Vegetation structure, distribution and Carbon sequestration potential of mangroves along soil salinity gradient in Coringa Wildlife Sanctuary, Andhra Pradesh

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By

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CERTIFICATE

This is to certify that **Mr. Dipak Anand**, student of Wildlife Institute of India has carried out an original piece of research work entitled **"Vegetation structure, distribution and Carbon sequestration potential of mangroves along Soil salinity gradient in Coringa Wildlife Sanctuary, Andhra Pradesh"** for the partial fulfilment of the M.Sc. Degree in Wildlife Science from the Saurashtra University, Rajkot, India. These investigations were carried out under our supervision from December 2014 to June 2015. We also certify that this research has not been submitted for any other degree to any University.

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Summary

1. Globally, it is expected that increasing concentrations of atmospheric CO_2 and other "greenhouse gases" will bring variations in the climate. It is also predicted that global carbon concentration will increase to 300 to 350 Mmt by 2020 and 480 to 840 Mmt by 2050 (IPCC, 2014). All countries including India, who are signatory to the IPCC have committed to reduce their carbon emission by 25 – 30% at the end of 2025 using the year 2005 as base level. Blue carbon concept in REDD+ seems to be the best effective way to reach this target more effectively and efficiently. Blue carbon concept improves the carbon sink level with the help of coastal and oceanic habitats. Mangrove habitat has been considered to be an important contributor in carbon sink and also have been categorized as second most important source for carbon balance after coral reefs at global level. In this context, this study was carried out with aim of understanding the mangrove dynamics along with carbon storage abilities of various mangrove species that occur in the Coringa Wildlife Sanctuary and also the various environmental factors that would probably determine the mangrove structure, their distribution and carbon sequestration potential, from December 2014 to May 2015.

2. Influence of salinity on structural components of the mangrove (i.e, density, Complexity Index, Importance Value Index, above ground biomass, carbon content etc.) revealed a significant negative relationship. Diversity of the species was not so related with the salinity gradient and didn't show any significant relationship with salinity. 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. The influence of salinity revealed negative trend with all mangrove species except Sonneratia apetala and Bruguiera gymnorrhiza with respect to their basal area.

3. Importance Value Index (IVI) that is the combination of relative density, relative basal area and relative abundance, was highest for *Excoecaria* (115.560), and followed by *A. officinalis* (77.384), A. marina (37.693) *and Rhizophora apiculata* (14.920) respectively. Sonneratia apetala and *Bruguiera* had the same value of 9.753. *Lumintzera* and *Xylocarpus* have their index value of 3.574 and 3.304 respectively. Among all species, *Ceriops decandra* had the least index value.

4. Carbon sequestration potential of mangroves was varied between species. Highest carbon sequestration potential was observed in *Aegicerous corniculatum* (45.467 %), followed by *Avicennia officinalis* (44.818 %), *Bruguiera gymnorrhiza* (44.37%), *Ceriops decandra* (44.33%) and *Sonneratia apetala* (44.185%). *Excoecaria and Xylocarpus* spp. had a potential of 44.018 and 44.058% respectively. *Avicinnea marina* had a carbon sinking potential of 43.954% and *R. apiculata* of 43.971%. Among all the mentioned mangrove species, *Lumintzera* spp. had the least potential for carbon sinking (39.836%).

5. Abundances of mangroves in the Coringa Wildlife Sanctuary were varied between species. *Excoecaria* had the largest density (37675 trees per hac.), followed by *Avicennia officinalis* (7250 trees per hac.), *Avicennia marina* (7087 trees per hac.), *Bruguiera gymnorrhiza* (4875 trees per hac.), *Aegiceras corniculatum* (2950 trees per hac.), *Sonneratia apetala* (2225 trees per hac.) and *Rhizophora apiculata* (1962 trees per hac.) respectively. *Xylocarpus granatum* performed least and gained the least density (200 trees per hac.) among all the related species.

6. A significant (R^2 = 0.674) 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 (R^2 = 0.54) negative relationship with the increased salinity level.

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

were at a low salinity range. Although, *Avicinnea officinalis* were distributed at a salinity range of 14 to 36.5 ppm, the better abundances were at a range of 21.3 to 32.25 ppm and the best was at 24 ppm. *Avicinnea 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. Principal component analysis (PCA) was used to determine the pattern of inter- relationship among soil environmental variables of mangrove ecosystem. Canonical Correspondence Analysis (CCA) was done to understand the relationship between soil environmental variables and mangrove community structure. Generalized Linear Modeling (GLM) was done to identify the most regulatory variables that could control the mangrove structure, composition, distribution and Carbon sequestration potential of mangrove.

8. The results of PCA showed that there was a marked pattern of inter- relationship on three axes among all the variables. Salinity, Sodium, Potassium, Nitrogen, moisture were highly correlated with each other. There was also a relationship in between pH & P and N & Mg. Canonical correspondence analysis result clearly revealed that density of mangrove species had an influence of almost all the variables. Some variables had better correlation with mangrove species in comparison to others.

9. Ordination diagram revealed that the abundance of *Excaecoria agallocha* was mostly influenced by salinity, Na, pH, N, Ca, K and P. Abundance of *Avicinnea officinalis* 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 *Avicinnea 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.

10. Generalized linear models of Individual mangrove species showed different soil environmental variables controlling the density, basal area and carbon sequestration potential of mangroves. Generalized linear modelling showed the negative impact of salinity in most dominant species and positive impact of Potassium, Calcium and Magnesium with respect to density of individual mangrove species. Basal area of individual mangrove species revealed the influence of salinity as a negative factor and Magnesium, Potassium, Calcium and pH as positive factors.

11. Generalized linear models of mangrove species at a community level showed Salinity (-0.72773 ± 0.10886) as the most dominating factor that influenced the density of mangroves negatively. Salinity was followed by Phosphorus (-0.17836 ± 0.09594) as the negatively influenced factor and Ca (0.19476 ± 0.10874) as the positively influenced factor. Basal area of the mangrove community was also influenced by salinity (-6106 ± 1451) as the most important controlling factor and had a negative relationship with basal area. Basal area had a positive impact of nitrogen (2347 ± 1451). Carbon sequestration potential of mangrove had a negative impact of salinity (-0.2547 ± 0.0157) as the most dominating factor. Salinity was followed by N (-0.0843 ± 0.0188) and Ca (-0.0820 ± 0.0194) as the factors that influenced the carbon sinking potential of mangrove community negatively.

12. Moreover, India 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 India by providing right species with high potential of carbon sequestration without compromising overall environment settings of the landscape/seascape. Therefore, this study in the Coringa WLS has become important and provided more insights to the mangrove species and their carbon sequestration potential.

13. Further, 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 normal flow of freshwater from the landscape to coastal areas is imperative as a climate change adaptation strategy. Therefore, expected increase in coastal soil salinity due to predicted sea level increase would be compensated with fresh water flow into the mangrove ecosystem in the future.

14. Coringa WLS have 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 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 and more carbon. This study provides a holistic approach about the mangrove species; different governing factors, their carbon sinking potential and preferred salinity range by which management can choose the right species at right place and might be able to contribute in nation's goal with respect to carbon sink.

CHAPTER 1:INTRODUCTION

1.1Background

Mangroves are ecologically important forests of the tropical region. They are highly productive ecosystems and contribute 10–15% (24 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–BaptisteFourier 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 as a result of human activity. In recent years, temperatures have risen dramatically (Fig 1). The example includes glacier melt in the Himalaya and other parts of the world (Dyurgerov & Meier 2005).

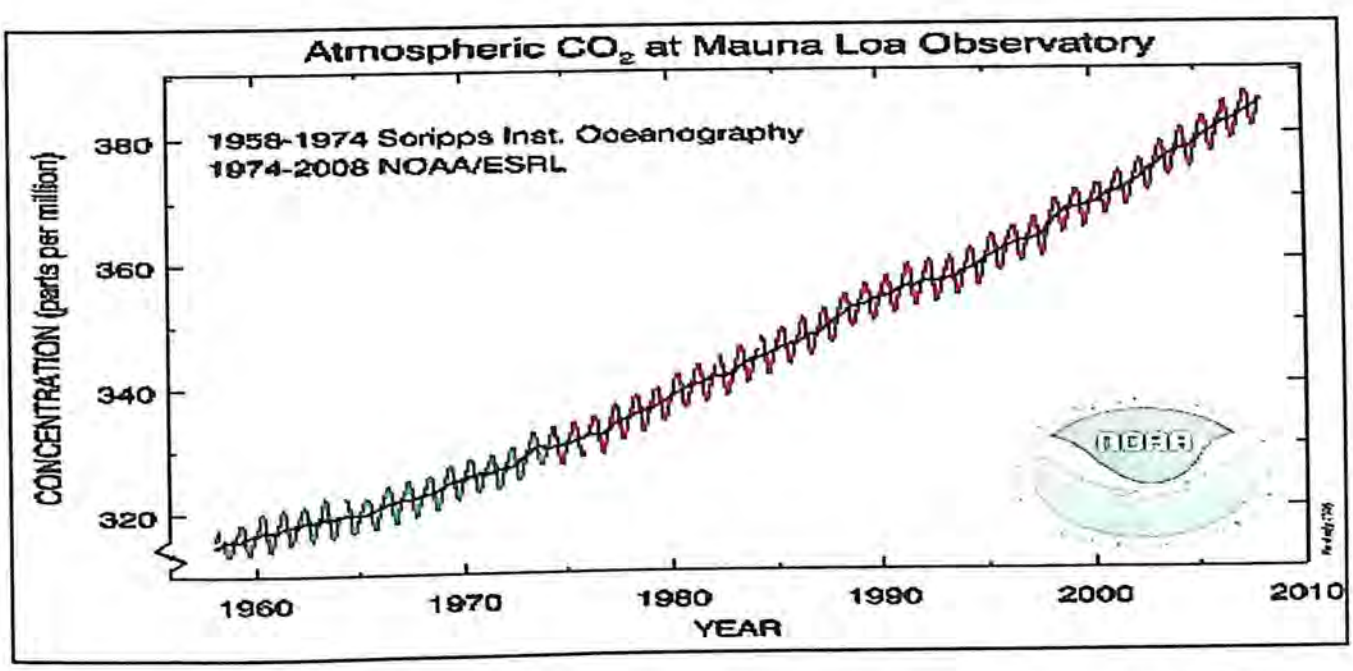

Figure 1 A composite trigonometry graph of Atmospheric carbon di- oxide at Mauna Loa observatory (Source: NOAA 2008)

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 CO_2

alone the total is about four metric tonnes 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 (Fig. 2) have signed and ratified the Protocol.

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

Brown – No intension of ratifying the Protocol

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 CO_2 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).

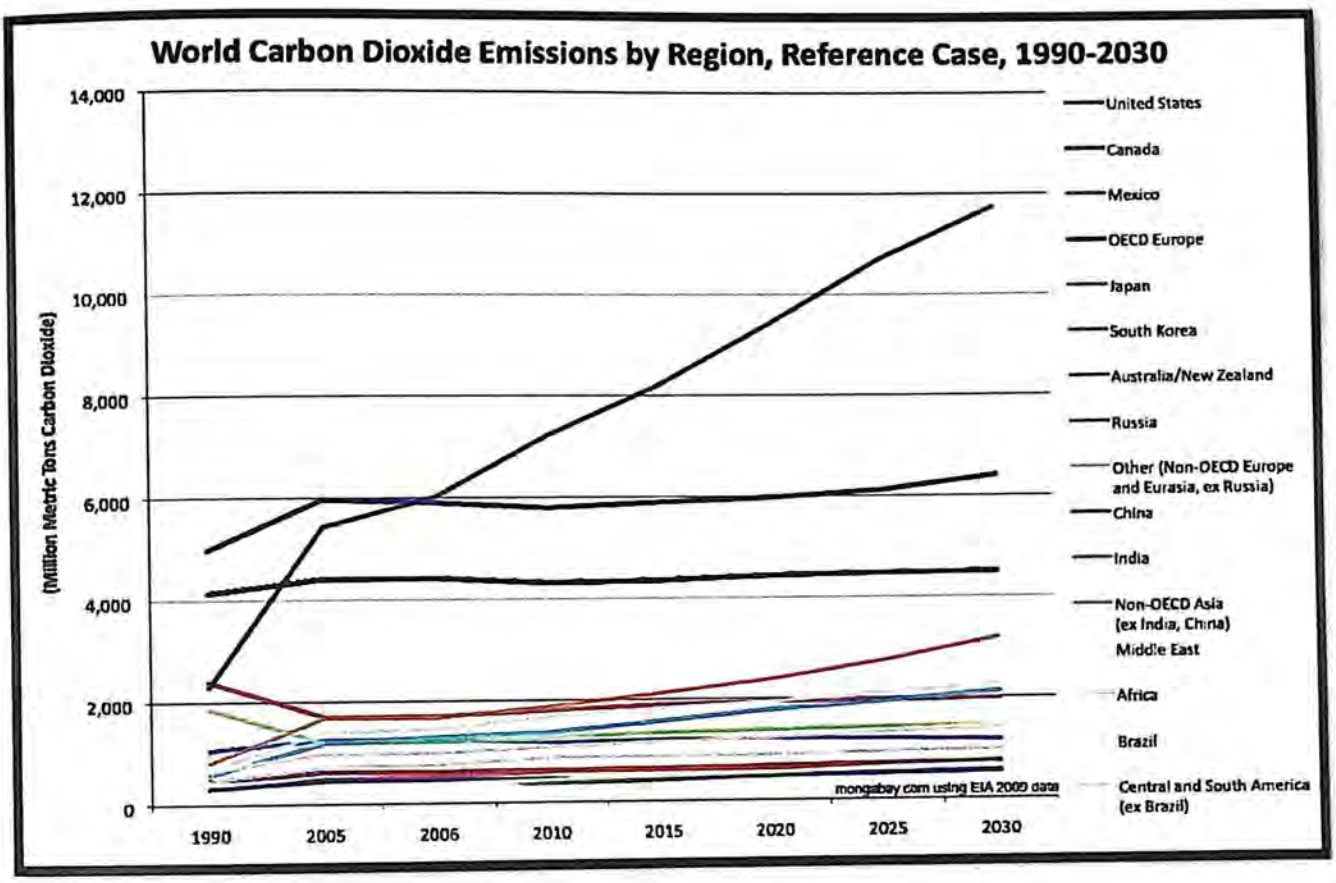

Figure 3. Graph showing World Carbon Dioxide Emission by different region

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 CO_2 was 393.82 ppm in 2012 and 396.48 ppm in 2013. The above-mentioned figure (Fig. 3) 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 CO_2 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 CO_2 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 CO_2 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 CO_2 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 CO_2, 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 CO_2 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 (CO_2). The carbon sequestered in vegetated coastal ecosystems, specifically mangrove forests, seagrass 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 considered to be 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 considered to be the maximum among all (Fig. 4), 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.

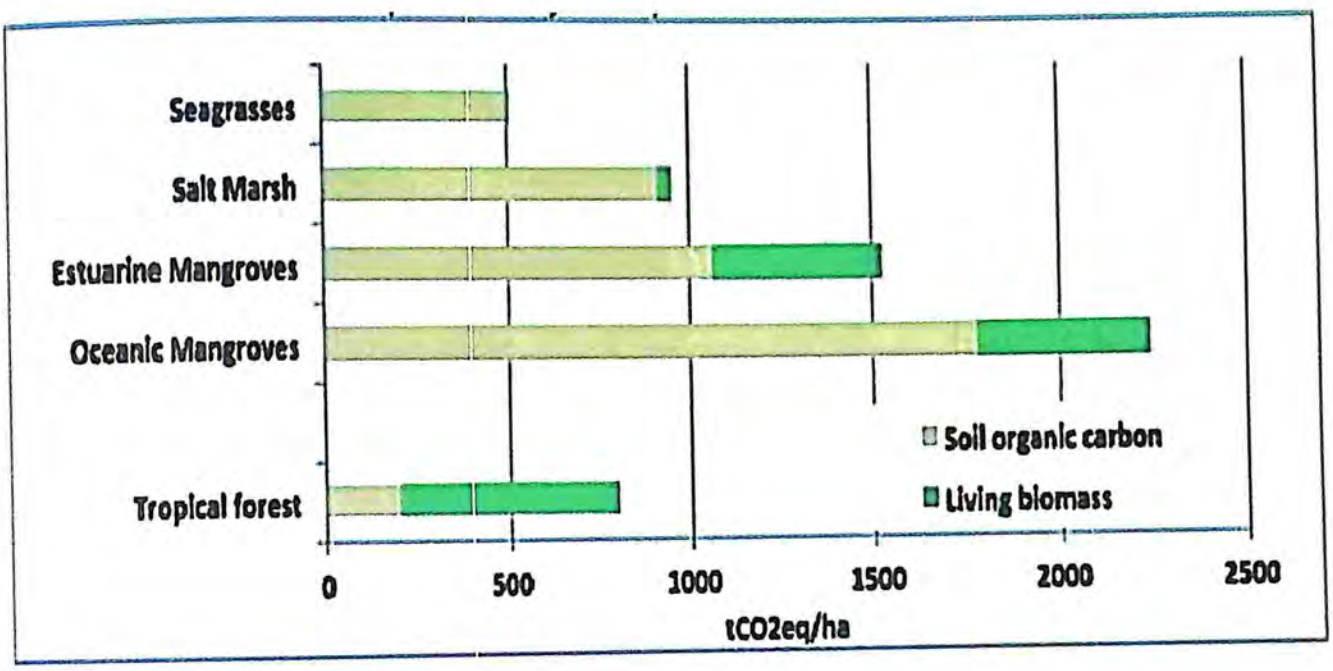

Figure 4. Global averages of carbon pools of coastal habitats, Tropical forests are included for comparison. Sources: Murray *et al* (2011)

Table – 1. Global estimate of carbon pool of mangrove and tidal salt marsh ecosystem.

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

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)

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. 1). 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).

1.1.1 Distribution of the Mangrove

Globally mangroves cover an estimated area of 152,000 km^2, less than one percent of all tropical forests (Spalding 2010). They grow in the intertidal zone of sub-tropical and tropical shores. Mangroves in India account for about five percent of the world's mangrove vegetation and are spread over an area of about 4,500 km^2 along the coastal States/Union Territories of the country (Bouillon *et al*, 2008). The deltaic mangroves are found along the east coast in the delta of Ganga, Brahmaputra, Mahanadi, Krishna, Godavari and Cauvery. Estuarine mangroves are found within the east coast in the estuaries of Indus, Narmada and Tapti. They are also seen in the backwaters, creeks and neritic islands. As compared to mangrove, the distribution of sea grasses, as well as salt – marshes, is very less in India. India has to reduce its carbon concentrations by significantly in the near future, and mangrove ecosystems are an important means to achieve this.

The vast majority of the nutrient pool of mangrove forests is stored in the soil and not in the trees (Alongi *et al* 2003). Similar to other plant communities, nutrient availability is one of the major factors influencing the mangrove forest structure and productivity. Many mangrove soils have extremely low nutrient availability, although nutrient availability can vary considerably among and within mangrove forests. Nutrient-conserving processes in mangroves are well developed and include evergreens resorption of nutrients prior to leaf fall, the immobilization of nutrients in leaf litter during decomposition, high root/ shoot ratios and the repeated use of old root channels. A complex range of interacting abiotic and biotic factors controls the availability of nutrients to mangrove trees, and mangroves are characteristically plastic in their ability to opportunistically utilize nutrients when these become available. Nitrogen and phosphorus have been implicated as the nutrients most likely to limit growth in mangroves. Ammonium is the primary form of nitrogen in mangrove soils, in part as a result of anoxic soil conditions, and tree growth is supported mainly by ammonium uptake. Mean estimates of net primary productivity (NPP) for mangrove range from 2 to 50 Mg C ha^{-1} $year^{-1}$ (Alongi 2009). How mangroves can sustain high levels of productivity in spite of nutrient limitation is the focus of many studies on mangrove nutrition. The emerging explanation is that the high productivity of mangroves is achieved where nutrients limit growth through efficient nutrient cycling and nutrient conservation strategies. Many mangrove soils have extremely low nutrient availability (e.g., Lovelock *et al* 2005), but nutrient availability varies considerably between mangroves and also within a mangrove stand (Feller *et al* 2003).

Coastal wetland ecosystems host a valuable biome and provide ecosystem services to local, regional and global communities. However, these ecosystems are threatened by human activities such as agricultural practices, logging, deforestation, engineering and urban development, and by the impact of climate change such as rise sea level (Duarte *et al* 2005; Mcleod *et al* 2011; Mitsch *et al* 2012; Chmura 2013). Thus, the wetlands vulnerability comes up when land-use change, habitat loss, and logging and fire interact with global and regional climate change forcing. Estimates of global loss of carbon pools indicated that the percentage of mangroves loss at the global level was between 30 to 50 % (since 1940s) and

20 % (since 1980s). The annual rate of global loss was estimated around between 0.7 to 3 %. In the case of salt marshes, the percentage of global loss was estimated to be 25% (since 1800s), with an annual rate of global loss of between 1 to 2 % (Mcleod *et al* 2011). Prolonged disturbance had changed wetland structure, nutrient dynamics, and biodiversity composition. The disturbance has also affected essential ecosystem services associated with global carbon cycles such as carbon sequestration, carbon density in soils, sediments and biomass, and carbon fluxes into the atmosphere. For instance, land use changes affect the carbon storage, climate regulation, hydrologic balance and biodiversity in the wetland ecosystem. Furthermore, coastal wetlands could shift from a net carbon sink to a net carbon source. Tidal salt marshes and mangroves store about 10.80 Pg C yr-1, mainly that carbon is stored in soils. However, land conversion and deforestation of mangrove and tidal marsh ecosystems by human and natural interventions cause carbon emissions from these ecosystems. Current threats to mangrove ecosystems are attributed to human pressures such as over-harvesting for timber and fuel wood production, reclamation for aquaculture and salt ponds (Bouillon *et al* 2009). Estimates of global carbon emissions from mangroves loss indicated that currently about 33.5 million tons of carbon are released annually; the estimation of global carbon emission from tidal salt marshes are calculated to be around 10.5 million tons of carbon/year (Siikamaki *et al* 2012).

1.2 Literature review

One of the most significant stress factors in mangrove ecosystems is salinity. Several studies have therefore attempted to correlate salinity to the standing crop of vegetation and productivity (Adams 1963; Good 1972; Lugo 1980). Influence of salinity on mangroves is proved to be the most influencing factor (Ukpong 1991; Chen & Twilley 1989). In general, mangrove vegetation is more luxuriant in lower salinities (Kathiresan *et al* 1996) and experimental evidence indicates that at high salinity, mangroves spend more energy to maintain water balance and ion concentration rather than for primary production and growth. It is also evident that under high salinity levels mangrove biomass production and retention are adversely affected (Suwa *et al* 2009). Several research studies proposed that mangrove doesn't prefer saline conditions because the saline environment provides a

hindrance to their growth and survival (Kathiresan *et al* 2001). Still they are present in such environment by adopting several survival strategies. The photosynthetic efficiency is seemed to be closely related to the productivity of species, and photosynthetic potential of species is closely correlated with the salinity of the environment. All these parameter are dependent on each other. It is considered that at higher salinity assimilation of CO_2 is lesser as compared to lower salinity (Lin G H & Sternberg LDSL 1992). Carbon assimilation is strongly correlated with stomatal conductance that varies in accordance with the salinity gradient. 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 the higher potential. As a result, a loss of water takes place from the plant. If such conditions persist 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 CO_2 concentration and intrinsic water efficiency. The potential of mangrove as carbon sinks is affected by several wetland characteristics such as the water level fluctuations, salinity, primary production and decomposition of organic matters, climatic conditions, microbial activities, and vegetation communities (Adhikari *et al* 2009).

Mangrove species have been found to be highly sensitive to variation in nutrient availability both in the natural as well as in the controlled condition in several studies conducted all over the world (e.g., Boto *et al* 1985; Naidoo 1987; McKee 1996; Yates *et al* 2002; Naidoo 2006; Onuf *et al* 1977, Boto & Wellington 1983; Feller 1995; Koch 1997' Feller *et al* 2003b; Lovelock *et al* 2005; Feller *et al* 2007; Lovelock *et al* 2007b; Naidoo 2009). In the Atlantic East Pacific biogeographic province, the response of the three dominant species, *Laguncularia racemosa*, *Rhizophora* mangle and *Avicennia germinans* to nutrient availability have been investigated in multiple studies, but in the Indo- West Pacific region, few studies documenting the effects of nutrient availability on mangrove species performances have been published. Most research on nutrient limitations of mangroves have engrossed on the macronutrients P and N, which have both been involved

as the nutrients most likely limiting primary productivity of mangrove ecosystems (Krauss *et al* 2008). N was considered the primary nutrient that limits growth, although more recent analysis reveals that N and P limit growth in approximately equal proportions (Elser & Hamilton 2007). An early theoretical analysis recommends that P limitation should be expected in areas with low exchange rates with the oceans and N limitation in more 'open' systems (Smith 1984). Additionally, variation in soil moisture may also affect the nutrient demand imposed by tree growth and, thus, the extent to which growth is nutrient limited (Krauss *et al* 2006), in addition to directly affecting nutrient availability. In the southern USA, mangroves have been experimentally shown to be both P limited (Lin & Sternberg 1992, Koch 1997) and N limited (Feller *et al* 2003). In Belize, both P and N limitation were observed, depending on location within the forest (Feller *et al* 2003). Nitrogen was seen to limit the performance of the species in the fringe area whereas permanently flooded island was controlled by the influence of phosphorus. In Bocas del Toro, Panama, growth of trees was found to be both nitrogen and phosphorus limited (Lovelock *et al* 2004). N was found to limit growth of *Avicennia marina* in South Africa (Naidoo 2009) and New Zealand (Lovelock *et al* 2007b). In more tropical latitudes, P was found to control growth in high intertidal scrub forests (Boto & Wellington 1983; Lovelock *et al* 2007a). The ratio Nitrogen: phosphorus in plant tissue has also been used to infer N or P limitations to growth (Gusewell 2004). Variation in leaf N: P, particularly where N: P is >32 (which is a global average for mangroves; Lovelock *et al* 2007), indicates that P may limit growth in many mangrove habitats (e.g., Malaysia, Kenya, China, Puerto Rico, Venezuela, Victoria, Australia, Florida and Honduras; reviewed in Lovelock *et al* 2007). All plants need potassium (K) for maintaining osmotic regulation, enzyme activation, intracellular electric neutrality, protein synthesis and photosynthetic metabolism (Leigh & Wyn Jones 1984). Potassium is one of the most important factor influencing crop metabolism, growth, development and yield. Potassium deficiency results in the decrease of photosynthetic rate (Peaslee & Moss, 1968). Inefficient photosynthetic process leads to less carbon assimilation in the plant and thus reduces the carbon sink potential. Decreased photosynthetic rate of K-deficient leaves has been related to lowered stomata conductance (Raschke, 1975). Stomatal conductance is directly linked to the carbon assimilation that shows their impact on carbon assimilation.

Furthermore, due to the saline conditions, Na+ cations can interfere with K+ uptake (Maser *et al* 2002), thereby reducing the efficiency of K+ uptake from the soil. In some Neotropical mangrove forests, K concentrations in green leaves were inadequately but positively correlated with growth rates (Feller *et al* 2009b). In a Belizean mangrove where P was a controlling factor for growth, the addition of K did not result in greater growth rates even when P limitation was lifted (Feller 1995), but K-use efficiency increased with growth rates, indicating that, when N or P limitation is relieved, K limitation to growth may develop. In other areas, such as Nigerian mangrove forests, percent cover was not strongly correlated with K availability in the soil (Ukpong 2000), but rather with other macronutrients and micronutrients such as calcium (Ca), P (phosphorus) and magnesium (Mg). This was also suggested in a pot study where interacting effects between N, P and K availability and mangrove seedling growth were detected (Yates *et al* 2002).

The pH of a soil significantly affects plant growth, primarily due to the change in availability of both essential elements such as phosphorus (P), as well as non-essential elements such as aluminium (Al) that can be toxic to plants at elevated concentrations (Black 1993; Slattery *et al* 1999; Woodruff 1967).

Mangrove soil is frequently waterlogged, and the amount of oxygen in the pore is very low. This leads to the condition of reducing oxygen in the soil moderately, as sharply reducing oxygen is not suitable for the proper growth and development of the mangrove species. The anoxic condition of the soil results into the high rate of denitrification and in this case ammonium is the primary source of nitrogen in the soil. This provides a detrimental effect on the growth process and nitrogen metabolism of the plant. Phosphorus is released into the soil water and it is also not available to the plant. The anoxic condition also enhances the level of sulphide ion in the soil that creates a toxic environment for the plant (McKee *et al* 1988).

1.3 Justification of the study

Climate change is one of the most debatable issues, for which every developed and developing countries are making some strategy to tackle its effect in near future. The IPCC

is determined to reduce the carbon level to sustain the life on this planet. India being signatory is committed to implementing IPCC recommendations and initiated various activities to minimize the carbon emission that include the increasing forest cover of the country. Further, India has also taken a firm stance in favour of a comprehensive REDD+ approach. The introduction of Blue carbon concept as a part of REDD+ approach could be considered to be a better option to tackle the carbon problem. India has a potential to implement this option, but the only problem is quantification of carbon storage in blue carbon source of the country. Ocean and coastal vegetation has more potential to sink carbon as compared to terrestrial one (Alongi, 2014). Prior research studies show that mangrove is one of the most efficient sources as carbon sink. But, there is no detailed research in the India to understand the carbon storage potential of mangroves at the species level, and the relationship between carbon storage and environmental factors. Therefore, the present study attempts to quantify the carbon sinking potential of mangroves, and correlate it with the salinity and other important controlling factors to understand the influence of environment on carbon sequestration and structural dynamics. The Coringa mangrove is second largest mangrove ecosystem of India, comprising of 15 species of true mangrove. The climatic condition of this area is very conducive to the growth of the mangrove community. Water circulation in Coringa region is governed by seasonal freshwater inflow from Gautami Godavari River. The hydrodynamics of Kakinada Bay and Gautami estuary are regulated by tidal influence and play a significant role in the health of mangrove vegetation. This study mainly concentrates on the structure and distribution and carbon sinking potential of mangrove along the salinity gradient. As mangrove is in continuity so the justification for the role of salinity and other related confounding factors on mangrove growth, structure, distribution and their carbon sinking potential can be explained properly. Since past several years, the anthropogenic pressure in this area is on the soar. Agriculture and aquaculture are considered to be the most significant threat to the vegetation. Such activities alter the physical and chemical properties of the soil that seems to be detrimental to the vegetation. This study correlates the behavior of the forest community with salinity and other factors. This would be beneficial for the manager to manage this forest with respect to restocking, more efficiently

by applying such information. This study somehow will deliver a momentum to consider mangrove as a best carbon sinking option in the current scenario. Such information might be useful for future perspective also. The sea level is increasing day by day along with the climatic variation that clearly predicts the rise in salinity level in near future. This will detrimentally affect the carbon sequestration potential of mangrove. This necessitates the need to take new initiative that might support to conserve the nature and natural resources. The Coringa Wildlife Sanctuary (WLS) is also prone to periodic natural hazards that have deteriorated several patches of the mangrove vegetation inside the sanctuary (Fig. 5). The intensive survey work reveals the impact of aquaculture in and around of this protected area. People are cutting this valuable natural resource for getting more income by adopting aquaculture practices. The aquaculture practices not only have a severe impact on the mangrove vegetation but also the others microflora and fauna associated with the mangroves.

Figure 5.Patches showing the deteriorated mangrove vegetation due to natural and anthropogenic factors (Source: Google earth 2015)

Such incidences call for a supportive intervention by the management to restore the protected area and the natural process. There is a great need of restocking of mangrove in such areas for management per se.The present study helps in depicting a pattern for

different mangrove species with respect to their better performance in a particular salinity range. This information will assist in restocking the mangrove at a preferred salinity level so that the species will show their response very well and will be able to sink more and more carbon.

1.4 Objectives of the Study

1.4.1 To investigate the pattern of vegetation structure, species distribution and carbon sequestration potential of mangrove along the salinity gradient in the Coringa WLS.

The research questions are:

- What is the effect of soil salinity on changing mangrove structure (Density, diversity, IVI, basal area, Complexity index, richness, above ground biomass, total carbon content?
- What is the preferential salinity range of different mangrove species?
- What is the carbon sequestration potential of individual mangrove species?
- How do salinity gradient influences carbon sequestration potential of a mangrove species?

1.4.2 To investigate soil environment factors controlling the mangrove structure and their carbon sinking potential in the Coringa WLS.

The research questions are:

- What is the relationship between different exploratory soil environmental variables?
- What is the relationship among mangrove vegetation and soil environmental variables?
- Which soil environment variables influence the mangrove structure and carbon sequestration potential best?

CHAPTER 2: STUDY AREA

The study was conducted in the Coringa (WLS) mangrove forest, located on the East Coast of India south of Kakinada Bay in the State of Andhra Pradesh. In order to rehabilitate the saltwater crocodile which was on the verge of extinction and to protect the other endangered species, such as Olive Ridley turtles and Indian Otter, the Government of Andhra Pradesh declared a part of Godavari mangrove system as Coringa WLS in July, 1978. It is located between Lat. 16°30' and 17° 00' N and Long. 82° 14' and 82° 23' E in the East Godavari District. Coringa WLS covers an area of 235.7 square km. The sanctuary is a part of the Godavari estuary and has extensive Mangrove and Dry Deciduous Tropical Forest. The rivers Coringa and Gaderu and their deltic branches intersect the region, along with other water channels Flanked by the shallow bar-built Bay towards North and extensive network of estuarine creeks and canals emanating from River Godavari in the south. Coringa is the second largest mangrove formation in India, next to Sundarbans. The area of Coringa Reserve forest is 3156 hectares and of Coringa Extension forest is 9442 hectares including waterways. In Coringa WLS, totally 12 species of mangroves were recorded. The dominant genera are Avicennia, *Excoecaria,* Aegiceras, *Rhizophora* and *Sonneratia.*

2.1 Climate and Rainfall

The distribution and health of mangrove plants are largely governed by climatic factors such as solar radiation, temperature, rainfall, wind, etc. During 1995-97, atmospheric temperature ranged from 24.8 to 32.6°C. The annual rainfall was 871, 1627 and 1156 mm for the years 1995, 1996 and 1997, respectively. Annual mean wind speed ranged from 2.1 to 2.3m/sec. The observed high rainfall and temperature seem to be conducive for the health of mangroves in the Coringa WLS.

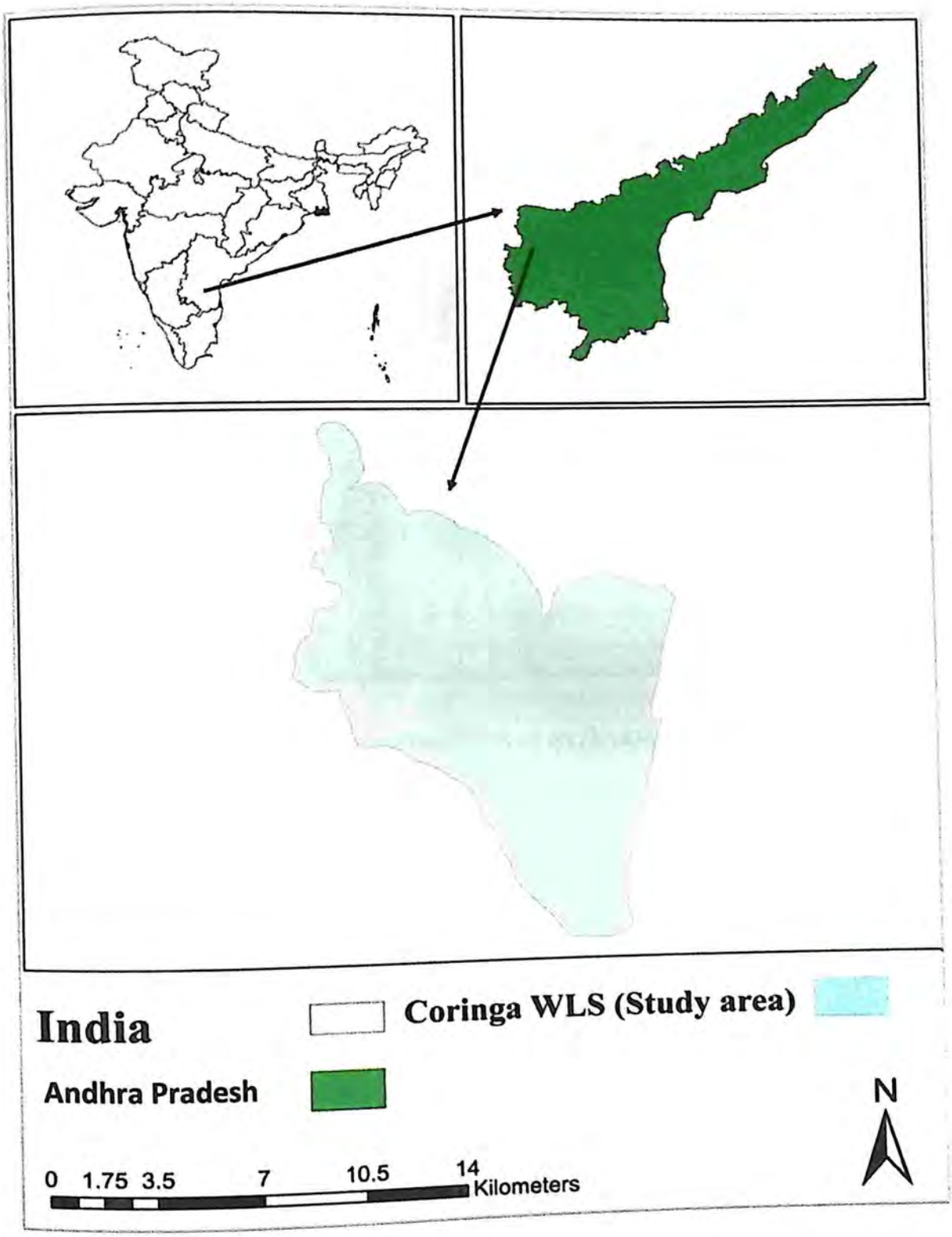

Figure – 6. Map showing location of study area

Figure – 7. Map showing the intensive sampling work in the study area

2.2 Physical environment

2.2.1 Geomorphology

Coringa WLS does not show any significant topographical feature, except the Kakinada coast, which is largely a low-lying area. The lower part of the delta is made of a series of sand ridges interpreted to be ancient beach ridge forms, due to high waves and detrital material brought by the river from its drainage basin. Fractures have controlled the drainage and truncated some of the river courses. Geomorphology of this area is classified as mudflat, mangrove swamp, sandy beach and Sandy Island.

2.2.2 Soil

The deltaic region mostly contains black cotton soil with deep extensions in sub - surfaces. They are moderately drained. The texture of the soil is 'silty clay' with 50-65% of clay. The

dominant clay mineral is smectite. These soils are low in organic carbon, which ranges from 0.3-0.5% indicating rapid mineralisation.

2.2.3 Topography

The Coringa mangroves are bordered on the northern side by Kakinada Bay. On the western side is the mainland, formed of deltaic and flood plains. The coastal strip north of Kakinada consists of windblown sand and sand dunes that are succeeded landward by laterites, sandstones and khondalites. The south-eastern part has marshy islands known as Hope Island. In the present study, Matlapalem creek, Coringa River, Gaderu River and Pillavarava Creek contributed significantly to the dynamic morphological changes. While Matlapalem Creek and Coringa River have become passive, the Gaderu River and Pillavarava Creek are active and provide a significant amount of freshwater and sediment loads.

2.3 Mangrove vegetation growth structure

Sampling plots were laid along Gaderu and Coringa River in Coringa WLS. Mangrove vegetation on both these river revealed that maximum trees fall under the circumference range of 11 – 25 cm (Fig. 8 & 9). Such circumference range clearly showed that mangrove forest of this sanctuary was not old. The new recruitment was more, and the forest was in the phase of successive growth.

2.4 Socio economic condition

2.4.1 Anthropogenic pressure

Fishing was the major activity in this region followed by agriculture. The fishermen population was the highest in this district as compared to other districts of Andhra Pradesh. About 18 villages were located around Coringa region. Among all villages, Tallarevu has the highest population. There is more awareness among the people about education and the literacy level is about 47.2% in Tallarevu and Coringa. Besides, fishing and agriculture, people also depend upon livestock and aquaculture activity for their

livelihood. Mangroves are the main source of firewood, wood for construction, etc., and fodder for cattle.

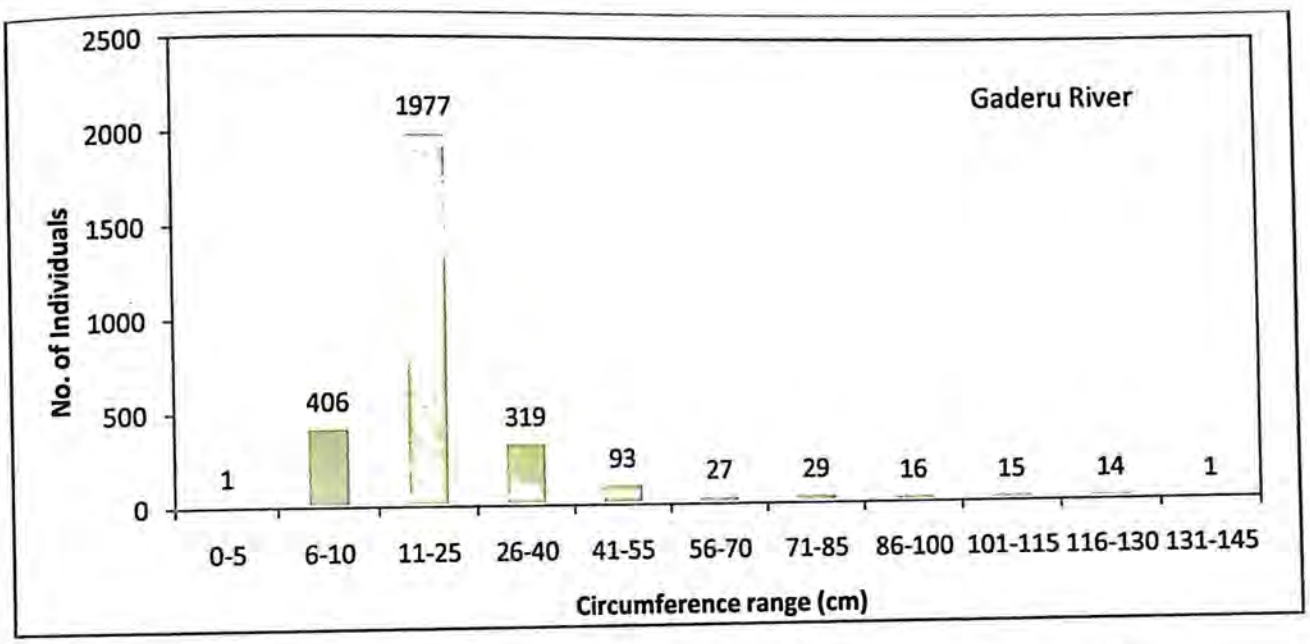

Figure8. Diagram showing the growth pattern of mangrove species along Gaderu River of Coringa Wildlife Sanctuary

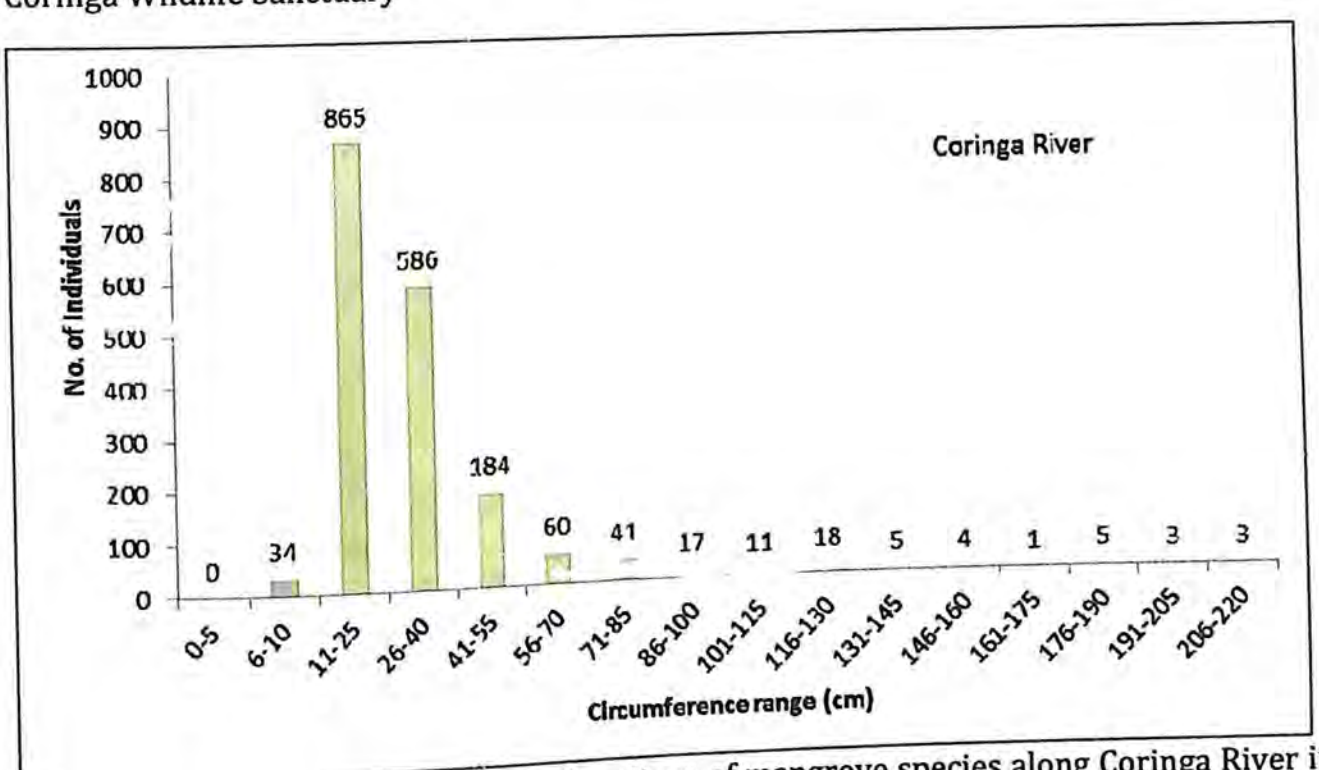

Figure 9. Diagram showing the growth pattern of mangrove species along Coringa River in Coringa Wildlife Sanctuary

CHAPTER 3: METHODOLOGY

3.1 Reconnaissance survey

A preliminary reconnaissance survey was conducted in the entire Coringa WLS to choose the intensive study area for a week period. During the reconnaissance survey, dynamics of the tidal flow, mangrove distribution patterns, mangrove species composition etc were studied.

3.2 Geomatics

Remote Sensing and GIS

Global Positioning System

The location was taken in the Universal Mercator format. These points were recorded using Garmin GPS 72 H and eTrex Vista.

Google Earth:

The software Google Earth was used to choose the boundaries of the present study area and also to plot the sampling point within the sampled plot.

3.3 Field method for the first objective: Effect of soil salinity on mangrove structure, distribution and carbon sequestration potential of mangroves

Two rivers (Coringa and Gaderu) that flow through the Coringa WLS had been selected for the sampling of mangrove vegetation. The first as a primary and the later, as the replicate River. Vegetation samplings were started from the mainland and moved towards end of the bay on either sides of the river. There were 16 plots that have been laid on each river at an interval of 400 meter. Each plot consists of 4 subs – plots, having a dimension of 10*10 meter. Quadrats were laid perpendicular to each of the river where as plots were laid parallel to the stream (Perera et al 2013). In this study data collected from all the four quadrats of a plot were averaged and the cumulative data were used for the analysis purpose. Four quadrats were laid in a single plot to obtain a true estimate of variables

without any error. There was always a variation in the salinity of the soil in the river bank due to tidal flow and it decreased towards inner parts of the mangrove forest. The salinity variation in a plot was found to be constant beyond a perpendicular distance of 30 mt. therefore, 4 quadrats were selected for obtaining the correct estimate of variables in a respective plots. A total of 128 quadrats were laid and the samples collected from each and every quadrat. At each quadrat, variables that would useful for estimation of density, richness, growth pattern of mangroves were collected. Further, plants and soil samples for estimation of carbon etc have also been collected from all quadrats. The location of soil samples were at the centre of the quadrats. Soil sample were collected from each and every quadrat except where quadrats occurred in areas which were obviously disturbed, such as large gaps created by cyclone damage to an otherwise continuous forest canopy. Soil cores were collected by driving a PVC pipe (8 cm diameter) into the ground to a depth of 30 cm. The core was sealed on site in a polythene bag and transported to the laboratory for further soil parameter analysis. The water content of the soil was calculated as a percentage of the fresh weight. A quantify of 10 gm wet soil from each quadrat was taken and it was considered as the wet weight of the soil. The collected soil sample was then sun dried and weighed for its dry weight. Later, moisture contents of the soil were measured using a prescribed formula. For measuring salinity of the soil $EC_{1:5}$ methods were used, in which 1 part of the dry soil sample was suspended in 5 parts of the distilled water, shaken well , and allowed to stand for 24 hours at room temperature before measuring the salinity of the soil. The collected soil samples were sun dried and the dried samples were used for different soil parameters (Ca, Mg, P, Na, C, N etc.) analysis in the laboratory. Precautions were taken that soil samples used for laboratory analysis should not kept in an oven, as it cause the loss of minerals of the soil, therefore it is recommended to dry the soil sample only in open sun. Plant parts (leaves, stem wood and branch wood) were collected for estimation of carbon in a mangrove species. Samples were collected from each and every quadrat. For each species, three individual trees of the same species having different diameter class were selected in each plot. Wood samples from the stem and branch were collected with the help of bark gauge. All the collected samples were collected in a paper bag so that there might be no any fungal infection in the collected sample. All the collected

plant samples were then kept in hot air oven as well as in open sun for complete removal of moisture. All the dried materials were further used for the laboratory purpose for estimation of carbon from the sample.

3.4 Laboratory method for the second objective: Factor influencing mangrove structure and their carbon sequestration potential

3.4.1 Estimation of nitrogen content of soil samples:

Nitrogen in soil is mostly present in the organic form with small quantities of ammonium and nitrate together. Kjeldahl methods (Subbiah & Asija 1956) were used for the estimation of nitrogen in the soil samples with the help of Nitrogen distillation unit. This method measures only organic and ammonical forms, therefore nitrate was excluded. The sample was digested in a mixture of H_2SO_4, K_2SO_4, selenium (Se) which converts all N in to ammonium sulphate. The distillation of ammonium sulphate, liberate ammonia, which was collected in boric acid and titrated against standard acid. Concentrate H_2SO_4, 40% Sodium hydroxide, 2% Boric acid, 0.01N Sulphuric acid was used as a reagents. 1 gm of soil samples were taken in 250 ml Kjeldahl tube. 5 ml of 0.32% $KMnO_4$ and 5 ml of 2.5% NaOH solution were mixed in the tube. The mixture was then kept for digestion in block digester for 1 hour at 400 degree Celsius. After digestion, tube was fixed in the distillation unit. In the distillation unit samples were mixed with alkali and mixed indicator. Care was taken to run a blank solution without soil for each set of sample.

3.4.2 Estimation of pH of soil samples

The pH of the soil was measured Potentio- metrically in a 1:3 soil – water suspensions with the help of pH meter. First the apparatus is calibrated with the buffer pH in the range of 4, 7 and 9. Potassium chloride was used as a reagent. 10 gm of air dried, 2mm sieved soil sample was taken in to 50 ml flask and 30 ml of distilled water was added in to the flask to make the final volume 40 ml. The solution was properly mixed and left for 6 hours so that all the contents might be available in the distilled water. After the final calibration of the instrument, the pH value of each and every soil sample was determined. The pH scale of the device was calibrated by at least two buffer solutions. Usually one of the buffers used

for calibration had pH 7.00 and the second was selected depending on the range where the measurements were to be taken. pH of 9.20 for basic solution and 4.01 for acidic solution were generally taken in to consideration. This correlates the measured potential of the indicator electrode with the pH scale (Singh *et al* 1999).

3.4.3 Estimation of Electrical Conductivity of Soil samples:

Conductivity meter measures the ionic conductivity of a liquid. The number it gives cannot directly be related to hardness, but rather, the total ion content of the liquid. The measurement of EC gives the concentration of the soluble salts in the soil at any particular temperature. $EC_{1:5}$ Method is used for measuring the salinity of the soil. 10 gm air dried, 2 mm sieved sample is taken in in to 100 ml flask and 50 ml of distilled water is added in to the flask to make the final volume 60 ml. The solution is properly mixed and left for 6 hours so that all the salt contents might be available in the distilled water. After the final calibration of the instrument, the salinity of each and every soil sample is determined. Potassium chloride is used for the calibration of the Electro conductivity meter (Buurman *et al* 1996)

3.4.4 Estimation of Na and K content of soil samples:

Sodium and Potassium concentration of the soil samples were measured with the help of flame photometer. Flame photometer measures the spectral intensity of metals present in the metallic salt. Heat of the flame vaporizes the sample constituents by which molecules and ions of the sample species are decomposed and reduced to give atoms. Excited atoms revert to ground state by emission of light energy of the characteristic wavelength which is measured by the detector. 0.5 gm soil sample was taken in the cylindrical tube. Nitric acid and per chloric acid was mixed in the sample in the ratio of 4:7 (4 ml: 7 ml). The mixture was kept for 2 hours at the room temperature for proper reaction. After that the sample was set for digestion in a block digester at a temperature of 400 degree Celsius for 2 hours. The digested sample was kept first for some time at room temperature for cooling and after that the digested sample was filtered by Whatman # 42 filter paper in a volumetric flask. The final volume of the volumetric flask was made 50 ml by adding distilled water in to it.

This solution was used for determining Na and K content of the sample with the help of Spectro- photometer (Hanway & Heidq 1952).

3.4.5 Estimation of Calcium and Magnesium content of soil samples

Calcium and Magnesium cations of the soil sample were determined with the help of Atomic absorption spectrophotometer. Spectro photometer is analytical equipment based on atomic absorption Spectro-photometry. When a sample is aspirated in to the instrument, it is subjected to a heavy thermal environment and as a result, "the ground state" atom absorbs light energy of a specific wavelength and enters in to the excited state. As the number of atoms in the light path increases, the amount of light absorbed increases in a predictable way. By measuring the amount of light absorbed, a quantitative determination of the amount of analytic element present can be made. Three standards are formed before determining the cations present in the soil sample. The first is at the top of linear range. The concentration of the second standard is approximately 3 times the concentration of the first and the concentration of the third standard is approximately 6 times the concentration of the first standard. 0.5 gm soil sample was taken in the cylindrical tube. Nitric acid and per chloric acid was mixed in the sample in the ratio of 4:7 (4 ml: 7 ml). The mixture was kept for 2 hours at the room temperature for proper reaction. After that the sample was set for digestion in a block digester at a temperature of 400 degree Celsius for 2 hours. The digested sample was kept first for some time at room temperature for cooling and after that the digested sample was filtered by Whatman # 42 filter paper in a volumetric flask. The final volume of the volumetric flask was made 50 ml by adding distilled water in to it. 1 ml of this solution was taken in a separate tube and 9 ml of selenium suspension was added in to it to make the final volume 10 ml. This solution was used for the determination of Ca and Mg in the soil sample with the help of AAS (Buurman *et al* 1996).

3.4.6 Estimation of Phosphorus content of soil samples

Two methods "Bray I" for acidic soil and the "Olsen" for alkaline soil is generally used for determination of available phosphorus in the sample (Bray & Kurtz 1945). Phosphate in

the sample was extracted with a sodium bicarbonate solution of pH = 8.5 in an acid ammonium fluoride solution. After the extraction, the phosphate was determined calorimetrically with ammonium molybdate as the colouring reagent. Spectrophotometer was used for the determination of phosphorus in the soil sample. Ammonium molybdate was used as a mixed reagent. 0.5 gm soil sample was taken in the cylindrical tube. Nitric acid and per chloric acid was mixed in the sample in the ratio of 4:7 (4 ml: 7 ml). The mixture was kept for 2 hours at the room temperature for proper reaction. After that the sample was set for digestion in a block digester at a temperature of 400 degree Celsius for 2 hours. The digested sample was kept first for some time at room temperature for cooling and after that the digested sample was filtered by Whatman # 42 filter paper in a volumetric flask. The final volume of the volumetric flask was made 50 ml by adding distilled water in to it. 1 ml of solution was taken in a separate tube and 9 ml of mixed reagent was mixed and the final solution is made 10 ml. The concentration of the solution was measured at 720 nm, using spectrophotometer.

3.4.7 Estimation of carbon Content of the Plant samples

Carbon content of the plant samples were calculated using "Loss on Ignition method" (ASTM 2000). Leaves, stem wood and branch wood were collected for determination of the carbon content of the plant. The collected sample was first transferred in to the paper bag and it was kept in an oven for 48 hours at a temperature of 55 degree Celsius for proper drying. After that all the three parts were separated (leaves, stem wood and branch wood) and are crushed with the help of grinder. All the grinding materials were kept separately for analysis of carbon content. 0.5 gm of each fine sample was taken in a crucible and was mixed properly. Crucible was then kept in a muffle furnace for 12 hours at a temperature of 550 degree Celsius. At this temperature all the material converted in to organic ash. The ash content was again weighed and this organic part was valid for 1.5 gm of sample.

Weight of Crucible= A, Weight of Sample = 1.5 gm

After burning = Weight of Crucible+ Weight of sample = A+ Ash

Organic matter = Weight of sample – Weight of Ash

3.4.8 Estimation of moisture content of the soil samples:

Soil moisture content of the soil sample was measured by Gravimetric method (Buurman *et al* 1996). The soil moisture content may be expressed by weight as the ratio of the mass of water present to the dry weight of the soil sample. First the sample weight (wet wt.) of soil was taken and after that the sample was transferred to dry oven at temperature among 100 – 110 degree Celsius. This provided dry weight of the soil sample. Putting all these parameter in the formula provided percentage water content of the soil.

Soil Moisture content (%) = Wet wt. of soil- Dry wt. of soil/ Dry wt. of soil * 100

3.5. Data analysis

3.5.1 Effect of soil salinity on structure, distribution and carbon sequestration potential of mangroves

In order to evaluate the relationship between mangrove structure and salinity gradient simple correlation and regression analysis were performed. Graphs had been generated using google doc and regression lines were fitted using XLSTAT (Version-2014.5.04) and Past software (Version-3.06). Diversity of the species was calculated using past software (Version-3.06).

3.5.1.1 Estimation of mangrove density:

Density is an expression of the numerical strength of a species at a given area where the total number of individuals of each species in all the quadrats is divided by the total number of quadrats studied. Density was calculated by using the following equation:

Density = Total number of individuals of a species in all quadrats/ Total number of quadrats studied.

3.5.1.2 Estimation of mangrove basal area:

Basal area of mangrove vegetation was calculated by applying the formula-

$BA = \pi r^2$

Or $BA = C^2 / 4\pi$

Where, C= circumference of the tree, Circumference was taken at the breast height (1.37m) of the tree.

3.5.1.3 Estimation of Importance Value Index:

This index was used to determine the overall importance of each species in the community structure. In calculating this index, the percentage values of the relative frequency, relative density and relative dominance was summed up together, and this value was designated as

the Importance Value Index or IVI of the species (Curtis, 1959).

IVI= Relative Frequency (%) + Relative Density (%) + Relative Dominance (%).

a. Relative Density:

Relative density is the study of numerical strength of a species in relation to the total number of individuals of all the species and can be calculated as:

Relative Density= Number of individual of the species/ Number of individual of all the species * 100

b. Relative Frequency:

The degree of dispersion of individual species in the area in relation to the number of all the species occurred.

Relative Frequency= Number of samples where species is found/ Total no. of samples * 100

c. Relative Dominance:

Dominance of a species was determined by the value of the basal cover. Relative dominance is the coverage value of a species with respect to the sum of coverage of the rest of the species in the area.

Relative Dominance=Total basal area of the species/Total basal area of all the species * 100

3.5.1.4 Estimation of Above Ground Biomass:

Above ground biomass of Mangrove was estimated through allometric equation, in which two independent variables were used in the allometric equation for calculation of above ground biomass.

$AGB = 0.251p\ (D)^{2.46}$

Where AGB = aboveground biomass (Komiyama *et al*, 2005 and world agroforestry cente data set), R^2= 0.98, N= 346

p = wood specific gravity

D = Diameter of tree at breast height

3.5.1.5 Estimation of Complexity Index

It is a mathematical construct that summarizes the effects of two or more structural attributes in a single number or index value. Such an index functions as the reliable indicator of stand level biodiversity and provides a means of ranking stands in terms of their potential contribution to biodiversity.

CI = Number of species * density * basal area * mean height * 10^{-5}

3.5.2 Estimation of preferential salinity range of individual mangrove species

In order to evaluate the preferential salinity range of individual mangrove species, box plots were laid using software R (Version – 3.1.1) for each individual mangrove species. Data were selected on the basis of presence and absence of individual mangrove species in each sampling plots with reference of salinity. Only presence data of species along with salinity level in each sampling plots were finally used for the analysis work. Interpretation was done on the basis of median, first and third quantile of the box plot and total range of the salinity was calculated by considering the whisker pattern.

3.5.3 Factor influencing mangrove structure and their carbon sequestration potential

Principal Component Analysis (PCA) was used for the multivariate data analysis and for estimation of the correlation structure of the variables and interrelationship among them (Svante Wold 1987). It also showed the influence of exploratory variable on the objects (sampling plots). PCA was first used in statistics by Pearson, who formulated the analysis as finding lines and planes of closest fit to systems of points in space. Fisher and Mackenzie considered PCA more suitable than ANOVA for modeling of response data. Principal component analysis was performed using the software R (Version – 3.1.1). Soil environmental variables per sampling plots were taken in to consideration as required by the PCA. The environmental variable matrix was consisted of Salinity, pH, Moisture, Na, K, Mg, Ca, N and P. Interpretation was done based on correlation matrix, loading of principal components, biplot and factor loading. The graphic interpretation of biplot gives a clear

frame to understand the influence of variables on the sampling plots and interrelationship among the exploratory variables.

In order to evaluate the relationships between tree species and environmental variables, a Canonical Correspondence Analysis (CCA) was performed using the software XLSTAT (Version-2014.5.04). CCA is a direct gradient ordination technique to cluster species abundance with environmental variables (Ter Braak 1986). As required by CCA, the data is set into two distinct matrices: the species matrix and the matrix of environmental variables. The species matrix contained the number of individuals of species per transects, and the environmental variables matrix was consisted of Salinity, pH, Moisture, Na, K, Mg, Ca, N and P. Finally, the selected tree species were analyzed in CCA ordination based on their compositional attributes, such as density in different transects sampled. Interpretation was done based on the weighted average of the variables and the loading of the component on primary and secondary axes. The graphic interpretation of biplot gives a clear frame to understand the distribution of the species with respect to different independent environmental variables.

GLM framework (GLM – Logit link and family – poisson) was used to model the factors (environment variables) influencing the number of mangrove individuals in program R (version 3.1.1).

Firstly, to investigate factor influencing no. of individuals against environmental variables, data were collected from 128 points and were modeled using linear regression. Environmental variables were checked for correlation between them by running a spearman correlation test and out of the highly correlated variable pair, the ecologically less meaningful and redundant ones were removed from the model. A full linear regression model with linear predictors (environmental variables) was constructed and then used backward selection AIC (Akaike information criterion) to obtain a reduced model. The regression coefficient was verified using univariate linear regression of predictor (environment variables) to infer significance of exploratory variables on the probability of occurrence of the species (Ter Braak 1995).

Secondly to investigate the influence of environmental variables on the basal area and carbon sequestration potential of mangrove species, GLM frame work (GLM – Identity link

and family – Gaussian) were used. Data was collected from 128 points. A similar linear regression model was run against environmental variables, such as Salinity, PH, Moisture, Na, K, Ca, Mg, N, P). Environmental variables were checked for correlation running a spearman correlation test and out of the highly correlated variable pair, the ecologically less meaningful and redundant ones were removed. A full linear regression model was constructed with linear predictors (environmental variables) and then used backward selection using AIC (Akaike information criterion) to obtain a reduced model.

4.1 RESULTS

4.1.1 Pattern of vegetation structure, species distribution and carbon sequestration potential of mangrove along the soil salinity gradient.

Mangrove species of the Coringa Wildlife Sanctuary performed differentially with respect to different structural parameters and all the components had a variation among each species (Table. 2). In case of density, *Excoecaria had* the largest density (37675 trees/ha), followed by *Avicennia officinalis* (7250 trees/ha), *Avicennia marina* (7087 trees/ha), *Bruguiera gymnorrhiza* (4875 trees/ha), *Aegiceras corniculatum* (2950 trees/ha), *Sonneratia apetala* (2225 trees/ha) and *Rhizophora apiculata* (1962 trees/ha) respectively. *Xylocarpus granatum* performed least and gained the least density (200 trees/ha) among all the related species.

Table 2 Structural data of constituent mangrove species of Coringa Wildlife Sanctuary

Species	Density (No. of tree/ha)	Mean basal area (m^2)	IVI
Avicennia marina	7087 (108.975)	0.843 (0.012)	37.693 (0.659)
Avicennia officinalis	7250 (134.5)	4.917 (0.060)	77.384 (0.903)
Exocaecoria agallocha	37675 (420)	1.291 (0.007)	115.560 (1.227)
Aegiceras corniculatum	2950 (156.75)	0.262 (0.010)	7.760 (0.163)
Bruguiera gymnorrhiza	4875 (243.775)	0.145 (0.012)	9.753 (0.233)
Ceriops decandra	300 (0.000)	0.195 (0.024)	1.677 (0.010)
Lumintzera racemosa	925 (61.235)	0.494 (0.014)	3.574 (0.109)
Rhizophora apiculata	1962 (42.5)	0.528 (0.003)	14.920 (0.263)
Sonneratia apetala	2225 (289.055)	1.247 (0.039)	9.753 (0.233)
Xylocarpus granatum	200 (5.225)	0.910 (0.050)	3.304 (0.093)

In case of mean basal area, *Avicennia officinalis* showed their best performance, having mean basal area of 4.917 m^2 followed by *Excoecaria* (1.291 m^2), *Sonneratia apetala* (1.247 m^2), *Xylocarpus granatum* (0.910 m^2), *Avicennia marina* (0.843 m^2), *R.apiculata* (0.528 m^2), *Lumintzera racemosa* (0.494 m^2), *Aegiceros corniculatum* (0.262 m^2), *Ceriops decandra* (0.195 m^2) respectively. The least growth performance was shown by *Bruguiera gymnorrhiza* having mean basal area of 0.145 m^2.

Importance value index (IVI) that is the combination of relative density, relative basal area and relative abundance, was highest *for Excoecaria* (115.560), and followed by *A. officinalis* (77.384), *A. marina* (37.693), *R. apiculata* (14.920) respectively. *Sonneratia apetala* and *Bruguiera* had the same value of 9.753. *Lumintzera* and *Xylocarpus* have their index value of 3.574 and 3.304 respectively. Among all species, *Ceriops decandra* had the least index value.

Vegetation structural parameters (Density, Basal area, Diversity, Complexity index and above ground biomass) performed differentially along different sampling site, having different salinity value (Table. 3). Sampling site 16 was indicating the site at sea mouth, having highest value for soil salinity and sampling site 1 was present towards mainland and had the lowest value for soil salinity. Salinity presented a clear descending pattern of salinity from sea mouth towards mainland (23.1 to 49.6 ppm). Stand density was fluctuating in the range of (5050 to 2112) from sea mouth towards mainland. Basal area showed a range of 117.93 to 21.891 m^2 per ha along different sampling plot. Complexity Index had a variation of 89.11 to 4.85 and above ground biomass of 477.711 to 72.420 metric ton/ha, along different sampling plots. Diversity of the species also showed difference in different sampling plots in the study area. Diversity index had a variation of 0.317 to 1.288. Lower and higher sampling plots had lower diversity, whereas medium salinity range was seen to be favorable for the higher diversity of the mangrove species at community level.

Table – 3. Summary of mangrove vegetation structural parameters and soil salinity recorded in each study sites at Coringa Wildlife Sanctuary. Standard error of the mean is given in the parentheses

Sampling site	Soil salinity (ppm)	Stand density (per ha)	Basal area (m^2/ha)	Species diversity	Complexity Index (C.I)	Above ground biomass (Metric ton/ha)
1.	23.1	5050 (145.85)	61.26766 (0.018)	0.553	27.84615 (1.254)	259.841 (0.284)
2.	26.35	4925 (125.775)	92.52237 (0.0317)	0.549	47.84563 (2.574)	263.720 (0.285)
3.	27.3	5037 (182.337)	117.9332 (0.046)	1.222	89.11329 (4.048)	485.878 (0.810)
4.	29.1	5725 (180.012)	69.63525 (0.088)	0.6588	41.85949 (2.654)	477.7112 (0.806)
5.	28.9	4537 (103.925)	75.65464 (0.057)	0.8868	41.19395 (2.582)	453.370 (0.769)
6.	29.6	4487 (103.30)	72.64448 (0.056)	0.192	29.33929 (1.265)	437.126 (1.002)
7.	30.85	4450 (89.837)	67.93449 (0.051)	1.021	31.74239 (1.286)	356.005 (0.680)
8.	31.65	4300 (93.65)	64.49093 (0.102)	1.288	33.27732 (1.294)	273.387 (0.721)
9.	33.6	4425 (73.5875)	55.01012 (0.077)	1.21	32.86167 (1.263)	327.089 (0.673)
10.	37.55	4550 (134.6375)	60.0319 (0.059)	0.9758	36.87459 (1.457)	284.993 (0.514)
11.	37.95	4362 (97.662)	51.84007 (0.014)	1.284	30.53056 (1.145)	232.315 (0.274)
12.	38.35	3450 (95.925)	51.59014 (0.048)	0.757	26.6979 (1.348)	318.245 (0.618)
13.	39.7	2900 (65.55)	48.8942 (0.066)	0.687	19.14208 (0.845)	263.464 (0.467)
14.	40.15	2862 (56.5)	48.73903 (0.102)	0.723	23.02005 (0.954)	239.231 (0.524)
15.	42.5	2487 (81.662)	38.31597 (0.076)	0.3571	10.00765 (0.412)	210.814 (0.234)
16.	49.6	2112 (74.212)	21.89179 (0.013)	0.317	4.855873 (0.042)	72.420 (0.156)

4.1.1.1 The 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 (Fig. 10). Lower salinity level represents a better index and it is decreasing as we proceeds 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. Higher distance of the plot from sea mouth shows higher complexity index value and vice – versa.

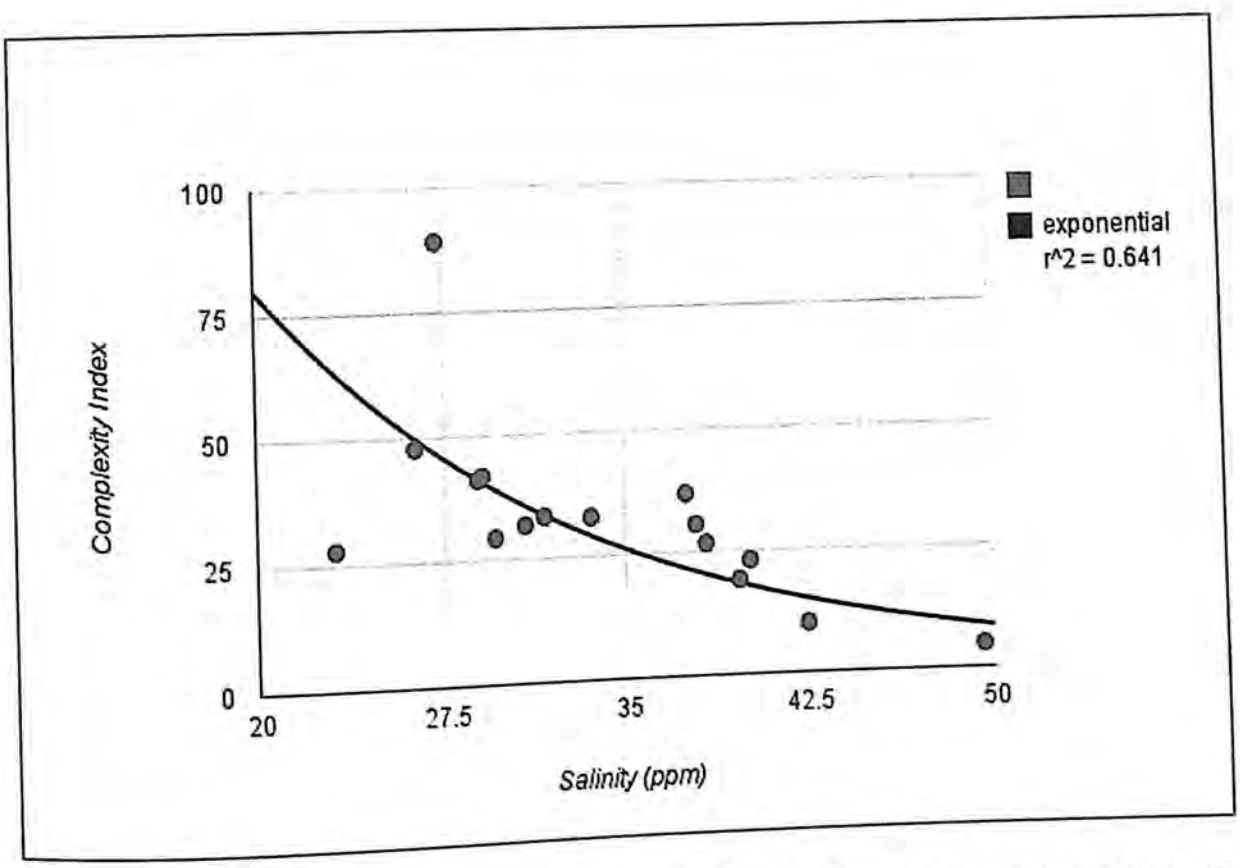

Figure – 10. Graph showing decreasing pattern of Complexity Index along increasing soil salinity level

4.1.1.2. The 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 all the negatively correlated species decreases with increase in salinity (Table 4).

Table – 4. Correlation between salinity and species basal area in Coringa WLS

	A.C	X.G	E.A	L.R	S.A	A.M	B.G	A.O	R.A
Pearson correlation coefficient (r)	-0.667	-0.421	-0.740	-0.880	0.785	-0.595	0.141	-0.864	-0.96
Number of transects	128	128	128	128	128	128	128	128	128

4.1.1.3 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 (Fig. 11-18). 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.

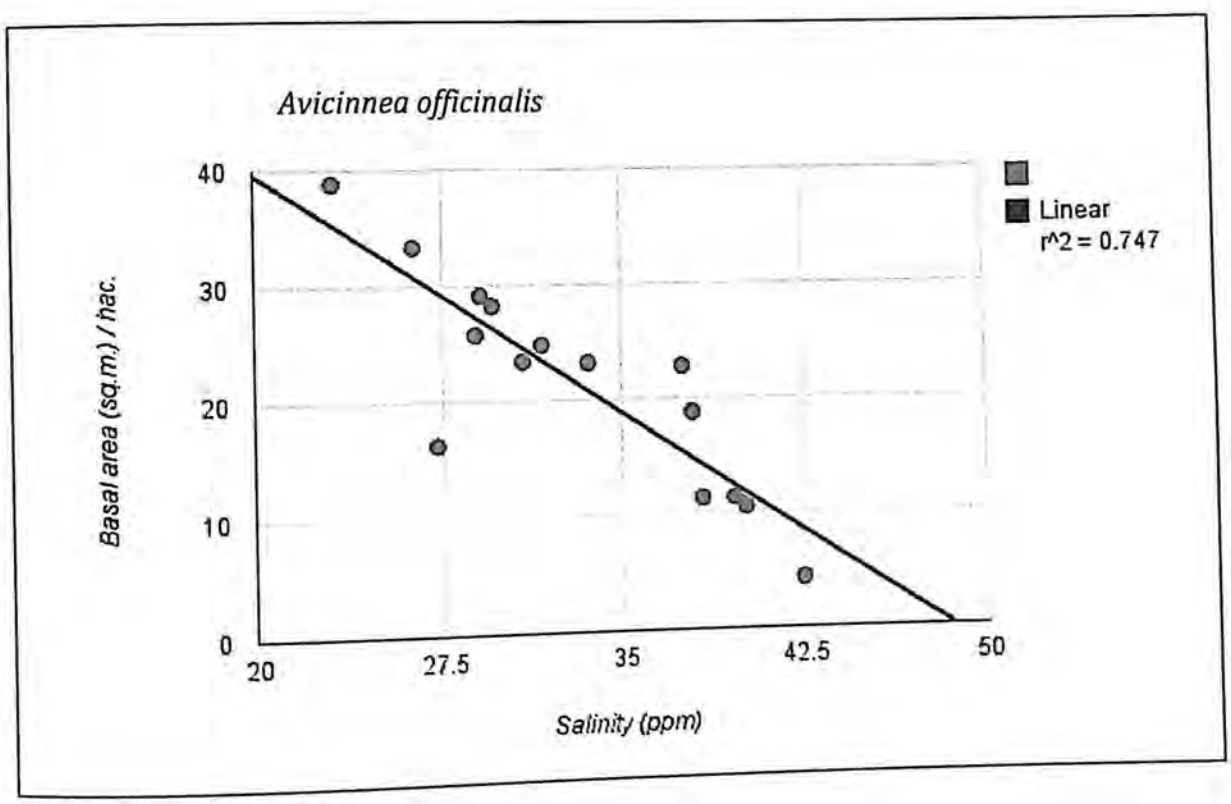

Figure – 11. Diagram showing the negative trend of basal area of *Avicinnea officinalis* with increasing salinity

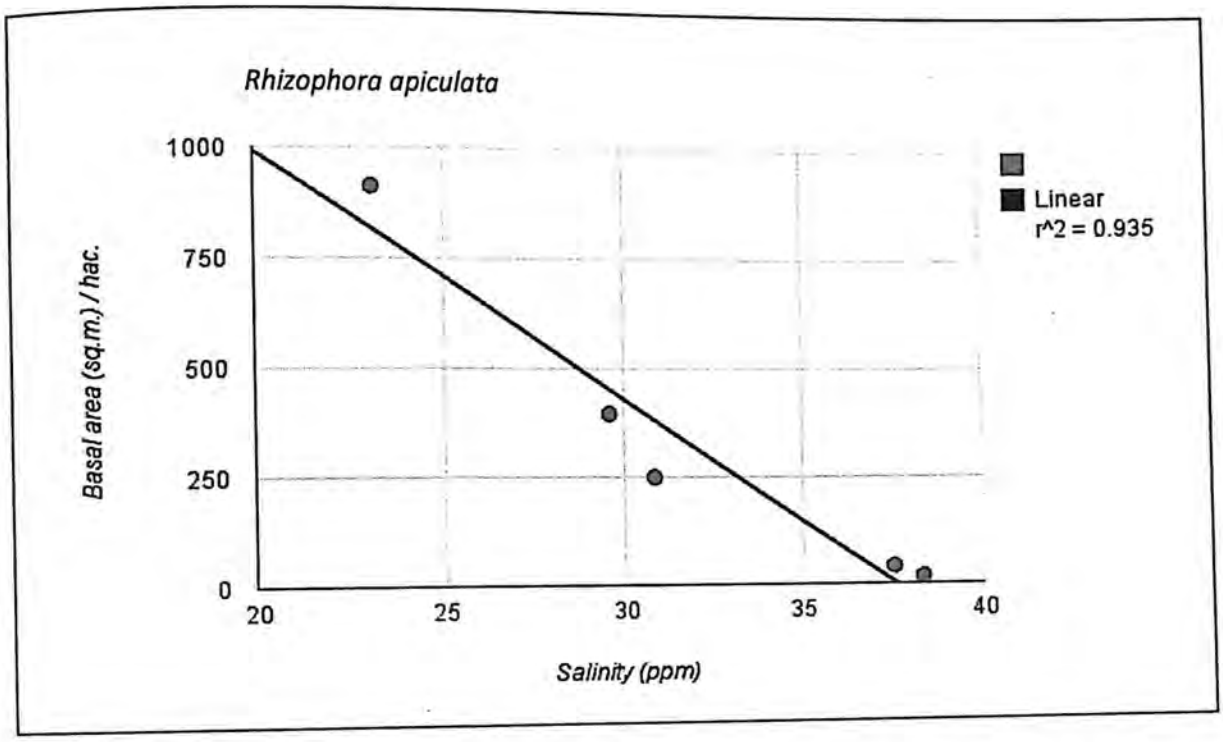

Figure – 12. Diagram showing the negative trend of basal area of *Rhizophora apiculata* with increasing salinity

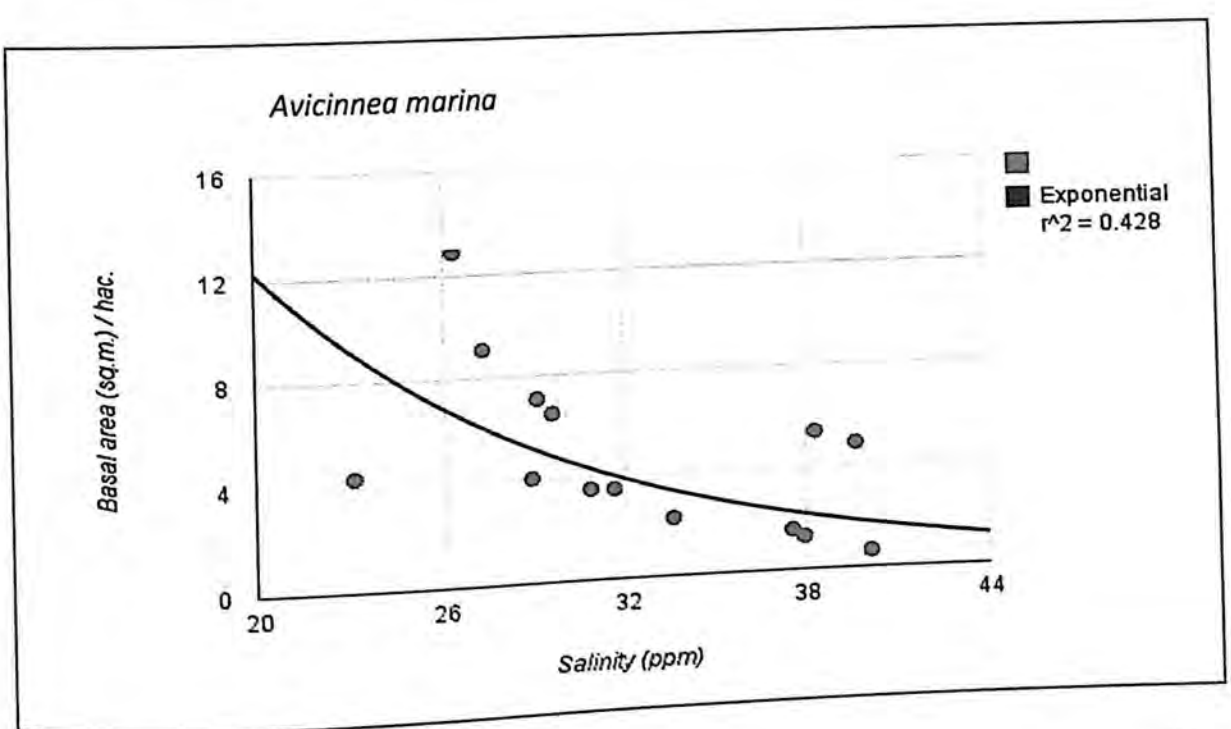

Figure – 13. Diagram showing the negative trend of basal area of *Avicinnea marina* with increasing salinity

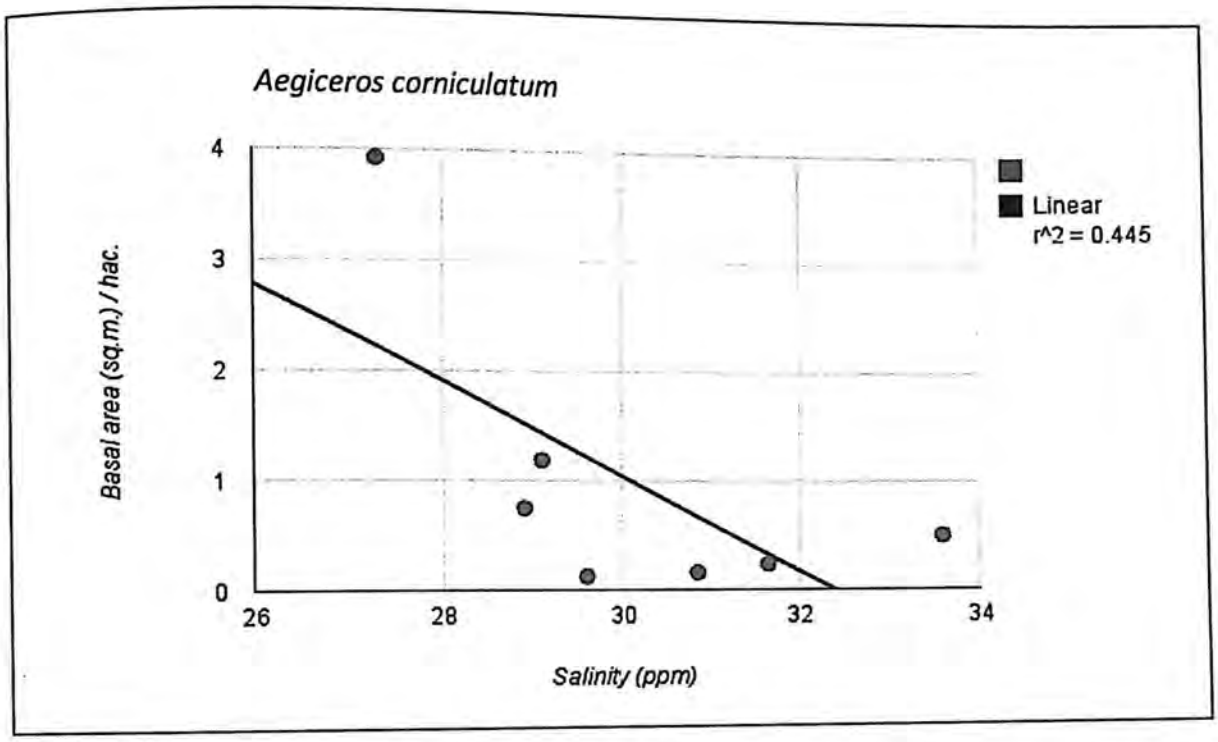

Figure – 14. Diagram showing the negative trend of basal area of *Aegiceros corniculatum* with increasing salinity

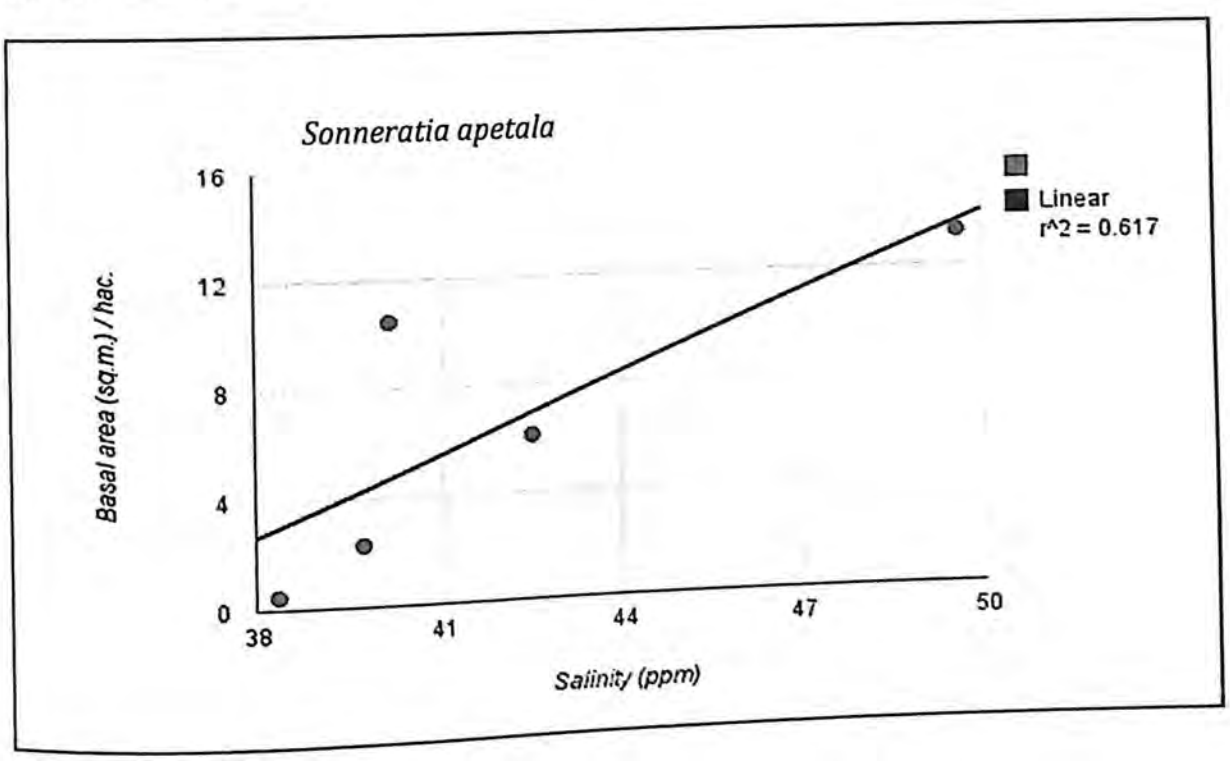

Figure – 15. Diagram showing the positive trend of basal area of *Sonneratia apetala* with increasing salinity

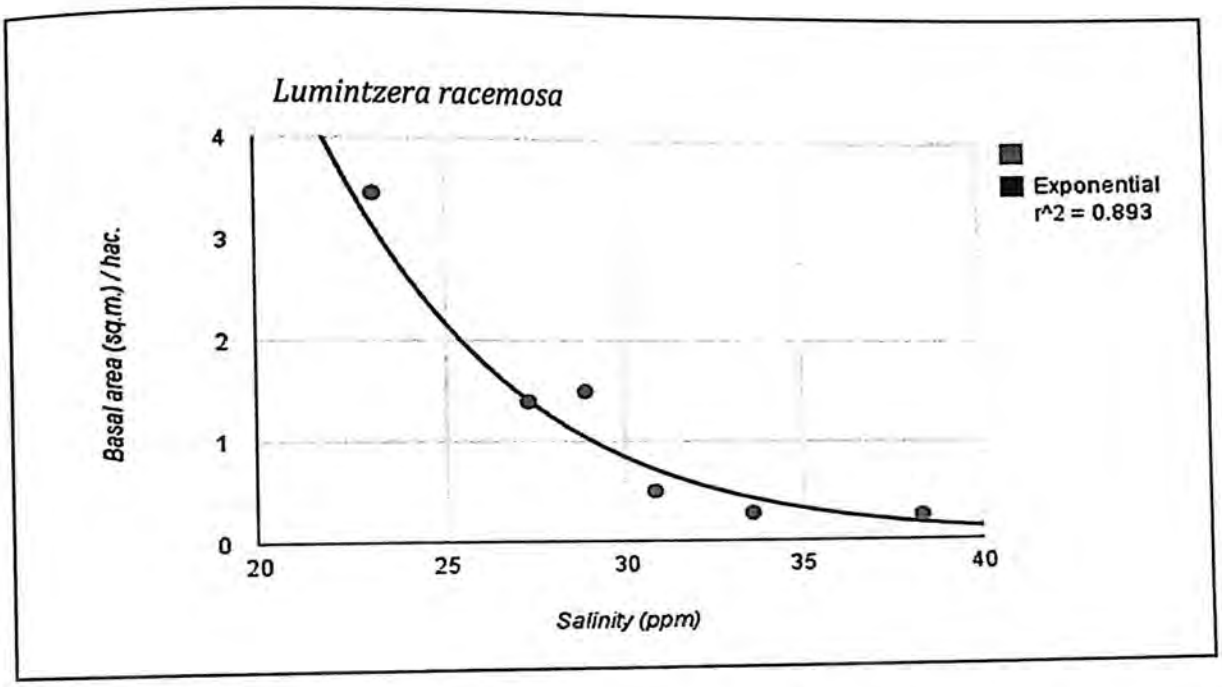

Figure – 16. Diagram showing the negative trend of basal area of *Lumintzera racemosa* with increasing salinity

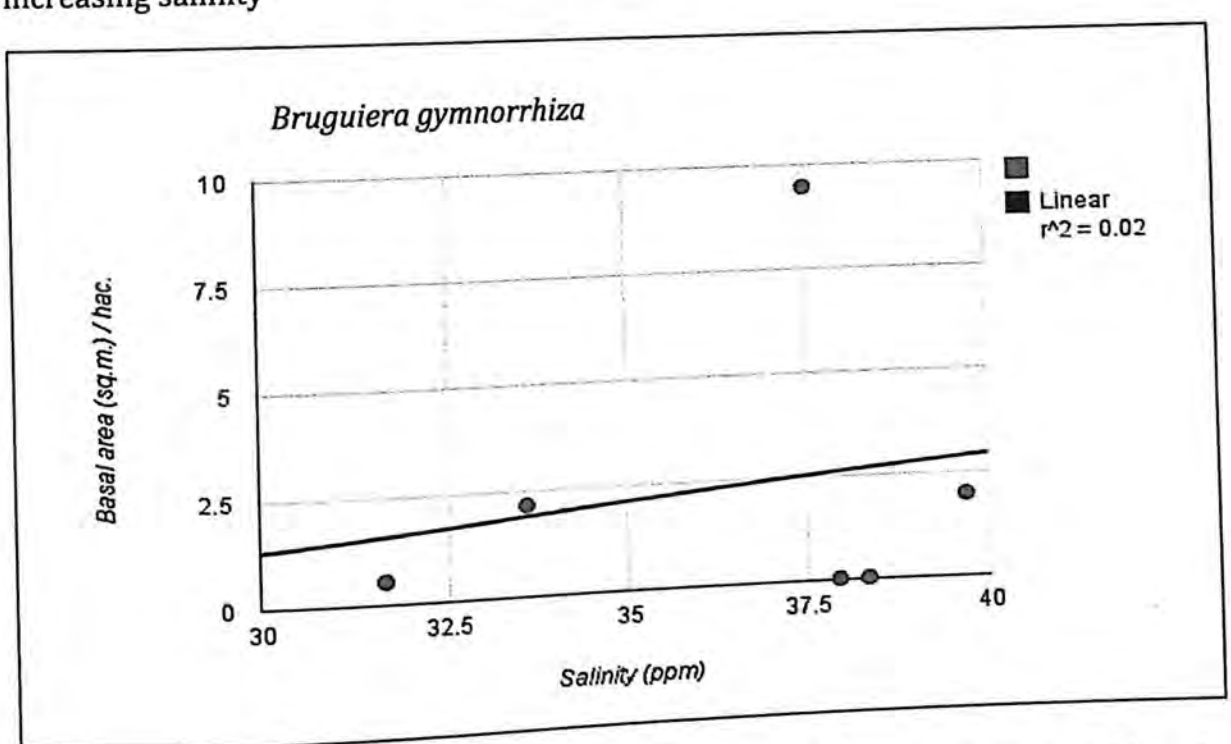

Figure – 17. Diagram showing positive trend of basal area of *Bruguiera gymnorrhiza* with increasing salinity

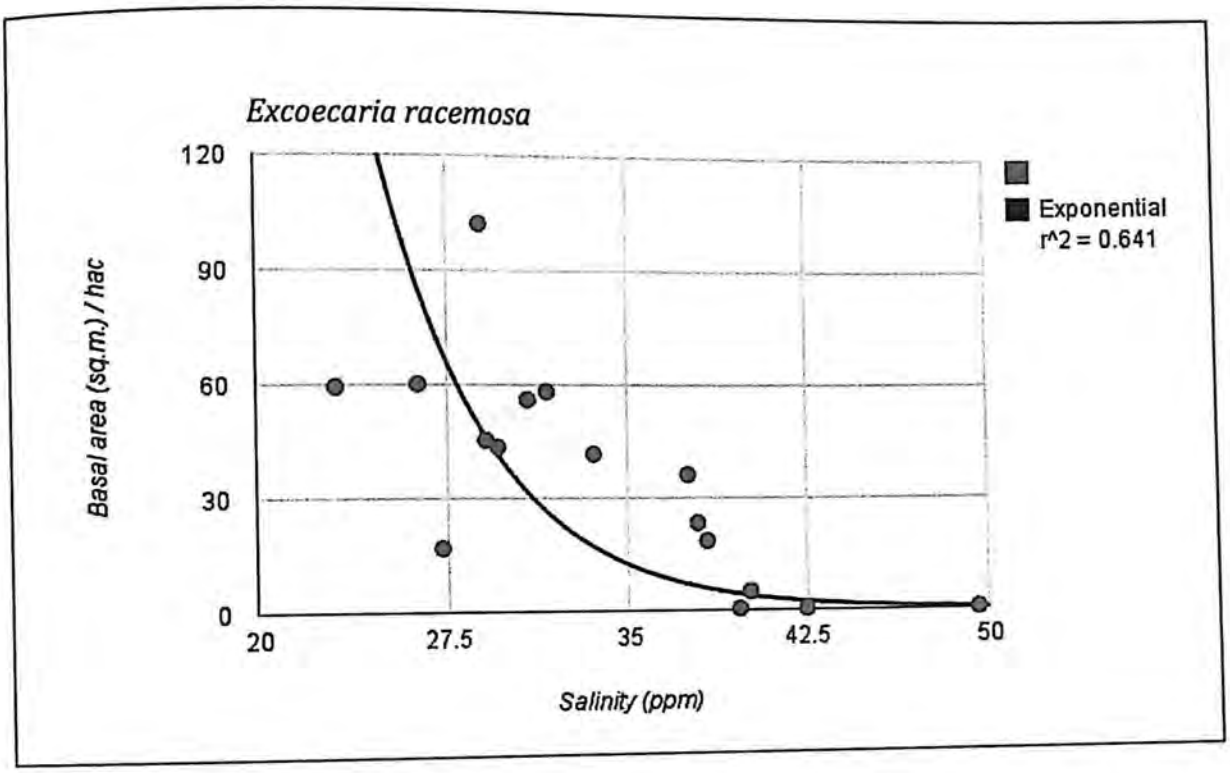

Figure – 18. Diagram showing the negative trend of basal area of *Excoecaria racemosa* with increasing salinity

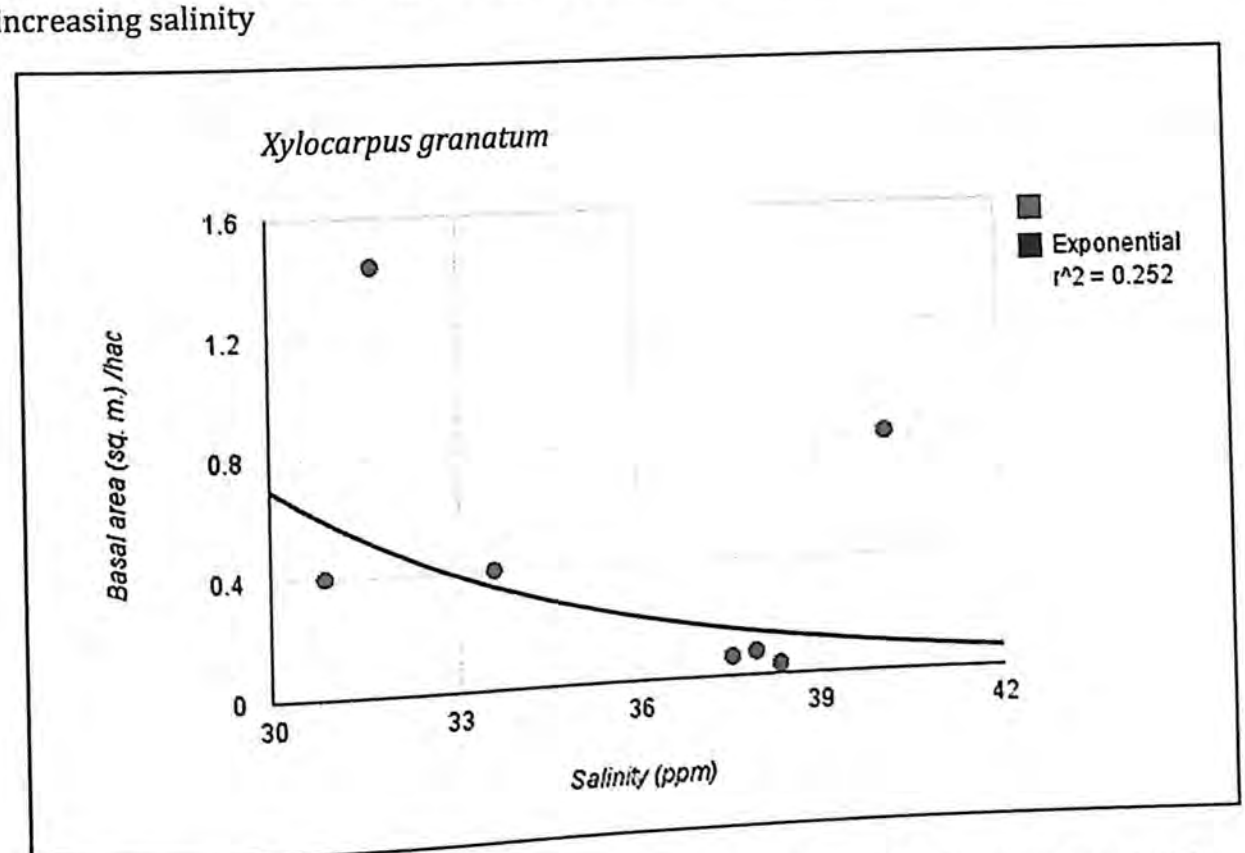

Figure – 19. Diagram showing the negative trend of basal area of *Xylocarpus granatum* with increasing salinity

4.1.1.4 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= 0.641) negative trend with increase in soil salinity (Fig.19). The overall basal area of mangrove species was decreasing with more or less 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.

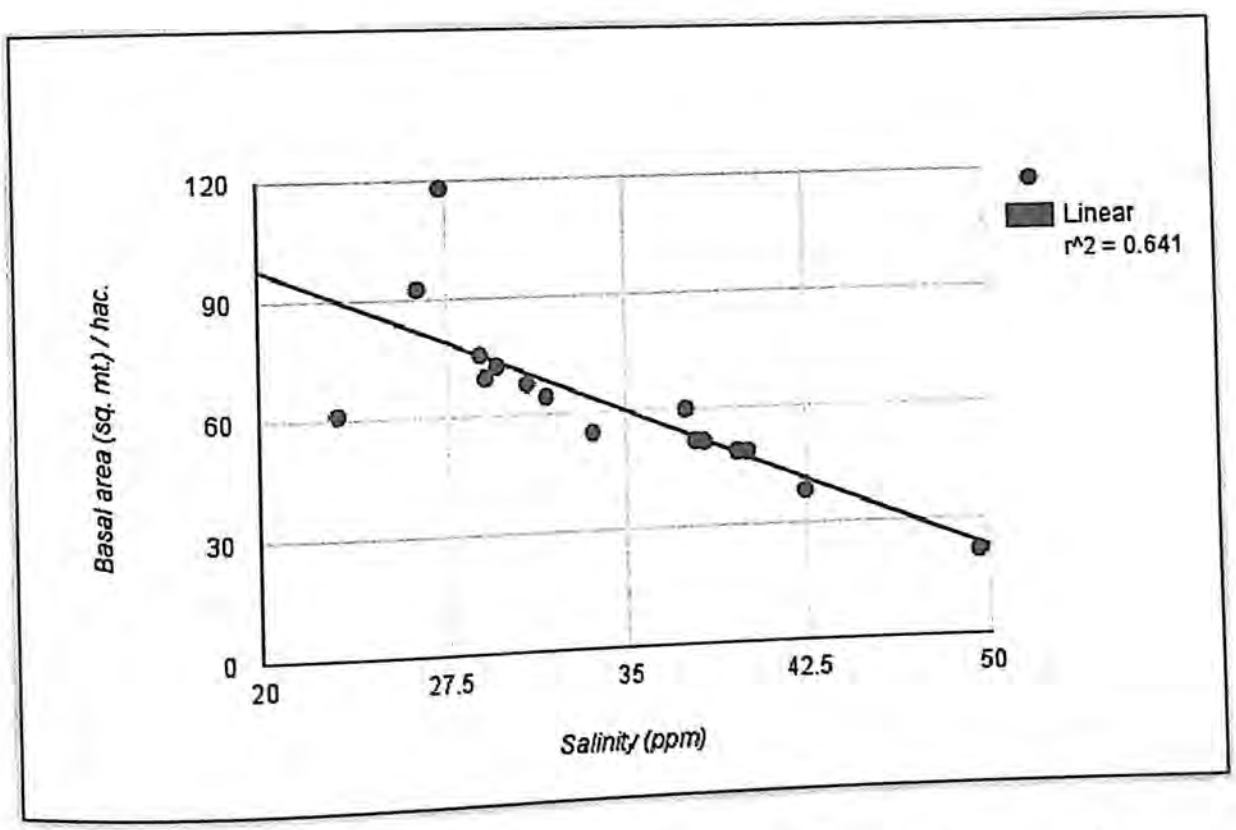

Figure – 20. Diagram showing the negative trend of basal area of mangrove species with increasing salinity at community level

4.1.1.5 Relationship between carbon content of the mangrove vegetation and salinity gradient at community level

A significant (r^2 = 0.674) negative trend was observed in a relationship between carbon content of the mangrove vegetation and salinity gradient (Fig. 20). Negative steep slope clearly revealed that vegetation carbon content was decreasing with higher level of soil salinity. The pattern was reversing in first 2 – 3 sampling plots but after wards the trend had changed to a constant decreasing pattern. The pattern showed a range in between 174.41 to 74.66 metric ton/ha.

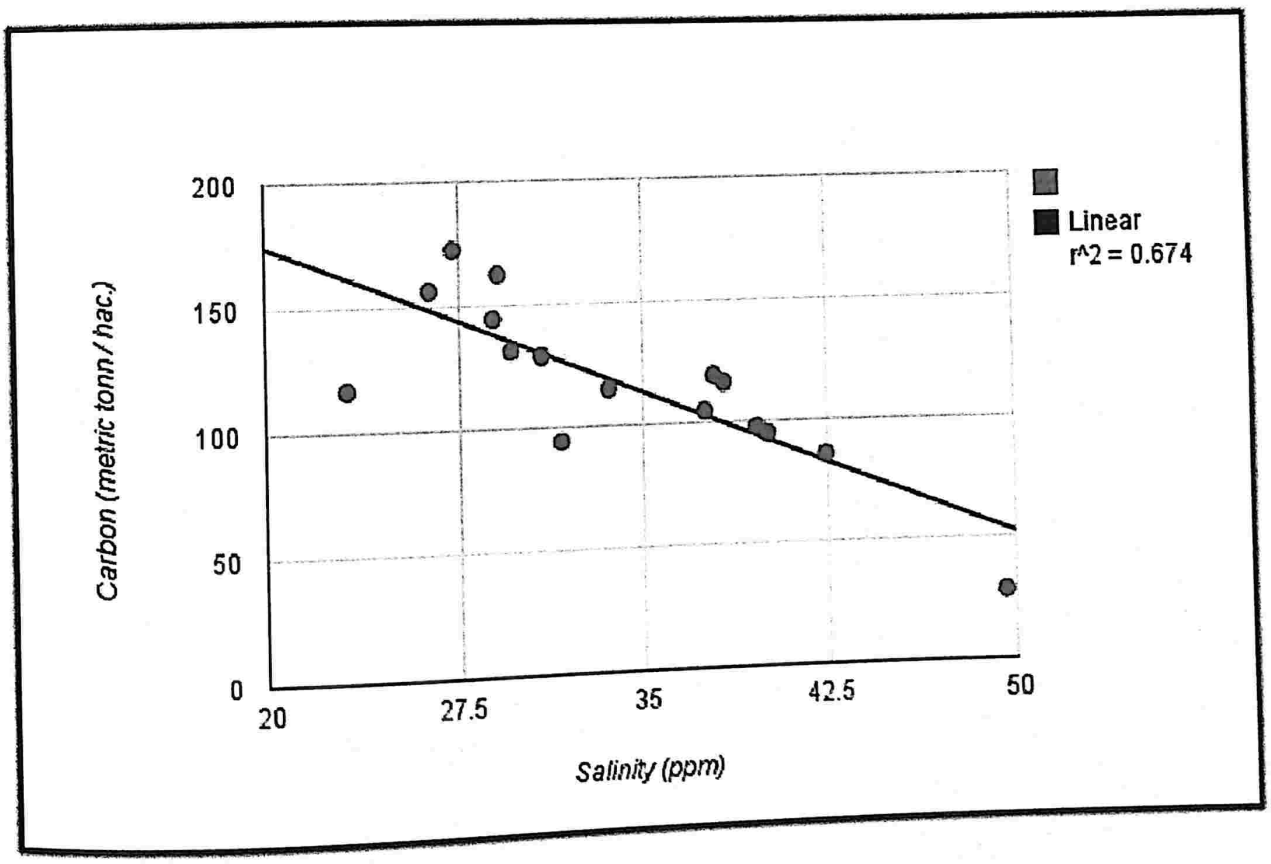

Figure – 21. Diagram showing the negative trend of Carbon content of mangrove species with increasing salinity at community level

4.1.1.6 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 (Fig.21). A negative slope showing decreasing pattern clearly revealed that the above ground biomass of the vegetation decreases with increase in soil salinity level.

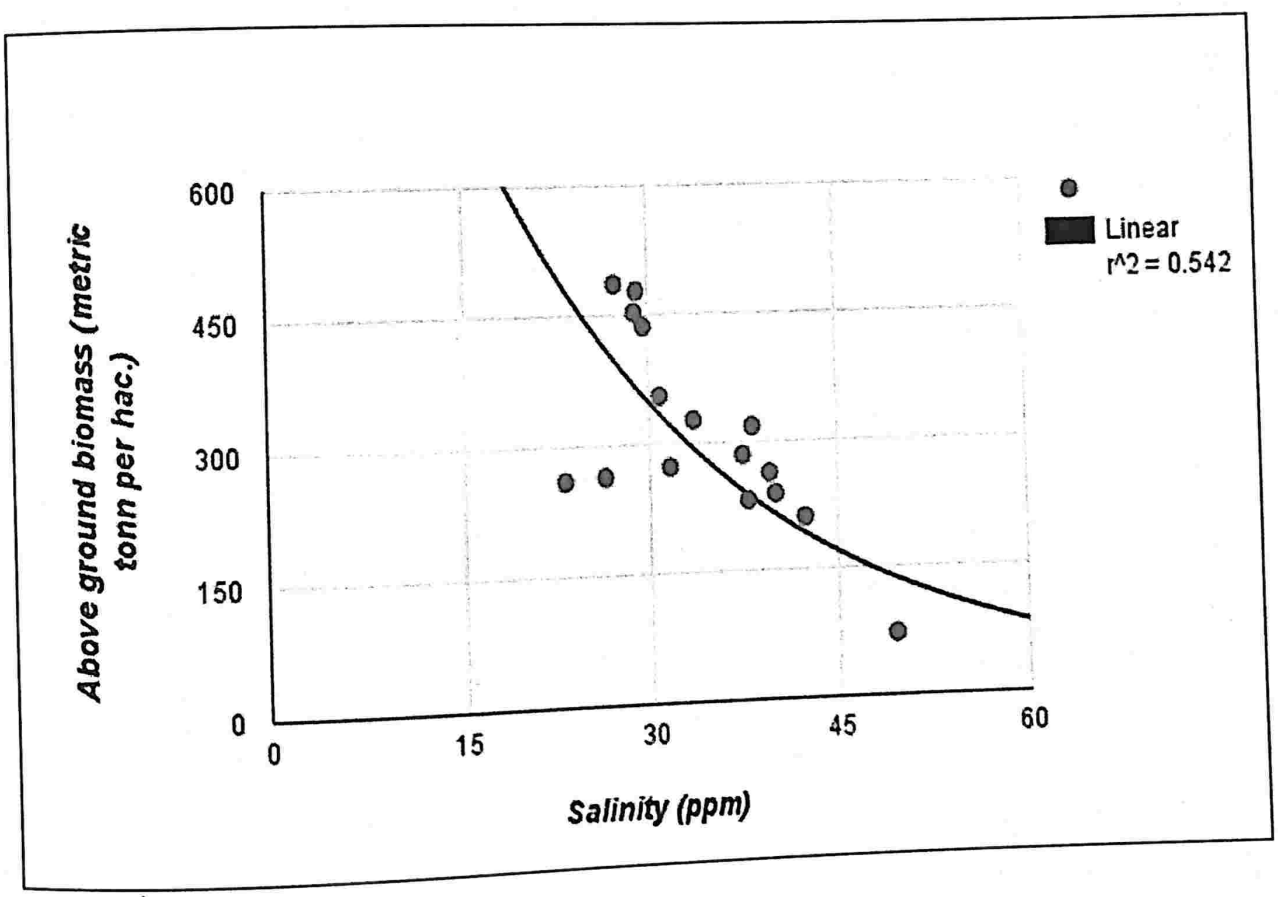

Figure – 22. Diagram showing the negative trend of above ground biomass of mangrove species with increasing salinity at community level

4.1.1.7 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 (Fig. 22). 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 *Avicinnea officinalis* and *Sonneratia apetala* that had positive relationship with the salinity. Density of both these species increased with increase in soil salinity.

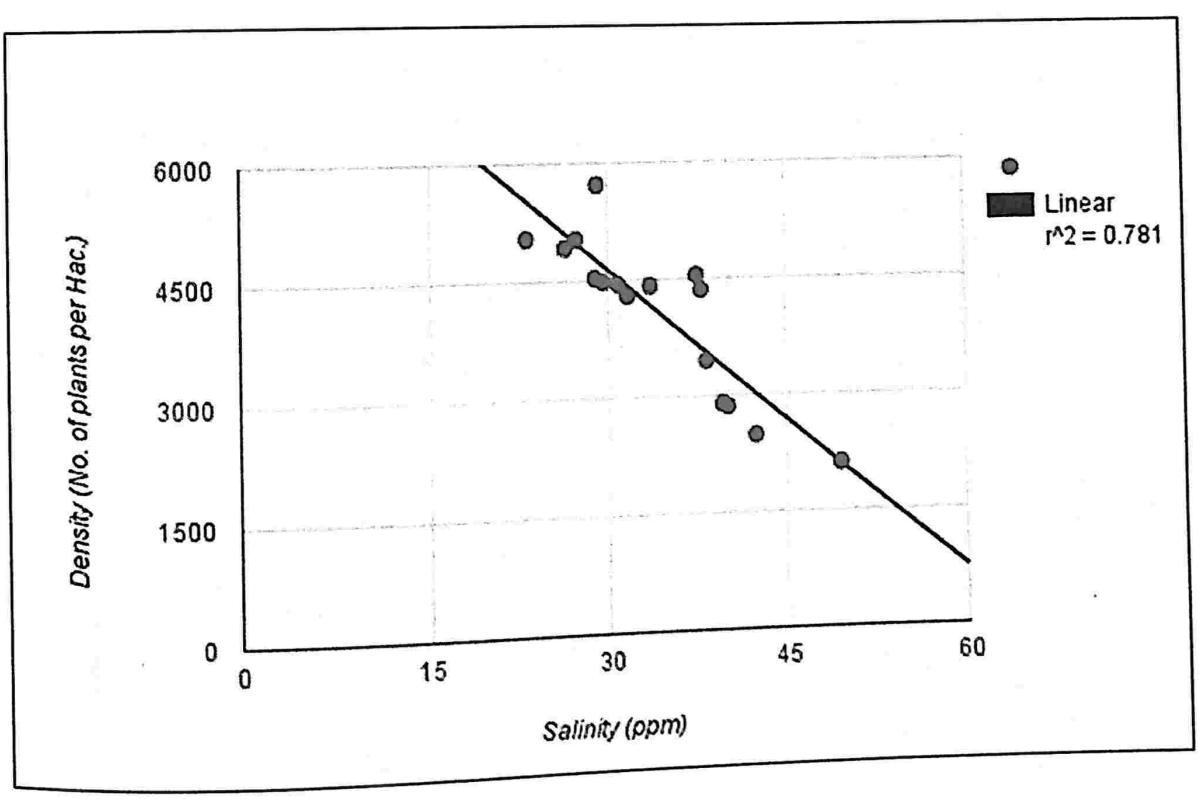

Figure – 23.Graph showing the decreasing pattern of density of mangrove species in Coringa Wildlife Sanctuary at community level

4.1.2 Preferential salinity range of different mangrove species in Coringa Wildlife Sanctuary

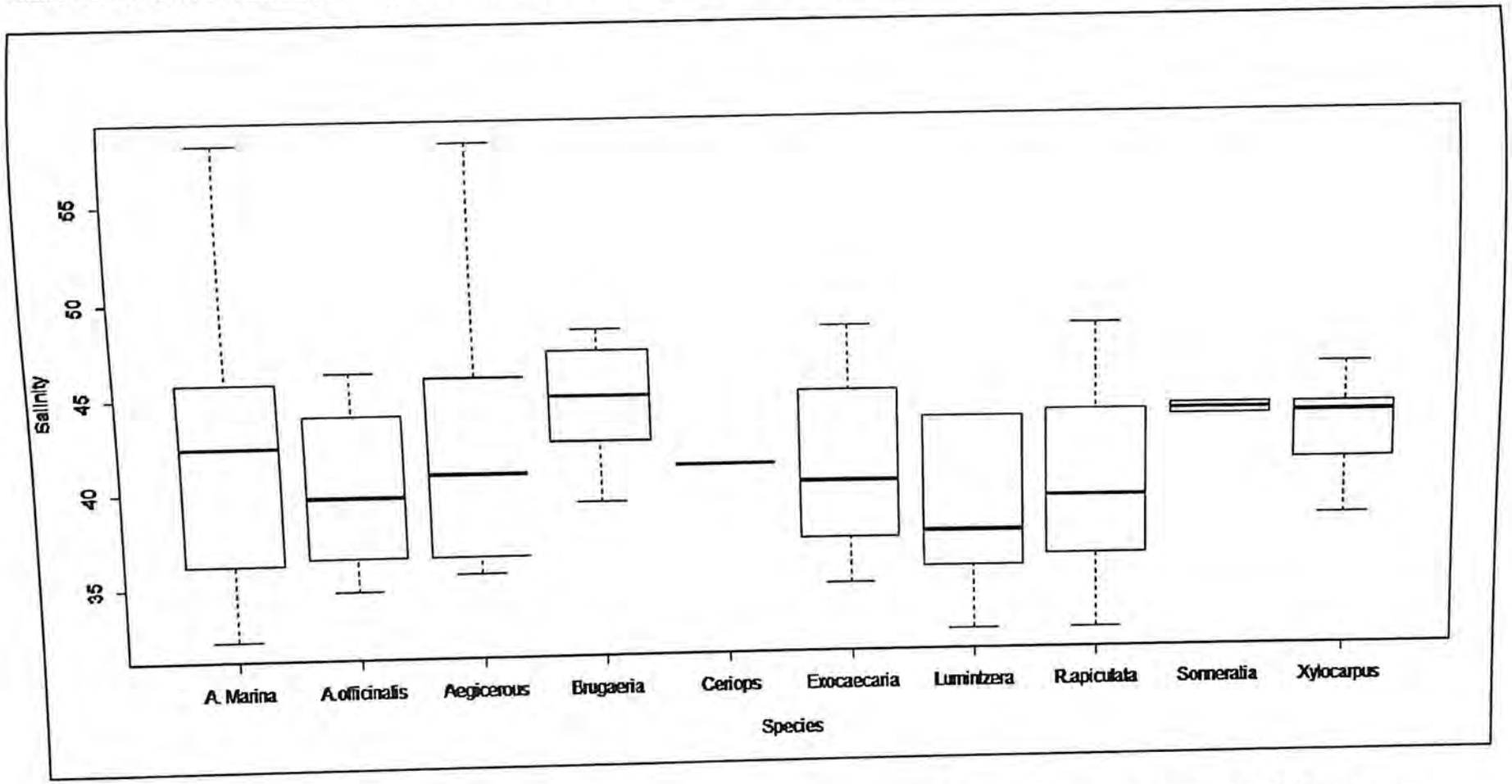

Figure-24. Graph showing preferential salinity range of mangroves species in Gaderu River of Coringa wildlife Sanctuary

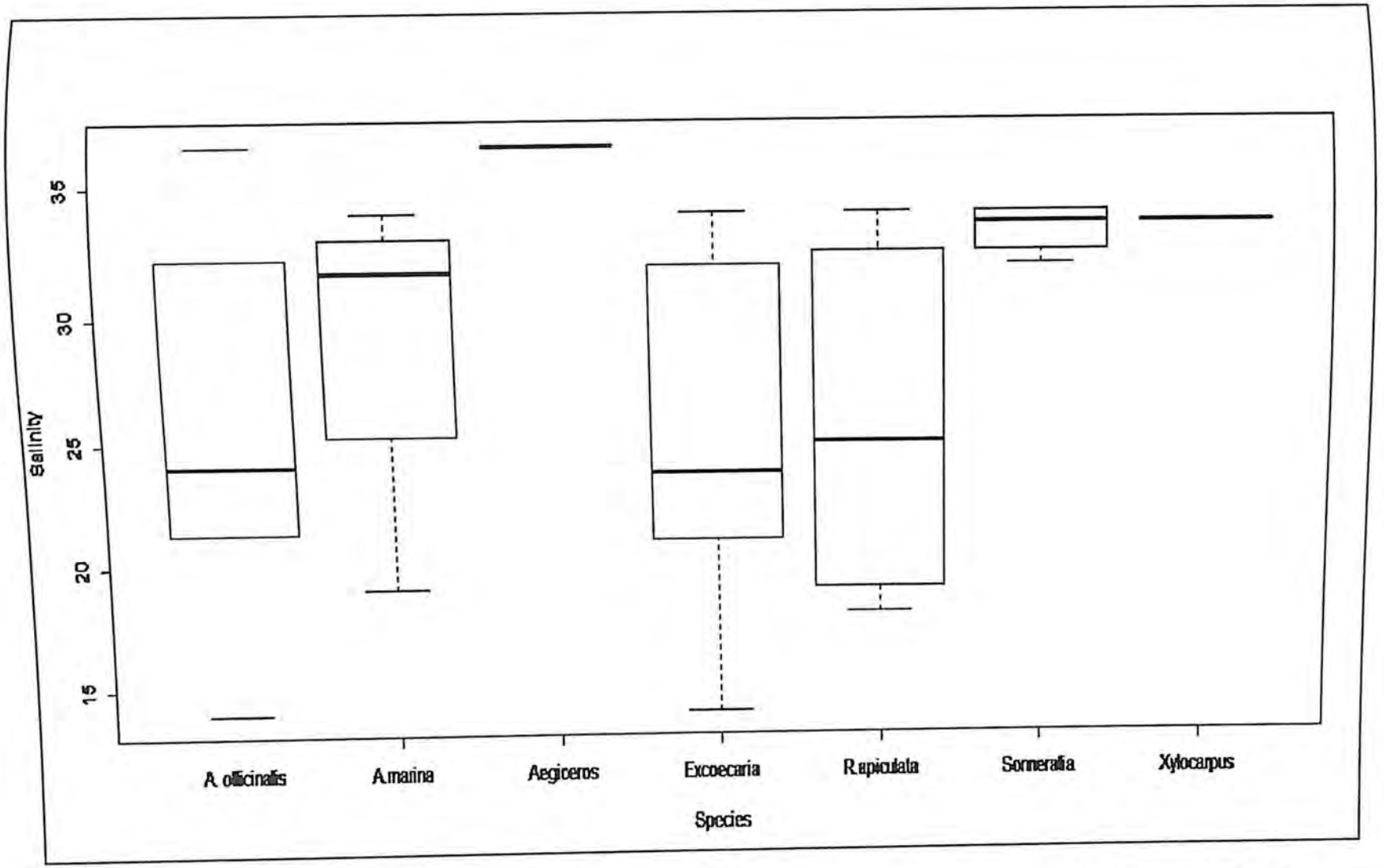

Figure-25. Graph showing preferential salinity range of mangroves species in Coringa River of Coringa wildlife Sanctuary

Table-5. Quantification of preferential salinity range of mangrove species along Gaderu River

Species	Q1	Median	Q3	Min	Max
A. Marina	36.35	42.40	45.40	32.2	58
A.officinalis	36.65	39.70	43.97	34.7	46.3
Aegicerous corniculatum	36.65	40.9	45.92	35.6	58
Brugaeria gymnorrhiza	43.22	45	46.85	39.3	58
Ceriops decandra	41.2	41.2	41.2	41.2	41.2
Excoecaria agallocha	37.4	40.25	44.5	34.7	58
Lumintzera racemosa	35.9	37.50	42.25	32.2	58
R.apiculata	36.2	39.30	43.9	32.2	58
Sonneratia apetala	43.6	43.90	44.2	39.3	45.8
Xylocarpus granatum	41.8	43.75	44.12	38.2	46.3

Figure mentioned in (Table. 5) revealed that in Gaderu River *Bruguiera gymnorrhiza, Sonneratia apetala, Xylocarpus granatum* and *Avicinnea marina* were present a high salinity range. *Aegiceros corniculatum, Ceriops decandra* and *Excaecoria agallocha* was present a medium salinity range, whereas *Lumintzera racemosa, Rhizophora apiculata* and *Avicinnea 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 *Avicinnea marina* was at 42.40 ppm. *Avicinnea 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. *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-6. Quantification of preferential salinity range of mangrove species along Coringa River

Species	Q1	Median	Q3	min	max
A. officinalis	21.3	24	32.25	14	36.5
A.marina	28.37	31.75	32.5	19	34
Aegiceros corniculatum	36.5	36.5	36.5	36.5	36.5
Excoecaria agallocha	23.75	21.15	31.87	14	34
R.apiculata	25	20.25	30.87	18	34
Sonneratia apetala	33.6	32.5	34	32	36.5
Xylocarpus granatum	33.6	33.6	33.6	33.6	33.6

Figure mentioned in (Table. 6) revealed that in Coringa River, *Aegicerous corniculatum*, *Sonneratia apetala* and *Xylocarpus granatum* was present at a higher salinity range. *Avicinnea marina* preferred the medium salinity range whereas *Excoecaria agallocha* and *Rhizophora apiculata* was at a low salinity range. *Avicinnea 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. *Avicinnea 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.

4.1.3 Relationship between salinity and carbon sequestration potential of mangrove species

4.1.3.1 Carbon sequestration potential of Individual mangrove species

Each individual mangrove species had a variation with respect to their carbon sinking potential (Fig.25). Highest sink potential was observed for *Aegiceros corniculatum* (45.467 %), followed by *Avicennia officinalis* (44.818 %), *Bruguiera gymnorrhiza* (44.37%), *Ceriops decandra* (44.33%) and *Sonneratia apetala* (44.185%).

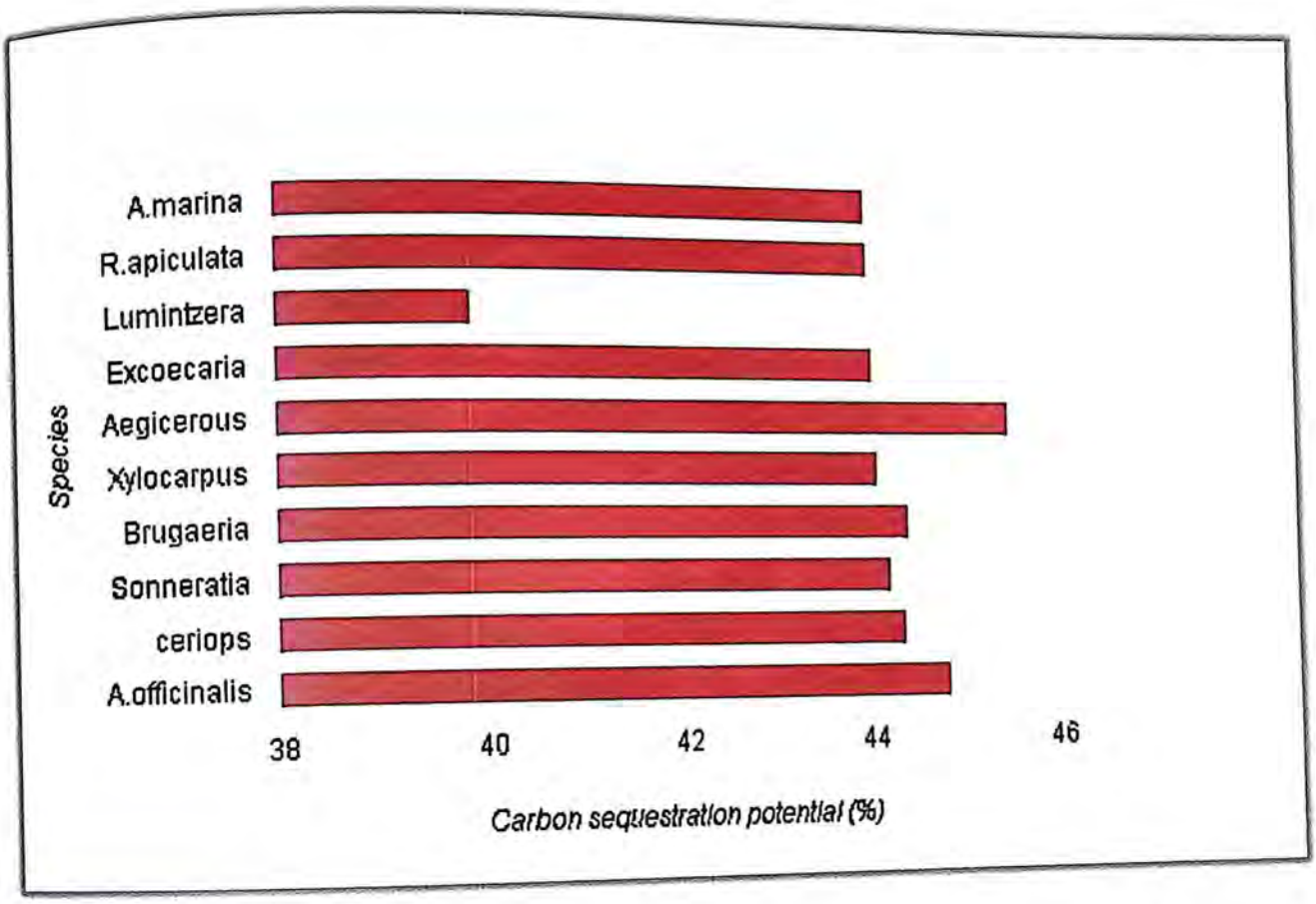

Figure – 26. Diagram showing Carbon sequestration potential of mangrove species in Coringa wildlife sanctuary

Excoecaria and*Xylocarpus*had a potential of 44.018 and 44.058 respectively. *A.marina* had a carbon sinking potential of 43.954% and *R. apiculata* of 43.971%. Among all the mentioned mangrove species, *Lumintzera* had the least potential for carbon sinking (39.836%).

4.1.3.2Relationship between Carbon sequestration potential of Individual mangrove species and salinity in Coringa Wildlife Sanctuary

Relationship between Carbon sequestration potential of mangrove and salinity gradient in Coringa WLS was mentioned in figure (26-34). 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. *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.

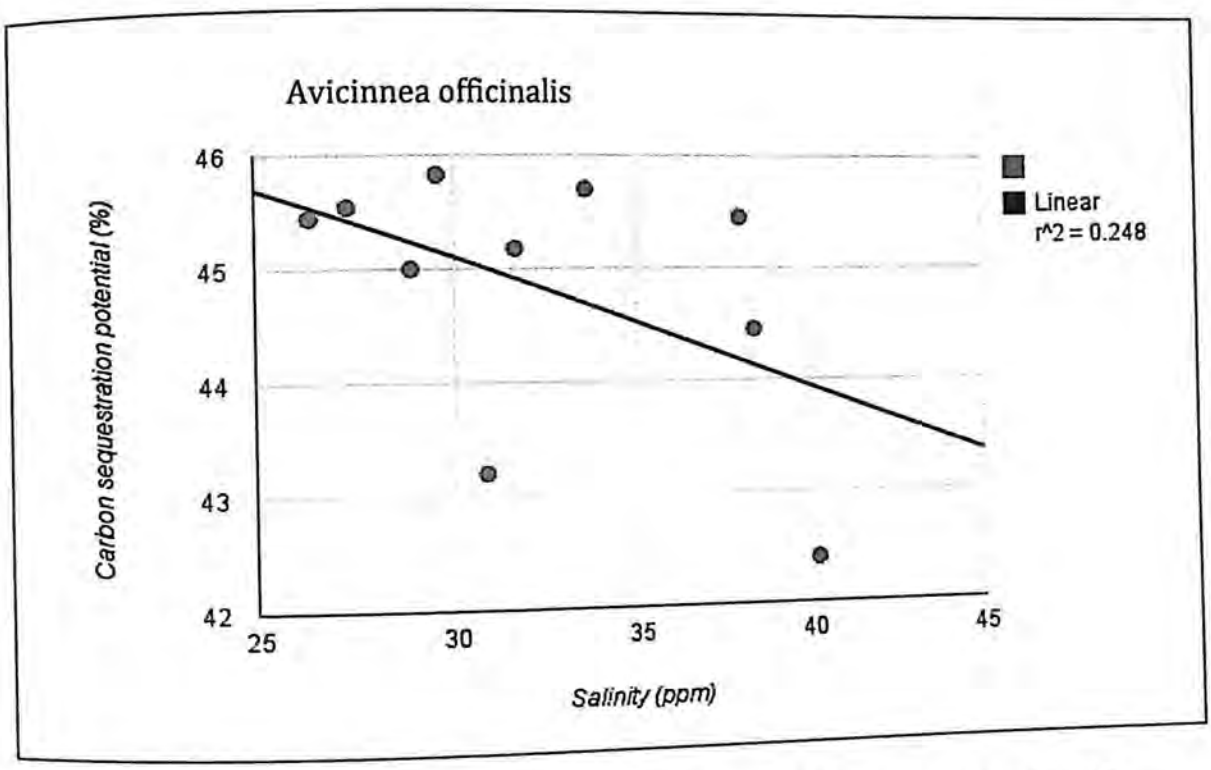

Figure – 27. Graph showing the negative trend of C.S.P of *Avicinnea officinalis* with increasing salinity

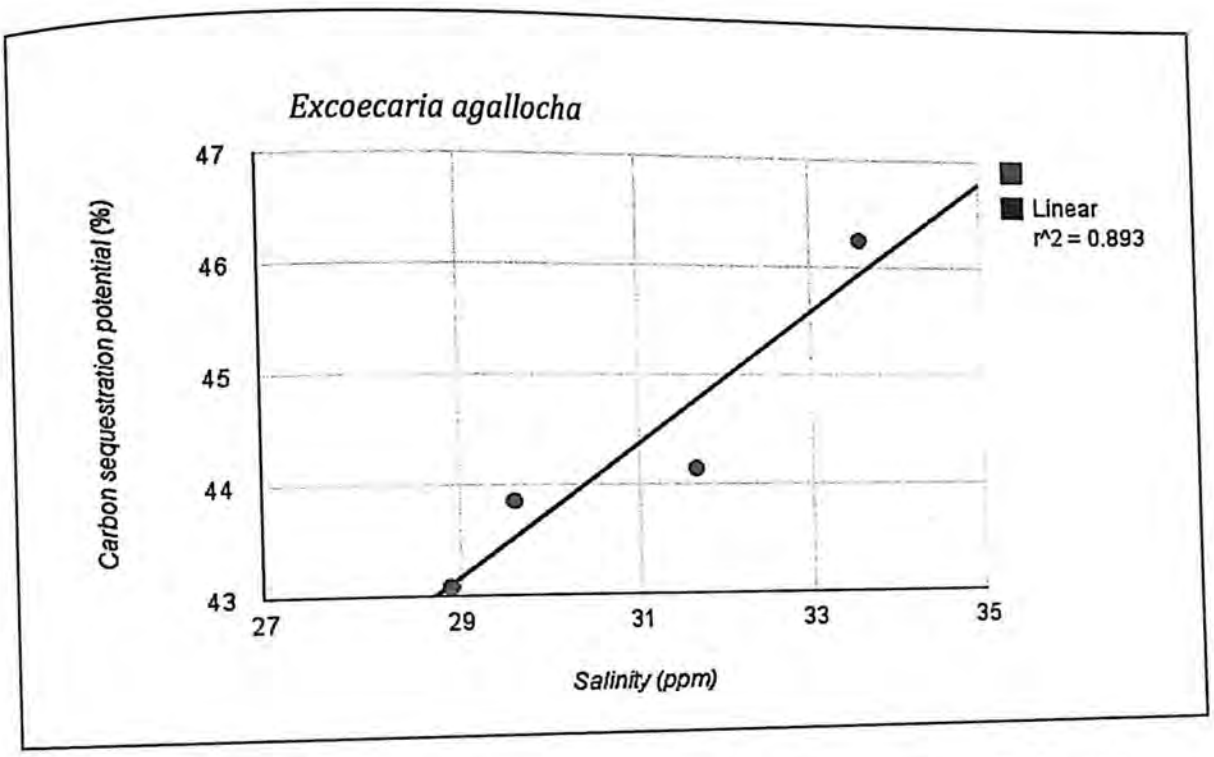

Figure – 28. Graph showing the positive trend of C.S.P of *Excoecaria agallocha* with increasing salinity

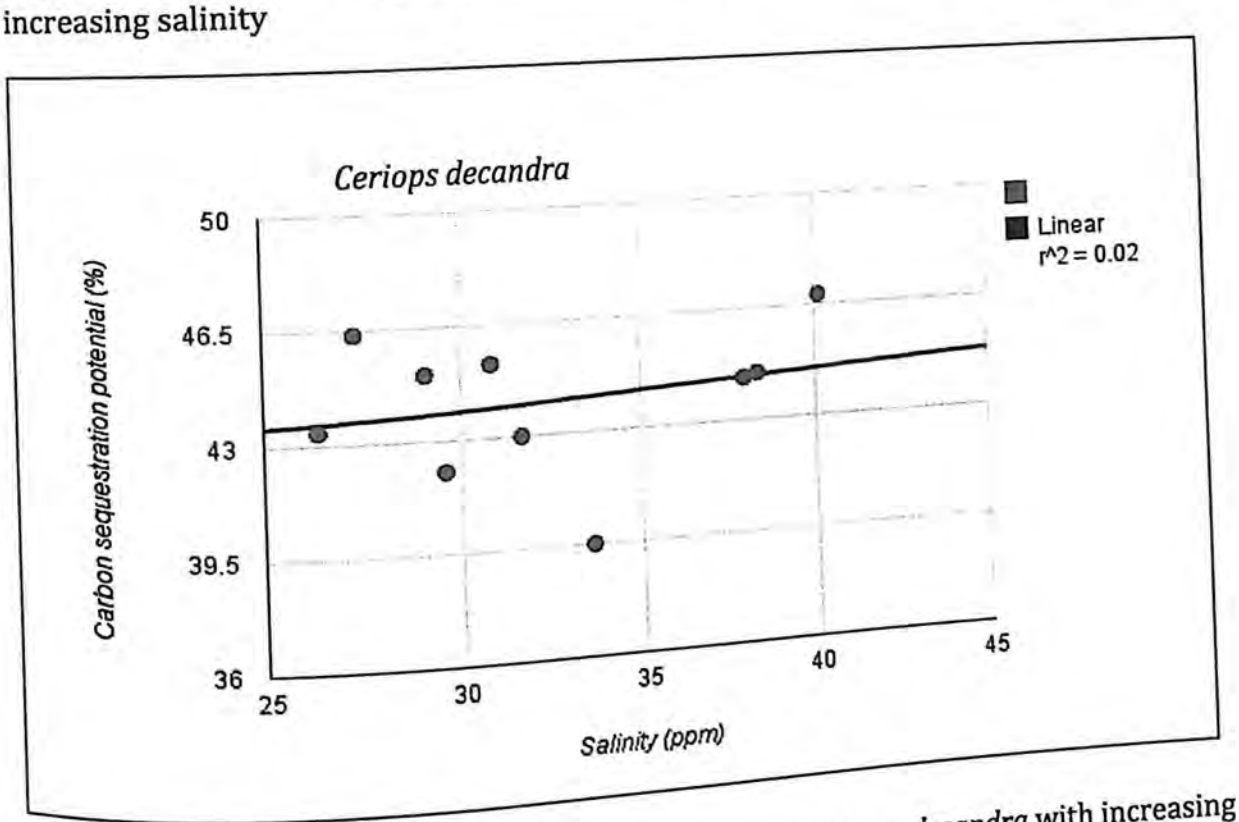

Figure – 29. Graph showing the positive trend of C.S.P of *Ceriops decandra* with increasing salinity

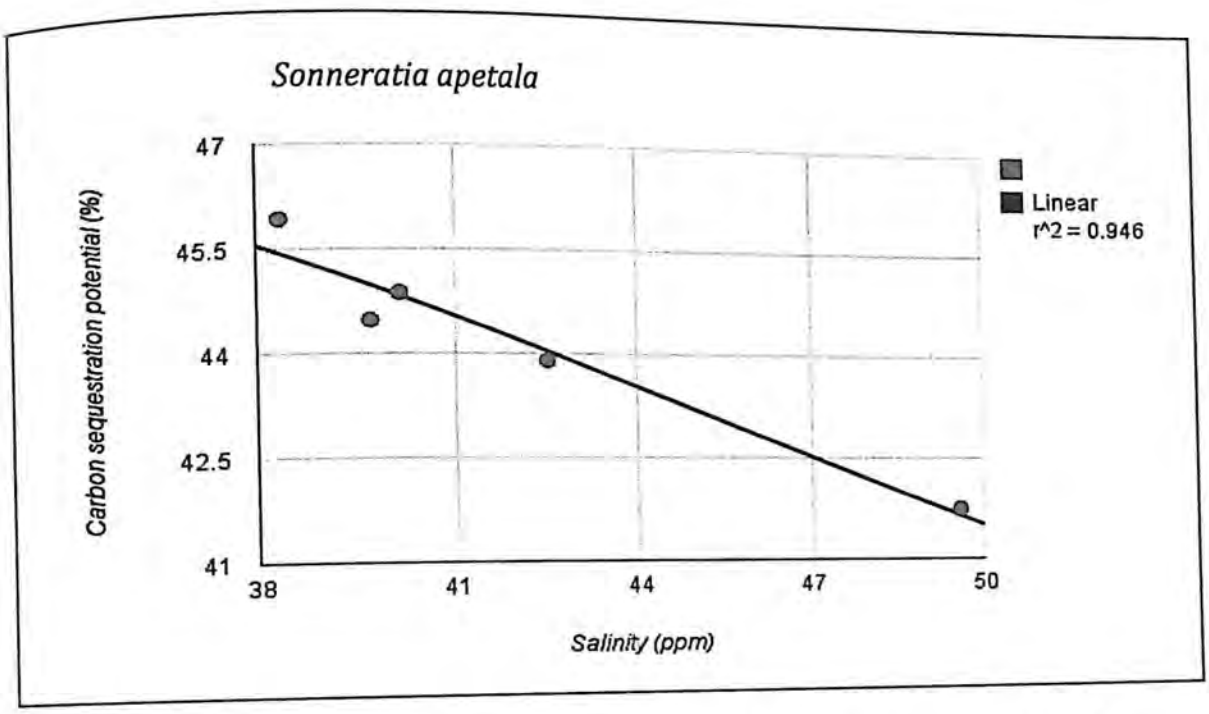

Figure – 30. Graph showing the negative trend of C.S.P of *Sonneratia apetala* with increasing salinity

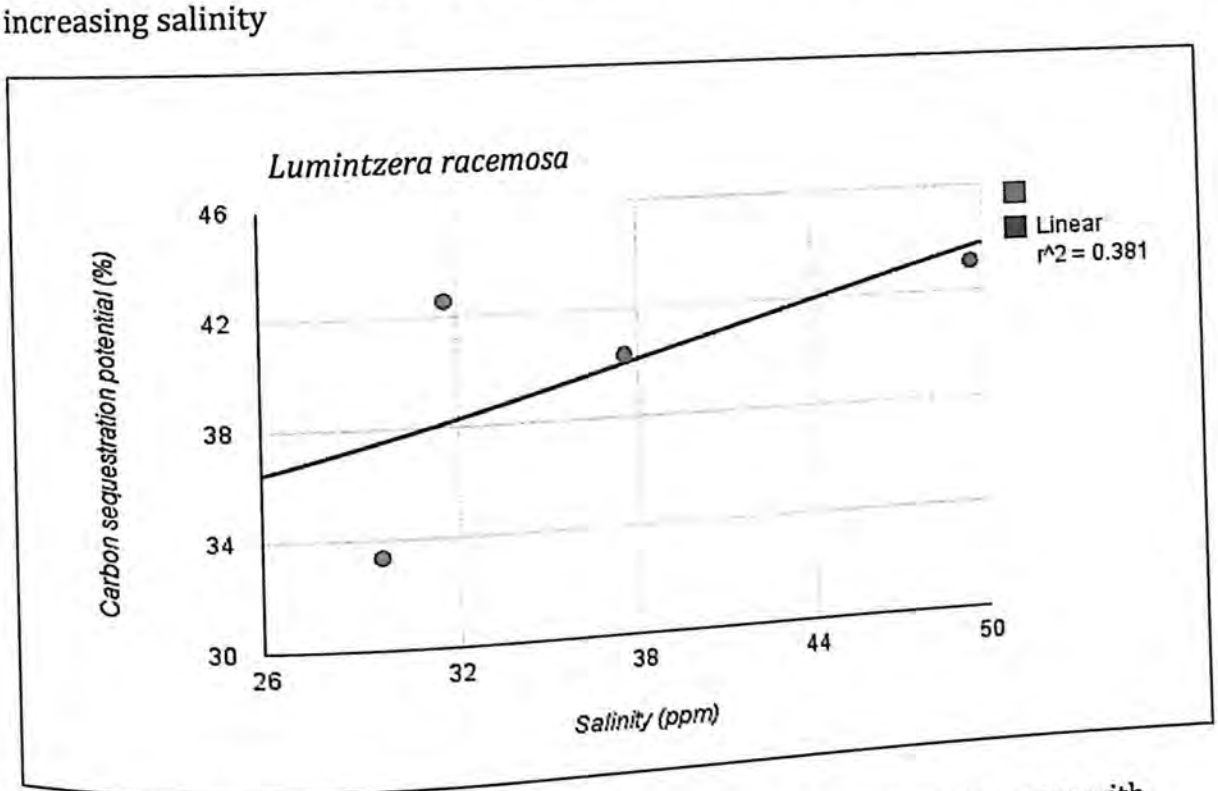

Figure – 31. Graph showing the positive trend of C.S.P of *Lumintzera racemosa* with increasing salinity

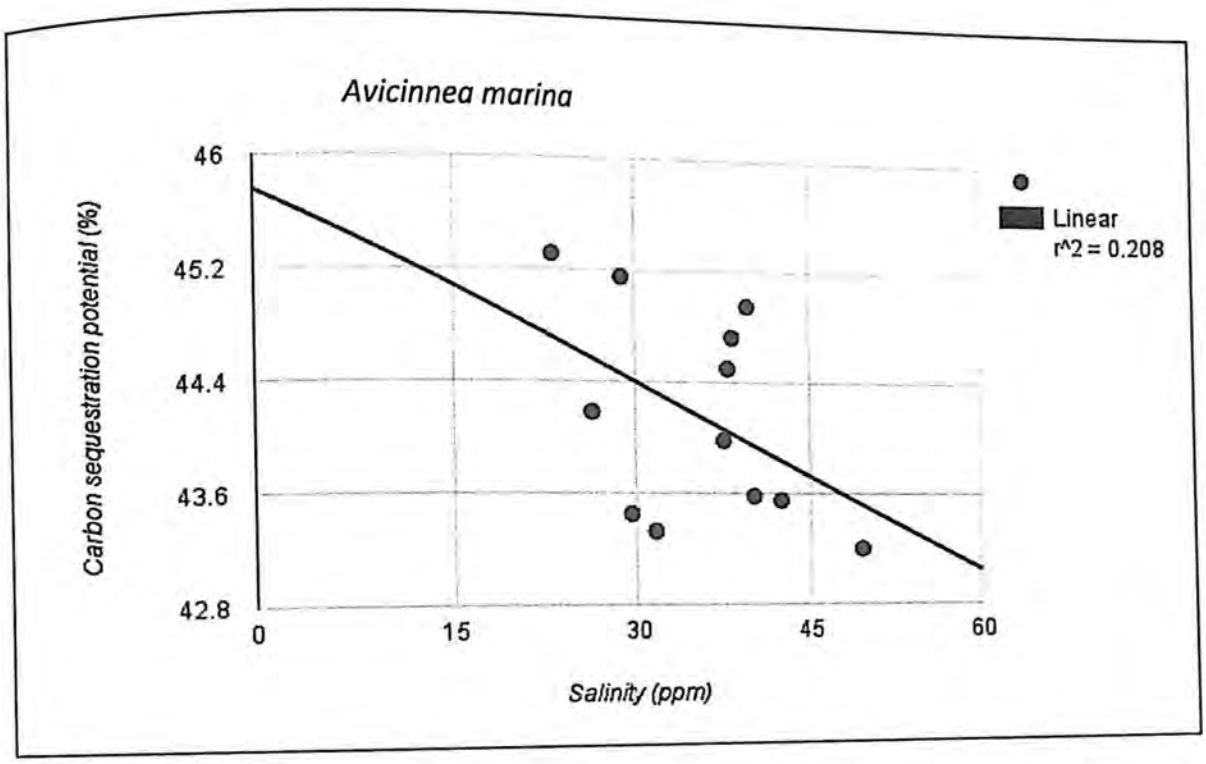

Figure – 32. Graph showing the negative trend of C.S.P of *Avicinnea marina* with increasing salinity

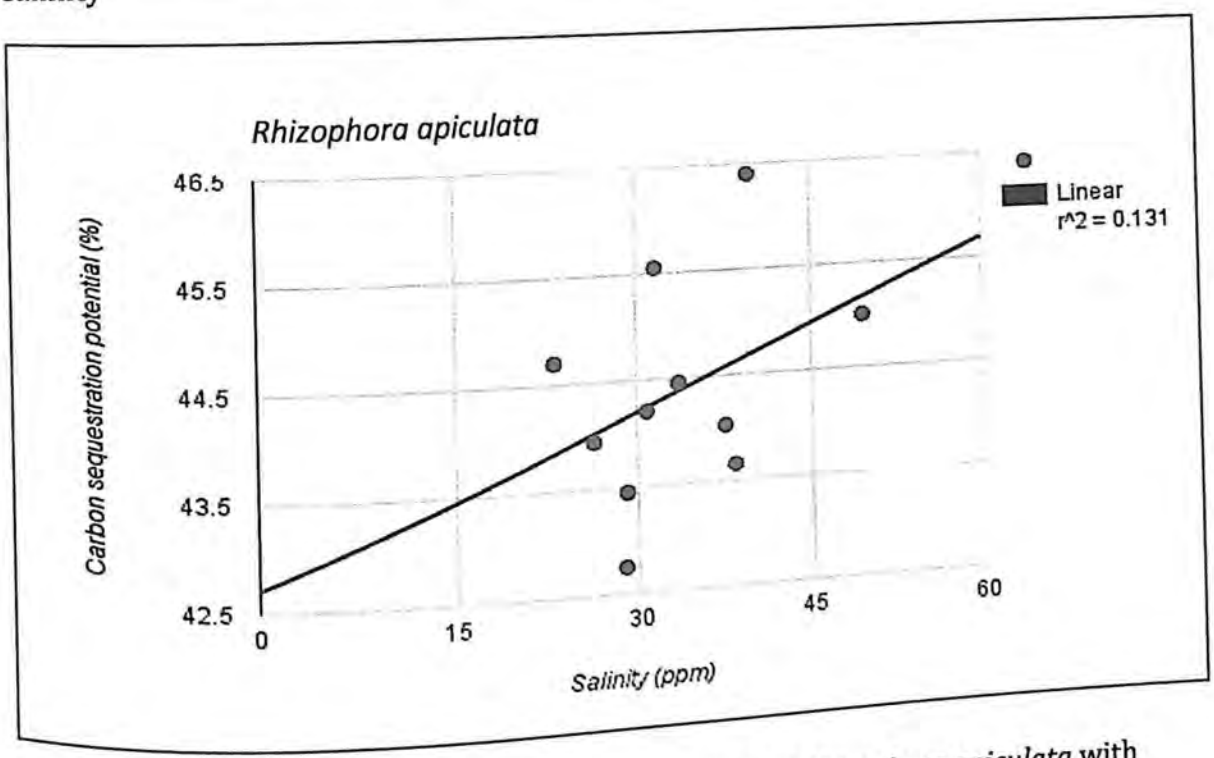

Figure – 33. Graph showing the positive trend of C.S.P of *Rhizophora apiculata* with increasing salinity

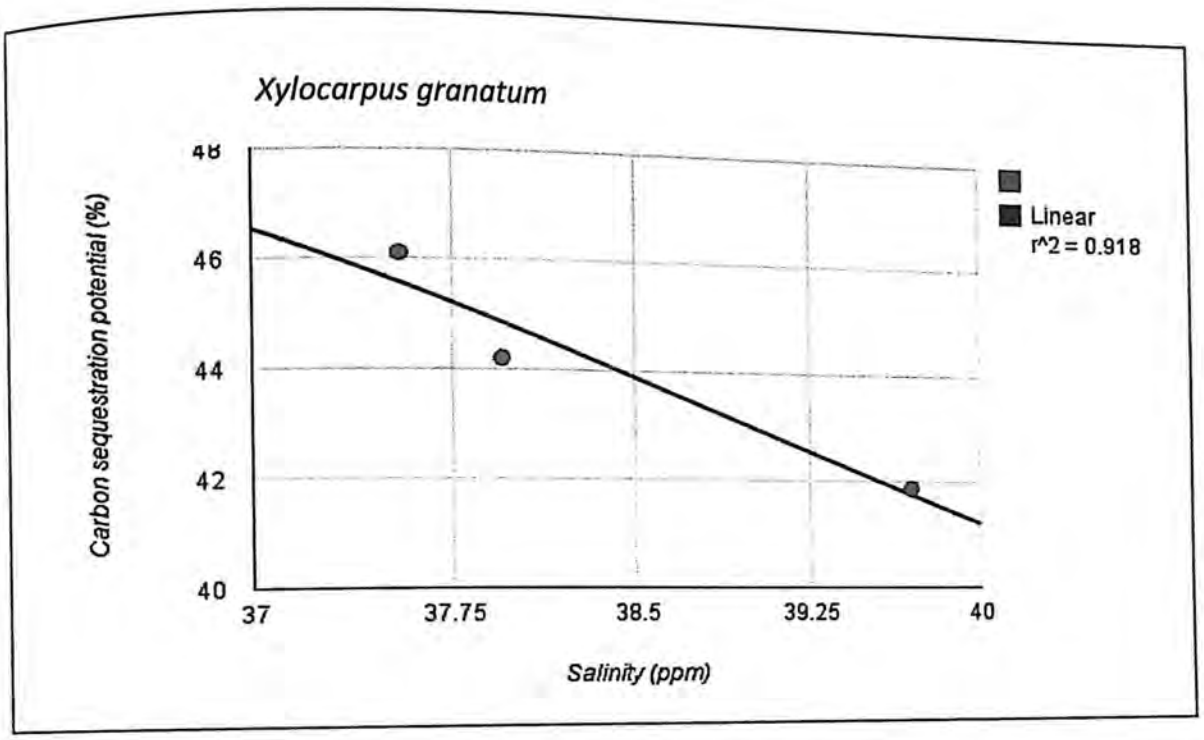

Figure – 34. Graph showing the negative trend of C.S.P of *Xylocarpus granatum* with increasing salinity

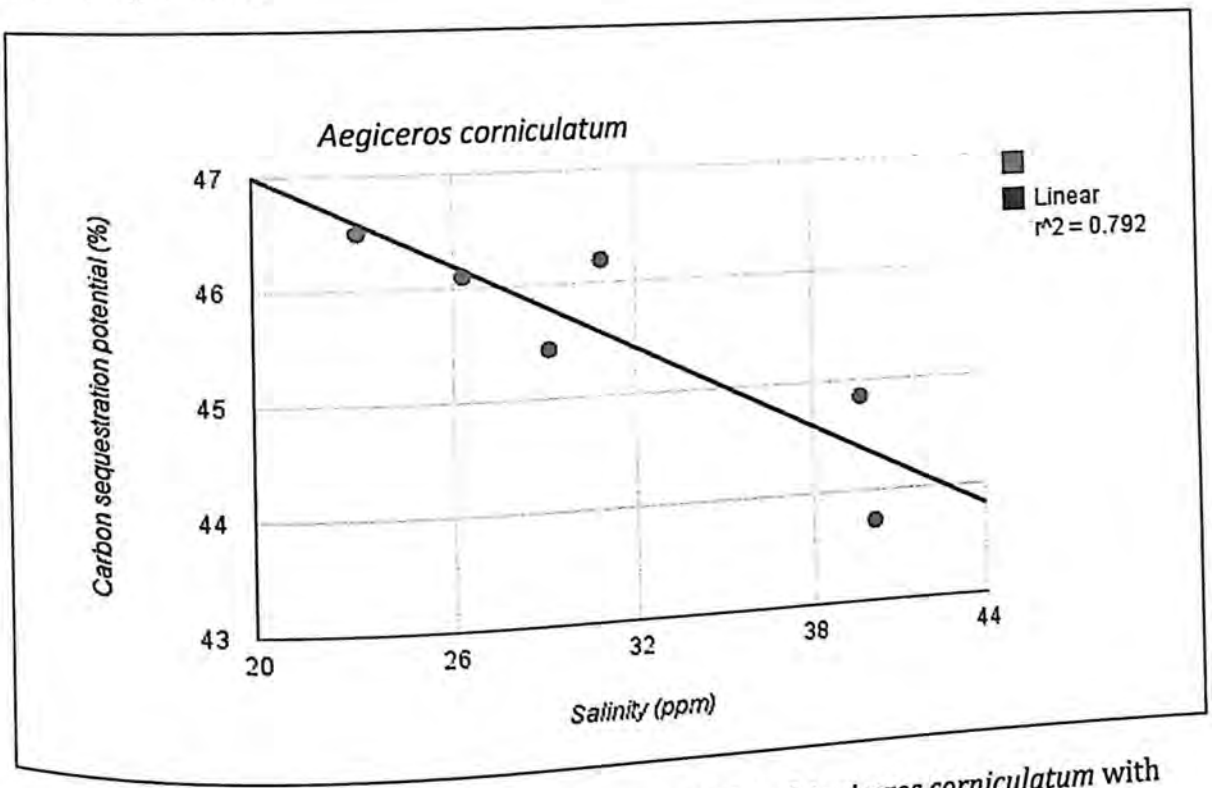

Figure – 35. Graph showing the positive trend of C.S.P of *Aegiceros corniculatum* with increasing salinity

4.1.3.2 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 (Fig 25 to 33). But, at a community level the pattern showed a negative steep slope (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 (Fig. 35) of the soil in Coringa WLS.

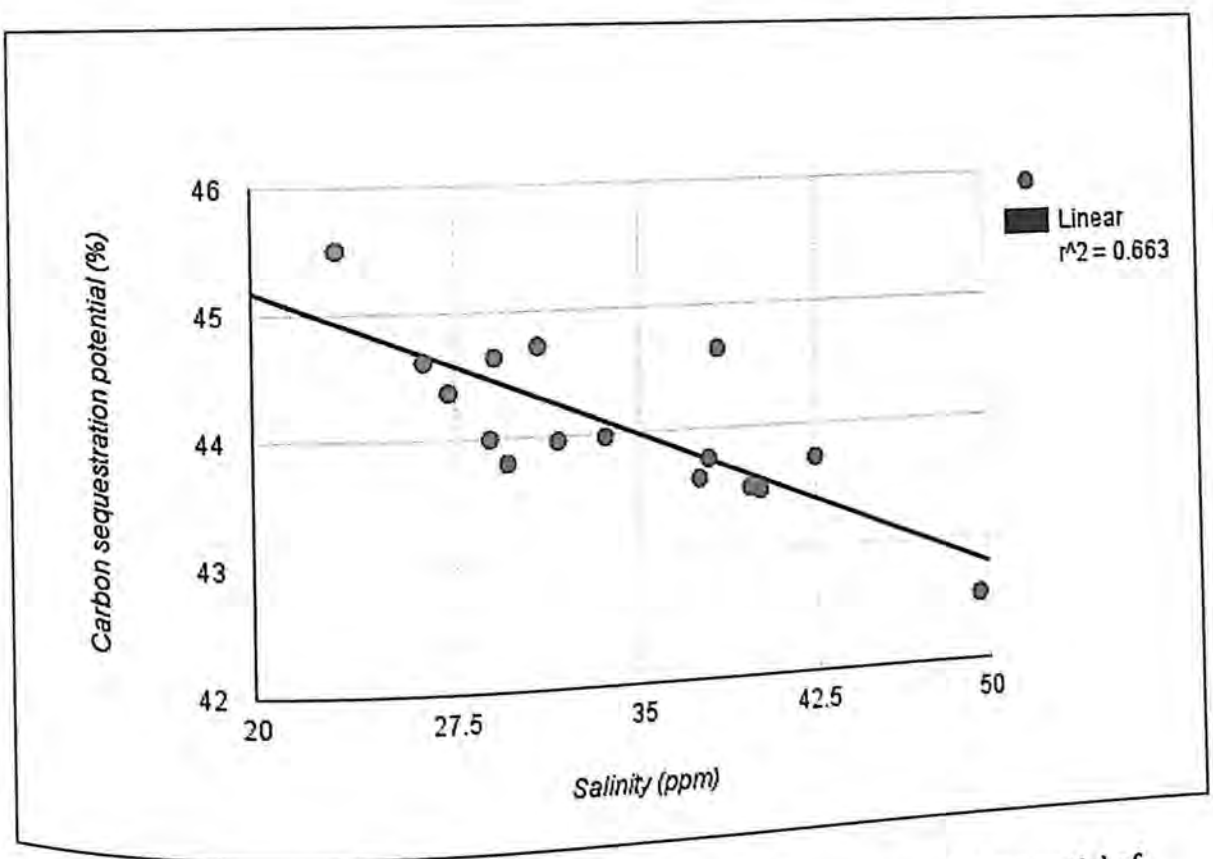

Figure – 36. Graph showing the negative trend of Carbon sequestration potential of mangroves with increasing salinity at community level

4.1.4 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. 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 (Fig. 37). Salinity and moisture was revealed to be highly correlated. A relatively high correlation was also observed in between salinity and potassium.

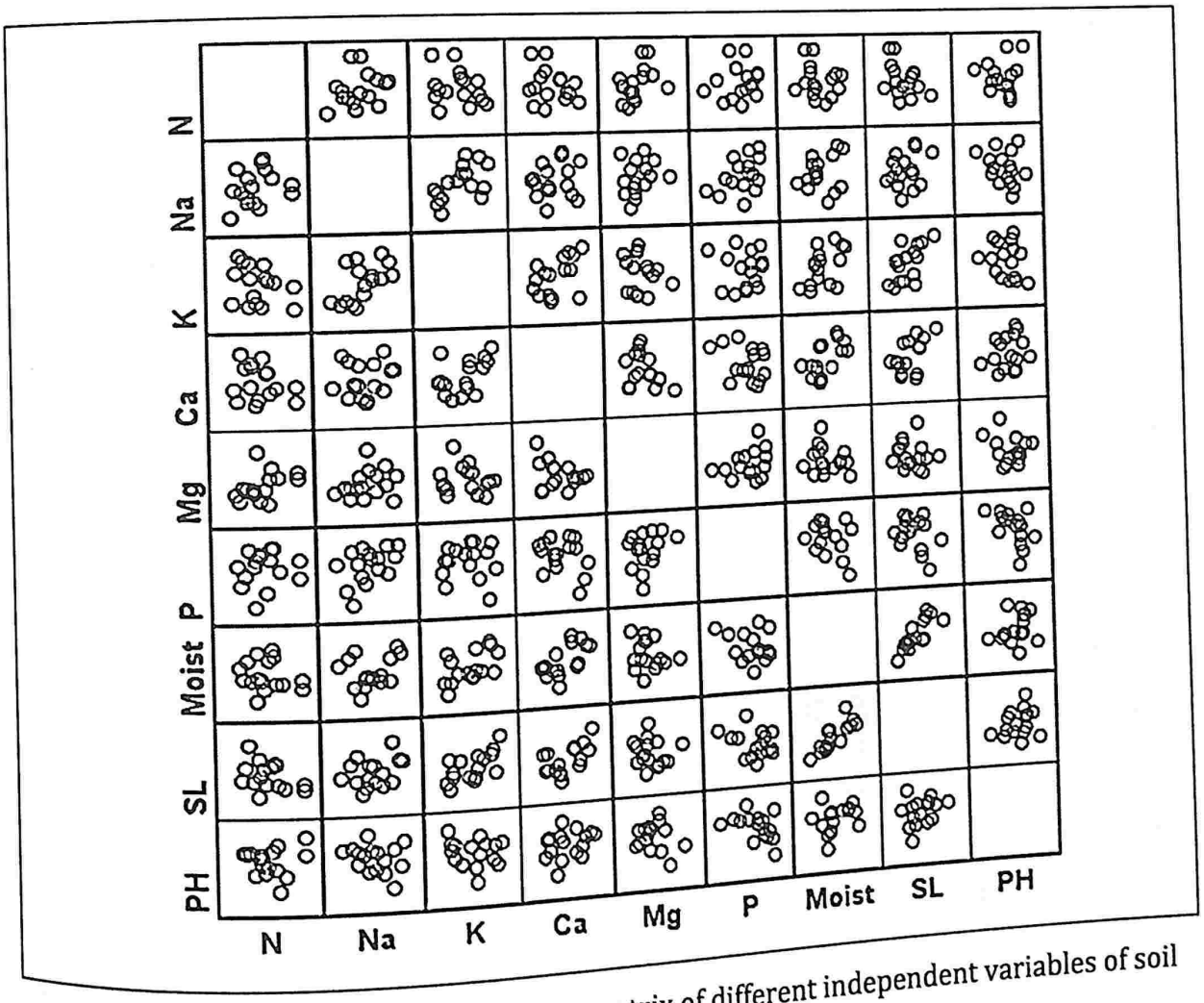

Figure 37 Graph showing the Correlation matrix of different independent variables of soil

Table 7 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 (Table. 7)

4.1.5 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 obtained was shown in Fig. 37. 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 *Avicinnea 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 (Fig. 38) revealed that *Excaecoria agallocha* density was mostly influence by Salinity, Na, pH, N, Ca, K and P. *Avicinnea 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 *Avicinnea 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 (Fig. 39) 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. Most of the mangrove species (*Lumintzera racemosa, Aegiceros corniculatum, R.apiculata, Bruguiera gymnorrhiza, Xylocarpus granatum* and *Ceriops decandra*) were distributed in a less number of sampling plots and had medium to high salinity condition. *A.officinalis, Avicinnea marina* and *Sonneratia apetala* were distributed in several plots and preferred the higher salinity condition.

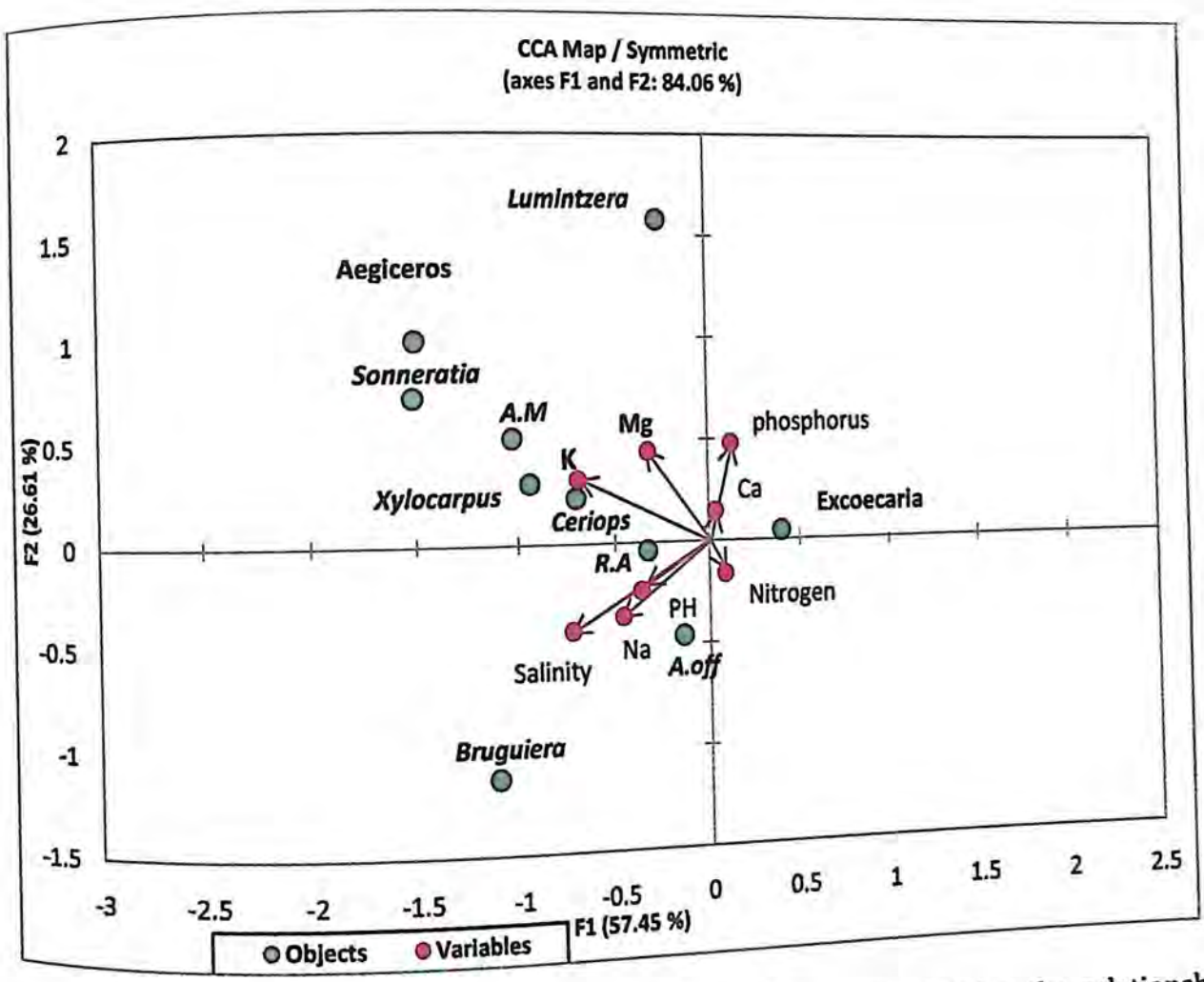

Figure 38 CCA (Canonical Correspondence Analysis) diagram, showing the relationship between 10 mangrove species abundance and soil variables in Coringa wildlife Sanctuary, Andhra pradesh.

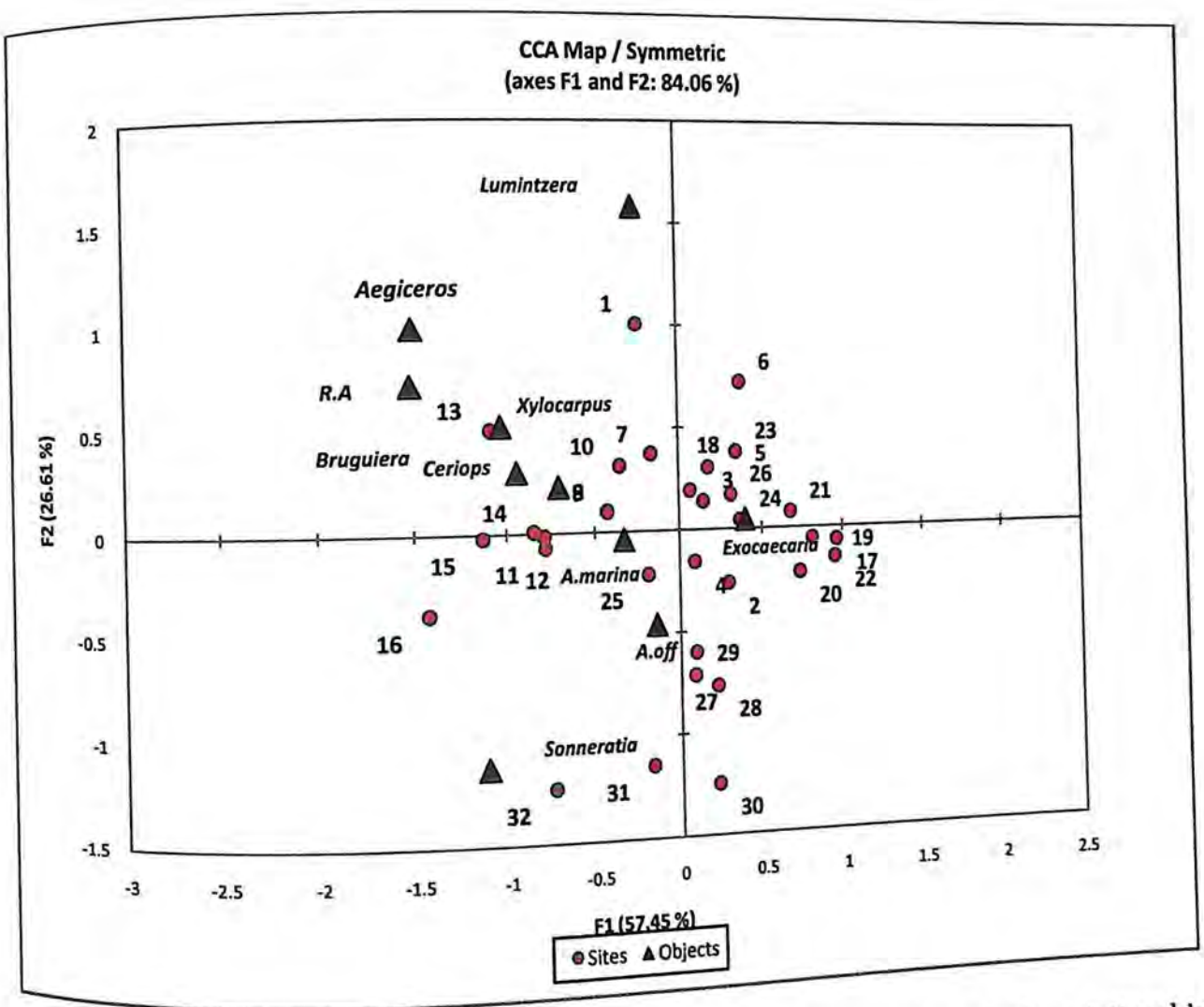

Figure – 39. CCA (Canonical Correspondence Analysis) diagram, showing the relationship of 10 mangrove species and sampling plots in Coringa Wildlife Sanctuary

4.1.6 Factors influencing the density, basal area and Carbon sequestration potential of mangrove species

4.1.6.1 Generalized linear modeling for density of individual mangrove species

Table-8.Model selection for generalized linear regression of density of *Avicinnea marina* against covariates for Coringa Wildlife Sanctuary

Sr. No.	Model	AIC value
1.	Density ~ Ca + Mg + N + PH + P + K + Na + Salinity	214.93
2.	Density ~ Ca + Mg + N + pH + P + K + Salinity	212.96
3.	Density ~ Ca + Mg + N + pH + K + Salinity	211.75
4.	Density ~ Ca + Mg + N + pH + K	210.84
5.	Density ~ Ca + N + pH + K	210.5
6.	Density ~ Ca + N + K	209.75

Table-9.Coefficient of the best generalized linear regression model for estimating density of *Avicinnea marina* for Coringa Wildlife Sanctuary

	Estimate (β – coefficient)	Standard Error	Z - value	Pr(|Z|)
Intercept	34.423	6.070	5.671	4.45e-06
N	-12.893	5.692	-2.265	0.03144
Ca	9.156	5.729	1.598	0.1212
K	6.170	1.663	3.710	0.00090

Null deviance: 29248 on 15 degree of freedom
Residual deviance: 17506 on 12 degree of freedom
AIC: 302.5

The removal of the variable was significant because it also gave a model with a reduced AIC value from 214.93 – 209.75 (Table. 8). Thus from reduced model, Nitrogen, having weightage (-12.893 ± 5.692) was a significant factor for governing the *Avicennia marina* species density and showing the positive relationship with the density. Nitrogen was followed by Calcium (9.156 ± 5.729) and K (6.170 ± 1.663). Calcium and potassium were positively related with *Avicinnea marina* density (Table. 9)

Table-10. Model selection for generalized linear regression of density of *Excoecaria agallocha* against covariates for Coringa Wildlife Sanctuary

Sr. No.	Model	AIC Value
1.	Density ~ Ca + K + Mg + Na + N + P + PH + Salinity	264.92
2.	Density ~ Ca + N + pH + P + K + Na + Salinity	262.95
3.	Density ~ Ca + N + pH + K + Na + Salinity	261.07
4.	Density ~ Ca + N + pH + K + Salinity	259.84
5.	Density ~ Ca + pH + K + salinity	258.39

Table-11.Coefficient of the best generalized linear regression model for estimating density of *Excoecaria agallocha* in for Coringa Wildlife Sanctuary

	Estimate	Standard Error	Z - value	Pr(|Z|)
Intercept	4.3182	0.0277	155.484	<2e-16
Salinity	-0.5532	0.227	-24.363	<2e-16
Ca	-0.1092	0.0205	-5.327	9.96e-08
pH	-0.1060	0.0190	-5.577	2.45e-08
K	-0.04719	0.0072	-6.516	7.23e-11

Null deviance: 2462.9 on 15 degree of freedom
Residual deviance: 1358.7 on 11 degree of freedom
AIC: 561.8

The removal of the variable was significant because it also gave a model with a reduced AIC value from 264.92 to 258.39 (Table. 10). Thus from reduced model, Salinity, having weightage (-0.5532 ± 0.227) was a most significant factor for governing the *Excoecaria agallocha* species density and showing the negative relationship with the density. Salinity was followed by Ca (-0.1092 ± 0.0205), pH (-0.1060 ± 0.0190) and K (-0.0471 ± 0.0072). All the variables (Ca, pH and K) were negatively correlated with *Excoecaria mangrove* density (Table. 11).

Table-12.Model selection for generalized linear regression of density of *Avicennia officinalis* against covariates for Coringa Wildlife Sanctuary

Sr. No.	Model	AIC Value
1.	Density ~ Ca + K + Mg + N + Na + P + PH + Salinity	183.81
2.	Density ~ Ca + K + N + Na + P + PH + Salinity	181.93
3.	Density ~ Ca + Na+ Mg + P + PH + Salinity	180.09
4.	Density ~ N + pH + P + Na + Salinity	178.3
5.	Density ~ pH + P + Na + Salinity	176.52
6.	Density ~ P + Na + Salinity	174.99
7.	Density ~ P + Salinity	173.97

Table-13.Coefficient of the best generalized linear regression model for estimating density of *Avicennia officinalis* for Coringa Wildlife Sanctuary

	Estimate (β –coefficient)	Standard Error	Z - value	Pr(|Z|)
Intercept	16.250	2.5624	6.342	6.27e-07
Salinity	-1.641	0.5878	-2.791	0.0365
P	-1.6080	0.6854	-2.346	0.0265

Null deviance: 7242 on 15 degree of freedom
Residual deviance: 6093.1 on 13 degree of freedom
AIC: 266.79

The removal of the variable was significant because it also gave a model with a reduced AIC value from 183.81 to 173.97 (Table. 12). Thus from reduced model, salinity, having weightage (-0.5532 ± 0.0277) was a most significant factor for governing the *Avicennia marina* species density and showing the negative relationship with the density. Salinity was followed by Ca, having weightage (-0.1092 ± 0.0205), PH (-0.1060 ± 0.0190) and K (-0.0471

± 0.0072). All the variables (Ca, pH and K) were negatively elated with *Avicinnea officinalis* density (Table. 13).

Table-14. Model selection for generalized linear regression of density of *Bruguiera gymnorrhiza* against covariates for Coringa Wildlife Sanctuary

S. No.	Model	AIC Value
1.	Density ~ Ca + K + Mg + Na + N + P + pH + Salinity	206.85
2.	Density ~ Ca + K + Mg + Na + P + pH + Salinity	204.86
3.	Density ~ Ca + pH + P + K + Na + salinity	202.98
4.	Density ~ pH + P + K + Na + salinity	201.44
5.	Density ~ pH + P + Na + Salinity	199.89
6.	Density ~ pH + P + Na	198.78

Table-15 .Coefficient of the best generalized linear regression model for estimating density of *Bruguiera gymnorrhiza* for Coringa Wildlife Sanctuary

	Estimate (β –coefficient)	Standard Error	Z - value	Pr(|Z|)
Intercept	1.5686	0.09245	16.97	<2e-16
Na	0.8998	0.0639	14.06	<2e-16
pH	0.5647	0.0475	11.88	<2e-16
P	-0.2121	0.0186	-11.41	<2e-16

Null deviance: 1020.51 on 15 degree of freedom
Residual deviance: 568.31 on 12 degree of freedom
AIC: 629.38

The removal of the variable was significant because it also gave a model with a reduced AIC value from 206.85 to 198.78 (Table. 14). Thus from reduced model, Sodium (Na), having weightage (0.8998 ± 0.0639) was a most significant factor for governing the *Bruguiera gymnorrhiza* species density and showing the positive relationship with the density. Sodium was followed by pH having weightage (0.5647 ± 0.0475) and P (-0.2121 ± 0.0186).

pH was positively and P was negatively related with *Bruguiera gymnorrhiza* species density (Table. 15).

Table-16.Model selection for generalized linear regression of density of *Sonneratia apetala* against covariates for Coringa Wildlife Sanctuary

Sr. No.	Model	AIC Model
1.	Density ~Ca + K + Mg + Na + N + P + pH + Salinity	117.68
2.	Density ~ Mg + N + pH + P + K + Na + Salinity	115.68
3.	Density ~ Mg + N + pH + P + K + Salinity	113.79
4.	Density ~ Mg + pH + P + K + Salinity	112.45
5.	Density ~ Mg + pH + K + Salinity	111.2
6.	Density ~ Mg + pH + Salinity	110.22

Table - 17. Coefficient of the best generalized linear regression model for estimating density of *Sonneratia apetala* for Coringa Wildlife sanctuary

	Estimate (β – Coefficient)	Standard Error	Z - value	Pr(|Z|)
Intercept	-0.03406	0.25070	-0.136	0.892
Salinity	-1.4334	0.29750	-4.818	1.45e-06
Mg	0.2980	0.0458	6.498	8.16e-11
P	0.2062	0.04973	4.147	3.37e-05

Null deviance: 240.40 on 15 degree of freedom
Residual deviance: 159.01 on 12 degree of freedom
AIC: 185.34

The removal of the variable was significant because it also gave a model with a reduced AIC value from 117.68 to 110.22 (Table. 16). Thus from reduced model, Salinity, having weightage (-1.4334 ± 0.29750) was a most significant factor for governing the *Sonneratia*

apetala species density and showing the negative relationship with the density. Nitrogen was followed by Mg (0.2980 ± 0.0458) and P (0.2062 ± 0.04973). Mg and P, both variables were positively related with the *Sonneratia apetala* species density (Table. 17).

Table-18. Model selection for generalized linear regression of density of *Aegiceros corniculatum* against covariates for Coringa Wildlife Sanctuary

Sr. No.	Model	AIC Value
1.	Density ~ Ca + Mg + N + pH + P + K + Na + Salinity	158.17
2.	Density ~ Ca + Mg + N + pH + P + K + Salinity	156.17
3.	Density ~ Mg + N + pH + P + K + Salinity	154.48
4.	Density ~ Mg + N + pH + P + K	153.18
5.	Density ~ N + PH + P + K	151.75
6.	Density ~ N + P + K	151.2
7.	Density ~ P + K	150.15

Table-19.Coefficient of the best generalized linear regression model for estimating density of *Aegiceros corniculatum* for Coringa Wildlife Sanctuary

	Estimate (β-coefficient)	Standard Error	Z - Value	Pr(|z|)
Intercept	-1.5097	0.4847	-3.115	0.00184
K	2.7639	0.3221	8.582	<2e-16
p	0.5650	0.0625	9.041	<2e-16

Null deviance: 258.60 on 15 degree of freedom
Residual deviance: 210.54 on 13 degree of freedom
AIC: 235.16

The removal of the variable was significant because it also gave a model with a reduced AIC value from 158.17 to 150.15(Table. 18). Thus from reduced model, Potassium, having weightage (-2.7639 ± 0.3221) was a most significant factor for governing the *Aegiceros corniculatum* species density and showing the positive relationship with the density.

Potassium was followed by Phosphorus (0.5650 ± 0.0625) and was positively related to species density (Table. 19).

Table-20. Model selection for generalized linear regression of density of *Lumintzera racemosa* against covariates for Coringa Wildlife Sanctuary

Sr. No.	Model	AIC Value
1.	Density ~ Ca + Mg + N + pH + P + K + Na + Salinity	79.4
2.	Density ~ Ca + Mg + N +pH + P + K + Salinity	77.41
3.	Density ~ Ca + Mg + N + P + K + Salinity	75.55
4.	Density ~ Ca + N + P + K + Salinity	73.93
5.	Density ~ Ca + N + K + Salinity	72.59
6.	Density ~ Ca + K + Salinity	71.6

Table-21. Coefficient of the best generalized linear regression model for estimating density of *Lumintzera racemosa* for Coringa Wildlife Sanctuary

	Estimate (β –coefficient)	Standard Error	Z - Value	Pr(|z|)
Intercept	-1.3254	0.6498	-2.040	0.04138
Salinity	-2.6323	0.9553	-2.756	0.00586
K	1.1141	0.2703	4.122	3.76e-05
Ca	0.3002	0.4377	0.686	0.49272

Null deviance: 148.494 on 15 degree of freedom
Residual deviance: 43.842 on 12 degree of freedom
AIC: 63.933

The removal of the variable was significant because it also gave a model with a reduced AIC value from 79.4 to 71.6 (Table. 20). Thus from reduced model, Salinity, having weightage (-2.6323 ± 0.9553) was a most significant factor for governing the *Lumintzera racemosa* species density and showing the negative relationship with the density. Salinity was

followed by Potassium (1.1141 ± 0.2703) and Calcium (0.3002 ± 0.4377). Both variables (P & K) were positively related with species density (Table. 21).

Table-22.Model selection for generalized linear regression of density of *Rhizophora apiculata* against covariates for Coringa Wildlife Sanctuary

Sr.No.	Model	AIC Value
1.	Density ~ Ca + Mg + N + pH + P + K + Na + Salinity	137.46
2.	Density ~ Ca + N + pH + P + K + Na + Salinity	135.53
3.	Density ~ N +pH + P + K + Na + Salinity	133.61
4.	Density ~ N + P + K + Na + Salinity	131.83
5.	Density ~ N + P + K + Salinity	130.64
6.	Density ~ N + K + Salinity	130
7.	Density ~ N + k	129.17
8.	Density ~ K	128.61

Table.23. - Coefficient of the best generalized linear regression model for estimating density of Lumintzera racemosa for Coringa Wildlife Sanctuary

	Estimate (β –Coefficient)	Standard Error	Z - Value	Pr(|z|)
Intercept	2.05721	0.08206	25.070	<2e-16
K	0.33460	0.03915	8.546	<2e-16

Null deviance: 303.16 on 15 degree of freedom
Residual deviance: 207.83 on 14 degree of freedom
AIC: 277.32

The removal of the variable was significant because it also gave a model with a reduced AIC value from 137.46 to 128.61 (Table. 22). Thus from reduced model, Potassium, having weightage (0.33460 ± 0.03915) was a most significant factor for governing the *Rhizophora apiculata* species density and showing the positive relationship with the density (Table. 23)

Table- 24. The β coefficients with the standard errors for mangrove density at a community level in Coringa Wildlife Sanctuary

S. No.	Species	Variables	β – coefficient ± S.E
1.	*Excaecoria agallocha*	Salinity	-0.5532 ± 0.227
		Ca	-0.1092 ± 0.0205
		pH	-0.1060 ± 0.0190
		K	-0.0471 ± 0.0072
2.	*Rhizophora apiculata*	K	0.3346 ± 0.0391
3.	*Avicinnea officinalis*	Salinity	-1.641 ± 0.5878
		Phosphorus	-1.6080 ± 0.6854
4.	*Lumintzera racemosa*	Salinity	-2.6323 ± 0.9553
		K	1.1141 ± 0.2703
		Ca	0.3002 ± 0.4377
5.	*Avicinnea marina*	N	-12.893 ± 5.692
		Ca	9.156 ± 5.729
		K	6.170 ± 1.663
6.	*Aegiceros corniculatum*	K	2.7639 ± 0.3221
		P	0.5650 ± 0.0625
7.	*Sonneratia apetala*	Salinity	-0.0340 ± 0.25070
		Mg	0.2980 ± 0.0458
		P	0.2062 ± 0.0497

Most of the mangrove species in Coringa WLS showed the negative influence of salinity and positive influence of Potassium and Phosphorus on density of the species at community level. The influence of calcium varied from species to species (Table. 24).

4.1.6.2 Results for second objective: Factor controlling the basal area of individual mangrove species

Generalized linear model for basal area of individual mangrove species

Table-25.Model selection for generalized linear regression of basal area of *Sonneratia apetala* against covariates for Coringa Wildlife Sanctuary

Sr. No.	Model	AIC Value
1.	B.A ~ Ca + K + Mg + Na + N + P + pH + Salinity	250.01
2.	B.A ~ Ca + Mg + Na + N + P + pH + Salinity	248.01
3.	B.A ~ Ca + Mg + Na + N + pH + Salinity	247.62
4.	B.A ~ Ca + Mg + Na + N + pH	246.58

Table-26.Coefficient of the best generalized linear regression model for estimating basal area of *Sonneratia apetala*in for Coringa Wildlife sanctuary

	Estimate (β- coefficient)	Standard error	t - value	Pr(>|t|)
Intercept	1232.6	484.4	2.545	0.02913
Na	2215.7	575.6	3.849	0.00322
pH	1753.8	567.7	3.089	0.01146
N	-1336.2	600.7	-2.224	0.05032
Ca	905.8	576.8	1.570	0.14738
Mg	815.6	598.4	1.363	0.20278

Null deviance: 154733384 on 15 degree of freedom
Residual deviance: 37265386 on 10 degree of freedom
AIC: 293.98

The removal of the variable was significant because it also gave a model with a reduced AIC value from 250.01 to 246.58 (Table. 25). Thus from reduced model, Sodium (Na), having weightage (2215 ± 575.6) was a most significant factor for governing the *Sonneratia*

apetala species density and showing the positive relationship with the basal area. Sodium was followed by pH and nitrogen respectively, having weightage (1753.8 ± 567.7) & (-1336.2 ± 600.7). pH was positively correlated with basal area where as nitrogen was negatively correlated with it (Table. 26).

Table-27.Model selection for generalized linear regression of basal area of *Avicinnea officinalis* against covariates for Coringa Wildlife Sanctuary

Sr. No.	Model	AIC Value
1.	B.A ~ Ca + K + Mg + Na + N + P + pH + Salinity	266.91
2.	B.A ~ Ca + K + Na + N + P + pH + Salinity	264.97
3.	B.A ~ Ca + K + Na + P + pH + Salinity	263.21
4.	B.A ~ Ca + Na + P + pH + Salinity	262.24
5.	B.A ~ Ca + pH + P + Salinity	261
6.	B.A ~ Ca + pH + Salinity	260.54

Table-28. Coefficient of the best generalized linear regression model for estimating basal area of *Avicinnea officinalis*in for Coringa Wildlife sanctuary

	Estimate (β –coefficient)	Standard Error	t - Value	Pr(>|t|)
Intercept	8267.1	785.3	10.527	2.05e-07
pH	2761.2	824.6	3.348	0.0058
Salinity	-1497.4	970.2	-1.543	0.0487
Ca	-1273.9	970	-1.313	0.2136

Null deviance: 267490740 on 15 degree of freedom
Residual deviance: 114527461 on 12 degree of freedom
AIC: 307.95

The removal of the variable was significant because it also gave a model with a reduced AIC value from 266.91 to 260.54 (Table. 27). Thus from reduced model pH, having weightage (8267.1 ± 785.3) was a most significant factor for governing the *Avicinnea officinalis*

species basal area and showing the positive relationship with the basal area. pH was followed by salinity and calcium respectively, having weightage (-1497.4 ± 970.2) & (-1273.9 ± 970). Salinity and calcium, both were negatively correlated with basal area (Table. 28).

Table-29.Model selection for generalized linear regression of basal area of *Rhizophora apiculata* against covariates for Coringa Wildlife Sanctuary

Sr. No.	Model	AIC Value
1.	B.A ~ Ca + K + Mg + Na + N + P + pH + Salinity	317.48
2.	B.A ~ Ca + Mg + Na + N + P + pH + Salinity	315.51
3.	B.A ~ Ca + Mg + N + P + pH + Salinity	313.7
4.	B.A ~ Ca + Mg + N + P + Salinity	311.97
5.	B.A ~ Mg + N + P + Salinity	310.5
6.	B.A ~ Mg + N + Salinity	308.99

Table-30. Coefficient of the best generalized linear regression model for estimating basal area of *Excoecaria agallocha* for Coringa Wildlife Sanctuary

	Intercept (β –Coefficient)	Standard Error	t- Value	Pr(>|t|)
Intercept	25925	3558	7.286	9.66e-06
Salinity	-16883	3950	-4.274	0.00108
N	-7820	4344	-1.800	0.09701
Mg	6077	4028	1.509	0.15726

Null deviance: 634848117 on 15 degree of freedom
Residual: 236609124 on 12 degree of freedom
AIC: 356.4

The removal of the variable was significant because it also gave a model with a reduced AIC value from 317.48 to 308.99 (Table. 29). Thus from reduced model salinity, having weightage (-16883 ± 3950) was a most significant factor for governing the *Excoecaria agallocha* species basal area and showing the negative relationship with the basal area. Salinity was followed by nitrogen and magnesium respectively, having weightage (-7820 ±

4344) & (6077 ± 4028). Nitrogen was negatively related with basal area, where as magnesium was positively correlated with basal area of the species (Table. 30).

Table-31.Model selection for generalized linear regression of basal area of *Rhizophora apiculata* against covariates for Coringa Wildlife Sanctuary

Sr. No.	Model	AIC Value
1.	B.A ~ Ca + K + Mg + Na + N + P + pH + Salinity	182.71
2.	B.A ~ K + Mg + Na + N + P + pH + Salinity	180.72
3.	B.A ~ Mg + Na + N + P + pH + Salinity	178.73
4.	B.A ~ Na + N + Na + P + pH + Salinity	176.82
5.	B.A ~ Na + N + P + Salinity	175.03
6.	B.A ~ Na + P + Salinity	173.57
7.	B.A ~ P + Salinity	172.91
8.	B.A ~ Salinity	171.52

Table-32. Coefficient of the best generalized linear regression model for estimating basal area of *Rhizophora apiculata* for Coringa Wildlife Sanctuary

	Estimate (β –coefficient)	Standard Error	t- Value	Pr(>|t|)
Intercept	147.51	50.75	2.907	0.0115
Salinity	-54.60	51.82	-1.054	0.3099

Null deviance: 608657 on 15 degree of freedom
Residual deviance: 563933 on 14 degree of freedom
AIC: 218.93

The removal of the variable was significant because it also gave a model with a reduced AIC value from 182.71 to 171.52 (Table. 31). Thus from reduced model Salinity, having weightage (-54.60 ± 51.82) was a most significant factor for governing the *Rhizophora apiculata* species basal area (Table. 32).

Table-33.Model selection for generalized linear regression of basal area of *Avicinnea marina* against covariates for Coringa Wildlife Sanctuary

Sr. No.	Model	AIC Value
1.	B.A ~ Ca + K + Mg + Na + N + P + pH + Salinity	257.49
2.	B.A ~ Ca + K + Mg + Na + N + P + Salinity	255.5
3.	B.A ~ Ca + K + Mg + N + P + Salinity	253.6
4.	B.A ~ Ca + K + Mg + P + Salinity	251.64
5.	B.A ~ K + Mg + P + Salinity	251.12
6.	B.A ~ K + Mg + P	250.52

Table-34. Coefficient of the best generalized linear regression model for estimating basal area of *Avicinnea marina* for Coringa Wildlife sanctuary

	Estimate (β- coefficient)	Standard Error	t- Value	Pr(>|t|)
Intercept	2246.9	683.4	3.288	0.00648
K	1811.9	734.5	2.467	0.02966
Mg	988.3	613	1.612	0.13292
P	-974.7	604.3	-1.613	0.13276

Null deviance: 108354903 on 15 degree of freedom
Residual deviance: 61215475 on 12 degree of freedom
AIC: 297.92

The removal of the variable was significant because it also gave a model with a reduced AIC value from 257.49 to 250.52 (Table. 33). Thus from reduced model potassium (K), having weightage (1811.9 ±) was a most significant factor for governing the *Excoecaria agallocha* species basal area and showing the negative relationship with the basal area. Salinity was followed by nitrogen and magnesium respectively, having weightage (-7820 ± 4344) & (6077 ± 4028). Nitrogen was negatively related with basal area, where as magnesium was positively correlated with basal area of the species (Table. 34).

Table-35.Model selection for generalized linear regression of *Lumintzera racemosa* density against covariates for Coringa Wildlife Sanctuary

Sr. No.	Model	AIC Value
1.	B.A ~ Ca + K + Mg + Na + N + P + pH + Salinity	169.62
2.	B.A ~ Ca + K + Mg + N + P + pH + Salinity	167.65
3.	B.A ~ Ca+ K + Mg + N + P + Salinity	165.92
4.	B.A ~ Ca + K + Mg + N + Salinity	164.49

Table-36. Coefficient of the best generalized linear regression model for estimating basal area of Lumintzera racemosa in for Coringa wildlife sanctuary

	Estimate (β- coefficient)	Standard Error	t- value	Pr(>|t|)
Intercept	78.85	47.17	1.671	0.12558
Salinity	-203.44	55.51	-3.665	0.00435
N	-120.56	46.17	-2.612	0.02597
Ca	90.62	49.74	1.822	0.09848
K	95.27	60.72	1.569	0.14771
Mg	76.32	45.19	1.689	0.12213

Null deviance: 573613 on 15 degree of freedom
Residual deviance: 219633 on 10 degree of freedom
AIC: 211.84

The removal of the variable was significant because it also gave a model with a reduced AIC value from 169.62 to 164.49 (Table. 35). Thus from reduced model salinity, having weightage (-203.44 ± 55.51) was a most significant factor for governing the *Lumintzera racemosa* species basal area and showing the negative relationship with the basal area. Salinity was followed by nitrogen and calcium respectively, having weightage (-120.56 ± 46.17) & (90.62 ± 49.74). Nitrogen was negatively related with basal area, where as magnesium was positively correlated with basal area of the species (Table. 36).

Table-37.Model selection for generalized linear regression of *Xylocarpus granatum* against covariates for Coringa Wildlife Sanctuary

Sr. No.	Model	AIC Value
1.	Ca + K + Mg + Na + N + P + pH + Salinity	172.12
2.	Ca + K + Mg + Na + P + pH + N + Salinity	170.12
3.	B.A ~ K + Mg + Na + N + P + Salinity	168.14
4.	B.A ~ Mg + Na + N + P + Salinity	166.18
5.	B.A ~ Mg + Na + P + Salinity	164.31
6.	B.A ~ Mg + Na + P	163.65
7.	B.A ~ Mg + p	163.35
8.	B.A ~ Mg	162.86

Table-38. Coefficient of the best generalized linear regression model for estimating basal area of *Xylocarpus granatum* for Coringa Wildlife Sanctuary

	Estimate B- coefficient	Standard Error	t- Value	Pr (>|t|)
Intercept	80.86	38.28	2.112	0.0531
Mg	61.91	39.14	-1.566	0.1397

Null deviance: 335755 on 15 degree of freedom
Residual: 328270 on 14 degree of freedom
AIC: 210.27

The removal of the variable was significant because it also gave a model with a reduced AIC value from 172.12 to 162.86 (Table. 37). Thus from reduced model magnesium, having weightage (61.91 ± 39.14) was a most significant factor for governing the *Xylocarpus granatum* species basal area (Table. 38).

Table-39. The β coefficients with the standard errors for mangrove Basal area at a community level for Coringa Wildlife Sanctuary

S. No.	Species	Variable	β- coefficients
1	*Sonneratia apetala*	pH	1753.8 ± 567.7
		N	-1336.2 ± 600.7
		Na	1232.6 ± 484.4
		Ca	905.8 ± 576.8
		Mg	815.6 ± 598.4
2	*Avicinnea marina*	K	1811.9 ± 734.5
		Mg	988.3 ± 613
		P	-974.7 ± 604.3
3	*Excoecaria agallocha*	Salinity	-16883 ± 3950
		N	-7820 ± 4344
		Mg	6077 ± 4028
4	*Rhizophora apiculata*	Salinity	-54.60 ± 51.82
5	*Avicinnea officinalis*	PH	2761.2 ± 824.6
		Salinity	-1497 ± 824.6
		Calcium	-1273.9 ± 970
6	*Lumintzera racemosa*	Salinity	-203.44 ± 55.51
		N	-120.56 ± 46.17
		K	95.27 ± 60.72
		Ca	90.62 ± 49.74
		Mg	76.32 ± 45.19

Mangrove species showed a negative influence of salinity and nitrogen and positive influence of Magnesium and phosphorus on basal area of individual species at community level in Coringa Wildlife Sanctuary, Andhra Pradesh (Table. 38).

4.1.6.3. Results for the second objective: Factors controlling mangrove species density, Basal area and their Carbon sequestration potential at community level

4.1.6.3.1. Factor 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-40. 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-41. 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	301.263	<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. 40). 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. 41).

5.1.6.3.2. 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-42. 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-43. 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. 42). 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. 43).

5.1.6.3.3. 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-44. 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-45. 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. 44). 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. 45).

4.2 DISCUSSION AND CONCLUSION

4.2.1 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 on Gaderu and Coringa River reveals that *Sonneratia apetala, Xylocarpus granatum, Avicinnea 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 *Avicinnea 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. *Avicinnea 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). *Avicinnea 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); *Avicinnea marina* accumulates glycine betaine (Ashihora *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 have 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 & Ghose 1993).

4.2.2 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 on the basis of heterogeneity, complexity and scale of measurement as introduced by McCoy & Bell (1991). Such explained variable can be determined only on the basis of 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 on the basis of 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).

4.2.3 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 *Avicinnea 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 *Avicinnea marina*, *Bruguiera gymnorrhiza*, *Sonneratia apetala* and *Avicinnea 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*, *Avicinnea officinalis* and *Bruguiera gymnorrhiza*. Interestingly, Calcium influence seedling establishment and growth of *Bruguiera gymnorrhiza*, *Lumintzera racemosa* and *Avicinnea 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 considered to be 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 gymnorrhiza* 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.

4.2.4 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 responds 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 & 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 & 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 & 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 considered to be 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.

4.2.5 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 *Avicinnea officinalis*, *Avicinnea 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 more and more individuals, than other species that have only one option to regenerate only through the seedling establishment (Blasco 1977). *Avicinnea 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 *Avicinnea 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 shows 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.

4.2.6 RELATIONSHIP BETWEEN CARBON SEQUESTRATION POTENTIAL OF MANGROVE AND SALINITY

It is considered that at higher salinity assimilation of CO_2 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 CO_2 concentration, and intrinsic water efficiency.

CO_2 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 CO_2 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 & Moss 1968; Langstreth & Nobel 1980). Decreased photosynthetic rate of K-deficient leaves has been related to lowered stomata conductance (Moss & Peaslee 1965; Raschke 1975). Although increased mesophyll resistance may be the primary factor using the reduction in photosynthesis (Terry & Ulrich1973; Peoples & Koch 1979).

4.2.7 FUTURE DIRECTION

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 was always confusion in selecting a suitable species for mangrove plantation. It is expected that increasing concentrations of atmospheric CO_2 and other "greenhouse gases" will bring changes in the global climate. It has been predicted that each decade could bring a 0.3° rise in air temperature and a 6 cm rise in the global sea level (Titus & Narayanan 1996; Wilkinson 1996; Gregory & Oerlemans 1998). 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 CO_2 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 as well as bringing the more coastal area under mangrove cover. India has a vast patch of mangrove areas and provides a 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. But, there was no detailed study on the 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 more 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. Further, the 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 the landscape to coastal areas is imperative as a climate change adaptation strategy. Therefore, increase in coastal soil salinity due to predicted sea level increase would be compensated 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. EGREE Foundation of the Andhra Pradesh Forest Department has already taken some initiatives to restore some 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. 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 a MPA site, is undergoing rapid development, and mangrove forests are being converted for aquaculture ponds and agricultural farms. Present study in Coringa WLS somehow contributes by several means for conservation of mangrove ecosystem and provides a logistic support for restocking the degraded area in and around of this sanctuary. Now there is an urgent need to apply such information for conservation of mangrove habitat and related ecosystem services in Coringa WLS for achieving nation's target under this project.

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