate change adaptation measures are often combination of two or more approaches discussed above.

Climate change adaptation in coastal cities

The first and most profound impacts of climate change will be on the coastal cities and communities. India has a long coastline of more than 7500 km which includes 9 states and 4 union territories. An estimated population of 171 million is present in 73 coastal districts, out of which the population of East Godavari district is 51, 51549 (Census, 2011).

Adaptation measures in coastal cities can be categorized into 2 types: 'hard measures' (engineering structures such as seawalls, storm surges, dykes, and bulkheads) and 'soft measures' (natural systems such as beaches, salt marshes, mangroves, coastal forests etc.). Hard measures are more popular choices in the major Indian coastal cities to prevent damages from natural hazards including climate change and they have proved to be highly effective in many cases. However, they entail high construction and maintenance costs and if they fail, they can instead exacerbate problems of coastal erosion (Brown et al. 2011, Stancheva et al. 2011). As an example, seawalls and bulkheads tend to intercept wave energy which increases soil erosion at their bases rendering them to be weak and decrease their potential to protect from storms or coastal floods. Similarly, jetties which protect harbors and act as anchoring points for fishing boats and other vessels can also lead to increased erosion (Rosenzweig et al.

2011). So, keeping these issues in mind the role of natural ecosystems in protecting (and mitigating) against the impacts of climate change has become highly important, especially in coastal landscapes.

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 salt marshes and 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. Similarly, salt marsh accretion is projected to increase in line with rise in sea levels at the rate of 5 mm per year (Temmerman, 2009). The existing natural ecosystems require minimum maintenance and therefore, costs are highly reduced. 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.

East Godavari district is already enduring most 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. In future, such natural hazards are projected to increase in frequency as well as intensity, especially cyclones. Another sign of climate change impacts is the effect on the Kakinada-Pithapuram Beach road which bears the constant brunt of strong waves and thus needs repairing every monsoon season. Our study has clearly indicated the shoreline changes which is occurring along this road which implies its vulnerability in the future. The mangroves of Coringa WLS also are showing signs of landward migration with erosion and intrusion of sand in the seaward side.

These are few and obvious symptoms of the level of stress existing in this landscape, which might be increased in near future due to increased developmental activities in

Kakinada after being declared as one of the first few cities in India to be a 'Smart City'. 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. To be climate-ready it is important to understand the important role of rich biodiversity of this district in protecting against the negative impacts.

Role of mangroves in coastal protection

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. Nevertheless, they act as important barriers against the various forces of nature and provide a valuable ecosystem service of protecting the local communities.

Due to their unique root systems, they have the tendency to reduce wave energy and erosion by trapping the sediments and nutrients (McIvor *et al.* 2011). In a study on role of mangroves in protecting a port in Odisha by Narayan *et al.* (2010) it was found that presence of a mangrove-lined island reduces chances of a high-wave event by increasing the time lag from 20 years to 60 years. The study also showed that a bigger patch of mangroves in the island is more effective than a 300-m strip along the island margins in attenuating the wave energy.

Mangroves have also been known to reduce the devastating impacts of tsunami (Dahdouh-Guebas *et al.* 2005; Kathiresan and Rajendran 2005). The study of Kathiresan and Rajendran (2005) noticed that death toll due to the 2004 Indian Ocean tsunami was considerably lower in areas adjacent to mangroves in India. In our study, also a positive perception of the local communities was observed towards the protective role of mangroves from natural hazards since majority of the respondents believed it to be a

barrier against cyclones and floods. 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. However, these studies lack conclusive evidence and are therefore criticized to be simplistic argument, still the role of mangroves in attenuating wave energy and trapping debris during major natural hazards is getting widely recognized (Alongi, 2008).

Role of other coastal forests

Due to the muddy shores, the main vegetation in East Godavari district are mangroves and other associated halophytes. The extent of beaches and sand dunes are relatively low and are mainly concentrated in the southern shores of the district. However, a 12-km long sand spit (aptly named Hope Island) is strategically located around Kakinada Bay providing natural protection to the Kakinada port and the city. These habitats and associated vegetation are also important components of natural barriers providing protection to the adjacent infrastructure and villages.

Like mangroves, sandy beaches, dunes, and sand spit also have the ability to attenuate wave energy and provide some extent of protection to sea level rise (Ba thuay et al., 2009; Defeo et al. 2009). The presence of vegetation is critical for maintenance of structural as well as functional role of these coastal habitats (Bhalla 2007). In India, most of the shores have been planted by *Casuarina equisetifolia* trees for stabilization and protection from storms and cyclones. However Casuarina trees are 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 ().

The structural components and age of the coastal forest are also important factors in determining its potential as a barrier. In a study by Tanaka et al. (2007), age, girth, density, and tree crown heights were found to be important parameters. An old forest

with trees of larger girth, for example, will have lower density and therefore will have reduced mitigation potential. Therefore, mixed species plantation of *C. equisetifolia* and *Pandanus odoratissimus* has been suggested by Tanaka et al. (2007, 2008). The authors also believe that apart from reducing the drag and trapping debris, these species also provide opportunities to save human lives by climbing or acting as soft-landing places.

Coastal vegetation is characterized by natural succession depending on the habitat conditions. Therefore, coastal management plans which integrate the native vegetation patterns can have better adaptive and mitigative capacity than haphazard plantations of trees, which is the norm in most cases. In a review of the Coastal Sand Dune (CSD) vegetation in India, Rodrigues et al. (2012) proposed developing coastal vegetation biozones based on the natural succession of species in a sandy habitat. The biozones as described by them are quoted below:

1. **Zone 1** would comprise of pioneer shallow rooted herbs such as *Sesuvium portulacastrum*, *Ipomoea pescaprae* and *Cyperus arenarius* on the frontal dune. These species can withstand burial by sand and salt stress, as the foredune areas receive maximum salt spray owing to their proximity to the sea. *Ipomoea pescaprae* would be ideal in the foreshore due to its occurrence and rapid vegetative propagation.
2. **Zone 2** would consist of a mid-shore zone of herbs and medium-rooted shrubs. *Cyperus arenarius*, *Launea* spp. and *Vitex* spp. are some of the species which could be used. Species from Zone 1 could also be used along with the shrubs so that a natural succession of vegetation is achieved. The use of *C. equisetifolia* would not be recommended in the foredune and mid-shore areas as they are known to pose a threat to marine fauna [50] and may obstruct the natural succession patterns of vegetation.
3. **Zone 3** could be represented by deep rooted CSD species of taller shrubs and trees such as *Anacardium occidentale*, *Ziziphus* spp. and *Cocos nucifera*. Although some of the plants (*A. occidentale* and *C. nucifera*) proposed in Zone 3 are not native to the country, these species have been introduced centuries ago and have got naturalized in the area. Also,

these trees provide socioeconomic benefits to the local inhabitants and their influence on the native flora is insignificant.

Role of biological engineers

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. These oyster reefs also provide other ecosystem services such as providing nursery habitats for several finfishes and shellfishes, provide protection from predators, benthic-pelagic coupling, water filtration. Due to these diverse roles played by oyster reefs, they are popular as soft measures to protect the shorelines and coastal ecosystems (Gregg 2010; Smithsonianmag 2015).

In an experimental study by (Scypher et al,) the efficacy of artificial reefs built of oyster shells to protect shoreline and enhance fish diversity was checked. Results showed higher abundances and species diversity near the oyster reefs than the control plots devoid of oyster reefs. Commercially significant species such as crabs, sea trouts etc were benefitted the most. But no significant impact on the wave attenuation and shoreline stabilization was observed as erosion rates were higher across all the plots. However, the study also points out if proper engineering technologies are integrated into the restored oyster reefs their protective role might be enhanced.

A similar study by Piazza et al. (2005) in Louisiana showed that shoreline retreat was reduced near sites with the restored oyster reefs (cultched sites) than those with non-oyster reefs (non-cultched sites) albeit only in low-energy sites (sheltered sites) and not in high-energy sites (characterized by constant winds, shallow and open waters). The cultched reefs also did not have any significant impact after two major storms during the study. There was no significant rise in the abundance of other associated fauna in either of the two sites. However, the experimental area was considerably small (smaller than the previous study also), which did not yield significant results.

The efficiency of oyster reefs in protecting the shorelines have not been conclusive till now but one must consider the financial as well as logistical challenges. Oyster reefs due to high fecundity can get well established and become self-sustained once they get conducive environment. But in many studies and oyster restorative programs lack of sustainable shell supply is a major drawback. Most importantly for these efforts to become successful collaborative efforts of ecologists, marine biologists, geologists, structural engineers, and social scientists is required (Scyphers et al. 2014).

In EGREE, oyster and clam colonies can be seen growing along the subtidal creeks in mangrove forests. They also have the potential to grow in the shallow parts of Kakinada Bay which are mainly in the western and southern regions of the bay. Similarly, the mudflats near Sacramento Island and Kandikuppa too have the potential for growing oyster reefs. Despite the drawbacks and challenges in restoring oyster or shell beds, they are better options than building sea walls or other hard structures, which also have an added advantage in improvement and sustenance of fisheries in the region. However as discussed above building oyster reefs or shell beds would need collaboration of various scientists and various departments of the government. They also provide good opportunities to involve the local communities as seen in restoration programs in USA which not just ensures increased awareness but also indirectly imparts a sense of ownership among the locals.

Role of environmental flows

Freshwater flow is a critical factor for maintenance of physical and biological features of estuaries and other near-shore habitats (Loneragan, 2005). River discharge affects the geomorphology, salinity, and turbidity of estuaries, which in turn influence the distribution and abundance of fish and crustaceans (Whitfield, 1996). Freshwater flow from the rivers loaded with sediments is also the major source of important nutrients

for estuaries and coastal ecosystems (Newell *et al.* 1995; Loneragan *et al.* 1997). The seasonal input of nutrients stimulates phytoplankton and benthic micro algal growth, which are the foundation for the coastal food webs (Fry & Wainwright 1991; Mallin *et al.* 1992; Newell *et al.* 1995; Loneragan *et al.* 1997). Therefore, the role of a river's flow regime becomes crucial for sustenance of fisheries and well being of the local communities.

Construction of dams and barrages coupled with increased extraction of water lead to disturbance in the natural flow regime of a river, thereby negatively affecting the biodiversity and ecosystem functioning of not just the river but downstream ecosystems such as estuaries. After construction of Aswan Dam in 1965, dramatic changes occurred in the downstream coastal Mediterranean ecosystem (Aleem, 1972). The dam allowed very little river discharge which restricted the input of nitrates, phosphates, and silicates into the downstream ecosystems. This led to marked decline in planktons, which in turn had a domino-effect on other species. Catches of plankton feeding fishes (such as sardines) declined from 15,000 t in the year before the dam was completed to 550 t two years after the completion of the dam. Catches of prawns/shrimp in the Egyptian sector of the Mediterranean were halved (8000 t to 4000 t) (Aleem 1972).

Increased realizations that such uncontrolled regulation of rivers is harmful for the river-dependent ecosystems as well as for fisheries lead to the concept of minimum flows which finally evolved into environmental flows (e-flows). In coming future when the flow regime of a river becomes unpredictable and the extreme events probably increase in frequency, the concept of e-flows will become very important to mitigate as well as to adapt. In Australia, environmental flows have been proposed as the primary adaptation measure to counteract the reduced flows due to climate change and regulation of rivers (Jenkins *et al.* 2011).

The significance of e-flows is very high for East Godavari district considering the proposed dam in Polavaram, the Indira Sagar Multipurpose Project popularly known as Polavaram Dam. As the example of Aswan Dam cited above shows the negative impacts of river regulation on coastal fisheries, Polavaram Dam also might have very profound impact on fisheries as well as other flora and fauna of EGREE.

Climate Change Adaptation Plan for Godavari estuary

Climate change is a virtual reality now, largely being caused by human activities and poses significant risks for a broad range of human and natural systems. Human activities largely determine the evolution of the Earth's climate, which are not just going to impact the next few decades, but the coming centuries and millennia. Climate change can be understood as a significant and lasting change in the statistical distribution of weather patterns over periods ranging from decades to millions of years. It may be a change in average weather conditions, or in the distribution of weather around the average conditions (i.e., more or fewer extreme weather events). Factors that bring about climate change include oceanic processes, biotic processes, variations in solar radiation received by Earth, plate tectonics and volcanic eruptions, and human-induced alterations of the natural world; these latter effects are currently causing global warming and "climate change" is often used to describe human-specific impacts. Scientists are actively engaged in understanding past and future climate by using observations and theoretical models.

Understanding the context - Coringa Wildlife Sanctuary

Being the largest sink for CO₂, oceans as well as coastal ecosystems are experiencing the most profound impacts of rising temperatures. The three-pronged impacts of climate change- warming, acidification and de-oxygenation are already manifesting their effects on the marine flora and fauna. Though estuaries and associated mangrove forests are less likely to experience the direct impacts of climate change apart from increase in

water temperatures, the indirect impacts of sea-level change as well as salinity changes will bring about significant changes in their physico-chemical as well as biotic components. Consequently, conserving and sustainably managing the coastal ecosystems as well as associated biodiversity is critical to addressing climate change in this country.

As mentioned earlier, EGREE encompasses the second largest mangrove forests in the eastern coast of India. In addition, the varied habitats of EGREE, characterized by river distributaries and channels, flood plains, natural levees, mangrove forests, tidal channels, tidal flats, lagoon, Kakinada Bay, sand spits, etc. support a range of aquatic fauna and flora. Therefore, this ecosystem plays an important ecological as well economic role for the region. The 44 villages around the mangroves of EGREE are directly or indirectly dependent on them and 40% of the population is engaged in active fishing in the estuary.

The Godavari mangroves cover an area of 32,140 hectares supporting a total of 35 species of which 16 are true mangroves and the rest are associated mangrove species. One Near Threatened mangrove species (*Ceriops decandra*) is reported from this region along with three rare species (*Sonneratia alba*, *Scyphiphora hydrophyllacea* and *Xylocarpus moluccensis*). This is probably the only place in India where three species of *Avicennia*, i.e. *Avicennia officinalis*, *Avicennia marina*, and *Avicennia alba* are found together in mixed patches.

The area is rich in avifaunal diversity with a recorded population of 119 bird species, of which 50 are migratory from Eastern Europe, Central and North Asia. Some of the rare winter migrant species are Golden Plover (*Pluvialis apricaria*), Woodcock (*Scolopax rusticola*), Common Snipe (*Gallinago gallinago*), and Long-billed Ringed Plover (*Charadrius placidus*). The wetlands of eastern Godavari delta are also reported to be

breeding grounds for the near threatened Spot-billed Pelican which qualifies it as an Important Bird Area.

The mangroves and surrounding areas in EGREE are home to some Scheduled mammals such as Fishing Cat (*Prionailurus viverrinus*), Indian smooth-coated otter (*Lutrogale perspicillata*), Golden Jackal (*Canis aureus*) etc. Apart from mammals, the Hope Island and the Sacramento region within the project area are important nesting sites for the endangered Olive Ridley turtle (*Lepidochelys olivacea*). The critically endangered Leatherback turtle (*Dermochelys coriacea*) and Green turtle (*Chelonia mydas*) are also reported to visit the region.

The East Godavari estuaries and the associated mangroves also act as nurseries for numerous fin and shell fishes, many of which are economically important. Dehairs (2003) estimated the value of the service provided by EGREE towards fisheries of the region as US\$ 2,700 per ha, which if extrapolated comes around US\$ 90,000 annually for the entire area. Apart from this, EGREE also serves numerous other important ecological services, notably among these are shoreline protection and carbon sink for excess atmospheric CO₂. This region also plays a major role in energy security of the country as it possesses major reserves of natural gas and oil.

Robustness of Coringa Wildlife Sanctuary

Features and attributes - situation analysis

Features and Attributes –Situation Analysis			
Features	Attributes	Comments, Condition, Sensitivity/ Vulnerability, Situation analysis etc.	Sources of Information
Mangrove	a) Size	195.3 sq.km out of which 18 sq.km is under high risk of reclamation in near future.	Land Use Land Cover Map
	b) Number of true mangrove species	16	Field Survey
	c) Number of associated species	19	Field Survey
	d) Number of threatened species	1 (<i>Ceriops decandra</i>)	IUCN Red List
	e) Protection Status	115.6 sq.km area declared as CWLS	Land Use Land Cover Map
	f) Freshwater discharge/inflow	Decreased in past decade. High probability of decrease due to upcoming multi-purpose projects in upstream parts of Godavari River.	CWC (Polavaram report)

	g) Sediment availability and quality	Decreased. Highly vulnerable due to upcoming multi-purpose projects in upstream parts of river.	CWC (Polavaram report)
	h) New accretions	Present, especially near river mouth and landward side. Highly vulnerable to uncontrolled fuelwood collection, anthropogenic disturbances, and sea level rise.	Site survey, Management Plan
Godavari Estuary	a) Size	353 sq. km	Land Use Land Cover Map, Management Plan of Coringa WLS 2013-2023
	b) Protection Status	Kakinada Bay along with the subtidal and intertidal creeks of Coringa mangroves is protected as Coringa WLS	Management Plan of Coringa WLS 2013-2023
	c) Freshwater discharge/inflow	Decreased in past decade. High probability of decrease due to upcoming multi-purpose projects and proliferation of aquaculture ponds, agricultural activities and other industries along Godavari River.	CWC (Polavaram report)
	d) Salinity	Mean salinity ranges from 1.3	Field Survey, IPCC fifth

		ppt to 32.8 ppt with a clear spatio-temporal gradient across the estuary. Mean salinity will increase in near future due to sea level rise and decrease in freshwater flow from Godavari River.	report (2014)
	e) Biodiversity	355 species of finfishes recorded from the estuary; 71 species of gastropods and bivalves and 19 macrofaunal groups recorded during our field survey; around 186 species of waterbirds also recorded. Indo-pacific humpback dolphins also sighted near the mouth of the estuary and eastern part of Coringa WLS.	Field Survey
	f) Anthropogenic Disturbances/Dependence	Very high and increasing. Frequency of vessel movement is high in Kakinada Bay; regular dredging activities are carried out in Bay and river mouth. Water pollution is another threat which can exacerbate other impacts.	Field survey

	a) Size	1/3 rd of CWLS (Kandikuppa, Pandi-Pora). 107.91 sq.kms	Management Plan
Tidal Mudflats	b) Protection status	Tidal flats in the eastern and southern parts of Kakinada are protected under the Coringa WLS.	
	c) Fauna	28 species of waders recorded from EGREE most of which are winter visitors. Extensive beds of bivalve species such as <i>Tegillarca granosa</i> , <i>Cerithidea cingulata</i> present on the southern part of Kakinada Bay serve as rich feeding grounds for these waders and other avifaunal species such as Asian open-bill storks, Painted storks, Black headed Ibis.	Field survey
	d) Anthropogenic Disturbances/Dependence	High. During low tide, locals collect mollusk species for commercial purposes in Kakinada Bay. Casuarina plantations along the mudflats near Sacramento Island might lead to gradual conversion of the mudflats into sandy beaches. Further, exploratory activities near Sacramento	Field survey.

		Island are a threat to mudflats associated fauna.	
	a) Size	Length of 17 km currently, 5 km head and 12 km tail; increasing due to new accretions	Site survey, Mishra, 1999; Management Plan, MSSF
Hope Island	b) Flora	Natural regeneration of <i>Avicennia officinalis</i> , <i>Avicennia marina</i> , <i>Excoecaria agallocha</i> ; Plantations of <i>Casuarina</i> sp. etc. also found.	Management Plan
	c) Threatened Fauna	Nesting grounds for Olive ridley turtles, Green sea turtles are also reported to visit the area.	Management Plan
	d) Protection Status	Partly protected; new accretions are yet to be declared as part of CWLS	Management Plan
	a) Population recorded in CWLS	Estimated abundance of 75 individuals	SECR Analysis
Fishing cat	b) IUCN status	Vulnerable	IUCN Red List 2016
	c) Protection status	Listed under Schedule-I of WPA, 1972; its habitats inside Coringa WLS are protected.	WPA, 1972
	d) Habitat availability	Naïve estimation indicates its strongholds are inside the mangrove forests. The mangroves in the northern	

		side are well protected under Coringa WLS but in the southern side, particularly below Pandi-Pora are fragmented and under high anthropogenic influence.	
	d) Habitat quality	A successful mangrove restoration program being carried out by Forest Department and MS Swaminathan Foundation has been able to decrease fragmentation inside the mangroves of Coringa WLS. However, due to absence/low maintenance of buffer zone around the sanctuary, landward fringes are highly vulnerable to degradation due to both aquaculture ponds and sea level rise.	Management Plan, Field Survey
Birds	a) No. Of species	Around 186, variable	Field survey
	b) Protection Status	6 species are listed under Schedule-I of WPA, 1972	WPA, 1972
	c) Nesting Frequency	Unknown	Management Plan and Monitoring Data
	d) Habitat	Declining. Vulnerable to land-	Management Plan and

	availability/quality	use changes and anthropogenic disturbances	Monitoring Data
	e) Habitat use	Good breeding and roosting sites exist for the aquatic birds inside the CWLS, including for migratory birds. Also, extensive feeding grounds in Kakinada Bay, channels and mud-flats during the low-tide	Management Plan and Monitoring Data
	f) Migratory birds	CWLS is an important part of the Central Asian Flyway for migratory birds	CMS (Convention of migratory species); Field Survey

Assessing Integrity of Coringa Wildlife Sanctuary

Assessing Integrity		
Key Questions	Y/N	Comments/Sources for evidences
Are the site's key features and attributes whole and intact?	N	Management Plan
Is the site of adequate size to ensure complete representation of features/processes that convey its significance?	N	Management Plan and scientific literature
What is the condition of the key features and their attributes?		
Are processes, relationships and dynamic functions essential to features maintained in good condition and at an appropriate scale?	N	Management Plan and scientific literature
Does the site suffer from the adverse effects of development, neglect or any other degrading process?	Y	Management Plan and scientific literature
Do you have control over the processes causing deterioration? Have adaptation strategies been identified and implemented?	Y/N	The habitats inside the Coringa Wildlife Sanctuary are legally protected but there is a lack of proper enforcement. However, certain activities/industries which release harmful effluents into the channels leading

		<p>into the sanctuary or proliferation of aquaculture ponds can not be controlled by the Forest Department. Declaration of Eco-sensitive Zones can regulate or limit the proliferation of aqua ponds and other industries around Coringa WLS but not other mangrove patches in EGREE.</p>
<p>Does the site have a buffer zone? If so, is it under any threat?</p>	<p>N</p>	<p>There is no differentiation of the sanctuary area into 'core' or 'buffer' zones. Moreover, fringes of Coringa WLS in the western side are under high level of threat due to proliferation of aquaculture ponds. These ponds are not just a grave threat to threatened mammal and bird species of EGREE but also lead to degradation of soil and water quality of surrounding regions and lead to degradation of mangroves.</p>

Legal and Policy Context

Legal & Policy Context (In Relevance to CWLS)	
International Legislation	
Ramsar Convention	Critical to put sufficient thrust on the government to get the tag of Ramsar site for this sanctuary.
Convention on Biological Diversity	High relevance due to dynamic ecosystem with possibility of reduction in diversity.
World Heritage Convention	Less relevant but it is an Important Bird Area. Also, along with Krishna Basin it is probably one of the best habitats for conservation of Fishing Cat, a vulnerable species.
Convention on Migratory Species	Already a part of the Central Asian Flyway for migratory birds. Since Coringa WLS is a wintering ground for several waterbird species, it holds high relevance for protection of the migratory as well as threatened avian species.
Convention on International Trade in Endangered Species of Flora and Fauna (CITES)	Very high relevance due to presence of several threatened aquatic fauna which have high demand in the neighboring countries. Illegal hunting of sharks and rays is rampant as well as extraction of mollusks from the mangroves and trade of such threatened fauna is rampant in the region.
National Legislation	
Wildlife Protection Act, 1972	Very crucial for protection and very stringent and effective law. However strong implementation is required.
Forests Protection Act, 1953	Governs protection of forest area and eco-development with neighboring villages
Environmental	Eco-sensitive zone around the periphery of the sanctuary

Protection Act, 1986	will be possible with this Act. Also regulates pollution.
Coastal Regulation Zone Notification, 2010	Highly relevant in this context. Coringa has been identified as one of the Critical Vulnerable Coastal Areas under this notification.
Water (Prevention & Control of Pollution) Cess Act, 1977; Air (Prevention & Control of Pollution) Act, 1981	Relevant due to the rampant industrial development surrounding the sanctuary and the discharge of pollutants from upstream as well as adjoining cities and settlements.
Andhra Pradesh Forest Act, 1967	Ensures protection and management of forests of Andhra Pradesh.

Site Design

SITE DESIGN of CORINGA WILDLIFE SANCTUARY	
Design issue	Comment/evidence/sources
Overall size: 235.70 sq.km.	Gazette Notification of the Park as per Wildlife (Protection) Act, 1972
Proportion of major habitat types <ul style="list-style-type: none"> i) Mangrove forests: 11822.3 hectares ii) Bay/Lagoon: 11367.28 hectares iii) Mud flats: unknown iv) Sea shore/Sandy beaches: 290.90 hectares 	M. V. Ramanamurty et. al., 2011
Shape & topography <p>The area covered by the Sanctuary is an estuarine area, of which about 49% is under the mangrove forests which forms the major type of vegetation due to the characteristic inundated soil and saline waters. Another 47% falls under the Kakinada Bay and back waters of the sea. A 17 km sand spit, Hope Island forms a barrier between the sanctuary and the sea, blocking the direct connection between Godavari River and the sea. Rest of the area is riddled with creeks, intertidal mudflats.</p>	Management Plan
Boundaries <p>The boundaries of Coringa Wildlife sanctuary are delineated in the map kept at the office of the Principal Chief Conservator of Forests, Andhra Pradesh, Hyderabad and Divisional Forest Officer,</p>	Management Plan

<p>Wildlife Management Division, Rajahmundry which are as follows:</p> <p>North: Starting from station “A” denoted on map, the boundary line starts from the North-West corner of the Coringa extension Reserve Forest. The line runs in North easterly direction in a straight line upto sea coast station “B” denoted in the map which is the northern trip of Hope Island.</p> <p>East: Thence the line runs from station B along the coast line, the eastern boundary of Coringa extension Reserve Forest, up to southern bank of Neelarevu and includes the linear strip of Hope Island.</p> <p>South: Thence the line runs in the westerly direction along the southern boundary of Coringa extension Reserve Forest up to some distance and there after along the artificial boundary of Bhyravapalem Reserve Forest till it reaches Godavari River. It then runs along the western bank of Gaderu till it reaches, Sarihaddukalva. Thereafter it follows southern bank of Sarihaddukalva reaches station “D”.</p> <p>West: Thence the line runs along the boundary line of Coringa Reserve Forest in the northern direction and joins the station at a North-west corner of the sanctuary.</p>	
<p>Buffer zone</p> <p>No demarcation in Core and Buffer zone but different use zones proposed in the last Management</p>	<p>Management Plan</p>

Plan.	
<p>Significant development</p> <p>Apart from Kakinada Port and Harbor, there are fertilizer and cement industries very close to the sanctuary. In addition, there are 44 villages abutting the sanctuary along with 2 major cities viz. Kakinada and Yanam (Pondicherry) near. However, proliferation of aquaculture ponds is the most immediate threat. Natural Gas extraction and exploration are regularly done in the Godavari basin.</p>	Site survey, Management Plan
<p>Wider setting</p> <p>Coringa Wildlife Sanctuary lies in a region which is economically significant for Andhra Pradesh as well as for the country. Due to the rich natural gas reserves of the Krishna-Godavari basin it is strategically located in an important region for the energy security of our country.</p>	Site survey, Management Plan

Management System

Issue	Y/N	Comments
Does the management system specify how the important features will be sustained through protection and conservation?	Y	Yes, the current management plan covers all aspects pertaining to sustaining its important features. However, management plan does not elaborate on the possible effects/strategies to mitigate future change in the climate.
Is the management system practically effective in achieving on-ground conservation outcomes?	N	No, the management system is not clear in stating the options for future.
Does the management system include a cycle of planning, implementation, monitoring, evaluation and feedback?	N	No, the system of feedbacks is not well defined. But review of strategies based on adoptive management has been added.
Does the management system recognize the capacity needs of staff?	Y	Skill development trainings are organised by the Department and the management system advocates for the same. However resource crunch and time availability is cause of concern.
Does the management system include an assessment of risk and how to respond to it?	N	No, the Management Plan is not explicit on the crisis redressal systems.
Is there adequate finance to meet current and future	N	No, funds are scarce to meet the current and future needs.

needs?		
Does the management system have priority over other types of systems	Y	Yes, the objectives of management plan take precedence over other development plans.
Does the management system involve stakeholders?	Y	The park is a government property and the neighboring villagers are involved in restoration and eco-tourism activities in the sanctuary.

Profiling Communities and Partners

WORKSHEET 10: PROFILING COMMUNITIES AND PARTNERS	
	Name of community group/partner/individual:
How the CWLS relates to them, and how they relate to the CWLS	<p>There are 44 villages abutting the Wildlife Sanctuary and except for 1 small village in Hope Island, there is no habitation inside the boundaries of CWLS. The park management depends on the local people to provide services such as labour, eco-tourism activities and awareness generation. Thus, the park management looks upon these communities as stakeholders to a certain extent. However, regular instances of conflict with the local communities also exist. Even though fishing inside the channels are allowed for the locals, extraction of mollusk species (<i>Placuna placenta</i>, <i>Meretrix meretrix</i>, etc.) and timber collection are regularly done by local communities inside the sanctuary. In addition, there are several places adjoining the WLS where number of aquaculture ponds exists that attract different avian and mammal species such as Waders, Smooth coated Otters, and Fishing cat. Since, many of these aquaculture ponds have electric fencing; instances of death of these threatened species dues to electrocution are high around the sanctuary.</p>

Level and type of power	Fishermen communities at some places are influential. However, the communities mostly belong to the economically weaker sections of the society.				
General level of knowledge of the CWLS	Extensive	Good	Some knowledge	Limited	None
		√			
General level of support for the CWLS and its aims	Good. In a questionnaire survey conducted in 13 villages around the sanctuary, almost all the respondents agreed to the importance of protecting the mangrove forests of Coringa.				
Particular areas of concern (if any)	Local communities, especially the fishermen are aware of the cyclone protection and fishing services provided by the mangrove forests of CWLS and therefore are also willing to take part in its protection. However, many of them also depend on these mangroves for fuelwood and timber. Our questionnaire survey revealed that most people who depend on fuelwood partly or entirely are not ready to stop its use due to easy availability and low costs of mangrove species. The locals from certain villages are also involved in shell collection inside CWLS which is illegal and unsustainable. Species such as <i>Placuna placenta</i> (Window pane oysters) have suffered decline in population because of this. Lastly the most immediate threat is the proliferation of aquaculture ponds around the sanctuary and use of electric fences by them. This not only renders threatened species such as Fishing cats and Smooth Coated Otters to be highly vulnerable to injuries and death but also act as obstruction to the natural migration of mangroves towards land.				

Threat and the risks and management actions

Assessing climate change threats and risk analysis – site assessment

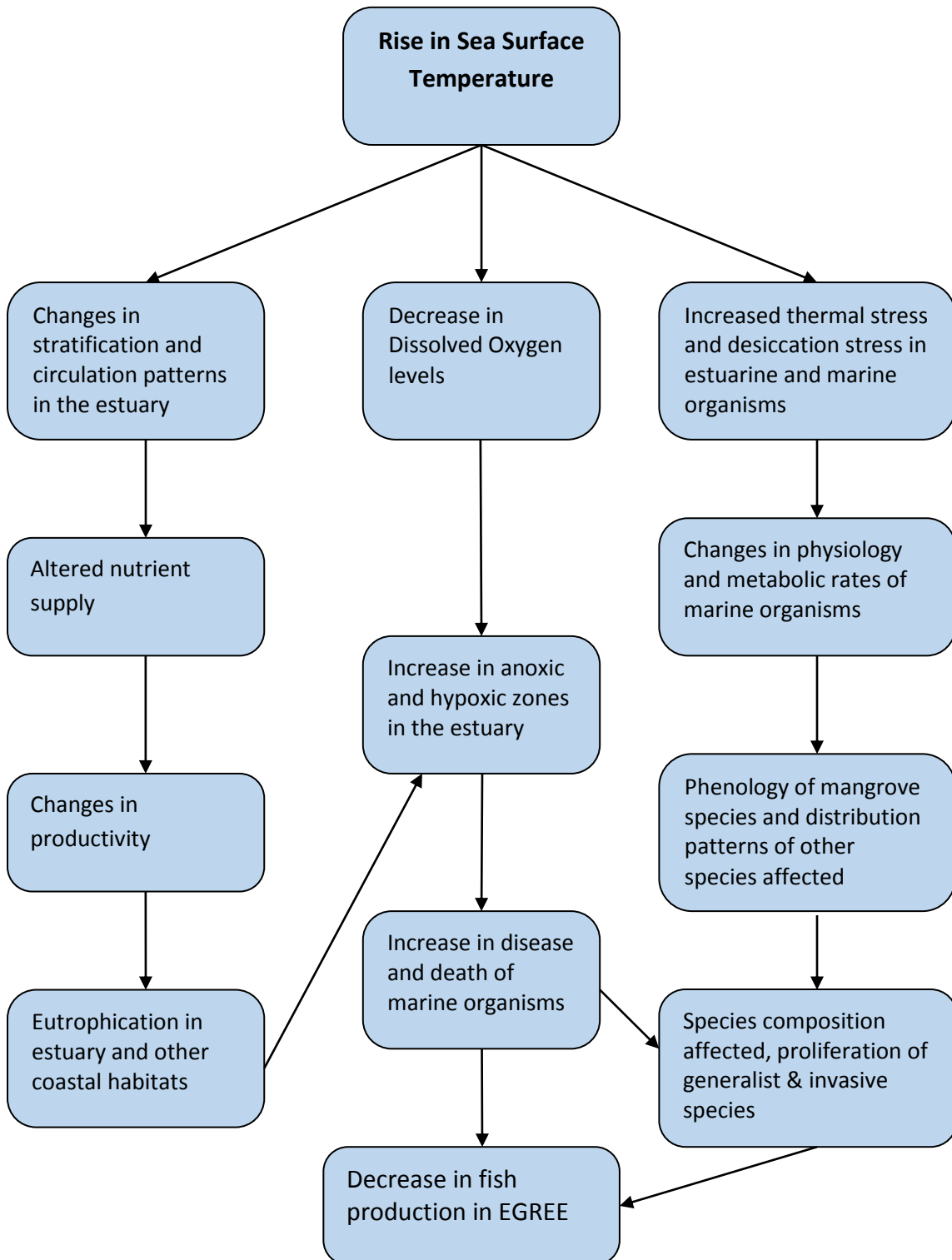
Key questions	Comments	Description of climate change drivers and their impact(s) on your site	Risk of impact - probability	Risk of impact - significance
Are the site's key features and attributes whole and intact?	The mangrove forests of Coringa WLS are well connected with high regeneration capacity but the mangrove patches outside the sanctuary are fragmented and prone to destruction from aqua ponds and other construction activities.	Sea level rise and increase in frequency of cyclones and storms will have a negative impact on mangrove forests of EGREE.	H	H
Does the site include all the elements necessary to express its ecosystem services?	EGREE landscape comprises of different types of coastal habitats	Sea level rise and rise in salinity will have varying impacts on the	H	H

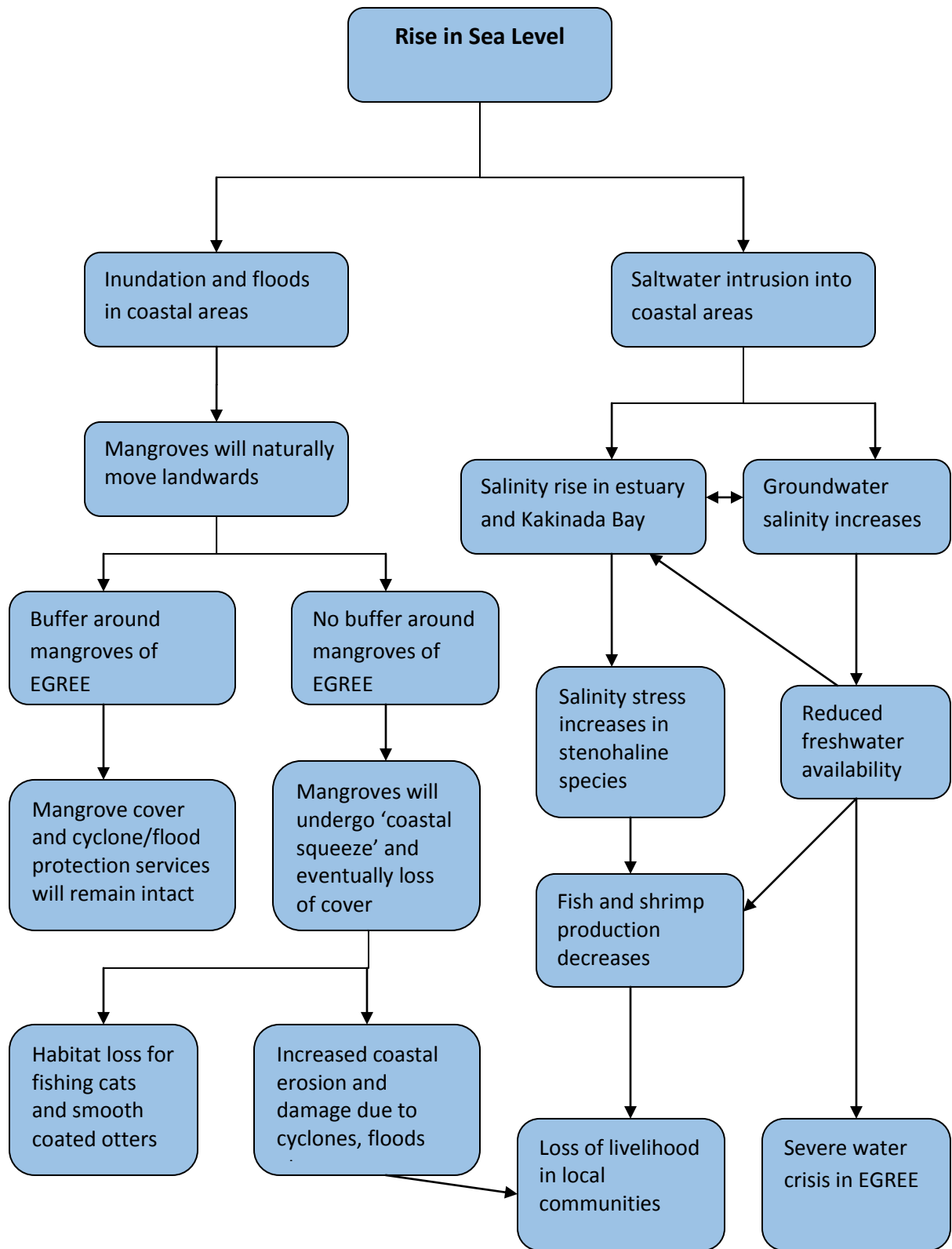
	<p>each of which support unique biological features and accrue certain economic value to local communities. But most of them are unprotected.</p>	<p>coastal habitats of EGREE particularly on the estuary and mangrove forests.</p>		
<p>Is the protected area of adequate size to ensure complete representation of features/processes that convey its significance?</p>	<p>No, Coringa Wildlife Sanctuary only provides legal protection to the mangrove forests and some parts of Kakinada Bay but the southern parts of mangroves and the riverine habitats in EGREE are largely unprotected and subject to high anthropogenic disturbances.</p>	<p>Godavari delta is highly dynamic and different studies have indicated high accretion rates on the river mouth and towards Hope Island. At the same time, erosion has been observed along the seaward side of EGREE with the mangroves potentially moving landwards. Sea level rise and reduction in freshwater flow</p>	H	H

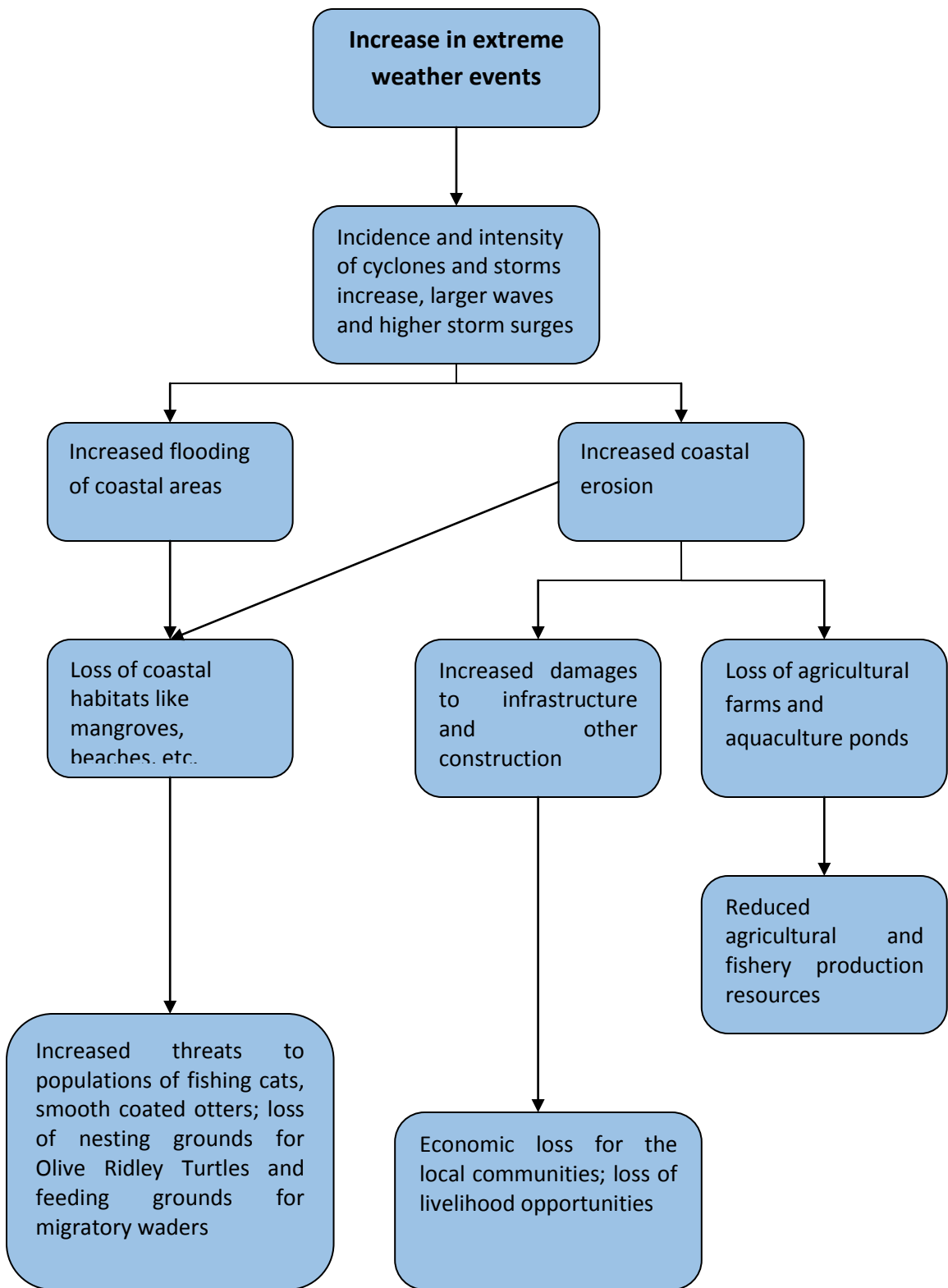
		will further cause habitat degradation in EGREE.		
What is the condition of the key features and their attributes?	The key features and attributes of mangrove forests are protected to a certain extent but other habitats such as Estuary, mudflats are subjected to high anthropogenic pressures. Proliferation of aqua ponds are a threat to the protected mangroves also in EGREE.	The estuary and tidal mudflats will be relatively more affected by the drivers of climate change. Avifauna, particularly migratory species might be affected by rise in ambient temperatures while Fishing cats will be indirectly impacted by decrease in mangroves due to sea level rise.	H	H
Are processes, relationships and dynamic functions essential to features maintained in good condition and at an appropriate scale?	No but more detailed and long-term studies are required at the landscape-level to ascertain the appropriate scale at which each	Rise in sea surface temperatures and salinity will lead to changes in circulation patterns and nutrient distribution in the ecosystem. These	H	H

	processes are occurring in EGREE.	will have further impacts on various aspects of the landscape in future.		
Does the site suffer from the adverse effects of development, neglect or any other degrading process?	Yes. But most immediate threat to natural ecosystems in EGREE is the proliferation of aqua ponds along mangrove forests.	The present level of anthropogenic disturbances will compound the impacts of climate change in EGREE.	H	H
Does the site have a buffer zone?	No.	-----	H	H

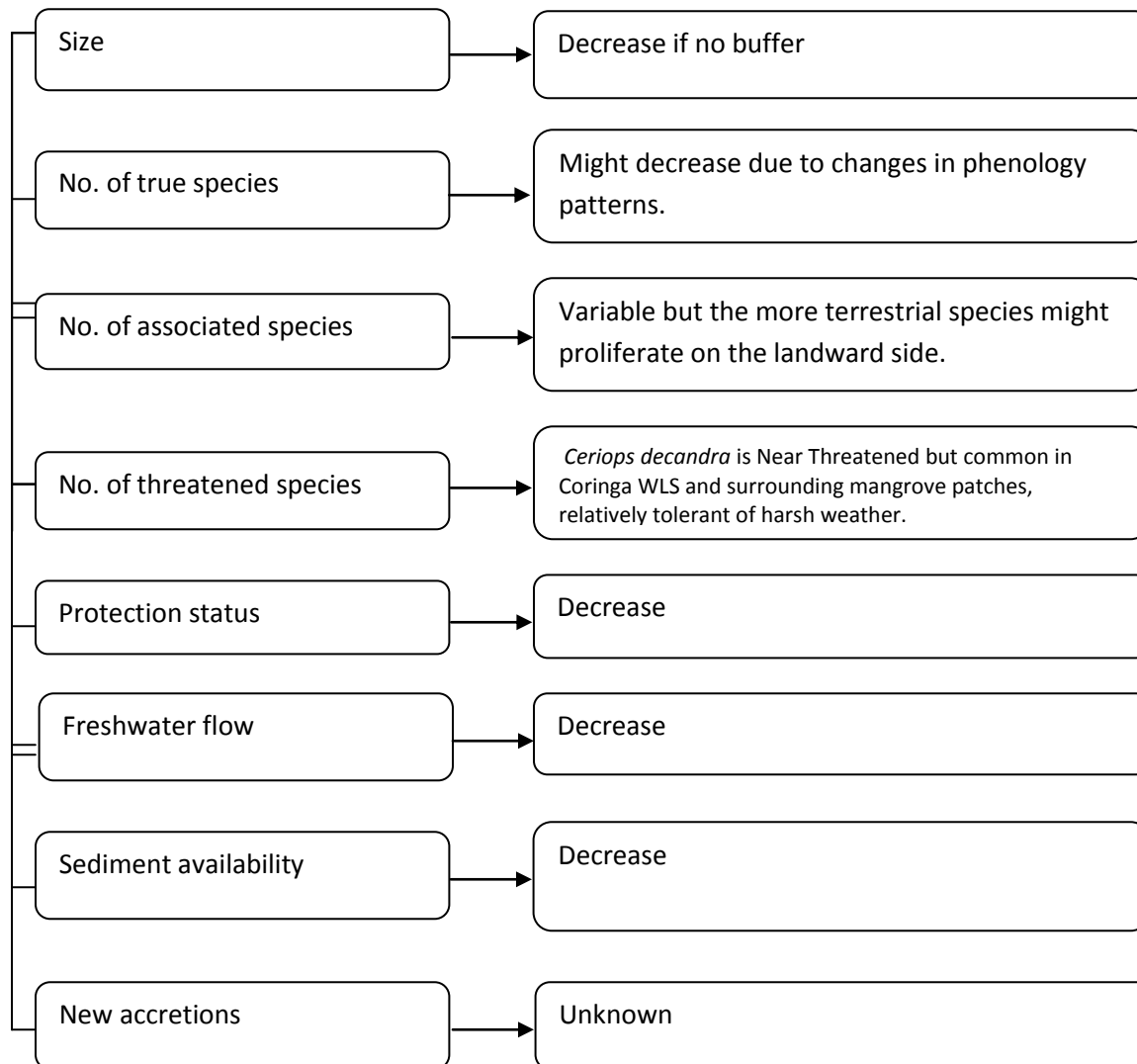
Considering Scenarios



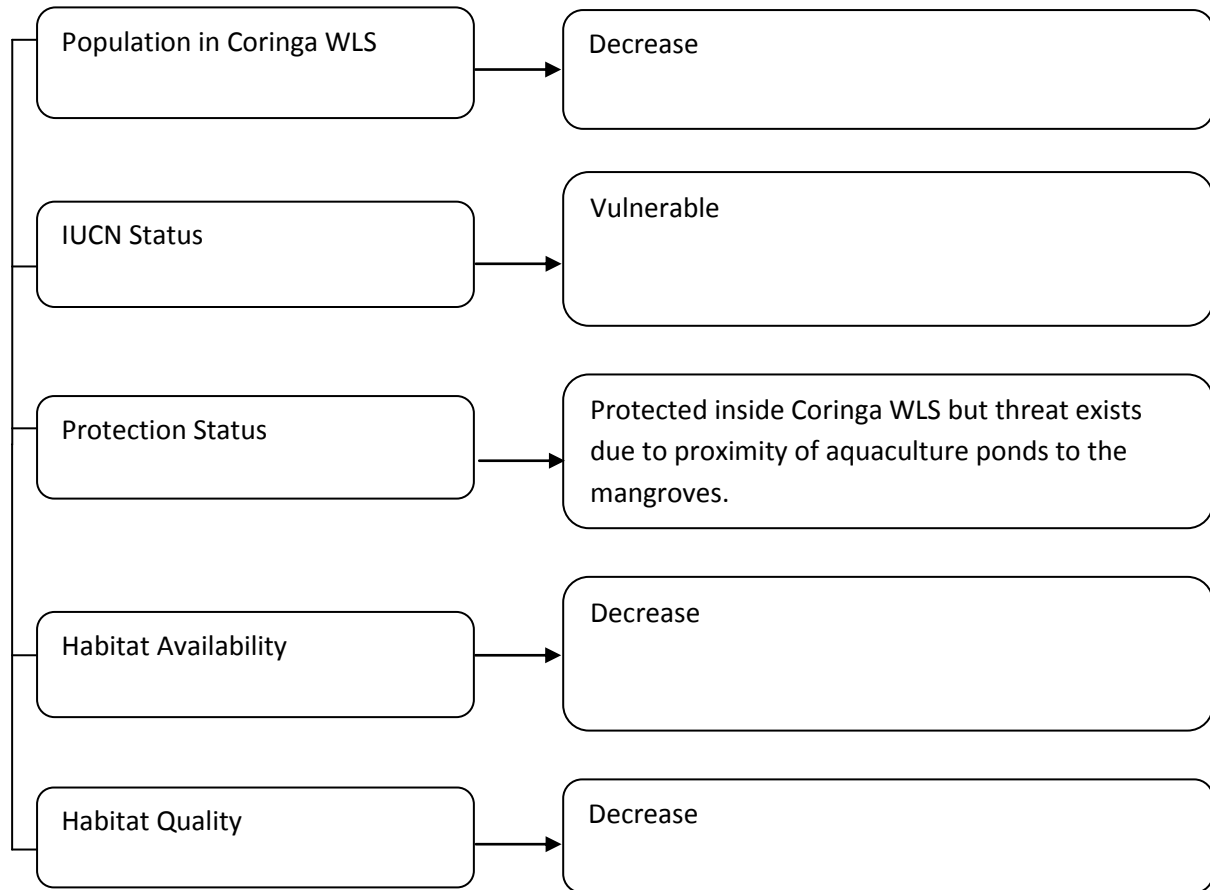




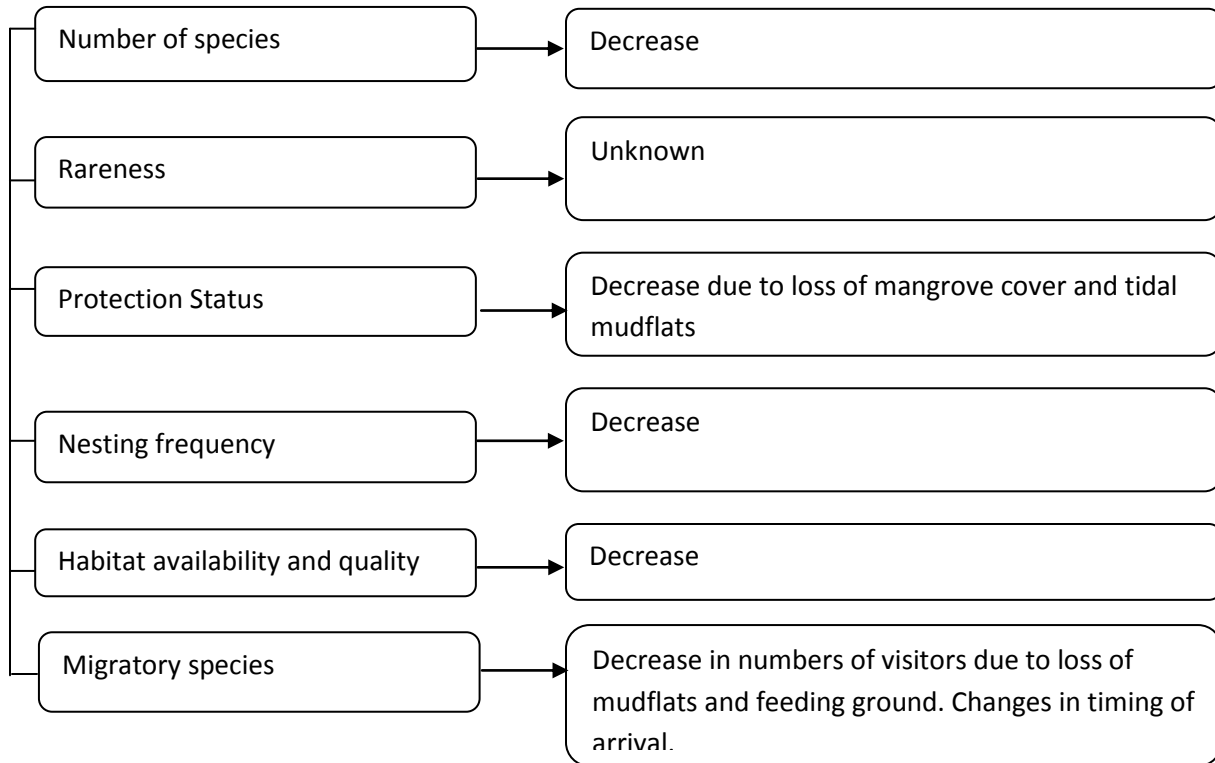
Feature 1: Mangrove



Feature 2: Fishing Cat



Feature 3: Shorebirds



ASSESSING STAFF CAPACITIES

STAFF RESOURCES	Numbers Actual	Numbers needed	Recording /reporting equipment available	Recording /reporting equipment needed	Technical expertise	Levels of awareness re-climate issues	Levels of relevant training re-climate issues
Management Key duties: 1. Protection 2. Monitoring 3. Habitat Improvement 4. Community participation 5. Ecotourism management 6. Infrastructure & communication	-		Wireless Systems-10, Camera, GPS, Jeep-1, Motorbike-1, Fiber Boat-3, Wooden Boats with engine-2	GPS, Binoculars, Range Finder, Camera Traps, Sampling Devices, Quality Testing Kits, Disease Diagnostic kit, Field Identification Manuals			
Senior field staff 1. DFO 2. Ranger	1 1	1 1			Training in Wildlife Management	H	L

Junior field staff							
1 Forest Section Officer (FSO)	2	1					
2 Forest Beat Officer (FBO)	7	-					
3 Assistant Beat Officer (ABO)	6	2					
					Training in Wildlife Management Needed	L	L

Capacity to Adapt - Summary of Strengths and Weaknesses

CAPACITY TO ADAPT - SUMMARY OF STRENGTHS AND WEAKNESSES		
	STRENGTHS	WEAKNESSES
LEGAL AND POLICY CONTEXT	Current laws are sufficient to deal with wildlife and forest management	Laws to curb pollution are weak. Policy on coastal development is poorly implemented. High dependence of local communities on mangroves, fisheries and molluscans.
STAFF	Moderately trained staff equipped to tackle ordinary issues.	High skill training, capacity building and modernisation are lacking. Staff numbers need to be increased for intensive management especially in the context of climate change.
SITE DESIGN	CWLS is aptly sized with a range of coastal habitats supporting different life forms.	Vicinity to Kakinada port, urban areas and natural gas drilling operations pose major threats.
COMMUNITY AND PARTNERS	Local people participate in active management.	Locals are highly dependent on the ecosystem for subsistence. It has high economic value in the country due to the rich fishing grounds as well as rich natural gas deposits.

MANAGEMENT SYSTEM	Suitable for the current needs. Addresses the concerns of stakeholders.	Needs to be oriented to incorporate international concerns over climate change vis-à-vis landscape level planning.
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Considering Options - Advantages and Challenges

HARD AND SOFT OPTIONS - ADVANTAGES AND CHALLENGES		
Hard Options	Advantages	Challenges
1. Restoration of mangroves outside the sanctuary area	It would lead to better protection from cyclones and storms; help in sustaining the local fisheries. By providing more habitats outside the sanctuary, it would also help in enhancing the conservation of threatened mammals found in EGREE.	Deployment of manpower and resources. Long-term protection of the restored patches outside the sanctuary..
2. Creating a buffer around the boundary of the mangroves	Critical for mangroves for landward migration in the event of sea level rise. Also this will help in decreasing the conflict of	Calculating the area of buffer zone. Removing the aquaculture ponds along the boundaries of mangrove forests specially those outside the sanctuary.

	<p>fishing cats and smooth coated otters with aquacultures ponds and local villagers.</p>	
<p>3. Building coastal flood defenses</p>	<p>It will help in preventing erosion and protect the villages and infrastructure from floods, storms, and storm surges.</p>	<p>Most often hard structures that prevent coastal erosion and floods are costly to construct and maintain. Studies have shown that such structures also contribute to coastal erosion on a long-term basis, thereby negating their short-term positive gains.</p>
<p>4. Regulating the proliferation of aquaculture ponds in EGREE</p>	<p>Proliferation of aquaculture ponds is a major threat to the mangrove forests in EGREE as well as threatened species inhabiting it. They are also leading to salinization of agricultural lands and ground water around the mangroves.</p>	<p>Bringing in a policy change and then implementing it seems to be an arduous task. Livelihoods of many local people depend on them and therefore, there might be resistance from them. However, the biggest challenge will be the political will to regulate this industry in the region.</p>
<p>5. Ensuring minimal environmental flow from upstreams dams and barrages.</p>	<p>Maintaining a minimum flow of freshwater from Godavari River is critical for the survival of the mangroves in EGREE. There are several other</p>	<p>The state government has been recommended to ensure minimum environmental flow of Godavari river from Polavaram Dam. However, once it becomes operational, regular monitoring is required of the river flow from the</p>

	<p>essential services that depend on the seasonal freshwater flow, such as fisheries in EGREE. Therefore, ensuring minimum e-flows will be crucial to mitigate the impacts of sea level rise in future.</p>	<p>dam and its impacts on Coringa mangroves.</p>
<p>6. Creating integrated coastal management zone</p>	<p>Certain activities have very serious impacts on the natural ecosystems of the coastal regions. A well-planned and scientifically designed integrated coastal zone management plan will help in ensuring that biodiversity conservation and adaptation to climate change are integrated with economic development.</p>	<p>A comprehensive study is required before designing the plan. Bringing the different stakeholders including the various government departments will be a challenge. Finally implementing and monitoring it also requires a well-planned system and sufficient resources</p>
<p>Soft Options</p>	<p>Advantages</p>	<p>Challenges</p>
<p>1. Increasing awareness among local communities in</p>	<p>Higher awareness will give an opportunity to the local communities to adapt to the changes in</p>	<p>In many instances knowledge does not really lead to changes in behavior. Participation of the local communities might be an issue; lack of financial</p>

climate change and its impacts.	their natural surroundings and adopt sustainable methods of resource extraction. It will also help them to prepare for the consequences of climate change.	resources to conduct awareness programmes.
2. Capacity development of the forest department staff regarding climate change.	It is important for the staff of Forest Department at all levels to be aware and have proper scientific information about the changes taking place in their landscape. It is also important to have a mitigation plan prepared for the negative consequences.	Full participation of the staff. Lack of resources.
3. Enhanced protection and enforcement inside CoringaWLS	Will help in preventing illegal timber collection and control over-exploitation of resources (Eg. fishes, prawns and shells) inside the sanctuary.	Lack of enough resources and equipments with the Forest Department. Making the locals aware and comply with the rules. Many people are still not ready to use alternate resources of fuel and cooking gas despite subsidies and want to continue using timber from the sanctuary.
4. Setting up of a climate	To study the exact causes of climate change and	Lack of sufficient resources and trained staff in the concerned departments.

monitoring station in EGREE	monitor its impacts in EGREE, long-term record of ambient temperature and surface temperature of the bay and creeks are essential.	Regular maintenance of the monitoring station and equipments.

PART -3

PAYMENT OF ECOSYSTEM SERVICES



ECOSYSTEM SERVICES

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 pressures, and thereby continue to be degraded and converted for alternate uses. This is largely attributed to policy decisions that fail to internalize and factor in the values of mangrove ecosystem services in a manner that supports their retention or rehabilitation. In many cases the tangible and financial benefits arising out of mangrove conservation are only considered when making such decisions; however, the substantial values arising from the intangible ecosystem services that are not traded into formal markets and thereby do not generate cash flows are largely unknown or ignored. Most often such decisions are based on incomplete knowledge of the ecological services leading to consequent loss of human welfare and negative impacts on human health and overall well-being. Therefore, quantifying and valuating the mangrove ecosystem services can facilitate improved policy and decision making.

In the recent years, scientific research elucidating the immense contribution of mangrove ecosystems in concrete economic terms have increased, making it possible to compare with alternate economic opportunities with defined cost and benefits. For example, in American Samoa, mangroves with an extent of just 0.5 sq km have an estimated annual value of US\$ 50 million (Spurgeon and Roxburgh, 2005). In southern Thailand, high values of US\$ 2.7 - 3.5 million per sq km have been reported for the mangroves (Santhirathai and Barbier, 2001). Similarly, few examples from India include estimating the opportunity cost of saving a life by mangroves in Odisha (Das and Vincent 2009), and using contingent valuation method to assess Total Economic Value of mangrove forests in Kerala (Hema and Indiradevi 2015).

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. 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. 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.

Overall a comprehensive understanding of the linkages of mangrove ecosystem services with various production sectors of the EGREE, and more specifically the conservation-development tradeoffs that emerge due to degradation and alternate use of the mangrove ecosystems remain a major gap in current conservation planning. An economic valuation of ecosystem services provided by Godavari mangrove ecosystems would assist in better appreciation of the conservation benefits in sectoral development planning. Additionally, it will also assist in scoping and design of instruments for capturing some of the ecosystem service values through market systems as payments for ecosystem services, with the ultimate objective of providing positive incentives for conservation stewardship.

A Comprehensive Framework

It is important to adopt an integrated framework to assess and evaluate the goods and services being accrued from Godavari mangroves in EGREE. It comprises of policy analysis, stakeholder analysis, function analysis, function valuation, and communication and dissemination to various stakeholder groups (Figure 108).

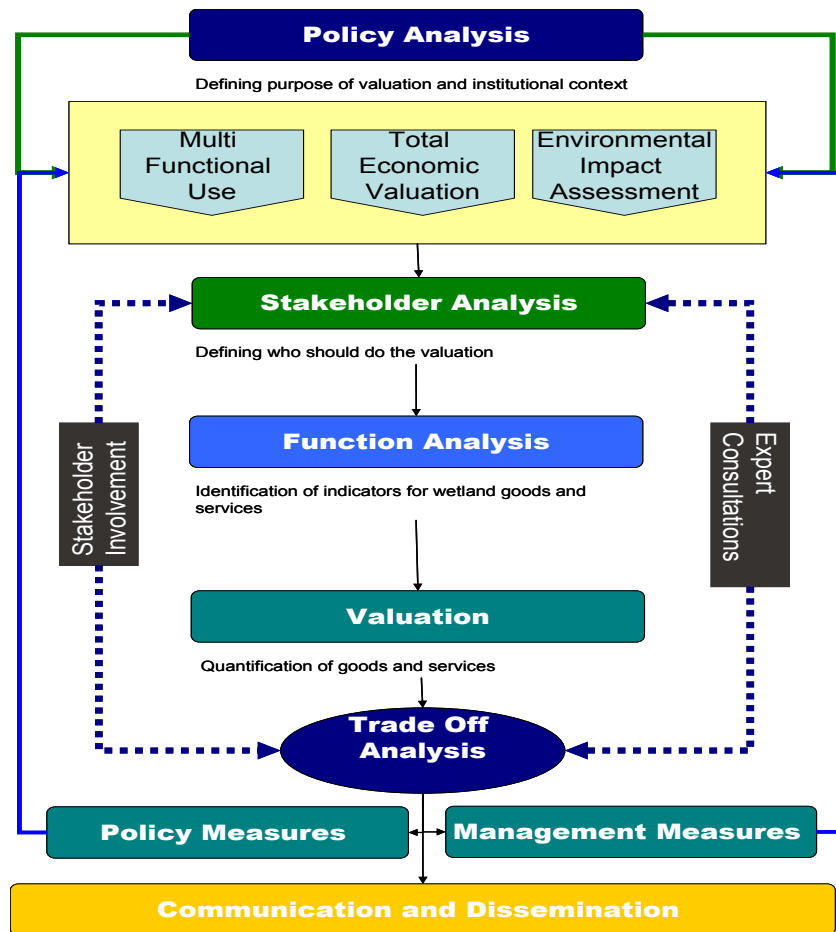


Figure 108: An integrated assessment framework for assessing mangrove ecosystem economic values

Importance of Ecosystem Services

Human beings have depended on the natural resources from the beginning of their existence. Major civilizations on Earth had their origins along a river mainly due to easy availability of freshwater and food. Even in this era of increased modernization and urbanization, our basic existence is derived from the services provided by natural resources.

Apart from the direct benefits that we derive from natural ecosystems such as food, livelihood, timber, fibre etc. most of the ecosystem services cannot be explicitly identified. However, the indirect benefits (eg. role of insect pollination in agriculture industry; erosion and flood control by wetlands and riparian forests) are also extremely

important for our survival and well-being. These types of ecosystem services are either unrecognized or under-valued unless they cease to flow. The increased incidences of major floods in Indian cities in the past decade can be attributed to a large extent to loss and degradation of natural wetlands.

It was in the initial years of the 21st century, when the Millennium Ecosystem Assessment was conducted to assess the various ecosystem services and the human impacts on them. It defined the ecosystem services as “*benefits people obtain from ecosystems*”. The major findings of this project have been that humans have modified and degraded natural ecosystems extensively that in turn would lead to significant reduction in the benefits to our future generations. However, most of the loss and degradation can possibly be reversed if our policies, institutional mechanisms, and practices are more aligned to include the cost and benefits of maintaining ecosystem services.

Types of Ecosystem Services

Ecosystem Services can be categorized into four main categories that can be described as follows:

1. Provisioning services: The direct benefits that can be extracted from nature. These are the most easily recognized. Examples include food, drinking water, timber, fuelwood, natural gas and oil, fibre, medicines etc.
2. Regulating services: The benefits provided by ecosystem processes that control or regulate natural processes. For eg. Pollination, decomposition, water purification, flood control, carbon storage, climate regulation.
3. Cultural services: The religious and/or cultural values derived from nature. It also comprises of recreation, aesthetics, and educational values of natural ecosystems.

4. Supporting services: These include the fundamental processes that drive and maintain the natural ecosystems. These are the basis for the other three types of services and include processes such as nutrient cycling, photosynthesis, production of oxygen, and provision of habitat.

Ecosystem Services of the Godavari mangroves

Based on the field surveys as well as earlier literature, the major ecosystem services provided by the mangroves in EGREE have been identified (Table 27). Further their relative importance to different communities has also been assessed at different levels.

Table 27: Determining Relevance of Various Types Of Ecosystem Services To The Communities, Nation And Global Communities

Method: Each kind of services have been scored using numbers from 3-1, placing 3= High relevance (80-100%); 2= Medium relevance (40-70%); and 1= Low relevance (<40%).

A. Provisional Services						
Ecosystem Services/ Criteria	Local relevance	Business/ local income	Cultural purpose	National Priority	Regional significance	Global value
Relative indicators that could be looked or weighted during the	Degree of dependence of/ Role in local communi	Market linkages, role in annual household income	Cultural association, education and research	Relevance at the national level	Upstream downstream linkages, transboundary	Site of global conservation priority, existence value

analysis	ties		relevance		issues, existence value	
Capture Fishes (commercial)	3	3	-	3	2	2
Capture Fishes (artisanal)	3	3	-	3	2	2
Cultivated fishes (Aquaculture)	3	3	-	3	2	1
Other aquatic food (prawns)	3	3	-	3	2	2
Other aquatic food (crabs, mollusks etc)	3	3	-	2	1	1
Fuelwood/ firewood	3	1	-	-	-	-
Timber/ wood	3	1	-	-	-	-

Poles/ shafts	3	1	1	-	-	-
Paddy cultivation	3	3	-	3	-	-
Cultivated vegetables	2	2	-	-	-	-
Plantations	1	2	-	-	-	-
Fodder	2	1	-	-	-	-
Genetic resources (especially wild species)	3	3	2	3	3	3
Shells	3	2	-	1	2	2
Hunting wild animals/ birds	1	1	-	-	-	-
Total Value	39	29	3	23	13	13
<i>B. Cultural Services</i>						
Recreation/ tourist spot	3	2	3	2	2	2
Spiritual significance	2	1	2	-	-	-
Boating	3	2	3	2	1	1
Education/ Research	-	-	2	3	3	3

Sacred groove/ Aesthetic value	3	1	3	2	2	1
Historic relevance	-	-	2	2	2	2
Total Value	11	6	15	11	10	9
<i>C. Regulating Services</i>						
Air quality maintenance	3	-	2	3	3	2
Carbon sequestration	3	2	3	3	3	3
Cyclone and Flood control	3	3	2	3	2	1
Prevention of soil erosion	3	3	2	3	-	-
Ground water source	2	2	1	2	-	-
Water purification	3	2	2	2	1	-
Decomposition	3	2	2	2	-	-
Pest and disease control	3	2	-	1	-	-

Pollination	3	3	2	1	-	-
Total Value	17	19	16	20	9	6
<i>D. Supporting Services</i>						
Presence of unique habitats	2	2	3	3	3	2
Habitat/nursery for threatened species	2	1	3	3	3	3
Habitat/nursery for commercially important species	3	3	3	3	2	2
Nutrient recycling	3	3	2	3	1	1
Photosynthesis	3	3	2	3	3	3
Biodiversity maintenance	3	3	3	3	3	3
Existence and Bequest value	3	3	2	3	3	3
Total Value	19	18	18	21	18	17
Overall Value	86	72	52	75	50	45

The above table in no means lists all the ecosystem services provided by the mangroves of EGREE. Neither has it intended to provide any empirical value to the services. The major goal of such comparison is to provide a context to the ecosystem valuation of the mangroves.

The assessment suggests that relative values of the Provisional Services are higher as compared to the other services but for most of these services already a well-established market exists both locally and nationally that makes it easier to assess their relevance in monetary terms. On the other hand, the regulating services and supporting services are highly relevant at local, national and global levels.

Carbon sequestration is one of the most important services provided by mangroves across the world. It not only is an important component of global nutrient cycling but also an important mechanism to mitigate the impacts of global warming. Therefore, the relevance of this service by existing mangrove forests is high at both local and global level.

Godavari mangroves along with Krishna mangroves are globally one of the most important sites for a threatened cat species, Fishing Cat. Therefore, the value of this service is highly relevant at a national and global level. Similarly, EGREE is also home to a Near Threatened mangrove species *Ceriops decandra* that has suffered habitat loss and degradation in its limited distribution range. Presence of such species with high conservation and cultural (in terms of education and research) significance accords high relevance to EGREE nationally and globally.

Valuation of Ecosystem Services

It is evident from the preceding sections that unless a market exists, it is difficult to recognize the value of a natural service. Economic valuation is a common tool to attach monetary values to a ecosystem service which then makes it easier to assess its importance and the impacts of human activities on it. In a pioneering study, Robert Costanza (1995) estimated the combined value of seventeen basic services provided by

the Earth's ecosystems to be higher than US\$ 33 trillion annually. This figure was more than the size of global exchange economy (US\$ 25 trillion) at that time.

The major premise of economic valuation is to find a market value for the natural goods and services (Figure 108). If a market is non-existent for any service, a virtual or artificial market is created for it to assess its hidden price. Yet there are certain services to which communities attach high significance but have no apparent utility either in present or future times (Existence and Bequest values). In such cases, other appropriate methods are used to estimate their monetary value.

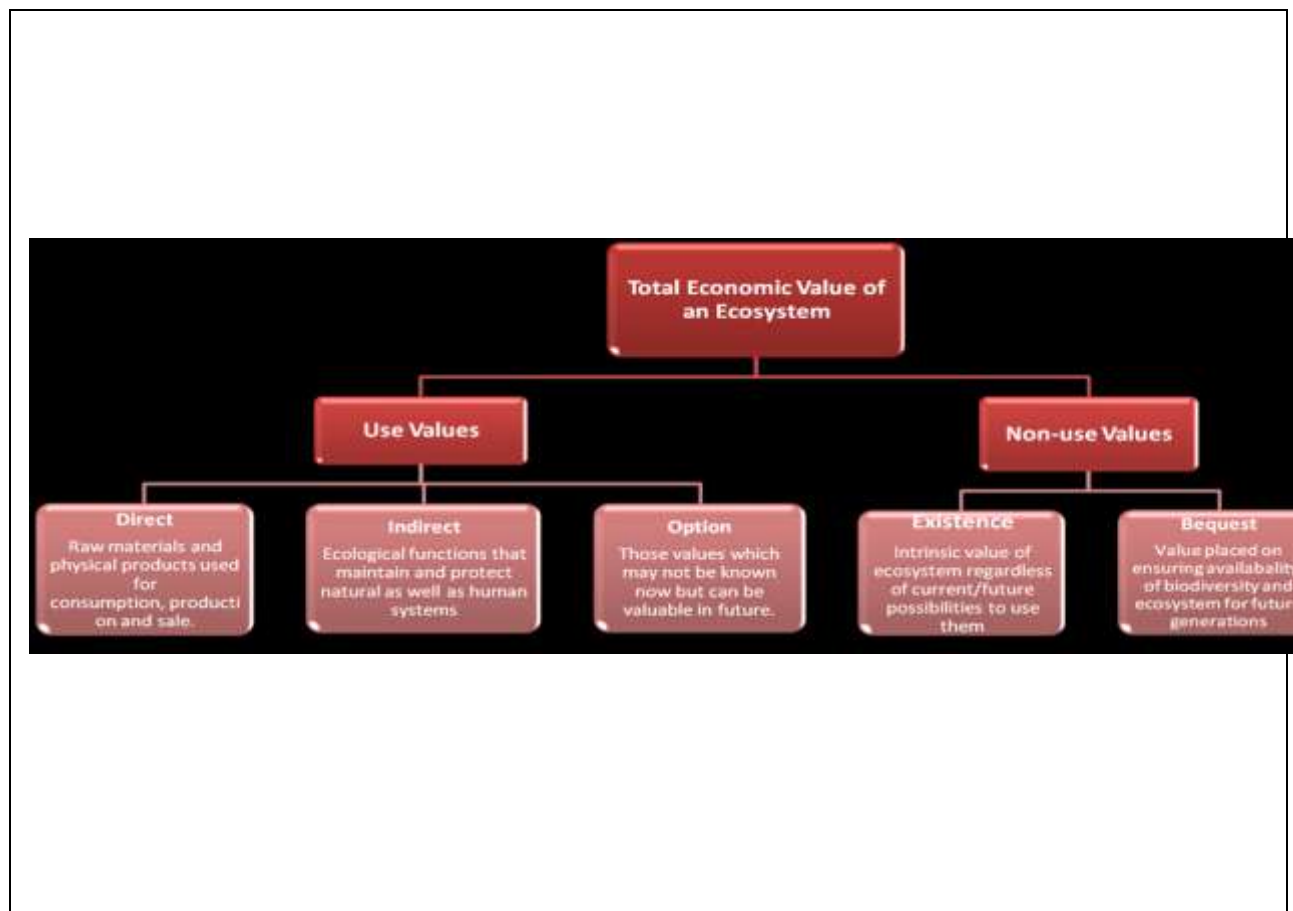


Figure 108: Use and Non-use Values of an Ecosystem

In the preceding sections, the most important ecosystem services have been identified. In the subsequent sections, some of the important goods and services provided by the

natural ecosystems of EGREE are discussed. The different sections include value of by-catch practiced in Kakinada Bay, the carbon sequestration potential of Coringa Wildlife Sanctuary, and the importance of freshwater flow for EGREE. Finally, based on extensive questionnaire surveys among the local communities, their willingness-to-pay for protection of the mangroves in EGREE is discussed.

Economic valuation of molluscan resources in EGREE

Any major fishing activity is associated with incidental catches of other marine organisms, which sometimes can be staggeringly high. By-catch is the term given to the incidental catches of non-target species; it can also include the juveniles or undersized individuals of the target species. Invertebrates such as echinoderms, dolphins, sharks and rays, sea turtles, and even sea birds can form a by-catch of fisheries.

A major proportion of invertebrate by-catch which is generally caught in trawls consists of benthic taxa such as molluscs, crustaceans, echinoderms, and benthic fishes. Despite their commercial value, some of them are occasionally discarded for various reasons (Venkataraman and Wafar, 2005, Sanchez *et al.*, 2007) while others go for production of fish meal/fertilizer. Because of such ongoing practices the benthic communities in the estuary become severely disturbed and affect the demersal fish assemblages which depend on them (Colloca *et al.*, 2003).

Several studies have been done on the incidental catch of non-target species (by-catch). Davies *et al.*, 2009, have studied that bycatch represents 40.4% of the total marine catch. Kelleher (2005) estimated the fishery discards at more than 7 million tonnes, of which 27% is contributed by shrimp trawl fisheries. Although bycatch is generally inevitable, it is possible to quantify the bycatch and identify the important bycatch species to reduce fishery discards and to effectively utilize the same (Kennelly and Broadhurst, 2002). Many studies have also been done on specific groups of taxa in the by-catch (Molluscs: Victor and Lazarus, 2000; Babuet *et al.*, 201; Crustaceans: Ajmal Khan and

Jayabaskar 1999; Bijukumar *et al.*, 2007; and Echinoderms: Balaji *et al.*, 2007; James, 2008).

This present study was aimed to study the Molluscan diversity caught in the trawls and estimate their economic value at Uppada, Kakinada port in East Godavari district, Andhra Pradesh.

Study site and methodology

This study focused at the by-catch collection in Kakinada Bay near the Uppada landing center. The landing center lies at the Yeluru River mouth near Uppada which is a small coastal village and an important marine fish landing center in Kakinada. Everyday around 80-100 boats operate near the shore and in Kakinada Bay at depths of 9-30 meters. The catch mostly consists of marine fishes, crustaceans, and mollusk species.

During the study period, sampling was done at the landing center for every alternate day during late afternoon or early evening hours when most of the fishermen return with the day's catch. After a boat enters the landing center, the by-catch is laid down on the beach which are then collected and sold by local women to local dealers. Most of the by-catch is comprised of bivalves, gastropods, and other crustaceans. Therefore, these are used in cement and pharmaceutical industries as well as used as feed in poultry and fish farms. Everyday nearly 20-30 fisherwomen are engaged in this activity.

The heaps of by-catch separated by the fisherwomen were randomly selected and then each heap was intensively searched for different species of gastropod and bivalve. Once a gastropod species was identified its frequency of occurrence was noted during subsequent surveys. If any species is not identified at the site, they were brought to the base camp, cleaned with brush, and identified using relevant references. Other than both live and dead mollusk species the by-catch also contained a variety of fish that were not of commercial value, Echinoderms, Brachyurans, and Mantis shrimps.

Results

Species composition

A total of 71 species of Gastropods and Bivalves were found belonging to 34 families and 49 genera (Appendix II). Of these Naticidae, Conidae, Bursidae, Nassaridae, Olividae and Aricidae families were found in highest frequency (Figure 111,112,113). 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.

Among the 49 genera, thirty-six species were represented by a single species, eight species were represented by eight species, four families were represented by four and three species and one family is represented by five species.

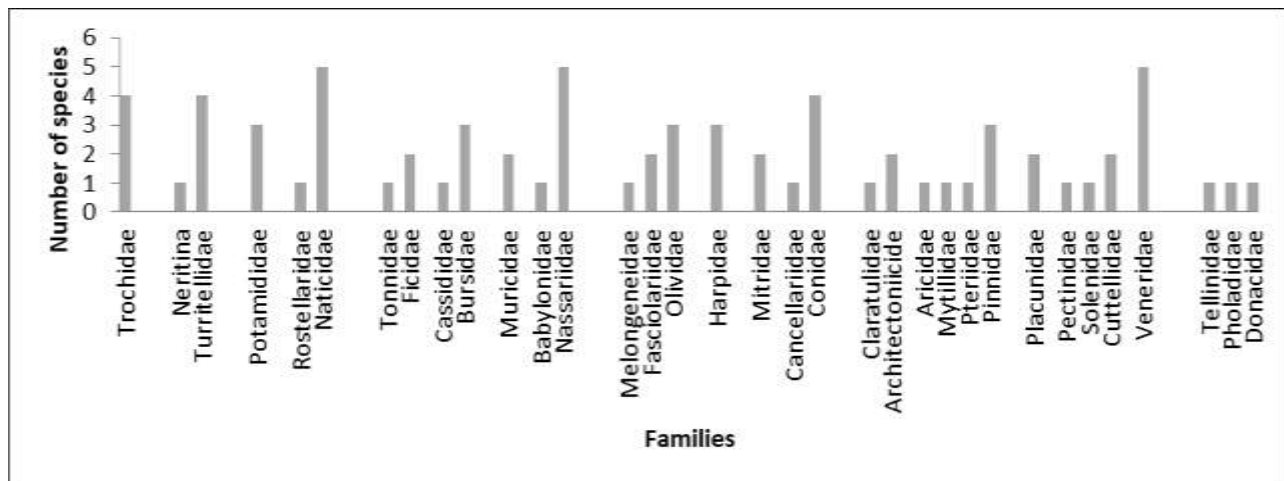


Figure 109. Dominant mollusk families recorded in the by-catch at Uppada Landing center

Economic value of the by-catch

The number of heaps of by-catch ranged from 11 to 23 per day. Each heap usually weighed around 10 to 12 kilograms. The selling price of the by-catch was determined

from the fisherwomen and the local dealers which was Rs. 10/- per kilogram. Using this market price and extrapolating for the entire year, the economic value of by-catch at Uppada was calculated to be Rs. 2,97,000/- per annum.

Discussion

During our regular visits to the different landing centers of Kakinada, we often came across large quantities of by-catch that is usually sold to the poultry or aquaculture industry as feed or fish meal. Apart from the molluscan species that were identified, by-catch also included large quantities of other invertebrate taxa and juveniles of different fish species. Many times, the by-catch also included sting rays which would be sold off separately by the fishermen. Interestingly, several fishermen were often observed to be engaged in trawling inside the Kakinada Bay, which is a part of the Coringa Wildlife Sanctuary. Most of these fishermen belonged to the villages near the Kumbabhiskam or Uppada landing centers. It is this by-catch that is sold as poultry meal or fish feed.

Trawling is the most destructive fishing technique in the world (Kelleher 2005). Since it is a non-selective method, it leads to drastic changes in the benthic communities and destroy their habitats (Tillin et al. 2006). Studies have also shown that trawling leads to functional changes in the marine ecosystem. Long-term trawling was shown to have most negative impact on the filter-feeders such as bivalves (Tillin *et al.* 2006). In Kakinada Bay, bivalves form an important part of the aquatic food web. They are an important food source for the Open billed storks and Painted storks as well as for number of other migratory waders that visit the region annually.

This destructive technique also has profound impacts on the local fisheries. The amount of by-catch is far higher in bottom trawling than in other methods. In one study, it was found that bottom trawling for shrimps lead to nine times more by-catch than other more selective techniques (Reilly et al. 2002). At the same time, bottom trawling has also been found to be highly unsustainable since it leads to a reduction in the catch of target species for the same amount of effort by a fisherman (Whitmarsh 2003). Further the

presence of juvenile fishes in the by-catch will seriously affect the recruitment process of commercially important fishes. If such practices are not controlled it will potentially lead to collapse of the fisheries in the bay.

Kakinada Bay is a sensitive ecosystem which acts as nursery ground for many important fish species and habitat for several others. It also acts as a link between the marine and brackish ecosystems of the Coringa mangroves along with being a feeding ground for the migratory bird species. Due to the presence of a harbor and port, this ecosystem is already vulnerable to the impacts of dredging and, movement of ships and boats. Considering the low economic returns and high cost accrued from the negative ecological impacts, it is therefore recommended to prohibit or regulate such destructive fishing activities in Kakinada Bay. In return, alternative livelihoods can be generated for those involved in this trade, mostly who are women from the nearby villages.



Figure 110: Heaps of bycatch in one landing center in EGREE

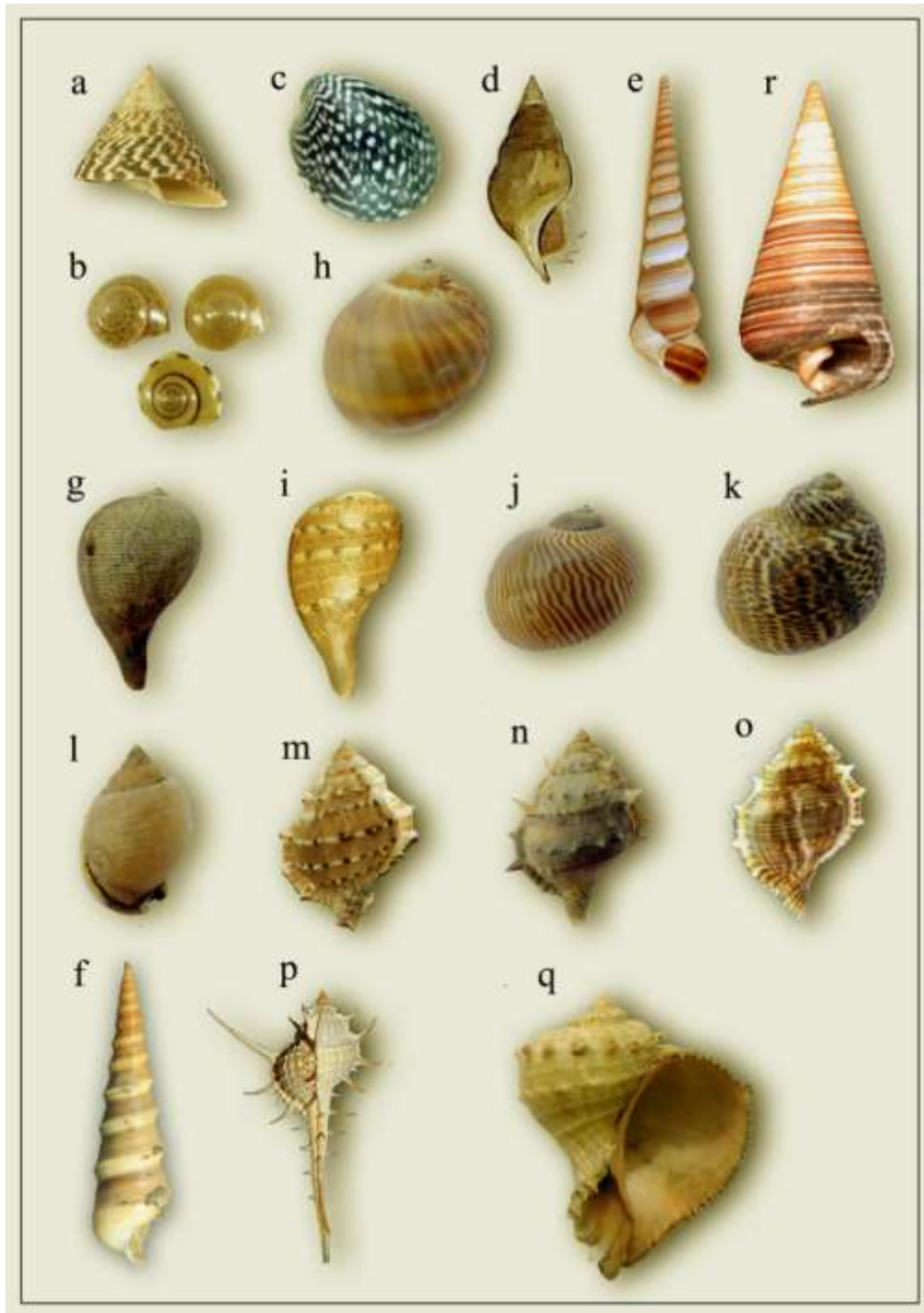


Figure 111. **a)** *Trochusniloticus*, **b)** *Umboniumvestiarium*, **c)** *Neritinaviolaceae* **d)** *Tibia spse)* *Turritellaterebra* **f)** *Turitellaspsg)* *Ficusgracilush)* *Neveritadidymai* **i)** *Ficusvariegataj)* *Naticavitellusk)* *Naticapicta* **l)** *Phaliumcanaliculatumm)* *Bufonariacrumenan)* *Bufonariaechinatao)* *Bursa ranap)* *Murex tribulusq)* *Rapanarapiformis*

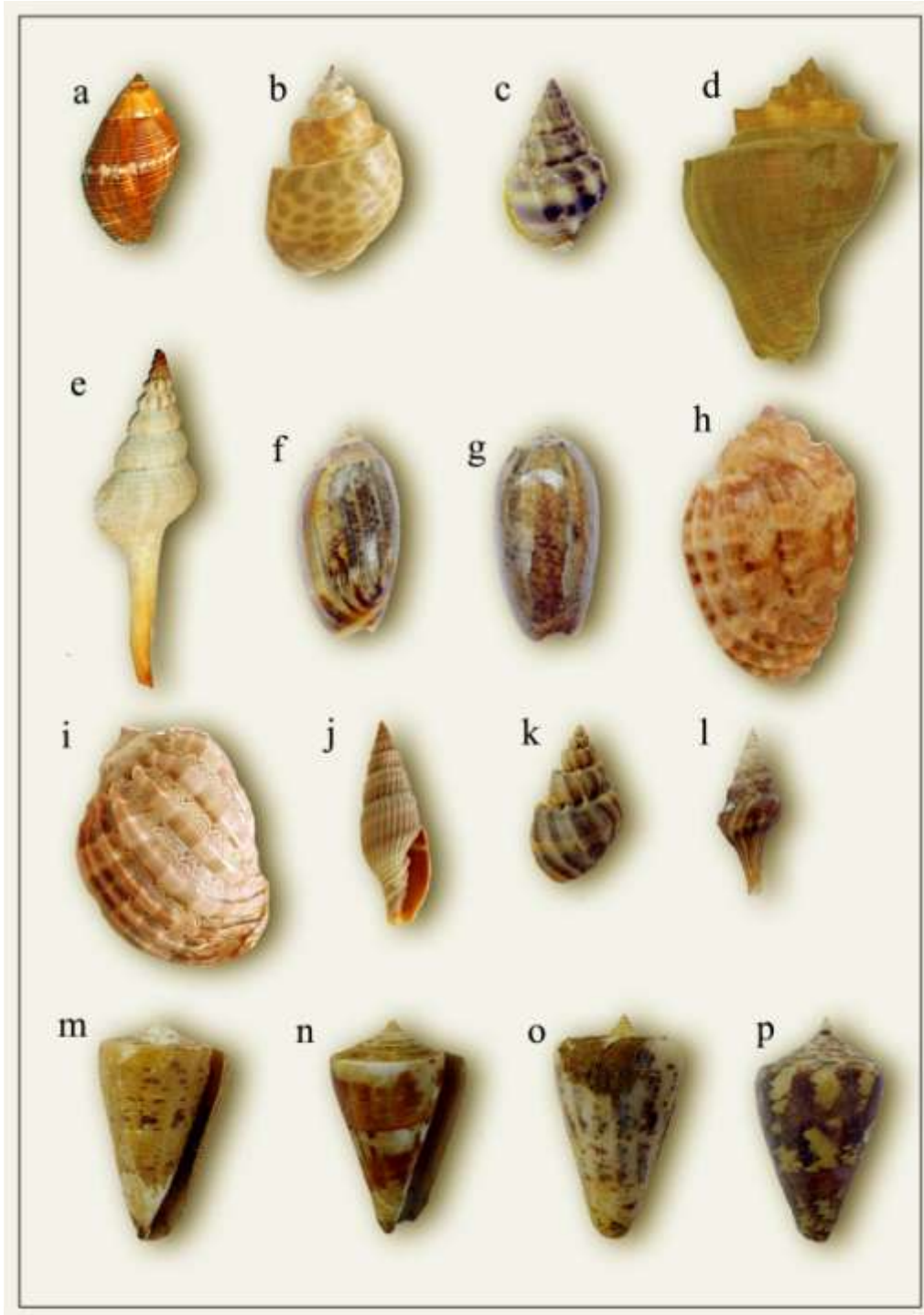


Figure 112. a) *Nassafrancolina* b) *Babylonia spirata* c) *Nassariausstolatus* d) *Pugilinacochlidium* e) *Fusinuscolous* f) *Olivancillariagibbosa* g) *Olivia viduah* h) *Harpaamourettai* i) *Harpadaavidis* j) *Mitra acuminata* k) *Scalptiacfscalarina* l) *Turrisjavanam* m) *Conuseburneus* n) *Conusinscriptus* o) *Conusmonilep* p) *Conuspraecellens*

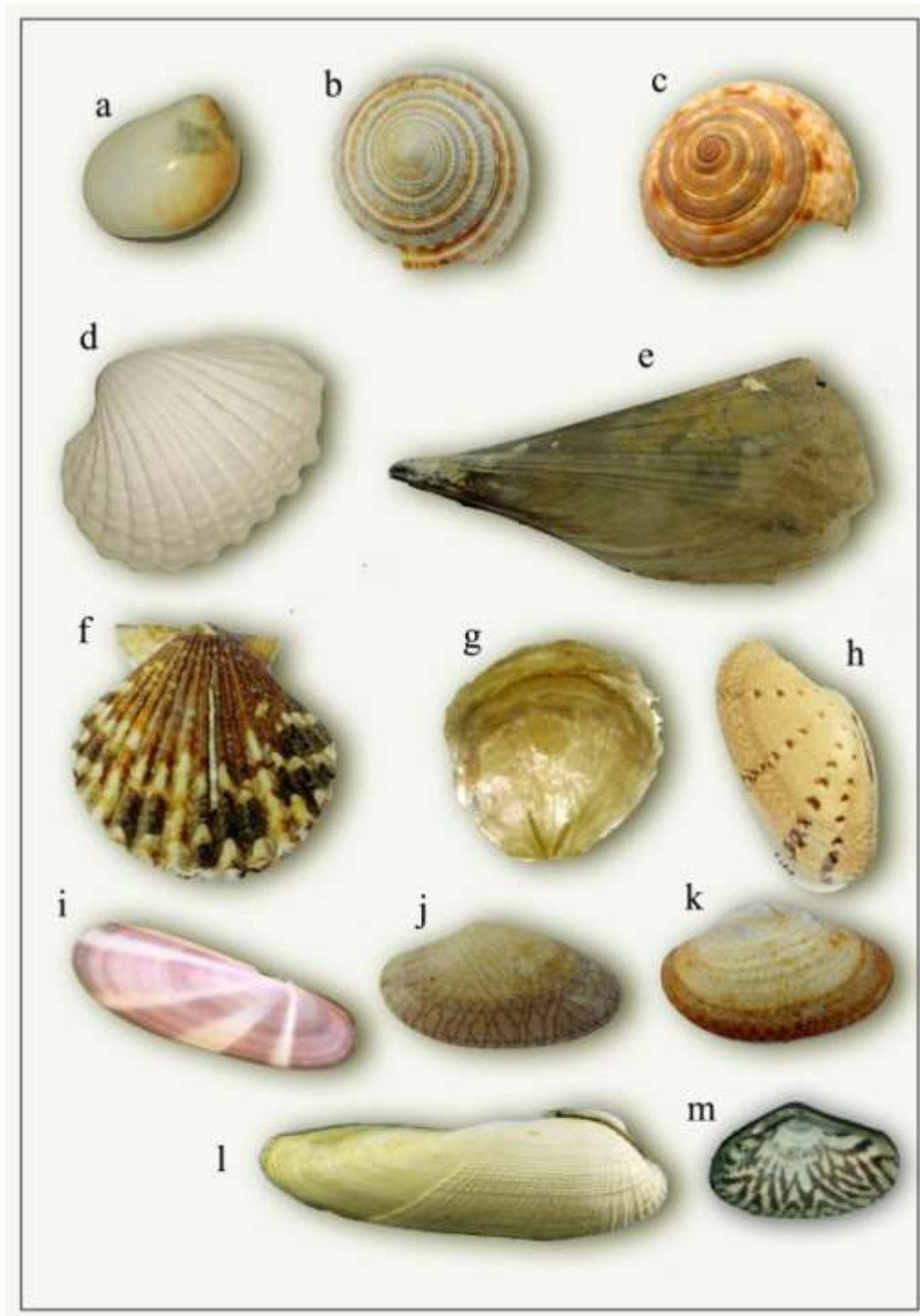


Figure 113. a) *Architectonia perspectiva* b) *Architectonia laevigata* c) *Tegilloriagranosa* d) *Tegilloriagranosa* e) *Pinna bicolor* f) *Pecten tranquebaricus* g) *Placuna placenta* h) *Paphia rotundata* i) *Siliquaradiata* j) *Paphia textile* k) *Sunetta* l) *Pholas orientalis* m) *Pholas orientalis*

CARBON SEQUESTRATION POTENTIAL OF THE MANGROVES IN CWLS

Mangroves are ecologically important forests of the tropical region. They are highly productive ecosystems and contribute 10–15% (24 terragrams of Carbon per year or Tg C y^{-1}) to coastal sediment carbon storage and export 10–11% of the particulate terrestrial carbon to the ocean (Alongi, 2014). Carbon is an element commonly found on earth in various form. It is an essential component of life. Nature provides a conducive environment when the governing processes are in balance but any disturbances in the composition and process in the environment that causes the inequalities that leads to changes in the environment. The recognition that gases in the environment trap heat close to the earth goes back to 1827 when Jean-Baptiste Fourier first noted it (Houghton, 1997). Since then scientists are increasingly more unanimous on human-induced global warming, a consequence of increased concentration of heat-trapping gases in the atmosphere released because of human activity (Figure 90). In recent years, temperatures have risen dramatically. The example includes glacier melt in the Himalaya and other parts of the world (Dyurgerov and Meier, 2005).

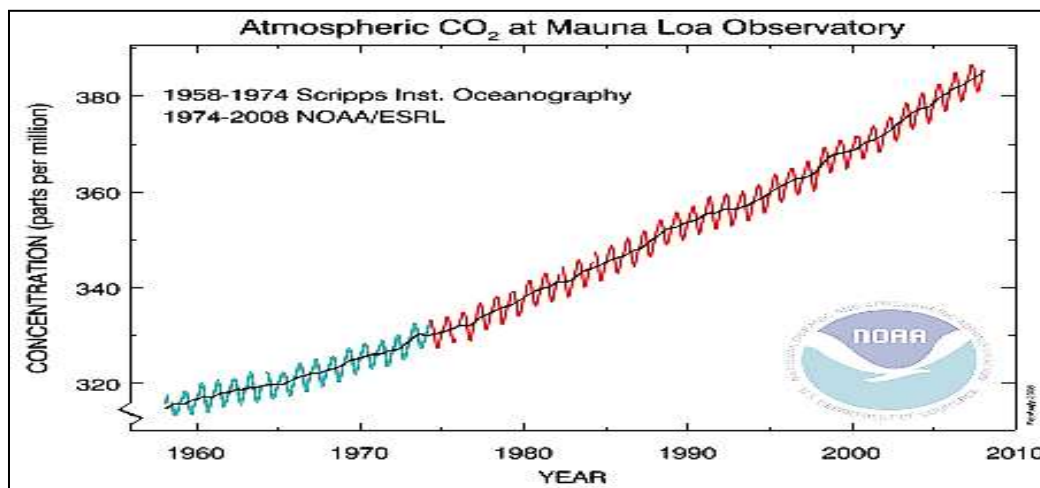


Figure 114. A composite trigonometry graph of Atmospheric CO₂ at Mauna Loa observatory (Source: NOAA)

While there is an ambiguity about the details of global warming due to incomplete understanding of the complex process involved, there is a consensus that climate change is happening, and humans are largely to blame for it. The amount of greenhouse gases that the humans add to the ambient air is enormous amounting 26 billion ton/year for CO₂ alone the total is about four metric tons per person per year (Henson, 2006). Earth's atmosphere has gone through countless temperature swings in its 4.5 b years of existence; the past raises the question: how can we be sure that global warming is not "natural" (Henson 2006). These concerns were tackled by the Intergovernmental Panel on Climate Change (IPCC) in its 2nd and 3rd assessment reports (1995; 2001). Referring to the work of the scientists across the globe these reports state that "there is a new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities" (IPCC 2001).

In 1997, negotiations in Kyoto, led to the formation of the Kyoto Protocol. The Kyoto Protocol to the United Nations Framework Convention on Climate Change aimed at reducing global warming by achieving "stabilization of greenhouse gas concentration in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. The IPCC second assessment report of 1995 provided critical inputs to and thereby paved the way for the adoption of the Kyoto Protocol in 1997. Currently, 192 states have signed and ratified the Protocol (Figure 115).

India is signatory to IPCC protocol and has accepted the carbon sequestration norm prescribed by the IPCC. The Intergovernmental Panel on Climate Change (IPCC) reported that the global atmospheric concentration of CO₂ has increased from a pre-industrial value of about 280 ppm to values of 379 ppm in 2005, and 391 ppm in 2011 (Solomon et al., 2007; Stocker et al., 2014). The following figure shows world CO₂ emissions by different regions (Figure 92).



Figure 115. Green - Countries that have signed and ratified Kyoto protocol
 Dark Green - Annex 1st and 2nd countries that have ratified Kyoto protocol
 Grey - Countries that have not yet decided

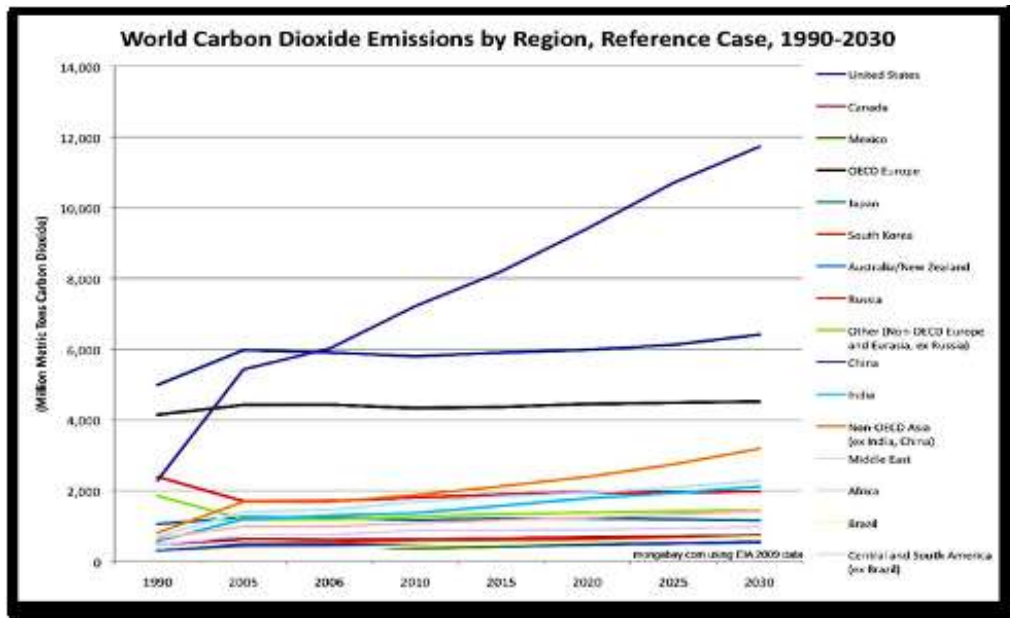


Figure 116. Graph showing World Carbon Dioxide Emission by different region

According to the Department of Energy's (DOE) and Energy Information Administration (EIA), India is expected to have significant growth of emissions over the next 20 years after China and United States who is major polluter of the world. The National Oceanic and Atmospheric Administration (NOAA) reported that the annual average of CO₂ was 393.82 ppm in 2012 and 396.48 ppm in 2013. The above-mentioned figure (Figure 92) depict that by 2030, India will able contribute more than 2000 million metric tons of carbon in the global basket. The Intergovernmental Panel on Climate Change estimates that, by the year 2050, global CO₂ emissions must be reduced by 85% from levels seen in 2000 to prevent a global mean temperature increase of 2°C (IPCC, 2007). According to the Copenhagen summit, every signatory has to reduce their carbon level by 20 – 25% by 2020 by considering 2005 as a base level. Reduction of Emission from Deforestation and forest degradation (REDD), is one of the most hotly debated issues in international climate change deliberations. Global deforestation is occurring at a rate of approximately 13 million ha/year. The Intergovernmental Panel on Climate Change estimated emission from deforestation in the 1990s to be at 5.8 gigatons of CO₂ per year of about 20% of annual global greenhouse gas emissions (CBD, 2011). India has taken a firm stance in the favour of a comprehensive REDD+ approach.

Since reduction of deforestation, and conservation and improvement of forests are two sides of the same coin, India believes both should be treated at par: that is, fairness requires that a unit of carbon saved by checking deforestation should be treated the same as a unit of carbon added due to conservation and afforestation measures. India's stand was finally accepted at the 13th meeting of the conference of the parties (COP 13) at Bali when elements of conservation, sustainable management of forests and enhancement of forest carbon stocks were incorporated in the Bali action plan.

Incorporation of "Blue carbon" concept into the REDD+ mechanism provides a real hope for reducing the carbon content of the atmosphere as well as to gain some better incentives for better management. Incorporation of blue carbon in the REDD+ readiness plans will make more countries to enter the readiness process, the applicability of blue

carbon to that process can strongly define future funding for coastal habitat protection. REDD+ schemes, particularly relevant for mangroves, provide a unique learning opportunity, given their focus on harnessing forests to mitigate climate change. REDD+ is designed to reduce greenhouse gas emissions by avoiding the release of carbon stored in trees when trees are cut down; encouraging the storage of additional carbon by leaving trees standing; and promoting reforestation (Jagger et al., 2010). Blue carbon concept incorporation in the REDD+ scheme is possible and India can easily make its stand in the other phase of REDD directly but the main problem with the blue carbon is availability of carbon accounting and proper methodologies related with carbon estimation. Blue carbon offsets will be required to compete not only with other REDD+ projects, but also with other carbon mitigation strategies as well (Gorden et al., 2011).

This calculation assumes that the reduction in emissions is the only mechanism by which we can reduce CO₂ concentrations. Several mitigation measures have been considered to deal with this increase of greenhouse gases. In recent years, researchers have focused their attention on the ability of wetlands to offset atmospheric CO₂ by storing it as carbon in plants and sediments (Zedler, 2012).

Wetlands are dynamic and highly productive ecosystems characterized by aquatic and terrestrial components that provide a variety of ecological functions and services. Ecological services provided by wetlands to humans include carbon sequestration, soil and water quality filtration, flood prevention, climate change mitigation, and many others (Chabreck, 1988). Coastal wetlands include tidal salt marshes in temperate climates, mangrove ecosystems in tropical climates, and tidal brackish and freshwater marshes in both. Recently, restoration efforts have been implemented to recover their ecological functions and services such as improvement of water quality, reestablishment of vegetation, habitat, and carbon sequestration in wetlands (Steere et al., 2001; King et al., 2009; Palaima, 2012).

The carbon sequestration function of coastal wetlands offers a potential to mitigate the increase of the atmospheric CO₂, which is associated with the rise of global warming. The exchange of carbon in coastal wetlands is a complex process between wetland vegetation and soil. Vegetation assimilates atmospheric CO₂ by the photosynthesis process and stores it as organic carbon in plant tissues.

Recent research has highlighted the valuable role that coastal and marine ecosystems play in sequestering carbon dioxide (CO₂). 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. Ocean is the largest carbon pool encompassing an estimated of 38000 gigatons of Carbon (Gt C). The geological carbon pool, composed primarily of fossil fuels, is the next largest pool, estimated at nearly 4000 Gt C. Vegetation, soils, and detritus hold around 2000 Gt C, followed by the atmosphere, which contains about 760 Gt C (IPCC, 2007).

Ocean ecosystem itself consists of mangroves, sea grasses, salt marshes etc., but the potential of mangrove ecosystem is the maximum among all (Figure 93), even higher than tropical dry forest and tropical rainforest (UNEP, 2014). It may be because of their efficiency in trapping suspended matter and associated organic C during tidal inundation.

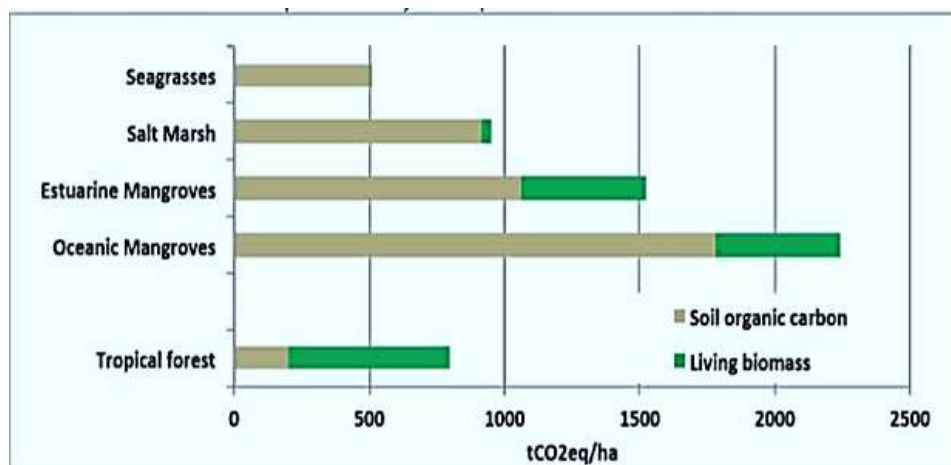


Figure 117. Global averages of carbon pools of coastal habitats, Tropical forests are included for comparison (Sources: Murray et al., 2011)

Table 28. Global estimates of carbon pool of mangroves and tidal salt marsh ecosystem. (Source: Twiley *et al* (1992), Chumura *et al* (2003), Duarte *et al.* (2005), Bridgham *et al.* (2006), Laffoley *et al.* (2009), Mcleod *et al.* (2011))

GLOBAL ESTIMATE	TIDAL SALT MARSH	MANGROVE ECOSYSTEM
Area of wetland (km ²)	51,000 - 203,000	137,000 - 300,000
Carbon accumulation rate in sediment (gCm ⁻² yr ⁻¹)	151 - 242	139 - 265
Soil carbon density (g C cm ⁻³)	0.036 - 0.039	0.028 - 0.059
Soil carbon pool (Tg C)	430 - 1990	20- 4900
Wood production (Tg C yr ⁻¹)		27 - 160
Biomass carbon pool (Tg C)	7 - 20	1120 - 4980
Total carbon pool (Tg c)	400 - 2010	4600 - 8900

Mangrove systems also are a significant biomass carbon pool with estimates ranging from 1220 to 4980 TG C. These estimates are almost 90-fold higher than the estimates of carbon biomass on tidal salt marshes, which range from 7 to 20 TG C (Table 13). The results suggest that mangrove forests are an important component in the global carbon cycle (Bouillon *et al* 2008; UNEP 2014). An explanation for these findings is that mangrove vegetation communities are favored by the tropical climate contributing to the high net primary production on these ecosystems. Moreover, the lower carbon levels in tidal marshes are related to the dominant herbaceous plants that do not accumulate carbon in wood as is the case of mangrove trees (Bridgham *et al.*, 2006). Carbon sequestration function performed by coastal wetlands can provide ecological opportunities in further wetland restoration efforts because of the capacity to sequester and store carbon.

Besides, the developing of protocols for quantifying carbon sequestration in wetlands along with the feasibility of implementing a market for trading credits of wetland carbon could guarantee financial aid. These incomes can be used to protect, enhance, and restore wetlands because of their importance as carbon reservoirs (Adhikari *et al.*, 2009).

As part of this project, a study to assess the Carbon Sequestration Potential of the mangrove forests of Coringa Wildlife Sanctuary was conducted. The results of this study are as following:

Relationship between Mangrove Density and Soil Salinity at Community Level in Coringa Wildlife Sanctuary

A significant (0.78) negative relationship was revealed in between salinity and mangrove density in the study area (Figure 117). Descending slope showed the effect of salinity on mangrove community. High saline condition resulted in to low density of mangrove. At individual basis, most of the mangrove species showed the negative relationship with the salinity in Coringa WLS. The only exception was *Avicinnia*

officinalis and *Sonneratia apetala* that had positive relationship with the salinity. Density of both these species increased with increase in soil salinity. Preferential salinity range of different mangrove species in Coringa Wildlife Sanctuary are given in Figure 119.

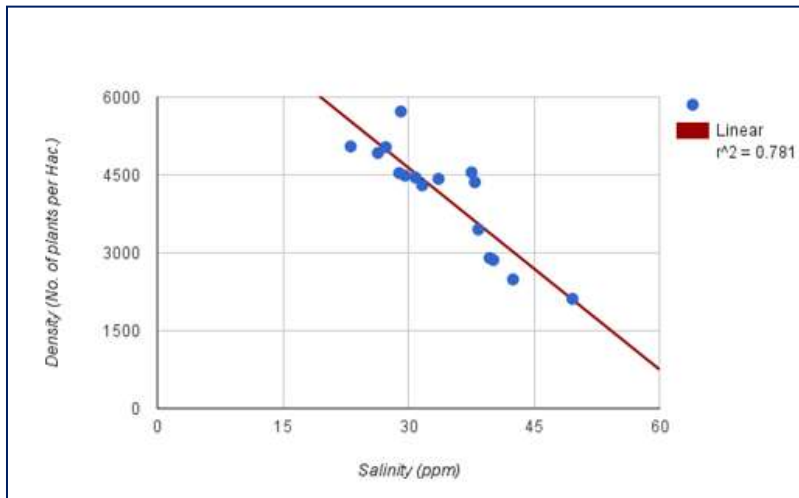


Figure 117. Graph showing the decreasing pattern of density of mangrove species in Coringa Wildlife Sanctuary at community level

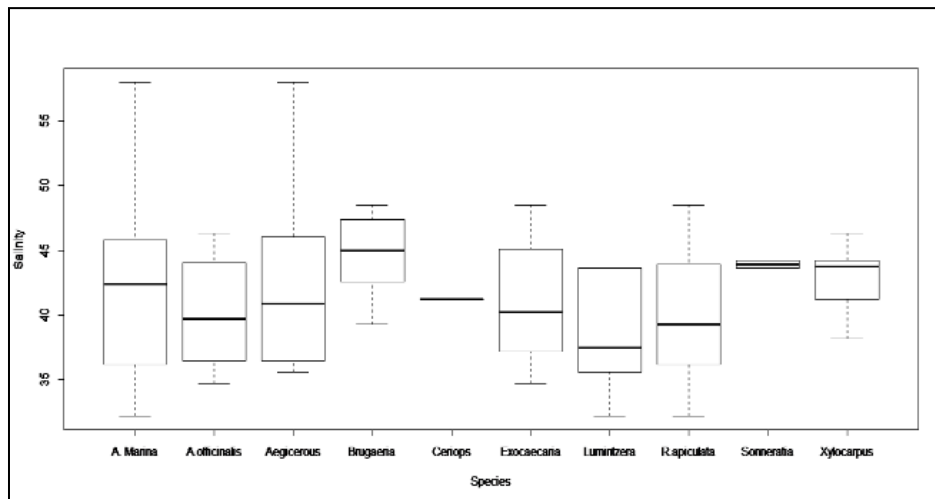


Figure 118. Graph showing preferential salinity range of mangroves species in Gaderu River of Coringa wildlife Sanctuary

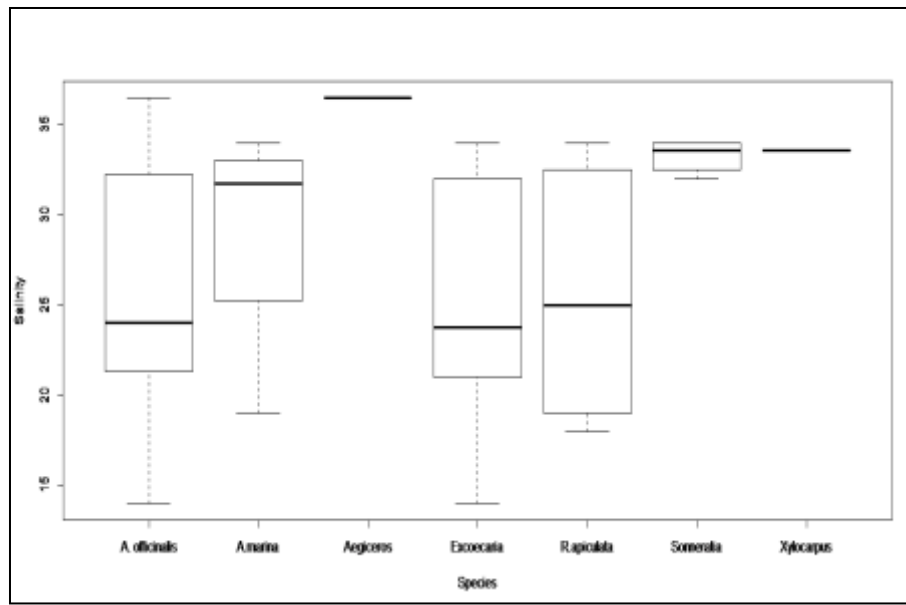


Figure 119. Graph showing preferential salinity range of mangroves species in Coringa River of Coringa wildlife Sanctuary

Figure 117 & 118 mentioned in (Table 28) revealed that in Gaderu River *Bruguiera gymnorrhiza*, *Sonneratia apetala*, *Xylocarpus granatum* and *Avicinnia marina* were present a high salinity range. *Aegiceros corniculatum*, *Ceriops decandra* and *Excaecoria agallocha* was present a medium salinity range, whereas *Lumnitzera racemosa*, *Rhizophora apiculata* and *Avicinnia officinalis* was distributed at a low salinity range. *Avicennia marina* was present at a salinity range of 32.2 to 58 ppm. This species showed their presence better at salinity range of 36.35 to 45.40 ppm and the best preferred salinity by *Avicinnia marina* was at 42.40 ppm. *Avicinnia officinalis* was present at a salinity range of 34.7 to 46.3 ppm, the better growth was at a range of 36.65 to 39.70 but the best performance was at 39.70 ppm. *Aegiceros corniculatum* was at a salinity range of 35.6 to 58 ppm, better growth was observed at a range of 36.65 to 45.92 ppm and the best preferred salinity was at 40.9 ppm. *Bruguiera gymnorrhiza* was at a salinity range of 39.3 to 58 ppm, species obtained healthiest growth at a salinity range of 43.22 to 46.85 ppm and the best presence was at 45 ppm.

Table 28. Quantification of preferential salinity range of mangrove species along Gaderu River

Species	Q1	Median	Q3	Min	Max
<i>A. Marina</i>	36.35	42.40	45.40	32.2	58
<i>A.officinalis</i>	36.65	39.70	43.97	34.7	46.3
<i>Aegicerous corniculatum</i>	36.65	40.9	45.92	35.6	58
<i>Brugaeria gymnorrhiza</i>	43.22	45	46.85	39.3	58
<i>Ceriops decandra</i>	41.2	41.2	41.2	41.2	41.2
<i>Excoecaria agallocha</i>	37.4	40.25	44.5	34.7	58
<i>Lumintzera racemosa</i>	35.9	37.50	42.25	32.2	58
<i>R.apiculata</i>	36.2	39.30	43.9	32.2	58
<i>Sonneratia apetala</i>	43.6	43.90	44.2	39.3	45.8
<i>Xylocarpus granatum</i>	41.8	43.75	44.12	38.2	46.3

Ceriops decandra was observed only at a salinity range of 41.2 ppm. *Excoecaria agallocha* was present at a salinity range of 34.7 to 58 ppm, better performance was in the salinity range of 37.4 to 44.5 ppm and the best selected point was at a salinity of 40.25 ppm. *Lumintzera racemosa* was seen at a salinity range of 42.25 to 58 ppm. The better performance was at a range of 35.9 to 42.25 and the maximum distribution was at 37.5 ppm.

Rhizophora apiculata showed their better distribution at a salinity level of 36.2 to 43.9 ppm and the best performance was at 39.30 ppm. *Sonneratia apetala* exhibited the greater salinity range of 43.6 to 44.2 ppm for better growth and the best was at 43.90 ppm. *Xylocarpus granatum* was also distributed at a higher salinity range of 41.8 to 44.12 ppm and the best growth of this species was at salinity of 43.75 ppm.

Table 29. Quantification of preferential salinity range of mangrove species along Coringa River

<i>Species</i>	Q1	Median	Q3	min	max
<i>A. officinalis</i>	21.3	24	32.25	14	36.5
<i>A.marina</i>	28.37	31.75	32.5	19	34
<i>Aegiceros corniculatum</i>	36.5	36.5	36.5	36.5	36.5
<i>Excoecaria agallocha</i>	23.75	21.15	31.87	14	34
<i>R.apiculata</i>	25	20.25	30.87	18	34
<i>Sonneratia apetala</i>	33.6	32.5	34	32	36.5
<i>Xylocarpus granatum</i>	33.6	33.6	33.6	33.6	33.6

Table 29 revealed that in Coringa River, *Aegiceros corniculatum*, *Sonneratia apetala* and *Xylocarpus granatum* was present at a higher salinity range. *Avicinnia marina* preferred the medium salinity range whereas *Excoecaria agallocha* and *Rhizophora apiculata* was at a low salinity range. *Avicinnia officinalis* was distributed at a salinity range of 14 to 36.5 ppm, the better distribution was at a range of 21.3 to 32.25 ppm and the best was at 24 ppm. *Avicinnia marina* showed their distribution 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. *Aegiceros corniculatum* showed best distribution at a salinity of 36.5 ppm.

Excoecaria agallocha showed better performance between 23.75 to 31.87 ppm and the best was at 21.15 ppm. *Rhizophora apiculata* was present at a salinity range of 18 to 34 ppm, better distribution was between 25 to 30.87 ppm and best performance was at 20.25 ppm. *Sonneratia apetala* preferred higher salinity range of 33.6 to 34 ppm and the best growth was at 32.5 ppm. *Xylocarpus granatum* showed better performance at a salinity of 33.6 ppm.

Relationship between Vegetation Structures In Terms Of Complexity Index (Ci) With Salinity in Coringa WLS

Complexity of index (CI) that represents the structural complexity of mangrove communities at each site shows statistically significant negative correlation soil salinity (Figure 120). Lower salinity level represents a better index and it is decreasing as we proceed to higher salinity. As salinity had a correlation with the distance of the sampling plot from the sea mouth, we could relate the complexity index with the distance of the plot also. The distance of the plot far from sea mouth shows greater complexity index value than the plot nearer to the sea.

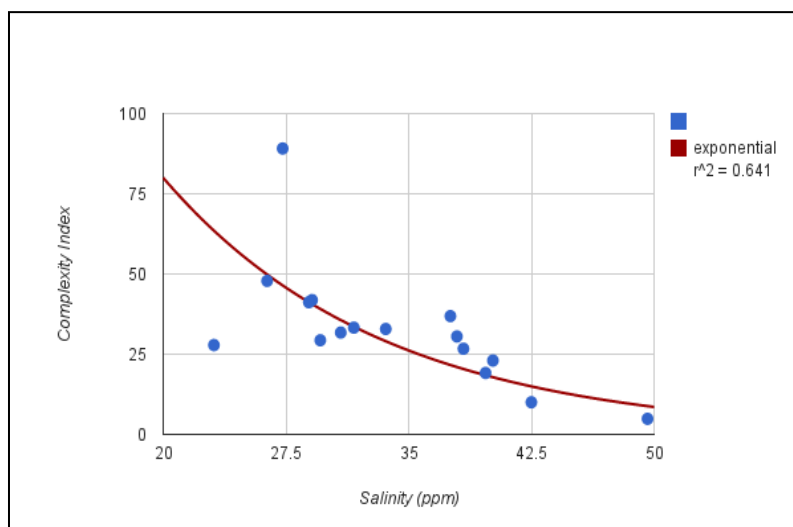


Figure 120. Graph showing decreasing pattern of Complexity Index along increasing soil salinity level

Relationship between Mangrove Basal Area and Salinity in Coringa Wildlife Sanctuary

A positive correlation was revealed between salinity and basal area of BG: *Bruguiera gymnorrhiza* ($r = 0.141$) and SA: *Sonneratia apetala* ($r = 0.785$). This implies that basal area of *Bruguiera gymnorrhiza* increases with increase in salinity. Basal area of AM: *Avicennia marina* ($r = -0.595$), AC: *Aegiceros corniculatum* ($r = -0.667$), XG: *Xylocarpus granatum* ($r = -0.421$), EA: *Exocaecaria agallocha* ($r = -0.740$), LR: *Lumintzera racemosa* ($r = -0.880$), AM: *Avicennia marina* ($r = -0.595$), AO: *Avicennia officinalis* ($r = -0.864$) and RA: *Rhizophora apiculata* ($r = -0.96$) shows a significant negative correlation with salinity. Basal area of negatively correlated species decreases with increase in salinity (Table 30).

Table 30. Correlation between salinity and species basal area in Coringa WLS

Pearson correlation coefficient (r)	-0.66	-0.42	-0.74	-0.88	0.78	-0.59	0.141	-0.86	-0.96
Number of transects	128	128	128	128	128	128	128	128	128

Relationship between Basal Area of Individual Mangrove Species and Soil Salinity Gradient in Coringa Wildlife Sanctuary

Basal area of mangrove species showed a great variation with the salinity gradient (Figure 121- 129). Except *Bruguiera gymnorrhiza* and *Sonneratia apetala*, all the mangrove species was showing a significant decreasing pattern with increasing salinity. Linear and exponential regression lines were used for fitting the regression line in the

following graphs. *Avicennia officinalis*, *Rhizophora apiculata* and *Aegiceros corniculatum* were showing a negative steep slope that clearly represents the decrease in the basal area with increase in soil salinity of the mangrove community. *Sonneratia apetala* and *Bruguiera gymnorrhiza* were positively correlated with the increasing salinity level. This reveals that both these species had a positive impact on their growth and structure with increased salinity. There might be a possibility of some sort of physiological process that make both the above-mentioned species to resist the higher salinity. Although majority of the mangrove species showing a negative correlation with the increased salinity, therefore it might be concluded that *Sonneratia* and *Bruguiera* were adapted to survive in high salinity due to their adaptability elasticity.

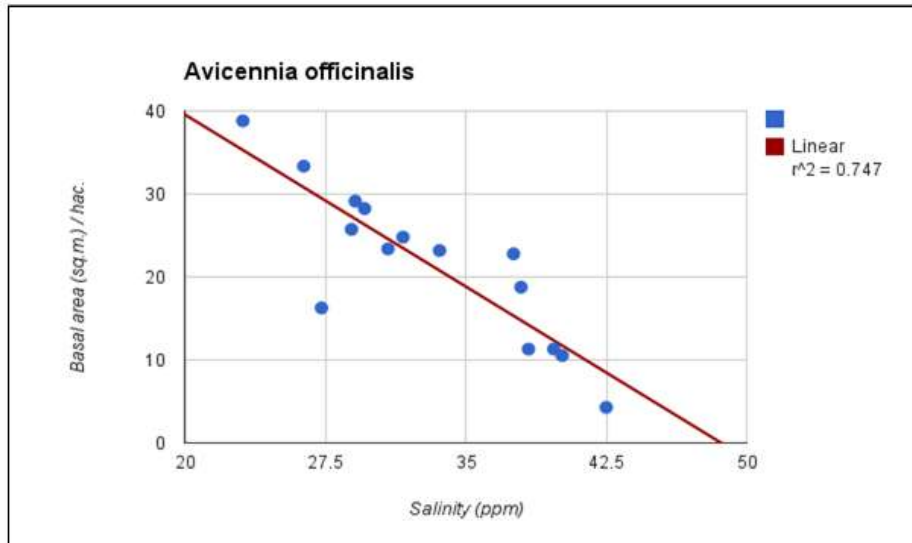


Figure 121. Diagram showing the negative trend of basal area of *Avicennia officinalis* with increasing salinity



Figure 122. Diagram showing the negative trend of basal area of *Rhizophora apiculata* with increasing salinity

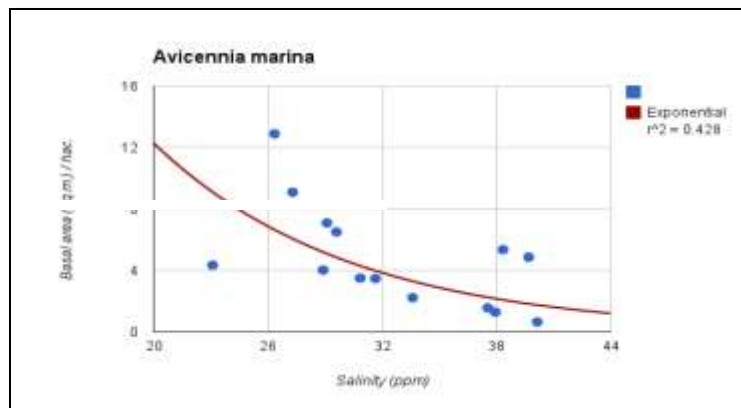


Figure 123. Diagram showing the negative trend of basal area of *Avicennia marina* with increasing salinity

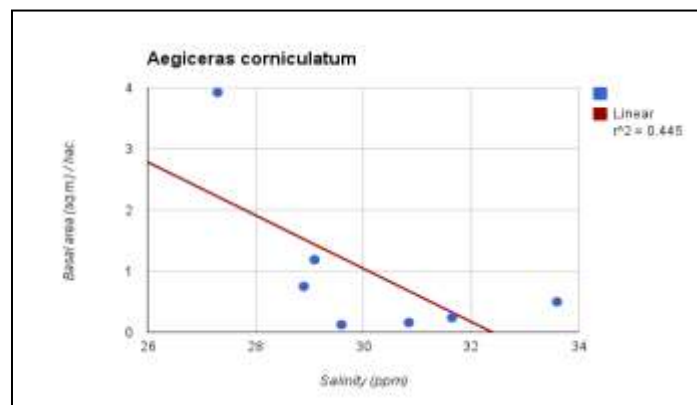


Figure 124. Diagram showing the negative trend of basal area of *Aegiceras corniculatum* with increasing salinity

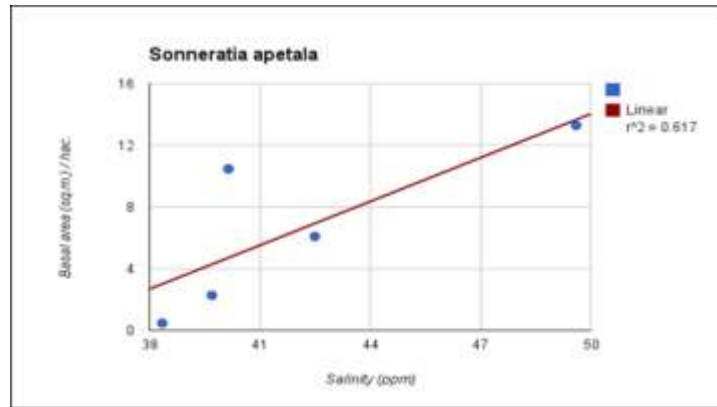


Figure 125. Diagram showing the positive trend of basal area of *Sonneratia apetala* with increasing salinity.

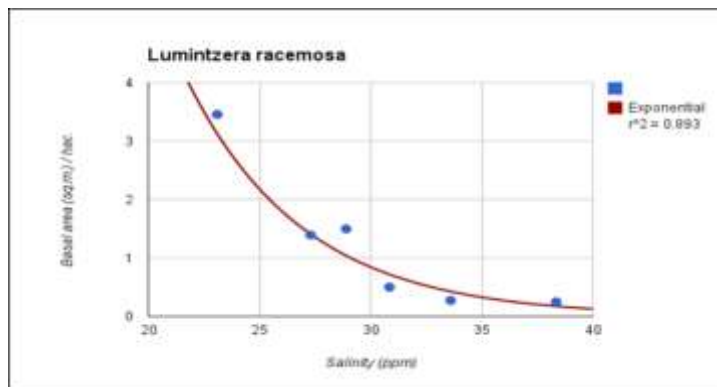


Figure 126. Diagram showing the negative trend of basal area of *Lumintzera racemosa* with increasing salinity

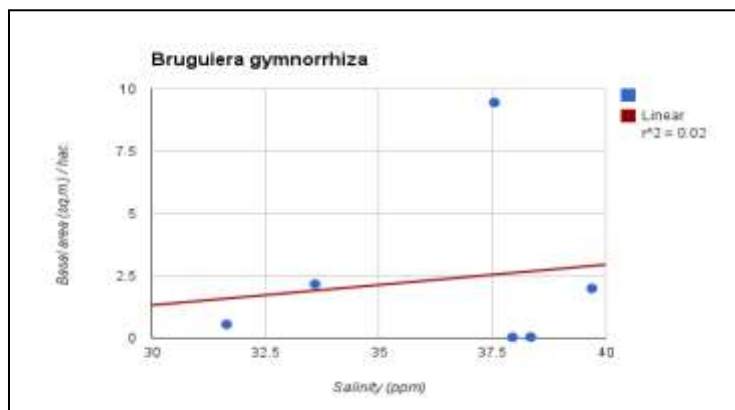


Figure 127. Diagram showing positive trend of basal area of *Bruguiera gymnorrhiza* with increasing salinity

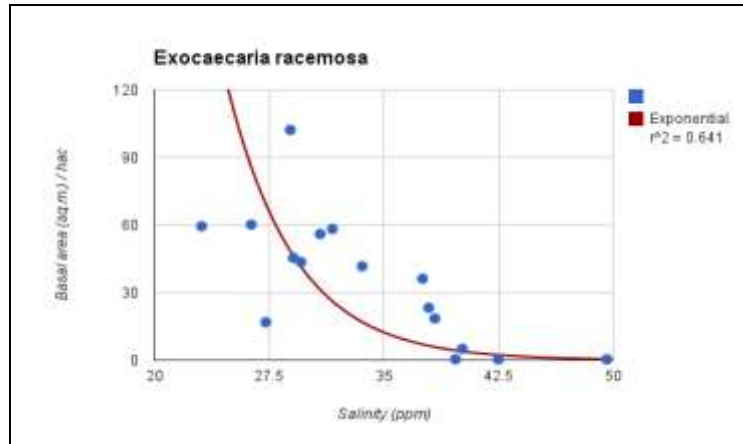


Figure 128. Diagram showing the negative trend of basal area of *Excoecaria racemosa* with increasing salinity

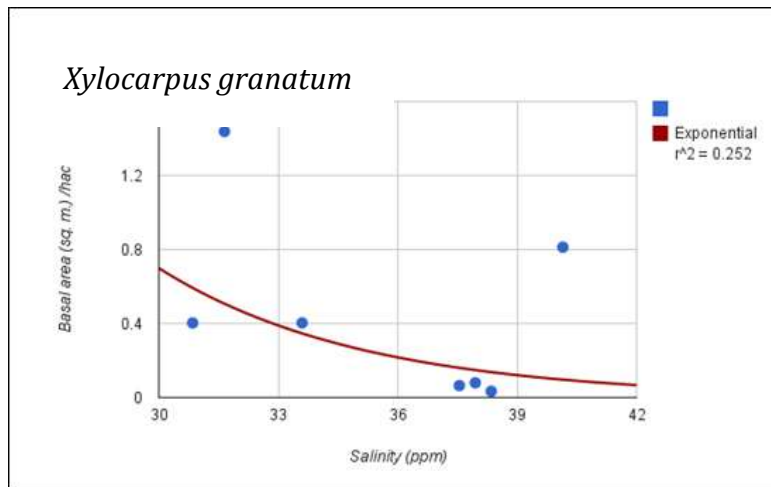


Figure 129. Diagram showing the negative trend of basal area of *Xylocarpus granatum* with increasing salinity

Relationship between Mangrove Basal Area and Soil Salinity at Community Level in Coringa Wildlife Sanctuary

Basal area of mangrove species showed a significant ($R^2= 0.64$) negative trend with increase in soil salinity (Figure 130). The overall basal area of mangrove species was decreasing with constant pattern with increasing salinity of mangrove soil. First two to

three sampling plots had an increasing pattern with increasing salinity afterwards the trend was changed to decreasing pattern.

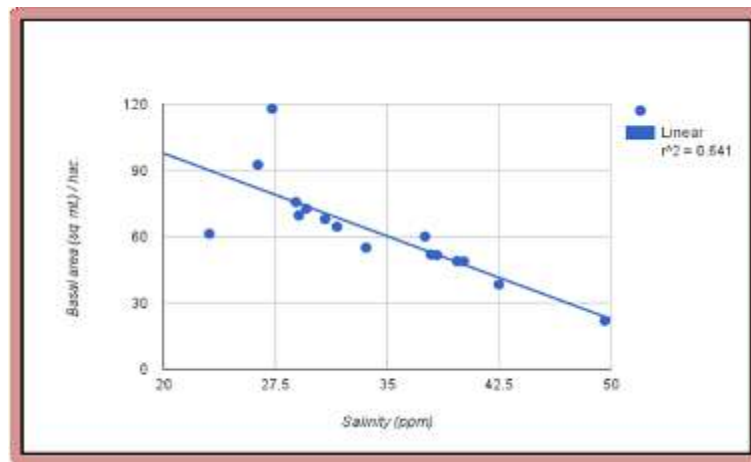


Figure 130. Diagram showing the negative trend of basal area of mangrove species with increasing salinity at community level

Relationship between above Ground Biomass (Agb) Of the Mangrove Vegetation and Salinity Gradient at Community Level:

A significant ($R^2 = 0.54$) negative relationship was observed in between the above ground biomass of the mangrove vegetation and salinity gradient (Figure 131). A negative slope showing decreasing pattern clearly revealed that the above ground biomass of the vegetation decreases with increase in soil salinity level.

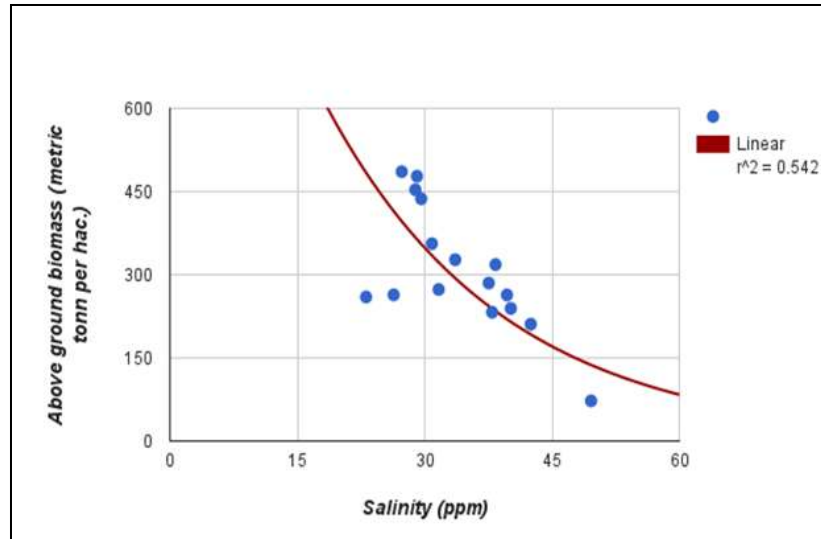


Figure 131. Diagram showing the negative trend of above ground biomass of mangrove species with increasing salinity at community level

FACTORS INFLUENCING MANGROVE SPECIES DENSITY:

Pearson's correlation test was first run to deduct highly correlated variables from the model. A relationship was first seen between covariates and response variable using scatter plot diagram. Since all the selected exploratory variables was showing a significant positive or negative relationship with the response variable (density), hence all was taken in to consideration for fitting the best model.

The GLMs were then built using uncorrelated points. The results from the generalized linear model have been computed in three separated models viz. the intercept model, the full model, and the reduced model.

The reduced model (model chosen after comparing AIC values)

The models were computed using habitat covariates, which had been hypothesized to explain some degree of influence on mangrove species density. This was done using three models shown below. The intercept model depicted the mean probability of

occurrence, while the full model predicts influence of all the habitat covariates on the probability of occurrence of the species in study area.

The number of covariates was reduced using backward selection based on AIC value and thus the reduced model with the best AIC model (97.02) was selected. The reduced model shows presence of explanatory variable, Salinity to be negatively correlated with density of species with high significance while Ca shows a negative relationship with density with less significance level.

Table-30: Model selection for generalized linear regression of Mangrove density against covariates for Coringa Wildlife Sanctuary

Sr. No.	Model	AIC value
1.	Density ~ Ca + Mg + N + pH + P + K + Na + Salinity	244.27
2.	Density ~ Ca + Mg + N + pH + K + P + Salinity	242.27
3.	Density ~ Ca + Mg + N + P + K + Salinity	240.28
4.	Density ~ Ca + Mg + N + K + Salinity	238.35
5.	Density ~ Ca + K + N + Salinity	236.88

Table-31. Coefficient of the best generalized linear regression model for estimating mangrove density in Coringa Wildlife Sanctuary

	Estimate (β - coefficient)	Standard Error	Z - value	Pr(> z)

)			
Intercept	5.0564	0.0167	301.26 3	<2e-16
Salinity	-0.25477	0.01576	-16.163	<2e-16
N	-0.08436	0.01881	-4.485	7.31e-06
K	0.08201	0.01947	4.211	2.54e-05
Ca	0.02816	0.0043	6.504	7.82e-11

Null deviance: 685.35 on 15 degrees of freedom

Residual deviance: 284.08 on 11 degrees of freedom, AIC: 511.91

The removal of the variable was significant because it also gave a model with a reduced AIC value from 244.27 to 236.88 (Table 30). Thus, from reduced model, Salinity, having weightage (-0.2547 ± 0.0157) is a significant factor for governing the mangrove species density and showing the negative relationship with the density.

Salinity was followed by Nitrogen (- 0.0843 ± 0.0188), Potassium (0.0820 ± 0.0194) and Ca (0.0281 ± 0.0043). Nitrogen and Calcium had a negative and Mg had a positive relationship with the mangrove density at community level (Table 51).

Factors Affecting Basal Area of Mangrove Species

Pearson's correlation test was first run to deduct highly correlated habitat variables from the model. Correlated variables beyond a value of 0.5 were removed from the model.

The correlation matrix showed that Moisture had a very strong and high correlation with the salinity. Since salinity would be a significant factor influencing basal area and

was ecologically more meaningful to do so and hence Salinity had been selected as more significant variable in place of moisture.

Table-32. Model selection for generalized linear regression of Mangrove basal area against covariates for Coringa Wildlife Sanctuary

Sr. No.	Model	AIC Value
1.	Ca + K + Mg + Na + N + P + pH + Salinity	284.99
2.	Ca + Mg + Na + N + P + pH + Salinity	282.99
3.	Ca + Mg + N + P + pH + Salinity	281.05
4.	Ca + N + P + pH + Salinity	279.1
5.	N + P + pH + Salinity	277.5
6.	N + pH + Salinity	276.53

Table-33. Coefficient of the best generalized linear regression model for estimating mangrove species basal area in Coringa Wildlife Sanctuary

	Estimate	Standard Error	Z - value	Pr(> z)
Intercept	25856	1308	19.756	4.415e-11
Salinity	-6106	1451	-4.207	0.00103
Nitrogen	-2347	1451	-1.617	0.12982
pH	2257	1025	2.201	0.013

Null deviance: 1158261220 on 15 degrees of freedom

Residual deviance: 346511133 on 13 degrees of freedom

AIC: 323.66

The removal of the variable was significant because it also gave a model with a reduced AIC value from 284.99 to 276.53 (Table 32). Thus, from reduced model, Salinity is a significant factor for basal area having weightage (-6106 ± 1451) and it is negatively correlated with the species basal area. Salinity was followed by Nitrogen, having weightage (-2347 ± 1451) and it is negatively correlated with basal area. Model shows more significance towards salinity as compared to Nitrogen (Table 33).

Carbon Sequestration Potential of Individual Mangrove Species

Each individual mangrove species had a variation with respect to their carbon sinking potential (Figure 108). Highest sink potential was observed for *Aegiceros corniculatum* (45.467 %), followed by *Avicennia officinalis* (44.818 %), *Bruguiera gymnorhiza* (44.37%), *Ceriops decandra* (44.33%) and *Sonneratia apetala* (44.185%).

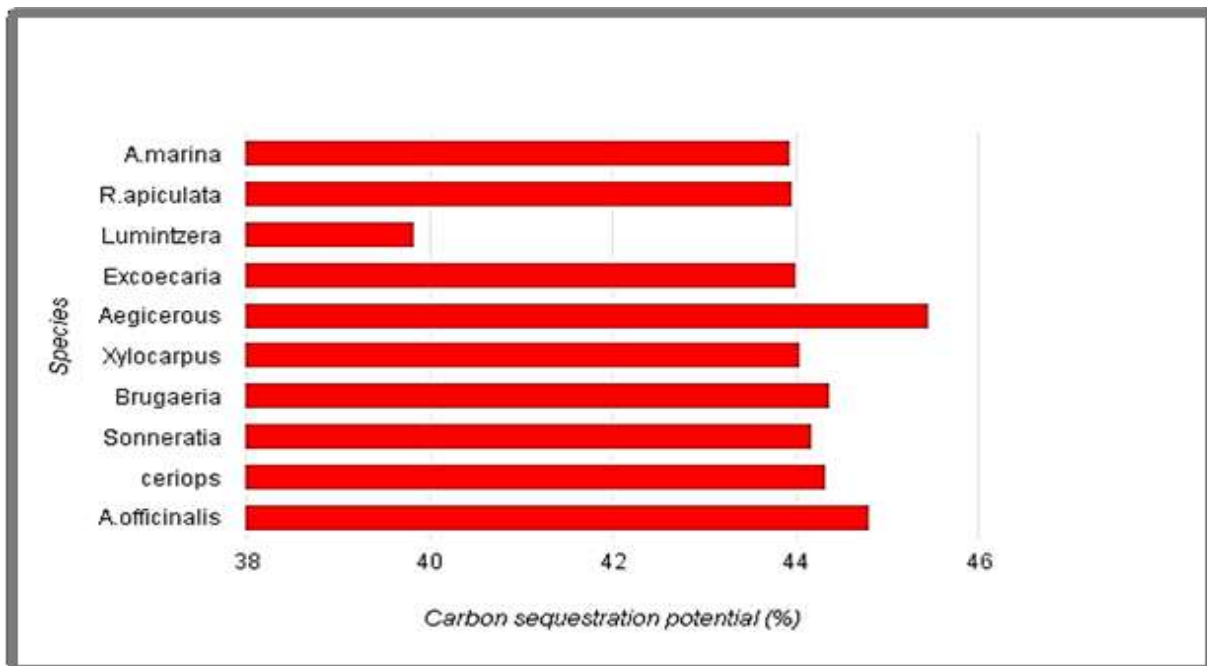


Figure 132. Diagram showing Carbon sequestration potential of mangrove species in Coringa wildlife sanctuary

Excoecaria and *Xylocarpus* had a potential of 44.01 and 44.05 respectively. *A. marina* had a carbon sinking potential of 43.95% and *R. apiculata* of 43.97%. Among all the mentioned mangrove species, *Lumintzera* had the least potential for carbon sinking (39.83%).

Relationship between Carbon Sequestration Potential of Individual Mangrove Species and Salinity in Coringa Wildlife Sanctuary

A significant relationship was observed between carbon sequestration potential of *Ceriops decandra* ($R^2 = 0.893$), *Sonneratia apetala* ($R^2 = 0.946$), *Xylocarpus* ($R^2 = 0.918$), *Aegiceros corniculatum* ($R^2 = 0.792$) and *Lumintzera* ($R^2 = 0.381$). *Ceriops decandra*, *Excoecaria agallocha* and *Lumintzera racemosa* had a positive trend with salinity i.e, the carbon sequestration potential of both these species increased with increasing salinity level (Figure 133 - 141). *Avicennia marina* ($R^2 = 0.20$) and *Rhizophora apiculata* ($R^2 = 0.13$) had negative trend with increase in salinity. *Avicennia officinalis*, *Aegiceros corniculatum*, *Xylocarpus granatum*, *Sonneratia apetala* also had a negative trend with salinity fluctuation, their carbon sinking capacity decreased with increase in salinity level.

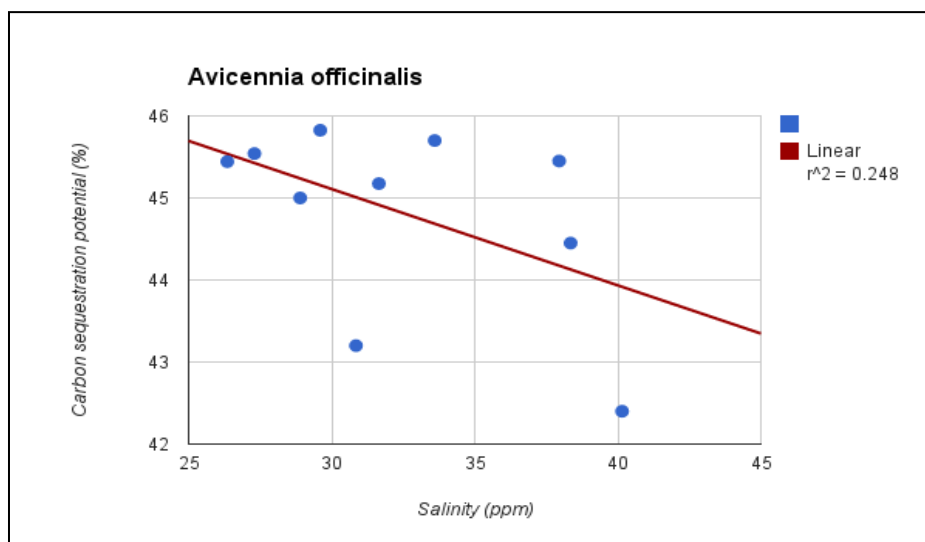


Figure 133. Graph showing the negative trend of C.S.P of *Avicinnia officinalis* with increasing salinity

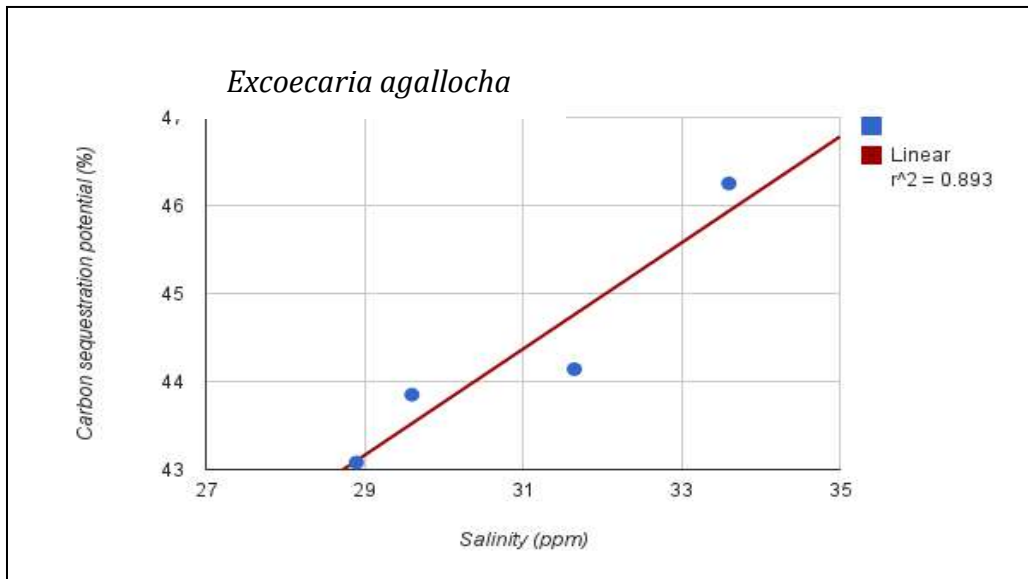


Figure 134. Graph showing the positive trend of C.S.P of *Excoecaria agallocha* with increasing salinity

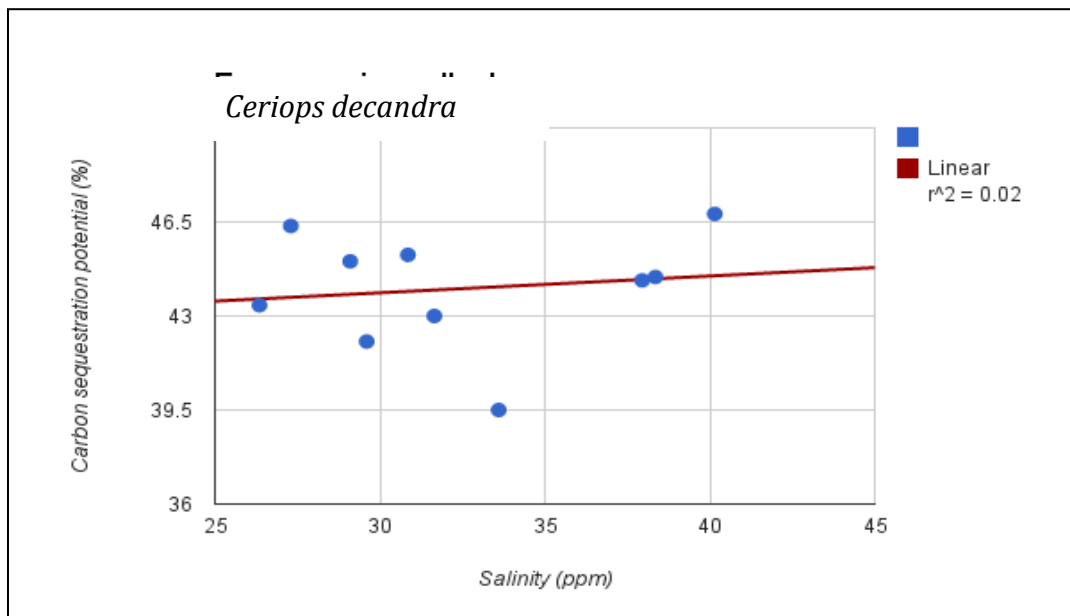


Figure 135. Graph showing the positive trend of C.S.P of *Ceriops decandra* with increasing salinity

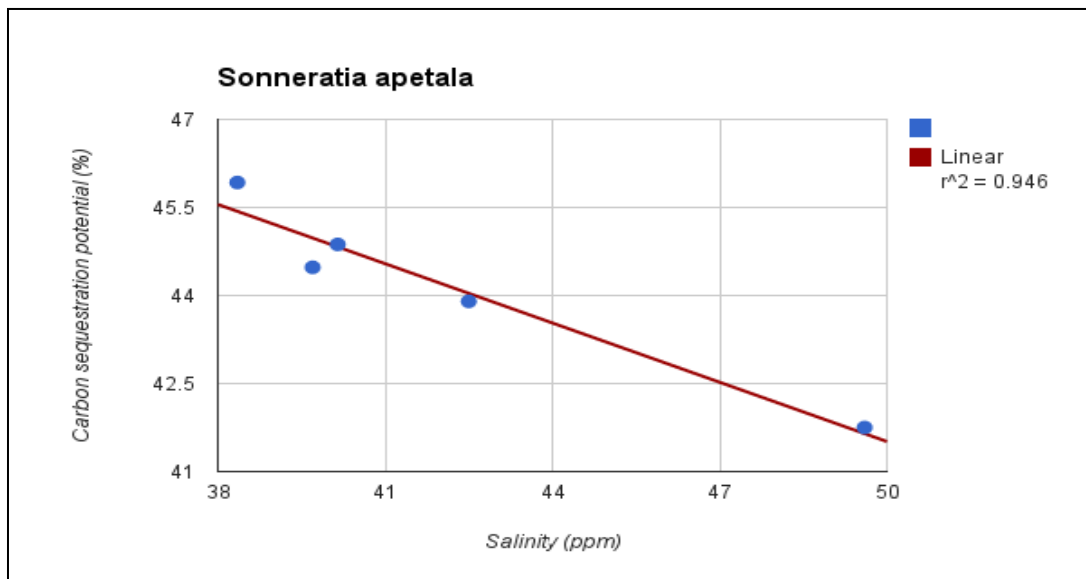


Figure 136. Graph showing increasing salinity the negative trend of C.S.P of *Sonneratia apetala*

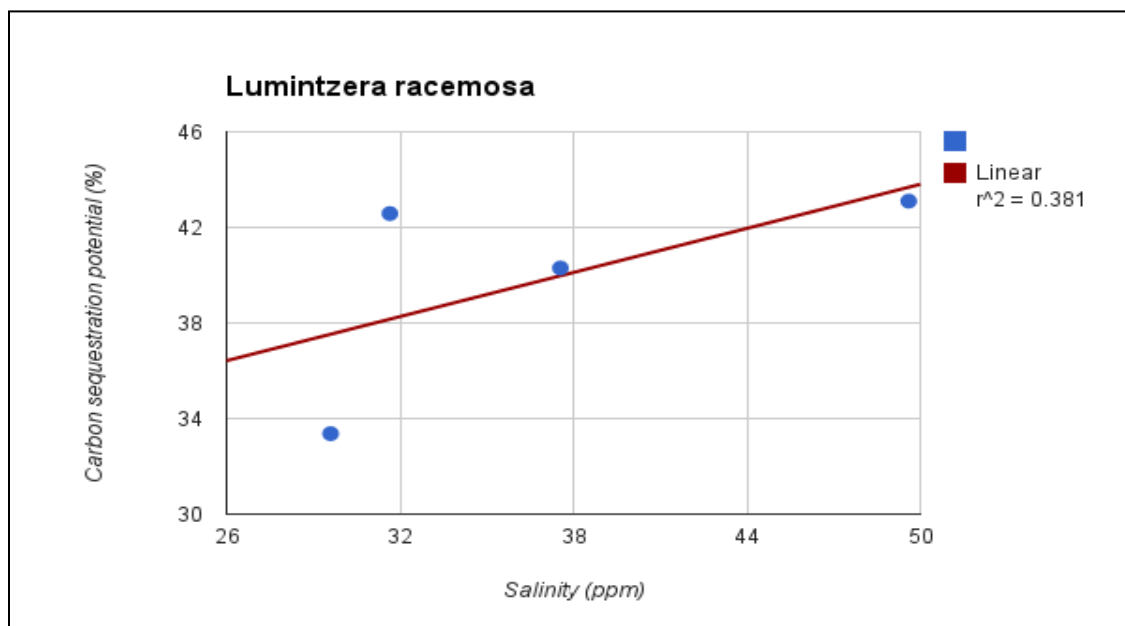


Figure 137. Graph showing the positive trend of C.S.P of *Lumintzera racemosa* with increasing salinity

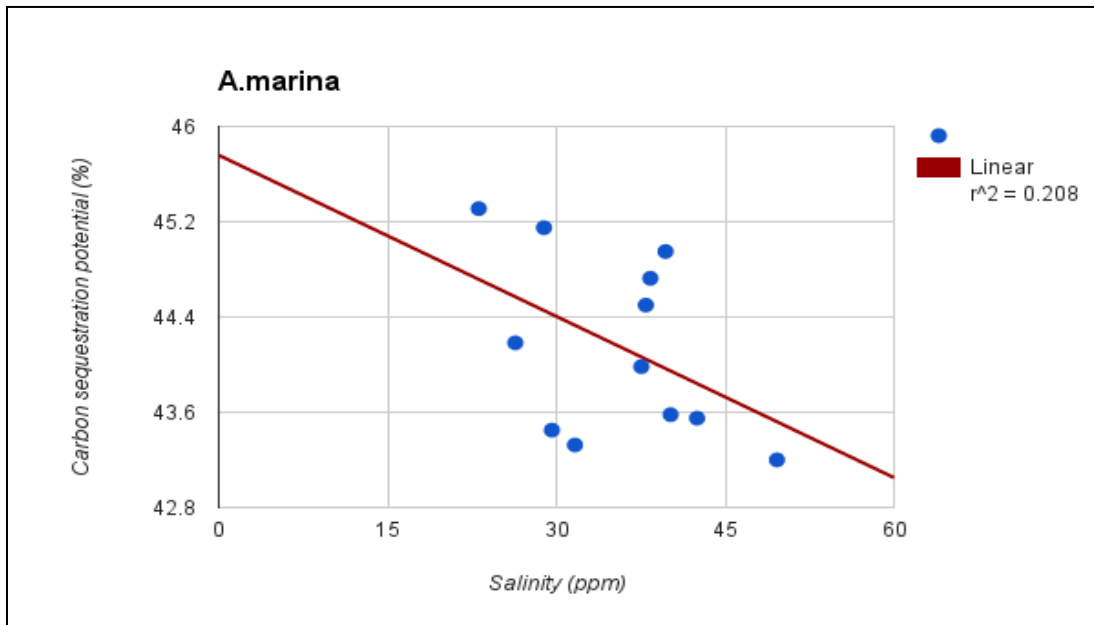


Figure 138. Graph showing the negative trend of C.S.P of *Avicinnea marina* with increasing salinity

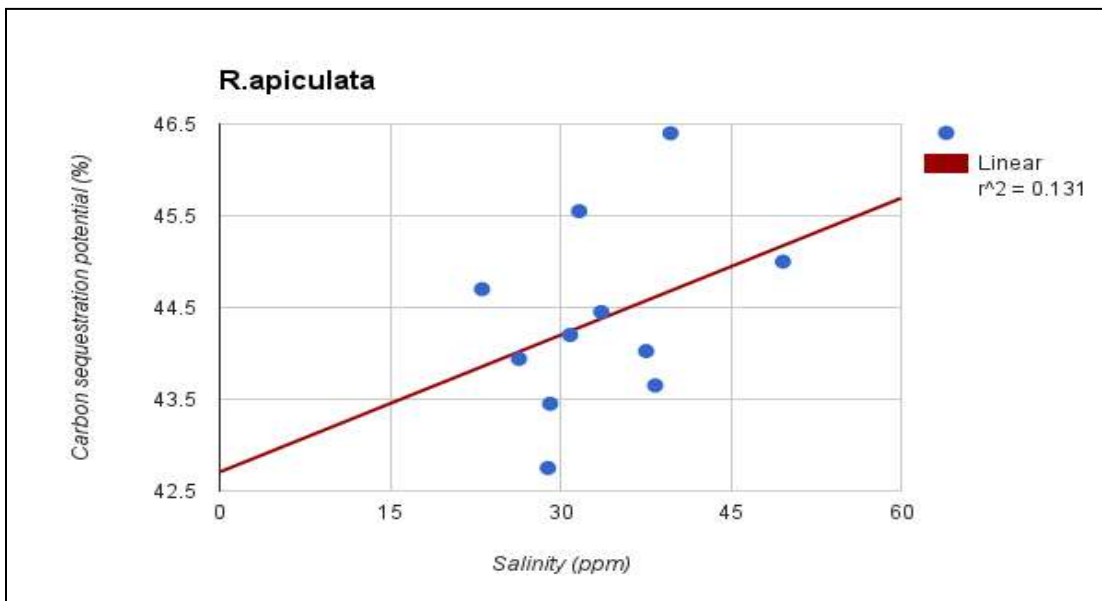


Figure 139. Graph showing the positive trend of C.S.P of *Rhizophora apiculata* with increasing salinity

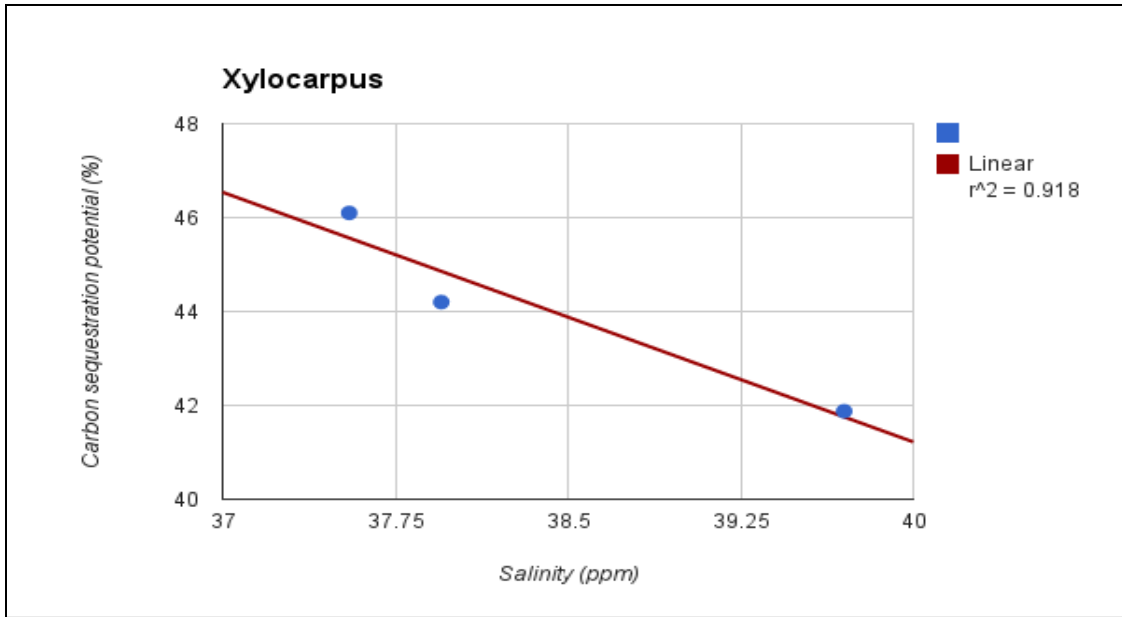


Figure 140. Graph showing the negative trend of C.S.P of *Xylocarpus granatum* with increasing salinity

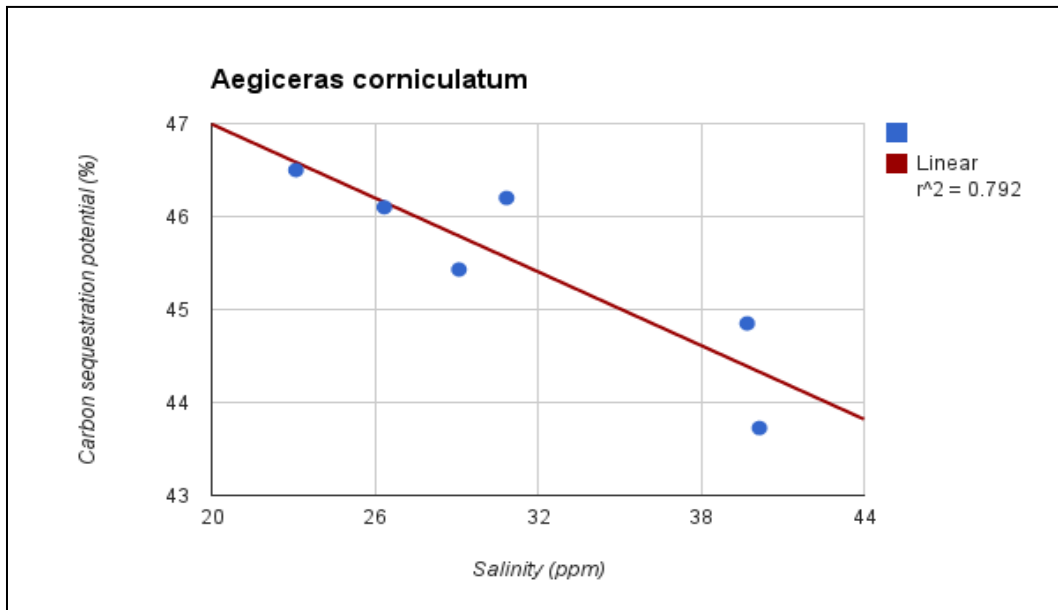


Figure 141. Graph showing the positive trend of C.S.P of *Aegiceras corniculatum* with increasing salinity

Relationship between Carbon Sequestration Potential of Mangrove and Salinity at Community Level in Coringa Wildlife Sanctuary

Carbon sequestration potential of individual mangrove species with increase in salinity level were varied among different species studied in the Coringa WLS. Carbon sequestration potential of few species increased if the salinity of soil high but majority of species showed the negative correlations between carbon sequestration potential and soil salinity. But, at a community level the pattern showed a negative steep slope gradient ($R^2 = 0.663$) of carbon sequestration potential of mangrove along increasing salinity gradient. This clearly revealed that there was overall reduction in the carbon sink potential of mangrove species with increase in salinity level of the soil in Coringa WLS (Figure 142).

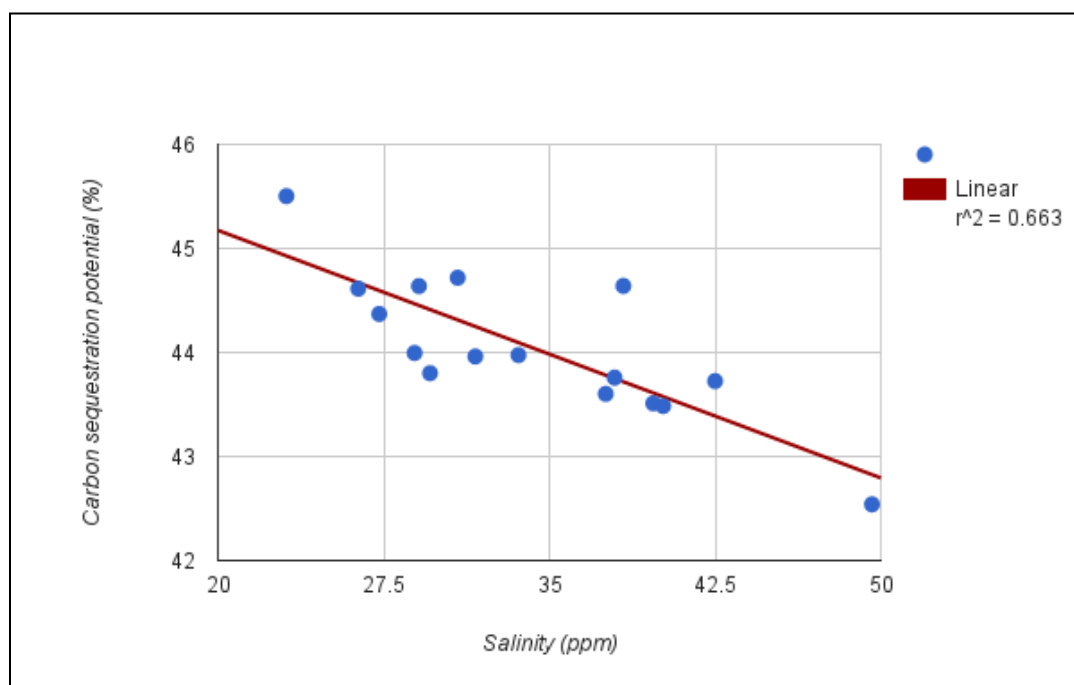


Figure 142. Graph showing the negative trend of Carbon sequestration potential of mangroves with increasing salinity at community level

Inter - Relationship between Soil Environmental Variables

All collected soil exploratory variables (eg. Na, K, Ca, Mg, N, P, pH, Salinity, Moisture) were treated with Principal Component Analysis to extract the factors of significant

contribution to variations, and PCA identified 3 factors (Table 17). The Kaiser – Meyer – Olkin test of sampling adequacy for factor analysis computed a value of 0.61 which is ranked as mediocre (Norusis, 1990). Correlation matrix showed the correlation within the independent variables (Figure 143). Salinity and moisture was revealed to be highly correlated. A relatively high correlation was also observed in between salinity and potassium.

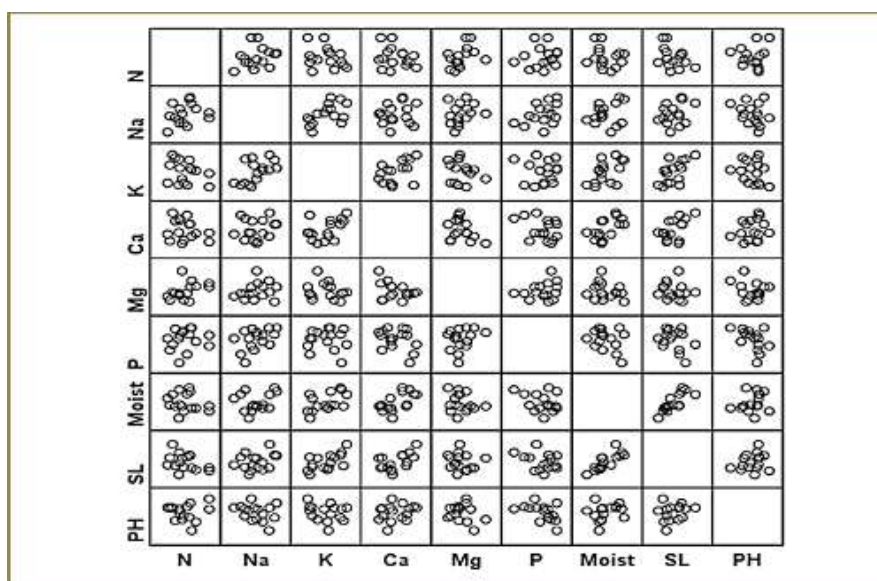


Figure 143. Graph showing the Correlation matrix of different independent variables of soil

Table 34. Results of Factor analysis by PCA after rotation of Factor matrix

FACTOR	EIGEN VALUE	% OF VARIANCE	VARIABLES
1	3.079	34.212	Salinity, Moisture, K, Ca, Na
2	1.982	22.020	pH, P
3	1.676	18.626	N, Mg

After rotation of the factor matrix, it was found that factor 1, 2 and 3 consisted of all the soil environmental variables that showed a higher amount of interrelationship.

Significant habitat component of factor 1 consists of Salinity, moisture, K, Ca and Na.

Factor 2 comprised of pH and phosphorus, whereas Nitrogen and Mg was the main component of factor 3.

Relationship between Mangrove Species Density and Soil Environmental Variables

A canonical correspondence analysis was performed for selected tree species with 8 independent variables (Such as, Salinity, pH, Na, K, Ca, P, Mg & Nitrogen) and the ordination diagram was obtained was shown in Fig. 105. Permutation test revealed the significant ($P = 0.004$, Significance level $\alpha = 0.05$) linear relationship between mangrove species and different sampling plots with soil environmental variables. The Eigen values for the first two CCA axes were 0.371 and 0.172 respectively. Cumulative 84.06 % of total variability is explained by these two axes. In other words, the accuracy of correspondence between related pair of species and environment was found to be good only for the first two axes. pH, Nitrogen, Salinity, Potassium, Phosphorus, and Magnesium operating on the first axes while the species co - ordination for t - value biplot gave rise to species *Avicinnia marina*, *R. apiculata*, *Excaecoria agallocha*, *Aegiceros corniculatum*, *Xylocarpus granatum*, *Sonneratia apetala* and *Ceriops decandra*.

Sodium and Calcium formed the major variables of the axes - 2 along which mangrove species *A. officinalis*, *Lumintzera racemosa* and *Bruguiera gymnorrhiza* were distributed.

Ordination diagram (Figure 144) revealed that *Excaecoria agallocha* density was mostly influence by Salinity, Na, pH, N, Ca, K and P. *Avicinnia officinalis* density had more influence of Na, pH, salinity, Ca, P and nitrogen. 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* density was mostly influenced by K, Na, pH, Mg and salinity. Density of *Xylocarpus granatum* was mostly controlled by K, Mg, Salinity, Na and PH whereas, k, Mg, salinity,

pH and Na was for *Avicinnia marina*. Density of *Sonneratia apetala* and *Aegiceros corniculatum* had k and Mg as controlling factor and *Lumintzera racemosa* had K, Mg, P and Ca as a most governing factor for density. The ordination diagram (Figure 145) revealed that approximately half of the sampling plots had the dominance of *Excaecoria agallocha* in the study area. This species was distributed from lower to higher salinity but the maximum distribution was in lower or medium salinity area.

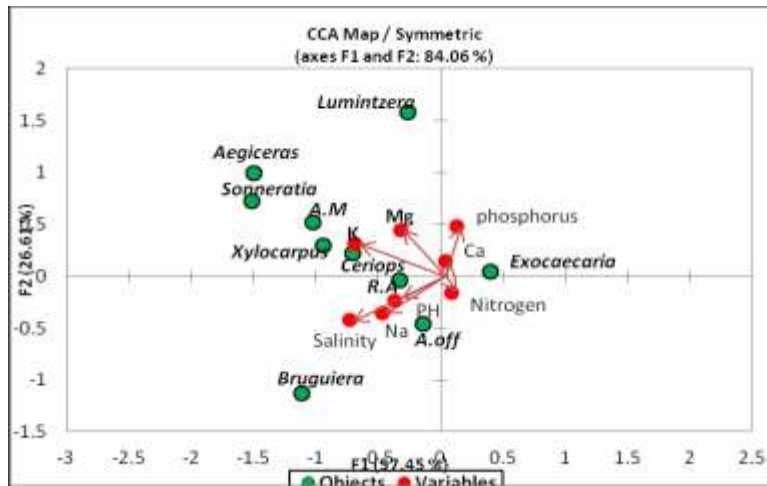


Figure 144. CCA (Canonical Correspondence Analysis) diagram, showing the relationship between 10 mangrove species abundance and soil variables in Coringa wildlife Sanctuary, Andhra Pradesh.

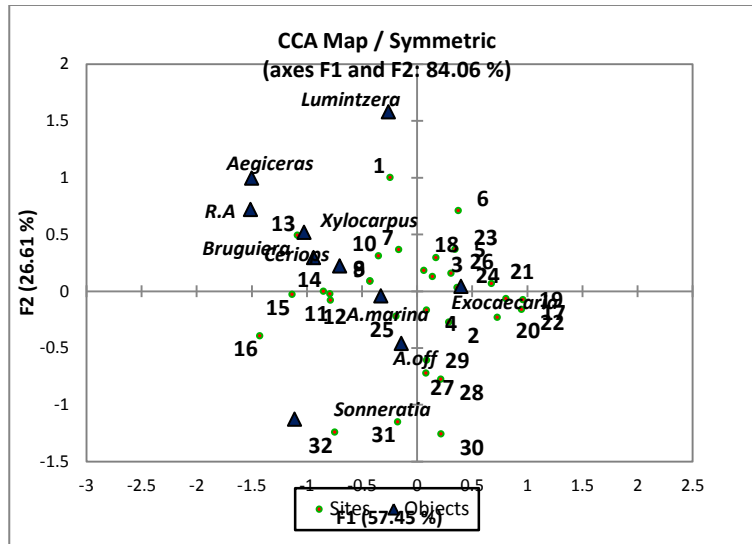


Figure 145. CCA (Canonical Correspondence Analysis) diagram, showing the relationship of 10 mangrove species and sampling plots in Coringa Wildlife Sanctuary

Most of the mangrove species (*Lumintzera racemosa*, *Aegiceros corniculatum*, *R. apiculata*, *Buguiera gymnorrhiza*, *Xylocarpus granatum* and *Ceriops decandra*) were distributed in a less number of sampling plots and had medium to high salinity condition. *A. officinalis*, *Avicinnia marina* and *Sonneratia apetala* were distributed in several plots and preferred the higher salinity condition.

Factor Affecting Carbon Sequestration Potential of Mangroves

Pearson's correlation test was first run to deduct highly correlated habitat variables from the model. Correlated variables beyond a value of 0.5 were removed from the model. The correlation matrix showed that Moisture had a very strong and high correlation with the salinity. Since salinity would be a significant factor influencing basal area and was ecologically more meaningful to do so and hence Salinity had been selected as more significant variable in place of moisture.

Table-35. Model selection for generalized linear regression of Mangrove carbon sequestration potential against covariates for Coringa Wildlife Sanctuary

Sr. No.	Model	AIC Value
1.	CSP ~ Ca + K + Mg + Na + N + P + pH + Salinity	-22.36
2.	CSP ~ Ca + K + Mg + Na + P + pH + Salinity	-24.36
3.	CSP ~ Ca + Mg + Na + P + pH + Salinity	-26.27
4.	CSP ~ Ca + Mg + Na + P + Salinity	-28
5.	CSP ~ Ca + Na + P + Salinity	-29.35
6.	CSP ~ Ca + P + Salinity	-30.89

Table-36. Coefficient of the best generalized linear regression model for estimating mangrove carbon sequestration potential in Coringa Wildlife Sanctuary

	Estimate	Standard Error	Z - Value	Pr (> z)
Intercept	44.15917	0.08710	506.997	<2e-16
Salinity	-0.72773	0.10886	-6.685	2.24e-05
P	-0.17836	0.09594	-1.859	0.0877
Ca	0.19473	0.10874	506.997	<2e-16

Null deviance: 7.0325 on 15 degrees of freedom

Residual deviance: 1.4076 on 12 degrees of freedom

AIC: 16.515

The removal of the variable was significant because it also gave a model with a reduced AIC value from -22.36 to -30.89 (Table 35). Thus, from reduced model, Salinity is a significant factor for carbon sequestration potential having weightage (-0.72773 ±

0.10886) and it is negatively correlated with the species Carbon sequestration potential. Salinity was followed by Phosphorus (P), having weightage (-0.17836 ± 0.09594) and Calcium (Ca), having weightage (0.19476 ± 0.10874) respectively. Phosphorus is negatively and Ca is positively correlated with the carbon sinking potential. Model shows salinity as most significant factor as compared to P and Ca (Table 36).

Preferential Salinity Range of Mangrove Species

Physiological attributes of species contribute to interspecific differences in distribution along the salinity gradient (Ball 1995). Most mangroves grow best in relatively low salinities, but they differ in the range of salinities in which their maximal growth rates are sustained. In general, the greater the salt tolerance of a species, the slower is its growth rate under optimal salinity conditions. Species could become distributed differentially along salinity gradient because of interspecific difference in salt tolerance offer competition for resources. Such interspecific difference in response to salinity could lead to competitive exclusion along a spatial gradient in salinity (Ball 1998). The distribution of mangrove species in Gaderu and Coringa River reveals that *Sonneratia apetala*, *Xylocarpus granatum*, *Avicinnia marina*, *Bruguiera gymnorrhiza* and *Aegiceros corniculatum* is preferring higher salinity as compared to other mangrove species. Among all mentioned species, *Bruguiera gymnorrhiza* have the capability to tolerate the maximum salinity and the *Avicinnia marina*, the least. Species that are present at a higher salinity are physiologically as well as anatomically adapted to the harsh environment, and thus salinity has a lesser impact on it.

Bruguiera gymnorrhiza possess ultrafilters in their root system. These filters exclude salts while extracting water from the soil. *Avicinnia marina* and *Aegiceros corniculatum* absorb some salt but excrete it through specialized salt glands present in the leaves (Dschida et al., 1992; Fitzgerald et al., 1992). Both these species allow more salt into the xylem than do the non-excretors, but still exclude about 90% of the salts (Scholander et al., 1962, Azocar et al 1992). *Avicinnia marina*, *Aegiceros corniculatum* and *Sonneratia apetala*

accumulate or synthesize other solutes to regulate and maintain osmotic balance (Werner and Stelzer, 1990; Popp et al., 1993). *Aegiceros corniculatum* accumulate mannitol and proline (Polania, 1990); *Avicinnia marina* accumulates glycine betaine (Ashihara et al., 1997) and *Sonneratia apetala* synthesize purine nucleotide that helps these species to adapt themselves to salt stress. Anatomical study of the mangrove species that are found in the high salinity range shows that species have narrow vessel running through the wood that checks the flow of water and thus save the water inside the plant. *Aegiceros corniculatum* and *Sonneratia apetala* have branched sclereids in abundant and are well developed. These sclereids also involved in the conservation of water (Tomilson, 1986). Less salt tolerant species also has minor adaptation to balance their osmotic potential. Species of *Lumnitzera* and *Excoecaria* accumulate salts in leaf vacuoles and become succulent. Salt concentrations in the sap may be reduced by transferring the salts into senescent leaves or by storing them in the bark or the wood (Tomlinson, 1986). In most species, a horn or beak-like cuticular outgrowth covers either the outer side of the stomatal pore or both the inner and outer sides. These structures reduce stomatal transpiration (Das and Ghose, 1993).

Behaviour of Soil Environmental Variables

As expected, there was a strong relationship between the mangrove abundance and its soil characters in Coringa. The soil environmental variables can't be segregated based on heterogeneity, complexity and scale of measurement as introduced by McCoy and Bell (1991). Such explained variable can be determined only based on complexity that involves an amount of structure. The only question that arises here is how these variables interact with each other and their functional role in mangrove habitat.

In this context, I carried out a PCA using these nine exploratory variables in which, Factor 1 show an interrelationship in between salinity, moisture, Na, K and Ca. These entire components are highly related to each other ecologically. Na and k relationship can be well explained by Na-k ionic equilibrium exchange theory (Maser et al., 2002). In

high saline conditions, the plants absorb more Na in place of K to maintain their osmotic balance that results in the check on the loss of water from the plant. New propagules and seedling of mangrove species prefers more K in comparison to Na, and deposit it in the leaves in high salinity area.

This provides an option to enhance the seedling establishment and ultimately the abundance of the species. Salinity and moisture have a definite inverse relationship between them. The enrichment of Ca over Na decreases the accumulation of Na in seedlings and thus mitigates the salt stress in the seedling and in consequence seedling finds more scope to grow and establish in perpetuity (Sheng & Bao 2000). On axes- 2, Effect of PH on phosphorus availability can be explained based on fluctuation of concentration of PH in the soil that changes the soil acidity and alkalinity directly. Phosphorus is proved to be an immobile element and not available to the mangrove species directly. With the help of Vesicular arbuscular mycorrhiza plant can absorb this nutrient (Smith *et al* 2003 and Sengupta & Chaudhary, 2002). At higher salinity, there is no association observed in between the VAM and roots of the mangrove species. Thus, indirectly higher salinity has an adverse impact on the availability of P in the mangrove species. There is also a relationship observed in between the PH and other micro and macro nutrients and between the N and P availability (Lovelock *et al.*, 2007).

Relationship between Soil Environmental Variables and Mangrove Structure

Canonical Correspondence Analysis was carried out to understand the effect of soil environment on mangrove structure in terms of their density. It is already seen in Section 5.5 that *Avicinnia marina*, *Rhizophora apiculata*, *Excoecaria agallocha*, *Xylocarpus granatum*, *Aegiceros corniculatum*, *Ceriops decandra* and *Sonneratia apetala* shows the influence of Salinity, pH, N, K, Mg and P on species density in terms of seedling growth and development. In the study area *A. marina*, *Xylocarpus*, *Bruguiera gymnorrhiza* and *Sonneratia* are distributed at a higher salinity level. All the above-mentioned species directly or indirectly have an effect of salinity. Salinity is proved to be injurious to the

overall performance of the species due to a difference of osmotic potential in between cell sap of the plant and soil. At higher salinity, always there is a need for balance in between sodium and potassium.

Mangroves are halophytes, and they survive by maintaining equilibrium in between sodium and potassium ion. At higher salinity mangrove species absorb more salinity in place of potassium to maintain the osmotic potential. Potassium content of the soil also has positive influence on the density of mangroves that are distributed at higher salinity levels. Increased density of mangrove species at higher salinity is the result of an increase in concentration of potassium. Propagules and seedling of the mangrove species exhibit good adaptive behavior towards salinity stress by increasing succulence due to absorption of large quantities of potassium ion in the leaves of the seedlings especially in case of *A. marina*, *Sonneratia apetala* and *R. apiculata*.

The contribution of Phosphorus is also considered to be an essential component for seedling growth and development. Phosphorus is supposed to be an immobile element, and it is not directly available to the plant. Vesicular arbuscular mycorrhiza (VAM) makes a significant contribution with respect to the availability of Phosphorus to the *Avicinnia marina*, *Bruguiera gymnorrhiza*, *Sonneratia apetala* and *Avicinnia officinalis*. This makes an association with the root of mangrove species and makes the Phosphorus available to the species. Without the contribution of Vesicular arbuscular mycorrhiza, the availability of phosphorus to the species is not possible. Species present at higher salinity are not able to maintain the association with VAM, because high salinity restricts the association of VAM with the roots of mangrove species and in consequence it can be proposed that phosphorus is not available to the species. The role of pH is not so clear but it makes their contribution in influencing the availability of other nutrients and sometimes gives rise to several other metals in the soil that acts like a toxic and have a detrimental impact on the seedling growth and their establishment. The occurrences of other factors of the axis like Mg may not be constructed as the immediate ecological correlate of the above-mentioned mangrove species but as an outcome of

inter-relationship of soil environmental variables. Magnesium is not so related to the mangrove propagules and seedling development with respect to the density of the species.

The next axis is influenced by Sodium and Calcium, soil environmental variable, and the distributed mangrove species are *Lumintzera racemosa*, *Avicinnia officinalis* and *Bruguiera gymnorhiza*. Interestingly, Calcium influence seedling establishment and growth of *Bruguiera gymnorhiza*, *Lumintzera racemosa* and *Avicinnia officinalis*. The enrichment of Ca over Na decreases the accumulation of Na in seedling and thus mitigates the salt stress in the seedling and in consequence seedling finds more scope to grow and establish in perpetuity (Sheng & Bao, 2000). Suitable Ca/Na in soil is the one of the important causes that mangrove can survive and regenerate in high salinity condition. Present study reveals the higher concentration of Ca over Na ion on sampling plots having higher salinity where *Bruguiera gymnorhiza* and *A. officinalis* species is in abundance. Thus, excess Calcium ion provides a better scope to mitigate and defend the harsh impact of the salinity on the propagule development in this mangrove species.

Relationship between Mangrove Structure and Salinity

Mangrove structure in Coringa WLS shows a significant pattern with salinity. Different components of mangrove structure of Individual mangrove species respond differentially with a different significance level. An overall estimation of mangrove structural components (Density, basal area, above ground biomass, complexity index, importance value index and diversity) shows a decreasing pattern with the increase in salinity.

Salinity plays a vital role in the distribution of species, their productivity and growth of mangrove forests (Twilley and Chen, 1998). Experimental evidences indicate that at high salinity, mangroves spend more energy to maintain water balance and ion concentration rather than for primary production and growth (Clough, 1984). It appears

that increasing salt-tolerance is at the expense of growth. Salinity results in a trade-off between growth rate and tolerance of environmental stress (Grime, 1979). Leaf area ratios decreased only at the highest salinity and most of the decline in relative growth rates with increase in salinity from 50 to 500mM NaCl could be attributed to decrease in net assimilation rate (Ball, 1988b).

High salinity can cause osmotic stress and reduce the availability of water, resulting in stomatal closure and reduced supply of carbon dioxide (Tanaka et al., 1999). At higher salinity condition Potassium, deficient leaves accumulate soluble sugars and decreased the rate of assimilates export before photosynthetic efficiency gets reduced (Ashley and Goodson, 1972; Mengel, 1980). Sucrose transport in K⁻ deficient leaves may be restricted by reduced synthesis of non- structural saccharides (Conti and Geiger, 1982) by reduced entry of sucrose into transport pool or by inhibition of some steps involved in phloem loading (Mengel, 1980; Thomson and Dale, 1981). The assumption is that the lower rate of photosynthetic potential ultimately decreases the productivity of the species. Several mangrove species synthesize different solutes (proline, glycine betaine etc.) that act as an anti - stress hormone at high salinity condition. Such solutes are formed by the disintegration of the nitrogenous compound in the species that ultimately reduces the total nitrogen content of the plant. Nitrogen is the essential component of the species that control several essential physiological functions especially the protein synthesis process. Protein synthesis mechanism considered to be the backbone of the life process of the species. Alteration in protein synthesis mechanism ultimately reduces the overall performance of the mangrove species.

Relationship between Mangrove Density, Salinity, and Other Soil Variables

Salinity has long been recognized as a controlling factor that determines the health and distribution of mangrove forests. Spatial differences in soil water salinity influence the species distribution of the mangrove species (Verheyden et al., 2005; Schmitz, 2008; Robert et al., 2009). In *Coringa WLS*, the effect of salinity on the species density can be

explained with the help of establishment of propagules, species regeneration pattern, and seedling dispersal. Generalized linear modeling done for finding the most important soil environmental factors influencing mangrove density clearly revealed that at the community level soil salinity is the most important factor that negatively affect the mangrove density.

At a species level, *Sonneratia apetala*, *Lumintzera racemosa*, *A. officinalis*, and *Excoecaria agallocha* proved salinity to be the major controlling factor. *Excoecaria agallocha* has the highest density among all the species and it is followed by *Avicinnia officinalis*, *Avicinnia marina*, and *Bruguiera gymnorrhiza* respectively. Higher salinity results in to disruption in maintaining the osmotic potential between seedlings and soil. This causes movement of water from the plant to the pore water and this leads to desiccation and ultimately the plant dies. Also, the dispersal of the propagules is severely influenced by the saline condition. Then the abundance of *Excoecaria agallocha* species in the study area raises a question that why this species has a maximum density of all the mangrove species. This species is distributed from a lower to higher salinity range and as a result it has better option for seedling dispersal and their establishment from one region to another (Di Nitto et al., 2008). *Excoecaria agallocha* has an advantage over the regeneration pattern i.e, regeneration occurs both by the seedling and by the coppicing. Coppice process provides a better option to regenerate increasingly individuals, than other species that have only one option to regenerate only through the seedling establishment (Blasco, 1977). *Avicinnia officinalis* and *Sonneratia apetala* does not have throughout distribution in study site but both these species have some nitrogenous solutes in their propagules that act as anti-stress hormone that helps in seedling establishment. The result obtained in Table 4.8 also proves that in addition to *Excaecoria agallocha* and *Lumintzera racemosa* several other mangrove species like, *Rhizophora apiculata*, *Aegiceros corniculatum* and *Avicinnia marina* have a positive influence of potassium on seedling development. Seedlings of above mentioned mangrove species absorb a higher quantity of potassium in their leaves that helps in shock resistance against higher salinity. A higher quantity of

potassium in the seedling prevents the outflow of water from the plant that retains the excess water inside the cell sap that helps in sustenance and development of seedling. Higher density of *Bruguiera gymnorrhiza* results due to certain lipid composition in the propagules that is salt tolerant and it helps in overall development of the seedlings. Previous studies on this species reveal that salt stress modulates the terpenoid concentration, whereas phospholipid and fatty acid composition in this species remains the same with respect to varying salinity (Oku et al., 2003). Recent studies show the correlation between ABA and antioxidant defense in *Bruguiera gymnorrhiza* and found that elevated ABA concentration under excess salt regulate the activity of antioxidant enzyme and thus avoid oxidative stress.

Relationship between Carbon Sequestration Potential of Mangrove and Salinity

It is considered that at higher salinity assimilation of CO₂ is lesser as compared to lower salinity. The present study clearly reveals that carbon assimilation is strongly correlated with stomatal conductance that varies with the salinity gradient.

Carbon sequestration potential of mangrove decreases with increase in the salinity level in Coringa WLS. In study area, different mangrove species responds differentially to salinity gradient as carbon sinking potential of individual species vary from each other. The overall estimation of carbon absorption potential shows a negative downward slope that clearly provides an idea that increase in salinity results in a reduction of carbon assimilation rate. At higher salinity, osmotic potential of the soil is greater as compared with the mangrove plant. Due to this water moves from lower potential to a higher potential; as a result, a loss of water takes place from the plant. If such condition persists longer then it might be dangerous for the plant. To check the water loss and also to maintain the osmotic equilibrium plants absorb more salt from the soil in place of potassium. As more salt acts like poison for the plant but at higher salinity it is necessary for their sustenance. There is a high correlation between salinity and stomatal conductance, intercellular CO₂ concentration, and intrinsic water efficiency.

CO₂ assimilation rate decreases due to two reasons, first at higher salinity the water status of the leaves decreases, and it leads to the creation of stress condition in the plant. Also at higher salinity the metabolic activity of plant increases several folds as compared with the normal state. Due to more metabolic activity the rate of respiration and transpiration increases that result in loss of water from the plant. To check the water loss stomata get closed and closing of stomata decreases the exchange of CO₂ that ultimately reduces carbon assimilation rate. Second as the plant reduces the uptake of Potassium from the soil, concentration of salt increases in the plant. Since potassium is considered to be one of the most important constituents of photosynthetic organ that results in loss of photosynthetic rate (Peaslee and Moss, 1968; Langstreth and Nobel, 1980). Decreased photosynthetic rate of K-deficient leaves has been related to lowered stomata conductance (Moss and Peaslee, 1965; Raschke, 1975). Although increased mesophyll resistance may be the primary factor using the reduction in photosynthesis (Terry and Ulrich, 1973; Peoples and Koch, 1979).

Future Direction

The carbon stock of mangroves in Coringa WLS has been estimated to be 148 mt/ha. Therefore, an approximate economic value per hectare of mangroves with respect to their carbon sink potential is equivalent to Rs.2,54,208/ha.

The Government of India has taken several steps to increase the mangrove cover in the country as a climate change adaptation strategy. However, due to lack of data on carbon storage ability of different species of mangrove that occurs in India, there is always confusion in selecting a suitable species for mangrove plantation. In most cases those species with high regeneration potential and lower turnover rate are selected, but restoration based on monoculture does not necessarily lead to a healthy, resilient state.

Since mangrove distribution is at the interface between land and sea, mangroves are likely to be one of the first ecosystems to be affected by global changes. Reduction of atmospheric CO₂ with the help of mangroves provides a better option for the

sustenance of this ecosystem itself and other life forms on this planet. This demands conservation of the remaining tracts as well as increasing the mangrove cover. India has vast patches of mangrove areas, particularly in the eastern coast that provide significant hope for carbon storage. 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. In this context, it is imperative to help stakeholders to increase the mangrove cover in India by providing right species with high potential of carbon sink and the right places for afforestation without compromising overall environment settings of the landscape/seascape.

There are still less number of detailed studies on mangroves with respect to carbon sequestration in the Indian context. Also, there is a lack of research on mangrove structure, their distribution, and related influencing factors. Therefore, the present study in the Coringa WLS is important and has provided insights to the mangrove species dynamics and their carbon sequestration potential. Further, this study has also identified the important governing factors such as soil salinity on structure, distribution and carbon sequestration potential of mangrove species. This study indicates that the predicted increase in sea level rise due to climate change would affect the overall salinity condition of coastal soil that would in turn affect the carbon sequestration potential of certain mangrove species in future. In this context, assuring the regular flow of freshwater from upstream landscapes to coastal areas is imperative as a climate change adaptation strategy. In this way increase in coastal soil salinity due to predicted

sea level rise would also be mitigated with fresh water flow into the mangrove ecosystem in the future.

Coringa WLS has several degraded patches in and around the boundary. The anthropogenic pressure is also high with respect to logging and aquaculture. Andhra Pradesh Forest Department is already taking some initiatives to restore the degraded patches in and around the Coringa WLS. However, restoration outside the boundaries of the sanctuary is complicated since most of the land is privately owned. Such land just abutting the sanctuary is highly vulnerable to being converted into aquaculture ponds or other developmental areas. Degraded mangroves areas may be planted with suitable mangrove species according to their preferred soil salinity so that their carbon sequestration potential would be more.

Coringa Wildlife Sanctuary is also a MPA (Marine protected area) site under UN Food and Agriculture Organization's Bay of Bengal Large Marine Ecosystem (BOBLME) Programme. It is a regional initiative that works to build support for coordinated, inter-governmental management of the coastal and marine resources that span the Bay of Bengal. This programme has eight participant countries along with India. Large marine ecosystem includes the coastal areas, islands, reefs, continental shelves, and coastal/marine waters of the Bay of Bengal. The priority issues of this project are overexploitation of living marine resources and degradation of critical habitats. Indian government is contributing in long term conservation of marine resources with associated ecosystem services and cultural values by forming different "Marine protected area".

Coringa WLS as an important MPA site of Andhra Pradesh is undergoing rapid development especially after its recognition as a future 'Smart City'. The mangrove forests are being converted for aquaculture ponds and agricultural farms. Present study on the carbon sequestration potential in Coringa WLS provides a backdrop for restocking the degraded area in and around of this sanctuary. By storing carbon, these

mangroves provide very important ecosystem services particularly in the context of global warming and its impacts on coastal regions. Therefore, there is an urgent need to protect and preserve these large tracts of mangroves in EGREE taking into account the results of this study. As a conclusion this study suggests a mixed species plantation for maintaining the mangrove community structure, for better conservation and for better resilience of EGREE to the impacts of climate change.

CHAPTER

13

Willingness to Pay under context of climate change in EGREE

The sustenance and well-being of human society is intricately linked to the wide range of services and goods provided by Earth's natural ecosystems and rich biodiversity. Most often these services are hard to quantify since they do not have any existing market value or apparent economic significance. Economic valuation, therefore, helps to express these hidden values by unraveling the various socio-ecological linkages affecting them.

The non-use values of an ecosystem are more difficult to estimate. Non-use values are different than the direct or indirect use values, in that they most often relate to the intangible emotions of humans. Just the knowledge of maintenance of or access to a service, in the present as well as for future can evoke strong emotional responses in people. Therefore, non-use values provide bigger challenges to estimate their values.

Contingent Valuation Method (CVM) is a popular method for valuation of both use and non-use values, though it is most commonly used for the latter. In this method people are directly asked to state their willingness to pay or accept (WTP or WTA) to maintain or compensate for an ecosystem service. In case of non-use values, the economic estimates cannot be revealed through purchases or behavior of the people. Thus, people are directly asked to state their values for that service.

Using Contingent Valuation Method, the value attached by the local communities to the mangroves of Coringa Wildlife Sanctuary was calculated. A questionnaire survey was conducted in some of the villages around the sanctuary in 2016. An attempt was also made to understand whether awareness of climate change makes any difference in the stated preferences of the people.

Methodology

This study was conducted in 13 villages around Coringa Wildlife Sanctuary viz. Matlapalem, Ramanapalem, Kotturu, Giriampeta, Pagadalapeta, Peddavalasala, Chinnavasala, Pedda Boddu Venkataypalem, Chinna Boddu Venkataypalem, Bhairavapalem, Gadimoga, Savitrinagar, and Dariyaltippa. Most of the respondents in these villages were fishermen by occupation. Shrimp fishery is a major source of livelihood for these fishermen but other fish species such as mullets, eels and catfishes also are important in the mangroves. The local communities are closely dependent on the mangrove forests for livelihood as well as fuelwood and timber. A small proportion also worked in aquaculture ponds or agricultural lands as workers.

The survey was conducted from September to Decemeber, 2016. A total of 383 households were surveyed from these 13 villages. The questionnaire had three parts to it; in the first part, general information related to the household, respondent and the village was asked. Other questions on timber collection or damage by cyclone or natural disasters were also asked. In the second part, the respondents were first asked about the

importance of the mangrove and fishery services that it provides. Thereafter they were asked the extant status of the mangrove forests around their village, whether the forests are degrading or increasing. In this part, we also asked about awareness level about issues related to climate change and sea level rise.

In the third part, the respondents were explained about the vulnerability of mangroves around their villages to sea level rise, and the continuing efforts of the government and local NGOs to protect them. They were given a hypothetical situation where they might have to pay a certain amount of money monthly to the forest department to protect the mangroves. The contribution would be voluntary and depending on their economic ability. If the respondent answered 'No' or was not willing to pay for the same, the value was recorded as '0'. If they replied in positive, they were then asked the amount they would be willing to pay monthly.

Willingness to pay (WTP) for a service or good can be affected by various factors such as respondent's age, gender, income, education level or cultural factors. For this study WTP was estimated through regression model with WTP as the dependent variable with a set of explanatory variables. The model used for this study was in the following form and the variables are explained in Table 37:

$$WTP = \{AGE, EDU, HI, OCCU, FM, TIM, MGST, CCAW\}$$

Table 37: Description of variables

Variable name	Description
Dependent variable	
WTP	Stated Willingness to pay to protect Coringa mangroves from climate change (Yes=1, No=0)
Explanatory variables	

AGE	Age of the respondent (number of years)
EDU	Years of education (number of years)
HI	Household annual income (in Rupees)
FM	Number of members in the household
OCCU	Type of Occupation (Categories:
TIM	Does the respondent collect timber from the mangrove or not? (Yes=1, No=0)
MGST	Whether the mangrove is decreasing (=0) or increasing (=1) near village as per respondent's observation?
CCAW	Is the respondent aware or not about Climate Change and its impacts? (Yes=1, No=0)

Among the explanatory variables AGE, HI, EDU, FM are quantitative variables; TIM, MGST and CCAW are binary variables; and OCCU is the categorical variable. Gender was not taken as a variable since all our respondents were males. Males were the head in most of the households surveyed, so females were not comfortable responding to our questions.

Based on these variables, the probability of a person to pay for the non-use values of mangroves was calculated. Using step-wise regression, the most important factors influencing the WTP were identified. The mean value of WTP was estimated through non-parametric methods.

Collection of timber

Based on the survey it was found that majority of the respondents (65.7%) did not collect fuelwood or timber from the sanctuary. Interestingly, those who collected timber or wood were not ready to abandon doing that since they use them as an alternate fuel for cooking or for construction purposes.

Importance and Perceived status on mangroves in Coringa Wildlife Sanctuary

Respondents unanimously agreed that the mangrove forests are very important for the sustenance and protection of their villages. They told that the mangrove forests around their villages provide protection during cyclones or storms. Around 88% of the respondents observed that the mangrove forest near their villages was increasing while only 11% observed that they were decreasing. Interestingly, in several villages almost everybody noticed an increase in mangrove cover, but relatively higher proportions of respondents from the villages of Peddavalasala (40%) and Gadimoga (31%) noticed a decrease.

Awareness on Climate Change and its impacts

The survey results reveal that although everybody noticed a rise in temperatures in past ten years but only 41.7% of the respondents were aware of the concept of Climate Change and their impacts on coastal areas. In contrast to the overall result, all the respondents from the villages of Dariyaltippa, Gadimoga, and Savitrinagar were aware of the concept but it was not so in the other villages. In Cholangipeta and Ramanapalem none of the respondents were aware of Climate Change and its impacts.

Willingness to Pay

Around 92.7% of the respondents agreed to pay a yearly amount for protecting and restoring the mangroves. The mean annual WTP was estimated as Rs. 637/- per household.

As per the probit modeling three factors were identified that influenced an individual's willingness to pay. The three variables are Education level of the respondent, annual

household income and awareness of climate change. None of the other variables show any significant impact on the WTP. Respondent's education level had a positive influence; with every increase in the year of education the willingness to pay of an individual increased. On the other hand, with every increase in household income the willingness decreased.

A final model was run with just these three variables which resulted in a lower AIC value as well as a better fit (McFadden's $R^2 = 0.208$). Therefore, the analysis revealed that probability of a person with higher education level, lower household income and awareness of climate change is more than others to pay for mangrove protection.

Discussion

The findings of this study reveal that despite the low incomes of the local communities, they are ready to pay for protection of the mangroves around them. The results show that the mangroves of EGREE have high significance in the lives of the local communities. However, the value of contribution varied depending on the personal situation of the respondent.

Most of the local people engage in fisheries and live a life of subsistence. Therefore, they are highly dependent on the mangroves around them. On asking the respondents some reasons for their willingness to pay, everybody pointed out that mangrove play a very important role in their lives by giving them livelihood as well as providing protection during cyclones and storms. This service is an important aspect since one of the major impacts of climate change in the region will be increase in intensity and frequency of cyclones.

The results show that education level, household income and awareness of climate change are important factors that determine the willingness to pay of an individual in the study area. The mean number of years of education in the study was calculated to be just 4.5 years, which is not even beyond primary level of schooling. In few villages, it was less than 3 years. However, WTP increases with the number of years of education.

Education has the potential to provide more information to the people about the various services of the mangrove forests around them. Many of the regulating or supporting services might not be obvious to the local communities but higher level of education might give them more perspective and knowledge.

On the other hand, a higher household income meant lower WTP of the respondents. This is surprising since common experience suggest a higher income increases the capacity of people to spend more on goods and services. This result can be interpreted in this way that a lower household income might mean a higher dependence of the family on the mangroves. A higher dependence would make protection of these forests more significant for such families. In other words, families with lower household incomes value the mangrove forests more due to their higher dependence.

It is important to note that there were some respondents who were collecting timber or fuelwood from the sanctuary despite availability of alternate sources. At the same time, majority of the respondents said that the mangroves around their villages were increasing in area. This perception could also be due to the successful restoration program by the forest department. These two results possibly indicate a lack of awareness or proper knowledge available to them. Our study shows that mangroves in the region are decreasing on the sea-ward side and are migrating towards the land. EGREE is experiencing a spurt in aquaculture ponds particularly around the mangrove forests and many local fishermen are opting for it; therefore, this perception might have a negative influence on a longer term.

There also exists a lack of awareness on issues related to climate change and its impacts among the local communities. A little more than half of the respondents did not know about it despite the increase in temperatures that they have experienced. This lack of awareness also had an influence on their willingness to pay. In other words, people who did not have awareness about climate change are more likely to attach less value to the mangroves or their protection.

Therefore, this study shows that the local communities attach high value to the mangroves and are even willing to pay for intangible services and goods. If people know about the benefits provided to them by a project, they will extend their support in ways they can (Chen and Jim 2010). Mangroves are often considered to be natural defense against natural disasters as well as the impacts of climate change.

EGREE has a large coastal area under the mangrove cover and much of it is protected. However, the mangroves are still highly vulnerable to degradation, encroachment, and reclamation by aquaculture ponds. To successfully restore and conserve these coastal forests, the forest department and the government need the support of local communities. This study shows that the locals are ready to support the mangrove conservation activities but education and level of awareness are very important in shaping their perspective.

Therefore, it is recommended that the authorities engage more with the local communities and create more awareness about the mangroves and services they provide. Mangroves of EGREE are already showing signs of coastal squeeze but their conservation is crucial to prevent and mitigate the impacts of sea level rise in the region. Thus, creating awareness about climate change and its impacts is also highly recommended.

FRESHWATER FLOW IN EGREE

River Godavari is the second longest river in India, and the largest river of peninsular India. It originates at Triambakeshwar, near Nasik, Maharashtra, travels around 1470 km and empties into the Bay of Bengal at Kakinada, Andhra Pradesh. It has a large catchment area, 3, 12,812 km² (Bharati et al, 2009) and is fed by several tributaries along the way. After going across the Eastern Ghats in Andhra Pradesh, it emerges into the plains and finally branches into two distributaries – the Gouthami and Vashishta – just downstream of Dowlaiswaram Barrage, near Rajahmundry. The two distributaries further divide into smaller branches and form the Godavari delta or estuary.



Figure 146: Godavari river flowing towards Bay of Bengal near Yanam town in East Godavari

Environmental flows are flows that are essential to maintain the normal ecological services of a river. Their purpose could be as general as maintenance of a 'healthy' riverine ecosystem or as specific as enhancing the chances of survival of a threatened species and other associated fauna (Smakhtin et al. 2007).

The flow regime is one of the important components of a river ecosystem. The flow can reflect its health, its geographic location, and the geological and topographic features of the area, apart from maintaining the socio-economic status of the region. Ecosystem components such as channel morphology and patterns, water chemistry and temperature and the biota of the channels, banks and associated wetlands reflect the nature of a river's flow pattern. In this study, the environmental flow was defined in the context of maintaining the health of river stretches downstream from Polavaram, the estuary and the mangroves at the mouth of the Godavari River.

Godavari River has a long-term average annual surface flow of 110 km³. During the south-west monsoons (June– September), when the region receives almost 80% of the average annual rainfall, the discharge of the river is highest.

Floods are also a common feature of the river during August–September as in addition to the catchment area of the region, the river also receives water from its upper and middle reaches in Maharashtra. The flow regime of the river (Fig. 147 and Fig. 148) can be ascertained from monthly discharge data of the past 40 years from two points, Polavaram and Rajamundry.

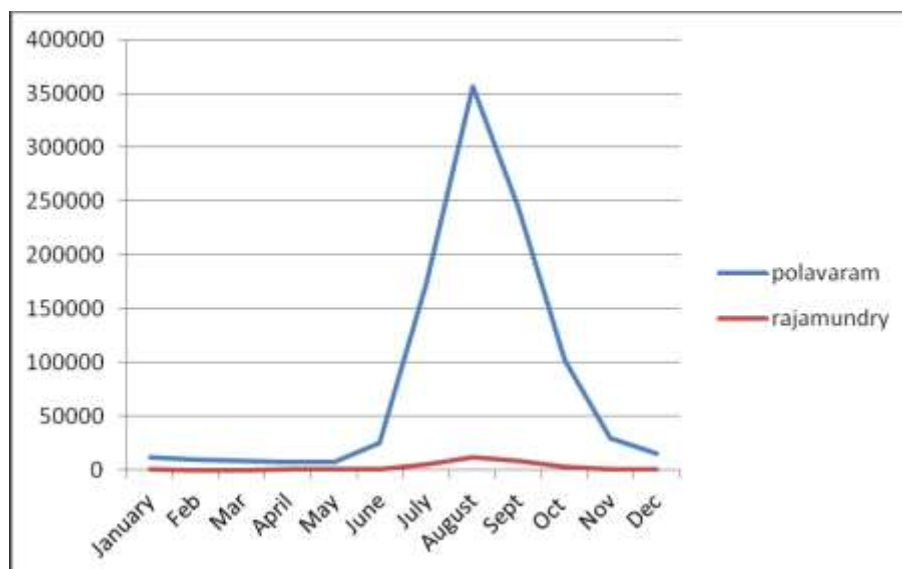


Figure 147: The average monthly discharge (cumecs) of the lower reaches of the Godavari River (1971–2012)

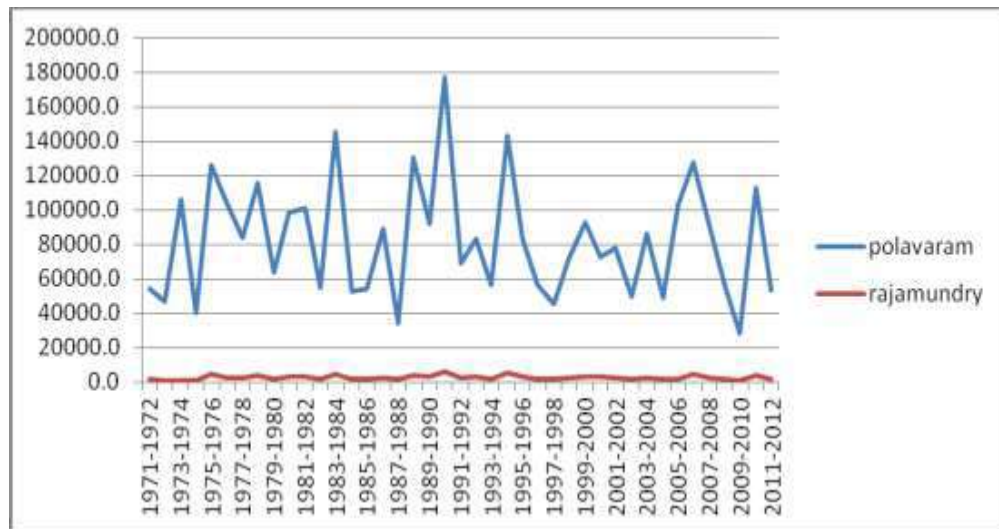


Figure 148: The yearly trend of discharge (cumecs) of the lower reaches of the Godavari River (1971–2012)

Fig. 147 shows the average monthly discharge of the Godavari River at Polavaram and Rajamundry from 1971–1972 to 2011–2012. The figure clearly shows that the discharge of the river is at its peak in August at both the points (around 3.5 lakh cumecs at Polavaram and 12,000 cumecs at Rajamundry), coinciding with the peak of the south-west monsoon in the region. The water flow remains high during this season, i.e. from June to October, after which the water level continues to recede. The water discharge decreases considerably from January to the summer months of April and May, with the lowest average discharge at Polavaram being recorded in April.

Fig. 148 shows the yearly trend in the flow discharges of the river at the same two points. The graph for Polavaram shows an irregular pattern of increase and decrease in the flow of the river. Interestingly, several times in the past 40 years, if in one year the discharge was very low, the following year experienced a steep rise in the discharge. The highest annual average discharge in the past 40 years at both the points was in 1990–1991, with Polavaram getting around 1, 77,315.4 cumecs and Rajamundry getting

6218.8 cumecs of water. In addition to this, a general trend of decreasing annual average discharge in the past four decades emerges from the graph. If we compare the peak annual discharges of the four decades, in the first decade (1971–1981) the highest annual discharge was 1, 26,189.3, in 1975–76. During 1981–1991, the highest annual discharge was 1, 77,315.4 cumecs, whereas for 1991–2001 it was 1, 42,846.6 cumecs. The decade of 2001–2012 saw a peak annual discharge of around 1, 27,187.9 cumecs in 2006– 2007, which is a considerable decline from the previous two decades. Also, the annual discharge at Polavaram has generally remained below 1 lakh cumecs during 2001–2012, with an all-time lowest discharge being recorded in 2009–2010 (27,993.0 cumecs).

Therefore, the flow regime of the Godavari River in its lower reaches may be deduced from the two graphs. The first deduction from the two graphs is the wide gap between the discharges at the two points, with Polavaram getting considerably higher discharges compared with Rajamundry. This can be explained by the geomorphology of the river basin. At Polavaram, the river passes through several hills and gorges which cause the river to narrow. As it emerges into the plains after Polavaram, the width of the river widens and thus the volume decreases in the downstream areas, such as Rajamundry. Further, the stretch near Polavaram lies inside a protected area, which prevents large-scale extraction of water by locals. However, in the downstream stretches, the river is lined by several big and small agricultural towns and industrial cities, which imposes a huge pressure on the river. The flow regime of the river is characterized by a peak monthly flow in August and a general but irregular trend of increases and decreases in the annual discharge. As pointed out earlier, the annual discharge of the river has decreased in the past decade.

Assessment of ecological status downstream of the Godavari River

The mean annual runoff (MAR) of Godavari river is 110 BCM. Normally, the ecological status of such larger rivers is assessed based on the EMC of that river. The definition of

the EMC should be based on existing empirical relationships between flow changes and ecological status/conditions, which are associated with clearly identifiable thresholds (Smakhtin et al, 2007). Limited evidence or knowledge is available of such thresholds (e.g., Beecher, 1990). In this connection, the EMC is a management concept that has been developed and used globally because of a need to make decisions regardless of the limited lucid hydro-ecological knowledge available (Smakhtin et al, 2007). In these conditions of uncertainty about which EMC is required for a particular river, the EMCs may be used as default ‘scenarios’ of environmental protection and associated environmental flows as ‘scenarios’ of environmental water demand (Smakhtin and Anputhas, 2006). It is possible to estimate the environmental demand corresponding to all or any of such default EMCs and then consider which one is the most feasible for a river in question, given the existing and future basin developments. We followed the methodology prescribed by the International Water Management Institute (Smakhtin et al, 2007) to assess the EMC of the downstream section of the Godavari River.

Ecological status of the downstream section of the Godavari River (Polavaram to Godavari estuary)

Indicator	Value	Score	Remarks
Rare and endangered aquatic biota	High	4	There are at least 16 threatened fish species in the reach, forming about 20% of the total fish diversity of the reach. Moreover, this is 13% of threatened species

			of fish in the country. The presence of other threatened species such as the otter and fishing cat in the river mouth is also important to note.
Unique aquatic biota	Moderate	3	<i>Hypselobarbus kolus</i> , which is endemic to the Western Ghats, was recorded for the first time in this reach during this study. Although this reach has at least 2 important threatened mammals, the otter and fishing cat, many species are unique to this catchment and use this part of the river for

			breeding migration, such as mahseer and <i>hilsa</i> . The mangroves and estuarine ecosystems that are close to the dam site are also unique because of their ecosystem services.
Diversity of aquatic habitats	Moderate	3	Presence of sandy banks, slow- and fast-flowing reaches, confluences of different rivers, streams, diversity of substratum, formation of islands and estuary
Presence of protected or pristine areas	High	4	Parts of both PNP and the Coring WLS fall inside the impact zone of this project.

Sensitivity of aquatic ecosystems to flow reduction	Very high	5	Any changes in the water flow will affect the estuary and its biodiversity as well as the mangrove ecosystem. Both estuarine and mangrove ecosystems are highly sensitive to the flow.
Percentage of watershed remaining under natural vegetation	Moderate	3	Large portions of the catchment of the Godavari are relatively disturbed
Percentage of floodplains remaining	>50%	3	Floodplains area reduced and degradation of floodplains also observed
The degree of flow regulation	High (reverse value)	3	Because of presence of Cotton Barrage at Dowlaiswaram the reach is

			already fragmented and water flow is highly regulated at least in summer and winter.
Percentage of watershed closed to movement of aquatic biota by structures or degree of flow fragmentation	Moderate (reverse value)	3	Movements of mahseer, <i>hilsa</i> , etc. have already been blocked by the Rajmundary Barrage.
Percentage of aquatic biota that are exotic	Moderate (reverse value)	3	At least four exotic species are present in the reach (<i>Cyprinus carpio</i> , <i>Clarias gariepinus</i> , <i>Oreochromis mossambicus</i> and <i>Pygocentrus nattereri</i>). <i>Pygocentrus nattereri</i> , a new exotic fish species for India,

			was recorded in this reach. Further, there might be more exotics in the estuarine region.
Aquatic species' relative richness	High	4	For the available area, 89 species of freshwater and brackish water fish represents a very high species richness. Several threatened animals and plants occur in this region, including eight threatened species of fish, the otter and the fishing cat.
Human population density as percentage of that in the main floodplains	High	4	Compared with parts of the Ganges, this stretch has a moderately low population.

Overall water quality	Moderate (summer)	3	The quality of water is moderate due to various anthropogenic activities downstream, especially the estuarine areas.
Sum of indicator scores		45	
Maximum possible sum of scores		65	
Percentage of the maximum		69	
Probable EMC		C	The habitats and dynamics of the biota of these rivers have been disturbed, but basic ecosystem functions are still intact. Some sensitive species are lost and/or reduced in extent. Alien species

			present (Smakhtin et al, 2007)
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Changes in sedimentation flows

Changes in the sediment transport and water quality are other important environmental impacts of river regulation. Due to construction of dams, the sediments and nutrients are trapped that starves the downstream stretches of the river. Due to this, the water flowing below the dam tends to erode the banks (McCully, 1996), rendering them to be weak and susceptible to subsidence. Reduction in sediment transport in rivers downstream of dam will also influence the morphology of the channels, floodplain, and coastal delta, altering habitats for fish and other groups of animals and plants in the Godavari estuary and Coringa mangroves.

Rao *et al.* (2010) studied shoreline recession in the delta of the Godavari and Krishna rivers and found that the suspended sediment load decreased three times in the Godavari delta, from 150.2 million tons during 1970–1979 to 572 million tons by 2000–2006, which they attributed to increased sediment retention in the reservoirs of dams on the rivers. In a similar study (Gupta et al, 2012), it was estimated that there would be a 74% decline in the historic sediments of the Godavari after the construction of dams in the Godavari. In this context, the ongoing Polavaram dam will further diminish the flow of sediments downstream, and that will adversely affect the Godavari estuarine ecosystem and the associated mangroves.

The sediment flow in a 118 km long stretch downstream of the dam site is expected to be reduced due to trapping of these sediments by the dam. Similarly, sediment will be trapped in the reservoir area, which will extend about 80 km upstream from the dam site. These changes in the sediment both upstream and downstream of the dam may not

be good for aquatic biota, especially the benthic and pelagic animals and plants of the Godvari River.

Changes in environmental flows

It is increasingly recognized that the distribution and abundance of riverine species are limited by the effects of flow regulation (Sivakumar and Choudhury, 2008; Sivakumar, 2008; Sarkar et al, 2011). A strong correlation exists between the stream flow and a river's physico-chemical characteristics, such as the temperature of the water and habitat diversity. Research on the distributional ecology of fishes suggests that fish assemblages form in response to the physiochemical factors of the environment. Change in the assemblage structure of stream fishes or species composition is imposed by temporal variations in the stream flow, which ultimately affects the entire biodiversity of the river ecosystem. However, the ever-increasing human population requires water for drinking, agriculture, etc., which affects the health of the river. Therefore, it becomes necessary to estimate the minimum environmental water flow and minimum environmental water level for rivers with reference to their biodiversity and the hydrological regimes.

Three kinds of adverse impacts on the aquatic biodiversity are expected because of changes in the natural flow due to dams in the Godavari River:

(a) Stagnated water in the submersible zones, which may not be conducive for certain stream/river fishes such as the mahseer;

(b) Less or no water flow in the dry zones of the project area, which is also expected to adversely affect the aquatic biodiversity (but it may be mitigated by maintaining the minimum environment flow); and

(c) Changes in the natural flow, which may also fail to provide the natural environmental cues to the aquatic biodiversity (such as *hilsa* and eels) to breed or maintain annual life histories (but this can again be mitigated by following minimum environmental flows even though it would help partially to maintain the current status of an aquatic ecosystem and its biodiversity).

In addition, the peculiar flow regime of the river is also essential for the geomorphology of the river as well as for riverine communities. Periodic droughts or floods provide signals to the fishes for breeding and spawning. For a large river such as the Godavari, the floodplain is the most important feature, which, according to McCully (1996), has 65 times greater diversity per unit area compared with the sea. This is a result of the annual flow regime of the river. However, a dam across the river will try to regulate this natural flow and change the seasonal lows or peaks of discharge.

Changes in nutrient flow

Changes in the nutrient flow will adversely affect the downstream fishes and other aquatic biodiversity, especially in the mangrove and estuarine ecosystems. On the contrary, the creation of reservoir will benefit a few generalist species leading to changes in the overall fish composition of the river. Nutrient availability is the major environment factor that determines the fish species composition in rivers (Sivakumar, 2008). Therefore, any changes in the nutrient flow will affect the overall composition of the fish community. Although these habitats may be useful for promoting fisheries, they will be detrimental to the native fish diversity of the region.

Trapping of nutrients will also lead to changes in the water quality of the reservoir as well as the downstream stretches. In the reservoir, in the initial years the biological oxygen demand will tend to be very high due to decomposition of the vegetation,

which will lead to a reduction in the dissolved oxygen, suffocating other aquatic organisms. Subsequently, algal blooms may occur due to warm weather, which will increase the productivity of the reservoir. While reservoir species and exotic species may benefit, there may be population declines of native river fishes.

On the other hand, the lower stretches will experience severe depletions in nutrients and dissolved oxygen, which is again harmful for aquatic communities. Further, there might be several effects on the way of life of the local communities who live in the floodplains, i.e. around the Godavari Estuarine Region. These effects will arise from biological changes due to physical changes downstream of the dam: (a) a reduction in the river flow, (b) saline intrusion close to the coast, (c) loss of deposition of nutrients in flooding valleys because flooding is stopped (which may affect agricultural productivity), (d) problems (such as dry wells) related to fluctuations of underground water levels and (e) the risk of the failure of the dam itself, which might produce a disastrous flood.

Impact on coastal landscape

All parts of a river ecosystem are inter-connected. Therefore, a disturbance in one part will create a greater or lesser response over much of the system. The Polavaram dam can stop migration of certain fish to their spawning grounds in the headwaters, impacting the estuarine fishery at the other end of the system. Management of rivers and their flows should thus consider all likely responses of the river to a planned disturbance.

Floods transport large amounts of sediment through the estuary, providing physical energy for circulation and promoting biological production. With the suppression of large floods by the dam, downstream sediment transportation will further decrease, and in situ estuarine production may further decline. Suppression of floods also might decrease the fluvial energy available for water movement and alters circulatory patterns

and salinity intrusion at the Godavari delta. Because the intrusion of salt water into the estuary depends on the amount of freshwater resisting the salt water, decreased maximum flows and increased minimum flows (regulated by dams) will reduce the seasonal variability of saltwater intrusion.

Due to reduction in freshwater flow and increased extraction of water, the mean salinity in the estuary will increase. The salinity regime or the spatial pattern of salinity across the estuary will also change affecting the distribution of most estuarine organisms. Our studies on fishes and the benthic organisms of the Godavari Estuary already indicated that salinity is the most important factor that influences their distribution pattern. Therefore, due to rise in salinity those species with narrow salinity tolerance will be under highly stressed environments while the ones with broad salinity tolerance will flourish. Some species might experience range extensions or altered distributions because areas that were formerly subjected seasonally to salinity levels that are intolerable for those species may now be habitable throughout the year.

Further, a significant reduction in the river flow will reduce the amount of sediments transported to the coast. This in turn will reduce the extent of the estuarine plume, which is an important migration cue for fishes, either during their larval or adult stages. Thus, the abundance of marine fishes that use the estuary as a spawning ground or as a nursery area will decrease. This way the Polavaram dam or any future regulation can cause further declines in coastal fisheries.

Mangroves are best developed in areas that receive freshwater runoff and are subjected to tidal water flushing. Rajmundry Barrage which was constructed for diverting water for irrigation has already resulted in poor flow of freshwater into Godavari mangrove swamps. To cite an example, in Pichavaram, south India, the mangroves are largely dying due to hypersalinity and other associated factors such as increasing temperatures, poor precipitation, poor flushing of mangrove soil by tidal waters, etc. The current

population structure of the mangroves and associated mangroves in Godavari estuary indicates that the abundance of typical mangrove species is less in the Godavari estuary compared with other halophytes or associated mangrove species. This might be due to topographical changes, aquacultural activities and reduced flow of water because of the Rajmundry Barrage.

The mangroves at EGREE are already threatened due to climate change-related impacts such as sea level rise, increased atmospheric CO₂ concentrations, fluctuations in the annual precipitation, fluctuations in temperature, high-water events such as storms and floods, etc. A rise in the sea level is also expected to cause erosion of sediments due to high-water events such as flooding and can prevent sediment accretion, which is crucial for mangrove survival in the Godavari mouth. As the hydrology is an important factor in a mangrove ecosystem, a rise in the sea level could alter the local salinity regime by bringing in more saline water, and freshwater mangroves along the landward side will be affected and more salt-loving mangroves will grow near the landward side. In this context, the expected reduced flow of the Godavari River due to the Polavaram dam will further aggravate the problems. These adverse impacts can be minimized through careful management of water releases, and in this regard, variability is very important. Therefore, the objective in optimizing water releases from the dam is to closely mimic the natural flooding regime.

Ground Water Salinity around Coringa Wildlife Sanctuary

Ground water samples collected from 94 source points (ponds, wells, hand pumps) in villages near the Coringa Wildlife Sanctuary (CWLS) that were tested for salt content using a salinity refractometer. The point values were then interpolated using Distance Weighted method in Arc GIS to prepare a ground water salinity map (Figure 87) for the EGREE landscape. From the map, the highest salinity in ground water is at the periphery of the CWLS whose outer boundary is spanned with prawn aquaculture

ponds. These ponds maintain a salinity value of 7-10 % for prawn production. This may be the reason for higher salinity values at the periphery of CWLS.

The following two maps (Figure 88 & 89) show interpolated salinity maps based on soil samples collected from 10 m distance of Aquaculture Ponds and from Agriculture Fields. From the interpolation map of salinity values based on Aquaculture Ponds samples, the soil salinity may be expected to be higher than 2% in majority of the landscape. Upon parallel comparison of both maps, there is quite some overlap between the areas where soil salinity is expected to be between 1-3%. Thus, we can infer that there is some influence of aqua ponds on the soil salinity in the landscape.

According to FAO report of 1985, 0.2% is the threshold level of salt tolerance in paddy. However, as can be seen from the map, the salinity, expressed in percentage ranges from 1% to 4% in the agricultural fields. This is because of these fields are adjacent to Aquaculture Ponds and the salinity is a result of salt water seepage through soil.

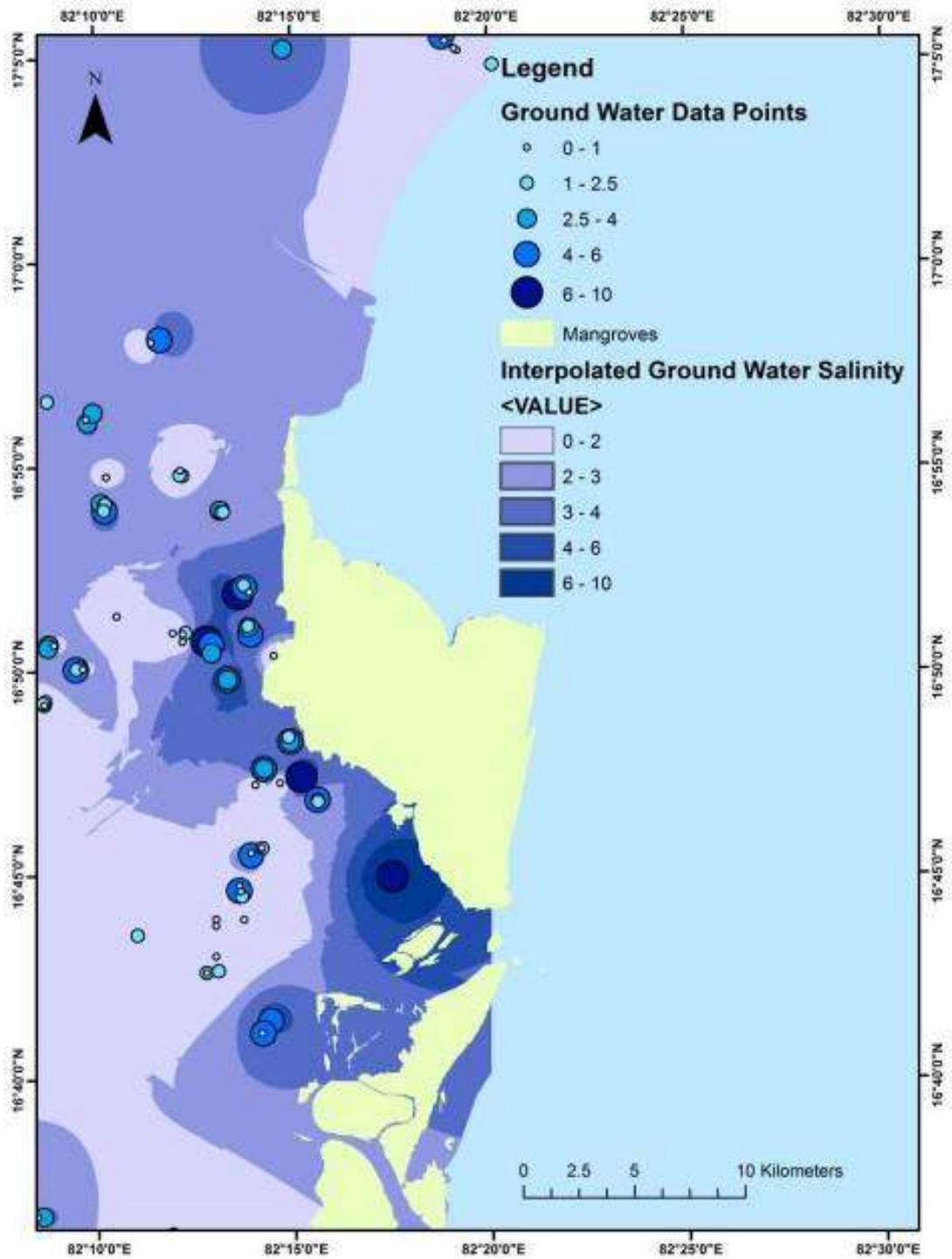


Figure 149. Interpolated Map of ground water salinity based on 94 Samples of Ground Water in percentage (%).

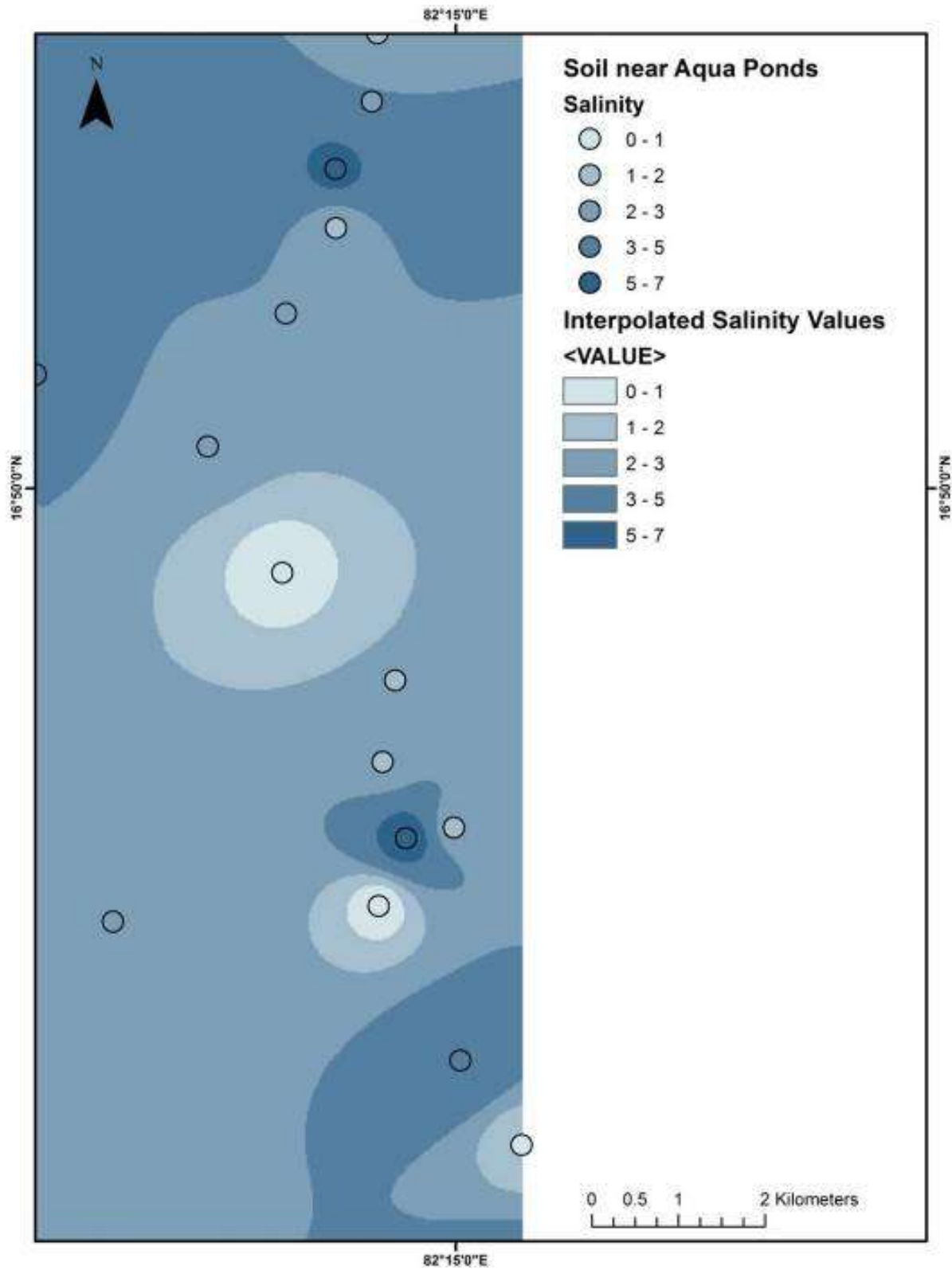


Figure 150. Map showing the soil salinity values near Aqua Ponds

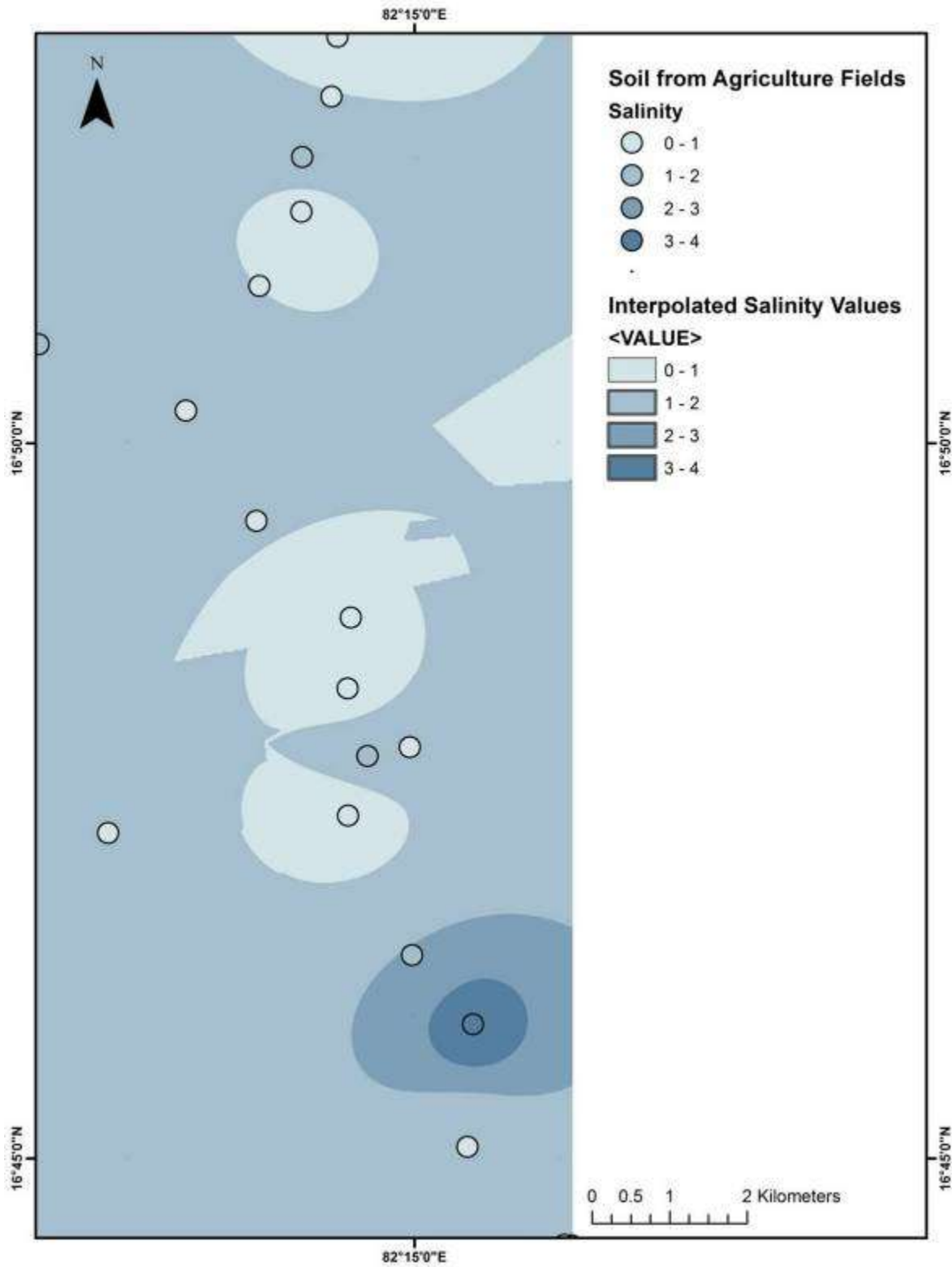


Figure 151. Map showing the soil salinity values from Agriculture

Conclusion

In conclusion, the Godavari River is the second largest peninsular river and has a huge area as its floodplain. Due to its peculiarity of seasonal floods during the monsoons, huge amounts of nutrient-rich alluvium have been deposited in its downstream reaches, which have also led to the formation of an intricate deltaic ecosystem at its mouth. It is due to the Godavari River and its delta that the region is blessed with extensive agricultural and fisheries wealth. However, regulation of the flow regime and entrapment of sediments in the reservoir of the Polavaram dam might lead to severe consequences not only for the flora and fauna of the region but also for its millions of people who are dependent on agriculture and fisheries.

The rising temperatures and rising sea levels will also lead to a rise in salinity levels in EGREE which might have domino effects on the entire estuarine biota. Therefore, freshwater flow into the estuary is an important mitigation measure against impacts of climate change. Since Polavaram Dam will be operational in few years it is still highly recommended that the minimum environmental flow of the river is maintained always, particularly in the dry season.

The rising sea levels will further increase the salinity of coastal soil and water. In the long-term this can lead to serious declines in agricultural productivity in the region. Therefore, a thorough investigation into the practices of aquaculture in EGREE is also recommended since our study shows its link with higher salinity of agricultural soil and underground water.

Suggestions for estuarine/mangrove conservation plan

The problems caused by the reduction of sediment transported to the coast can only be solved through expensive engineering works, namely beach nourishment and ultimately shoreline protection. Inhibition of floods results in marine sedimentary deposition at the river mouth, which may be solved only through dredging. Therefore, the management plan of the Coringa WLS or management plan of the Godavari estuarine area should clearly list out all action plans required to nourish the shoreline and remove marine sediments regularly from the mouth so that the marine flow into the estuarine is maintained. Further, the existing or proposed management plans of Coringa WLS and Godavari estuary should contain a preparedness plan with respect to the Indira Sagar Project as well as climate change.

In the Godavari estuary, where the river flow would be greatly controlled by the dam, there is a time lag between the maximum rainfall and maximum river discharge. This delay can sometimes compromise the recruitment of estuarine fish species. This would cause some negative impacts on fish populations and shifts in the natural patterns of other biological communities. It is in this sense that minimum flows should be allowed from the dam. Sometimes, it is difficult to make a compromise between effective nature conservation and economical improvement of an area. Positive impacts in the local economy should be achieved through sustainable and rational development of human activities in the area, including tourism. Tourism is regarded as one of the solutions for achieving economic development in the Godavari Estuarine Region.

Therefore, the scope of the eco-tourism plan of Coringa WLS may be extended to the estuarine region. But, the development of economically viable tourism in this region has to be ecologically sensitive and culturally appropriate. Therefore, nature protection and understanding the worth of the natural patrimony that characterizes the Godavari estuary/mangroves should not be neglected or forgotten. Mangrove forests are the

major coastal ecosystem found in the Godavari estuary and are among the richest and most productive ecosystems. A number of commercial and traditional products are provided by mangrove ecosystems. These include nutrient enrichment for the aquatic and terrestrial flora and fauna.

Mangrove vegetation plays an indirect but very important role in coastal protection. Mangrove forests occupy a unique ecological niche and form a habitat for a variety of marine and terrestrial animals. Similarly, estuarine and sandy beaches are known to be the nesting areas of sea turtles. Therefore, an integrated coastal zone management plan is required in the estuarine region of the Godavari River that addresses the entire gamut of issues related to conservation and sustainable use of biodiversity of the region. The functioning of the Godavari mangrove ecosystem is closely linked to land use practices. In particular, changes in water-flow regimes affect mangroves, and overdrawing of ground water may increase the danger of aquifer salinization and contamination. Consequently, the coastal zone should be considered an integral component of overall regional land use planning and development so that appropriate land use policies and action programmes may be formulated. Priority should be given not only to rehabilitation of degraded coastal lands but also rational use of land on a sustainable basis, including planned development of sustainable forest/marine products. Many of the uses and services of mangroves are compatible, such as honey collection, coastal protection and small-scale capture fisheries. Others are less so, and hence a zonation of the area according to primary land-use objectives is necessary. This underscores the need for a holistic approach within the framework of integrated coastal zone management planning.

This integrated management planning should also ensure that all goods, services and values are catered for. Management planning should therefore include periodic environmental impact assessment, and the actual management should be monitored periodically by environmental auditing. Good environmental management promotes

conservation of biodiversity. However, there is limited information on the biodiversity value of the Godavari estuary – hence the need for research. The mangrove/estuarine management action plan cannot succeed without taking into consideration the requirements and aspirations of all the people. Success depends, inter alia, on being able to match management objectives with the interest of local populations and, through extension, securing their support and commitment. Therefore, a degree of ‘self management’ should be encouraged among the various users of the mangrove environment so that they can be involved in protecting their own environment. In the recent past, there have been large numbers of incidental captures of whale sharks from off the Godavari mouth.

The whale shark is one of the most highly threatened sharks in the world, and it is protected under the Wildlife (Protection) Act, 1972. The Gujarat Government initiated an innovative compensation programme for fishermen who release incidentally captured whale sharks. A similar model may be taken up in the region to prevent killing of this species in this region. A lack of understanding of the importance of mangroves is an important cause of mangrove depletion and degradation. The state forest department should justify its mangrove management programme to the general public and other line departments. The authority should ensure that awareness and education programmes that inform the public about mangroves, their uses and services and how to maintain them, as well as government plans in relation to management of these resources, should therefore be developed and implemented. These programmes should be aimed primarily at the people who live near the mangroves/estuary and depend on them for various needs. These programmes should also be developed for planners, decision makers and the agricultural and public works sectors since their actions can have serious impacts on mangroves. Relevant audio-visual and visual aids should be developed, and seminars, talks, workshops and exhibitions on mangrove products and services targeted at various audiences should be conducted to create public awareness.

Expansion of ecosensitive zone around Coringa WLS

All the degraded mangroves around Coringa WLS sanctuary have to be declared either the eco-sensitive zone of Coringa WLS or a conservation reserve so that the necessary management interventions can be made to restore these mangroves habitats. The state forest department should strengthen its ongoing mangrove restoration programme and the sea turtle conservation programmes in the region with financial support from the Indira Sagar Polavaram Project.

In this context, it is suggested that both the banks of the river (with a width of 50 m) from the dam site to the Godavari estuary be declared an ecosensitive zone. A green belt needs to be developed using only native plants in this ecosensitive zone without disturbing its natural landscape.

Otters and fishing cats in the Godavari mangroves need special attention in the integrated management plan of Coringa WLS or the Godavari Estuarine Ecosystem. These two species are the umbrella or flagship species of this ecosystem. Any adverse impact due to the dam or climate change on the mangroves will ultimately affect the populations of these two species. Therefore, the integrated management plan of Coringa WLS should consider these two species as flagship species and try to restore their populations and their habitats. Interestingly, otters were observed close to human habitations but only at the fringes of mangroves. It was also observed that there was some conflict between the otters, fishing cats and aquaculture farmers. These wild animals are known to hunt fishes in the aquaculture farms nearby. In this context, it is important get the support of farmers for conservation of the otters and fishing cats in the region as these species are already highly threatened in India.

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Research Team presenting about the research work in different conference

