Trends of *Avicennia marina* Productivity as Influenced by Climatic Seasons: A Case Study of Mbweni Mangrove Forest Ecosystem

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Abstract: *Avicennia marina (Forsk.) Vierh. is a salt tolerant plant that grows in the saline environment along the coastline. A study was carried out at Mbweni Mangrove Forests aimed at evaluating the effects of different climatic seasons on the productivity, growth, survival and spread of A. marina. A. marina litter falls were collected in nine litter traps set randomly at different stands of the mangrove forest where A. marina occupied at a density of 0.10 individual/m^2. Monthly collected litter were sorted into separate components, i.e. leaves, stems and seeds, weighed, recorded and mean weight values were calculated. From the litter, Sodium ions were determined by using Atomic Absorption Spectrophotometer method while Chlorine ions were determined by Ion Chromatography method. In leaf litter accumulation, the highest production was found in September with a mean weight of 78.53g/m^2. For Sodium and Chlorine ions, the mean concentration started to rise during the dry season of June to September. Lowest leaf litter mean values were recorded in April with a mean weight of 7.23g/m^2 and the concentration of Sodium and Chlorine ions was found lower during the wet season of April and May. For the propagule organs, data were recorded for only three months in which the highest accumulation was found in April with a mean value of 19.3g/m^2. During wet season in the month of April, high rates of propagules accumulation with dispersal was accelerated by water runoff leading to establishment of new colonies. For the duration of dry season (June to August) the soils had extreme salinity due to low rainfall. The inorganic ions, sodium (Na) and Chlorine (Cl) started to accumulate in the plant in order to maintain the homeostatic control, turgor pressure and osmotic adjustment. Accumulation of these ions and salts resulted to high productivity of leaf litter in September as a means of removing excess ions and unwanted salts. This was facilitated by strong wind that finally brought short rains in the month of November that also resulted to new vegetation. From this study, it can be concluded that varying climatic seasons has effects to A. marina productivity, growth and survival in the salt stressed environment, indicating that mangroves have a salt tolerant characteristics.*

Key words: *Avicennia marina*, propagule organs, productivity, leaf litter, salinity.

INTRODUCTION

Mangroves are a group of physiologically specialized plants inhabiting muddy swamps, creeks, deltas and sheltered shores along tropical sea coasts periodically inundated by the tides (Mainoya and Siegel, 1986). The plants, also referred to as halophytes are morphological and physiological adaptations that enable them to grow and survive in marine and salty environments (Steinke, 1995). These plants generally grow to moderate sized trees or evergreen shrubs 1-10m high with a trunk up to 40cm in diameter (Little, 1983). Mangroves belongs chiefly to the genus *Rhizophora*, though the genera *Avicennia, Bruguiera, Ceriops, Lumnitzera, Acanthus, Kandelia, Sayphyphora* and *Sonneratia* are usually represented (Mainoya and Siegel, 1986). The most dominant genera found in the coast of Tanzania are *Rhizophora, Avicennia*, and *Racemosa* (Eurico *et al.,* 2003). *A. marina* is important in protecting coast belts from erosion triggered by storm tides, hurricane winds, waves and floods. It maintain the diversity of coastal ecosystems by contributing quantities of food/nutrients and favorable habitats serving as valuable nursery areas for shrimp, crustaceans, mollusks, and fishes (Tomlinson, 1986). Mangroves' water-resistant wood is used in building houses, boats, pilings, and furniture. The wood of the black mangrove and buttonwood trees has also been utilized in the production of charcoal. Tannins and other dyes are extracted from mangrove bark. Leaves have been used in tea, medicine, livestock feed, and as a substitute for tobacco for smoking. (Morrisey, 2007).

A. marina [*Mchu*-local name] is reported to accumulate salts as means of salt resistance mechanisms (Liang, *et al.,* 2008). The species has developed a mechanism that limit sodium uptake by roots by storing the salts in cell vacuoles. Excess sodium may also be stored in old plant tissue, limiting the damage to new growth. It is thought that Na^+ and K^+ homeostasis is crucial for salt-tolerance in plants (Horie, *et al.,* 2001). Growth and survival of halophytes are dependent on the high levels of ion accumulation in its tissue for the maintenance of turgor and osmotic adjustment (Flowers, *et al.,* 1977). The plants secrete the accumulated salt through hundreds of tiny salt-secreting glands on the mangrove leaf's upper surface called salt secreting glands (Duke, 1992) and get rid of excess salt by shedding older leaves.

Other mangroves exclude salts at their roots through ultra filtration. Specialized roots systems are also one of the main characteristics of *A. marina*. Respiratory roots (pneumatophores) grown vertically up from the underground root system (Duke, 1992). They possess numerous lenticels that aid breathing and maintain life support functions due to the soils being unable to supply enough oxygen and gaseous exchange directly above the surface (Republic of China, 2012). In order to adapt the poor surroundings, *A. marina* has developed a viviparous (bringing forth young plant) water dispersed propagules (material used for propagating an organism to the next stage in their life cycle) rather than producing dormant resting seeds like most flowering plants. The fruits of the mangrove plant do not immediately drop after reaching maturity, but continues to grow and develop in the tree growing out of the seed coat and the fruit before detaching from the parent plant. Then it gradually forms pencil-shaped viviparous seedlings that absorb its nutrients from the mother tree (Republic of China, 2012).

The litter, mainly leaves, represents about one-third of production of mangroves (Alongi, *et al.,* 2005) contributing via detritus, to the food chains in the benthic coastal systems (Snedaker, 1987). It may be re-mineralized by decomposition, accumulated in the sediments and/or exported to adjacent areas (Pool, *et al.,* 1975). Litter fall amount is a useful index of mangrove productivity since it is a major fraction of mangrove net productivity which supports aquatic organism. Because it is logistically and economically viable, litter production has been widely used to evaluate the productivity of mangroves (Ramos-e-Silva, *et al.,* 2006, Fernandes, *et al*., 2007). Litter production of mangrove forests usually presents seasonal variation because it is influenced by several factors mainly related to the chemical and physical environment (e.g. air temperature, solar radiation, rainfall, type of substrate, nutrient concentration, freshwater availability) (Clough, 1992; Twilley and Day, 1999). Mangrove forests are productive ecosystems and support a high abundance and diverse variety of wildlife (Ong, 1995). This is as a result of high leaf production, leaf fall and rapid breakdown of the detritus (Aksornkoae, 1986). In determination of mangrove nutrients, mature leaves are useful indicators of mangrove forest nutritional status (Boto and Wellington, 1983).

Sodium (Na) is a micronutrient that aids in metabolism, specifically in regeneration of phosphoenolpyruvate and synthesis of chlorophyll (Kering, 2008). In others, it substitutes for potassium in several roles, such as maintaining turgor pressure and aiding in the opening and closing of stomata (Subbarao, *et al.,* 2003). Excess sodium in the soil limits the uptake of water due to decreased water potential, which may result in wilting; similar concentrations in the cytoplasm can lead to enzyme inhibition, which in turn causes necrosis and chlorosis (Zhu, *et al.,* 2001). The compartmentalization of Na^+ into vacuoles averts the deleterious effects of Na^+ in the cytosol. Moreover, the compartmentalization of Na^+ (and Cl^-) into the vacuole allows the plants to use NaCl as an osmoticum, maintaining an osmotic potential that drives water into the cells (Blumwald, 2000).

Chlorine is a co-factor in photosynthesis, acts as a counter anion to stabilize membrane potential, and is involved in turgor and pH regulation (Xu, *et al.,* 2000, White and Broadley, 2001). As an essential element, chlorine has several biochemical and physiological functions within plants. In rapidly expanding tissues such as elongating cells of roots and shoots, chlorine accumulates in the tonoplast to function as an osmotically active solute (Maas, 1968, Hager and Helmle, 1981). This transport of chlorine into the tonoplast occurs in association with the proton-pumping ATPase activity at the tonoplast, being specifically stimulated by chlorine (Churchill and Sze, 1984).

The accumulation of chlorine in plant cells increases tissue hydration (Heckman and Corn, 1989) and turgor pressure Christensen, *et al.,* 1981). Chlorine along with potassium participates in stomatal opening by moving from epidermal cells to guard cells to act as an osmotic solute that result in water uptake into and a bowing apart of the guard cell pair (Lee and Assman, 1991). Increasing of salinity in A. marina decreases stomatal conductance and tissue water potentials (Naidoo, 1987).

Nutrient levels in litter components have been less studied than in fresh tissue and no data were available for *Avicennia marina* litter nutrient contents (Twilley *et al.,* 1986, YiMing and Stenberg, 2007, Woodroffe *et al.,* 1988). In particular, few studies have been carried out to understand the contribution of seasons to the litter-fall variations of mangrove specifically *A. marina* available in Tanzania. Therefore, the clear understanding of the respective contributions of *A. marina* is an important conceptual attribute for ecologists in view of promoting a sustainable forest ecosystem. Consequently, this experiment aimed at determining the quantity of litter fall and respective inorganic ions (Sodium and Chlorine) related to salinity at different seasons.

STUDY AREA AND METHODOLOGY

STUDY AREA

In this study the productivity of the litter falls of *A. marina* and Sodium and Chlorine inorganic ions were determined in a period of twelve months (January to December 2009) and analyzed on how the litter falls and inorganic ionsô trend to seasonal differences are related to the survival of the plant. Sampling was done at Mbweni Mangrove Forests at a small creek of river *Zihebi* [local name] along the Coast of Indian Ocean.

The site area is located in Kinondoni administrative district about 30 km north of Dar Es Salaam city center (Fig 1), in Tanzania at $6^{0}40'$S, $39^{0}12'$E (McCusker, 1971). The 2002 Tanzanian National Census showed that the population of Kinondoni was 1,775,049 (NBS, 2012) with an area 531 km². High temperatures are found between the month of October and April, while low temperatures are between May and September (Fig. 2). It has a tropical wet and dry climate with two rainy seasons, in April and May the long heavy rains and October and November for the short rains as seen in Figure 3.

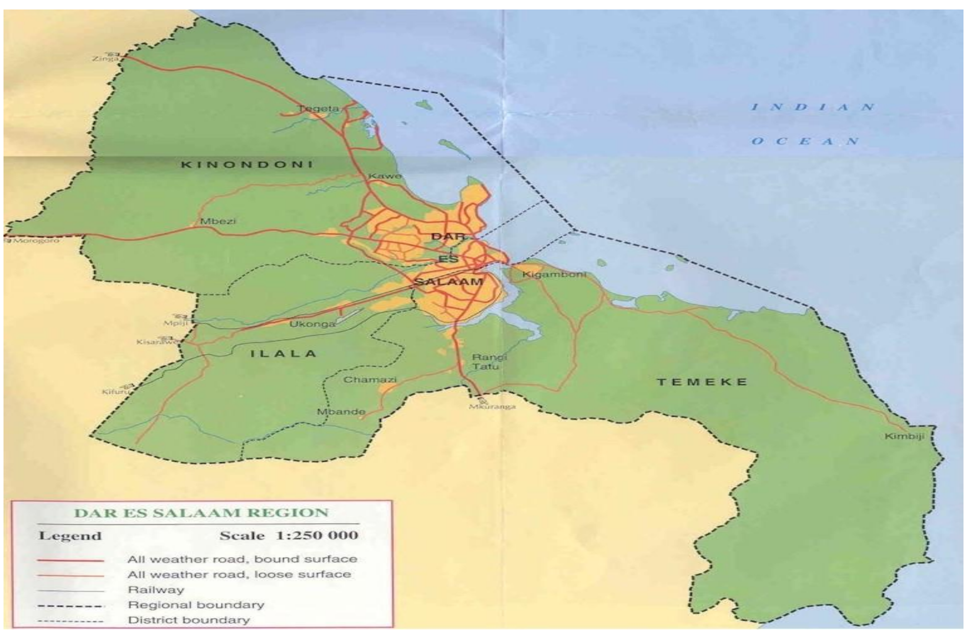

Figure 1: Map of Dar es Salaam with its Districts

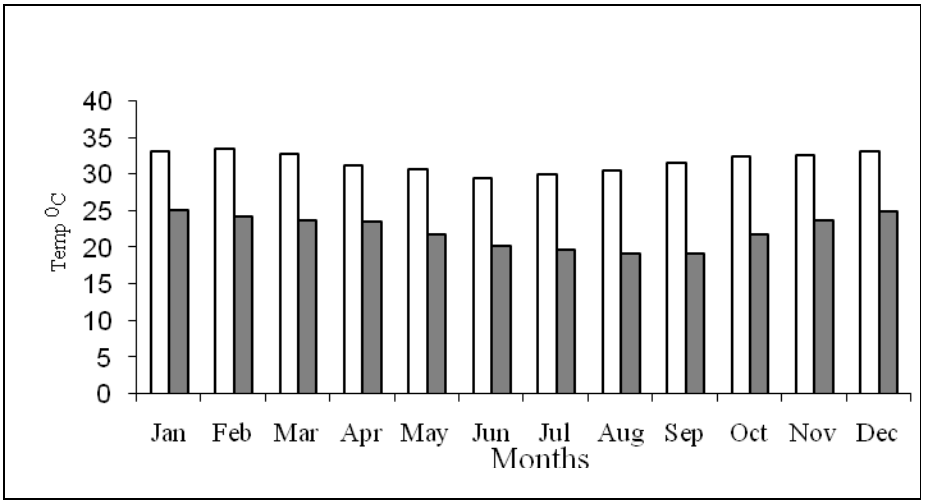

Figure 2: Mean monthly temperature in Dar es Salaam City
Source: TMA

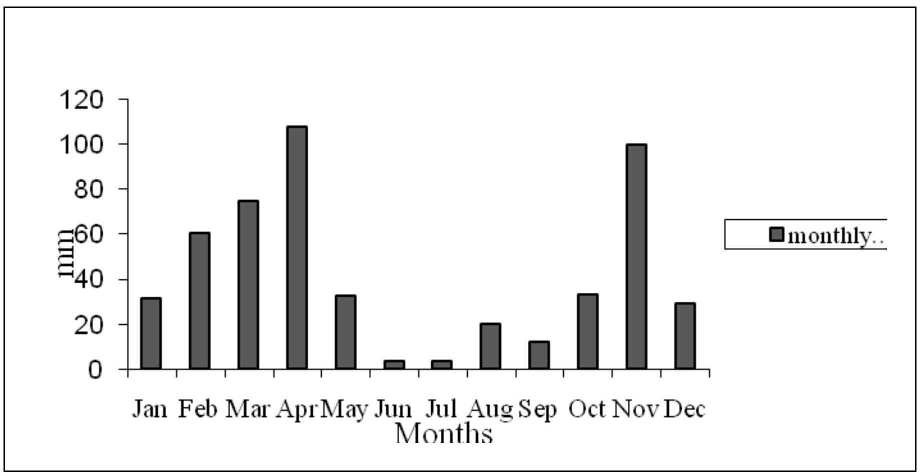

Figure 3: Mean monthly rainfall for Dar es Salaam city
Source: TMA

Data collection

The mangrove forest is a community of several tree species. Mbweni Mangrove Forest was dominated by *Ceriops, Rhizophora* and *Avicennia* and had a particularly high density of *Avicennia* seedlings (Wagner, 2004).

Inventory of mangrove forest at Pangani, Tanga showed the following species composition (Luoga *et al.,* 2004):

Ceriops tagal =75% of all species (dominant)
Rhizophora mucronata =22%
Xylocarpus granatum =2%
Bruguiera gymnorrhiza =0.5%
Sorenatia alba =0.5%

The litter falls of *A.marina* from Mbweni Mangrove Forest were collected from nine square wooden frames litter baskets (0.25m x 0.25m) forming an area of 0.0625m^2. Each had a thickness of 0.05m, 0.10m deep and 1.0 mm mesh nylon gauze (sieve like) to permit moisture loss. Using nylon strings, the leaf litter baskets were suspended randomly at different *A. marina* trees from the lower vegetative limbs of trees but above the highest tide level (Chale, 1993).

METHODOLOGY

After collection from each litter fall baskets, they were sealed to prevent loss of components and labeled by date and basket number. The litter was dried in an oven at a constant weight (80^{o}C for 96 hours), then sorted into separate leaves, leaf fragments, wood, seeds and insects, and weighed. Leaves and seeds (productive organs) were sorted, unidentifiable leaf fragments, wood and miscellaneous items such as insects were weighed and recorded separately to obtain the mean biomass (Snedaker, 1984).

Sodium from the leaf litter falls was determined by use of Atomic Absorption Spectrophotometry method (Roland and Irwin, 1952). The process was done for each month for the nine samples. 0.5g weight of the milled leaf litter falls were mixed with 10mls of de-ionized water. 2mls of the supernatant were further mixed with deionized water before and then injected into the spectrophotometer for reading the corresponding concentration values of the sodium ions. The readings were recorded from each sample monthly.

Chlorine from the leaf litter falls was determined by Ion Chromatography procedure (Peter, 2000). The sample weighing 0.1g of the milled leaf litter falls was taken and mixed with 10mls de-ionized water. This procedure was repeated in the nine test tubes for each composite sample. Composite sample was the material accumulated for the twelve months. Then all the test tubes were marked and heated in boiling water for one hour. After heating in boiling water, more water was added to make 10mls of the sample by volume. After cooling overnight, the supernatant was used to analyze the chlorine ions by Ion Chromatography method (Peter, 2000).

RESULTS AND DISCUSSION

From the results of the study as shown in Fig.4, the highest leaf litter accumulation was obtained in the month of September where the mean weight was 78.53g/m^2 and the lowest accumulation was seen in April with a mean weight of 7.23g/m^2. For the propagule organs, accumulation occurred for only three months in which the month of April had the highest mean accumulation of 19.3g/m^2. There was no collection for the rest of the months.

From the results in Figure 5, the highest sodium ions content was recorded in October with a mean concentration of 2.59mmolg^{-1}. The lowest mean concentration of 0.99mmolg^{-1} detected in May. The trend of sodium ions mean weight concentration showed a decrease between January and February, with an increase in March. Thereafter, there was a decrease to May beyond which it started again to increase to August with a slight decrease in September, and increased in October. The accumulation of sodium concentration subsequently showed a continuous decline to the month of December. The trend for chlorine ions mean weight concentration shown in Fig.6 coincided with those of sodium ions. The lowest accumulation was detected in May, with a mean weight concentration of 0.14mmolg^{-1} while the highest accumulation was detected in October, reaching a concentration 0.42mmolg^{-1}. From January to May, chlorine ions concentration decreased gradually. At the beginning of June, the concentration of Cl^- showed an increased. A slight decrease of Cl^- concentration appeared in September then an increase in October followed by a decrease from the month of November to December

These results showed that, during the dry season the soils surrounding the mangroves had high salinity due to low rainfalls (Mark, 2010). In order to maintain turgidity, *A. Marina* can decrease its tissue water potential that is more negative than that of soil (saline) thus they are called osmoregulators (Karimi, 1984). This is done by accumulating high levels of inorganic ions as sodium and chlorine as seen in Fig. 5 and Fig. 6 respectively. Sodium is responsible in homeostatic control of salts in the plants (Alongi, *et al.,* 2002) and also in maintaining turgor within plant stems. High concentration of Na^+ causes osmotic pressure to increase and water flows into the stem to maintain concentration equilibrium. During the rainy season, the pH of the soil becomes acidic (Rainwater pH = 5.6 (Kottlowski, 2006)). The lower the pH is, the greater the leaching power (Sylvia, 1998). Therefore, when the soils become more acidic due to rainfall, more H^+ were available and those can easily replace Na^+. This makes the Na^+ to be loosely bound and float freely thus easily being leached out of the plants. This argument was in agreement with the results of the study as presented in Fig. 5. Here it was clearly shown that less Na^+ was found in the leaf litter during the wet season. The balance between pressure inside and outside the plant cell changes hindering the process of water absorption. It regulates ion uptake thus high accumulation of Na^+ primarily in the vacuoles helped to maintain turgor within the plant (Jefferies, 1981). The above observation agreed with the results of the study that, salinity of the mangrove floor increased during dry season (Mark, 2010). Na^+ concentration tended to be high in the leaf litter so as to play its role of homeostatic control, maintained osmotic stress and balanced the ions inside from the outside. In the wet season, Cl^- was found to be low. Cl^- bound loosely to exchange sites (a highly mobile free anion) (Engvild, 1986) . Rainwater with pH 5.6 increased H^+ to the environment that easily bound with Cl^-, thereby lowering the concentration of Cl^- in the plants. In dry season, Cl^- ions in the leaf litter accumulated started to increase in concentration due to high salinity of the environment. It was apparent that, high salinity decreases turgor in the leaves therefore caused high accumulation of Cl^-. This was in agreement with its function of increasing tissue hydration (Heckman, 1989), turgor pressure (Christensen, 1981) and the net water use efficiency (Ball, 1988) in the plant. Cl^- was required for optimal enzyme activity (Rognes, 1980, Metzler, 2003, Churchill and Sze, 1984) before the vegetative phase of the plant.

Hence, accumulation of inorganic ions in mangroves helps in maintaining turgor and osmotic adjustment. To get rid of the excess ions, salts and unwanted chemicals, mangroves shed the old leaves (Naidoo and Chirkoot, 2004). This phenomenon was alleviated during the vegetative stage, a spring season of high wind prior to short rains, when there was high productivity of leaf litter (Table 2 and Fig. 4). Therefore, senescence, withering, death, and other stresses, as a result of causes such as wind, were factors that govern litter production. The high leaf litter production rate (as observed in Table 1) indicates optimal habitats for the mangrove, allowing the primary net productivity of mangrove forests to be favorably compared with tropical forests (Clough, 1992).

The highest accumulation of the propagule organs recorded in April was during the wet season (Fig. 4). Mangroves have the tendency of its seeds being attached to the parent tree for germination as it receive supplies of nutrients and water until they attain maturity, drops and floats away from the parent tree to start its own colony (Government of Republic of Taiwan, 2012). The high productivity of the propagule organs coinciding with the wet seasons implies that there was a need of water for them to be transported away from the parent tree to start a new colony. These results are supported by a research done in Southern hemisphere where most of mangrove bear mature propagules in late summer months and northern hemisphere in July and August. Likewise in the tropics and subtropics this generally coincides with, or is towards the end of, the rainy season (Saenger, 2002).

It was also observed on other studies done on accumulation of litter falls that resulted on 83% of *A. germinans* in Mexico (López-Portillo and Escurra, 1985) being leaf litter. Another study was done in New Zealand that resulted on 69.4% of *A. marina* litter falls collected was leaf litter (Davis, *et al.,* 2003). These results correspond with the results of this study as shown in Table 1 whereby, leaf litter collection was 75.79% out of all the litter collected.

Table 1. Litter falls collected

	Total mean weight (g/m^2) of leaf litter for 12 months	Total mean weight (g/m^2) of unidentifiable Fragments for 12 months	Total mean weight (g/m^2) of woods for 12 months	Total mean weight (g/m^2) of seeds for 12 months	Total mean weight (g/m^2) of miscellaneous for 12 months
Total	**436.49**	**52.32**	**29.76**	**23.32**	**34.03**
Percentage	**75.79%**	**9.08%**	**5.17%**	**4.05%**	**5.91%**

Table 2: Weight of Leaf litter and Reproductive organs

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Leaf Litter	**35.43**	**17.3**	**8.74**	**7.23**	**12.6**	**21.83**	**48.03**	**58.53**	**78.54**	**68.68**	**48.98**	**30.6**

Standard Error	**8.86**	**2.29**	**1.59**	**1.47**	**2.43**	**5.77**	**11.85**	**10.82**	**11.95**	**14.6**	**5.51**	**7.67**
Reproductive organs	**0.0**	**0.0**	**3.57**	**19.31**	**0.44**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Standard Error	**0.0**	**0.0**	**3.07**	**12.8**	**0.44**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

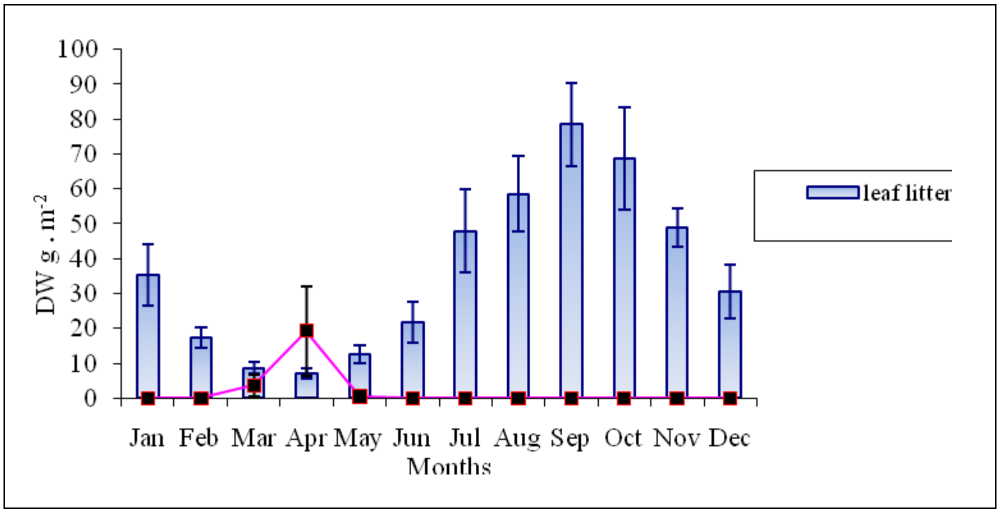

Fig. 4 Trend of dry weight in the litter falls of *A. marina* collected

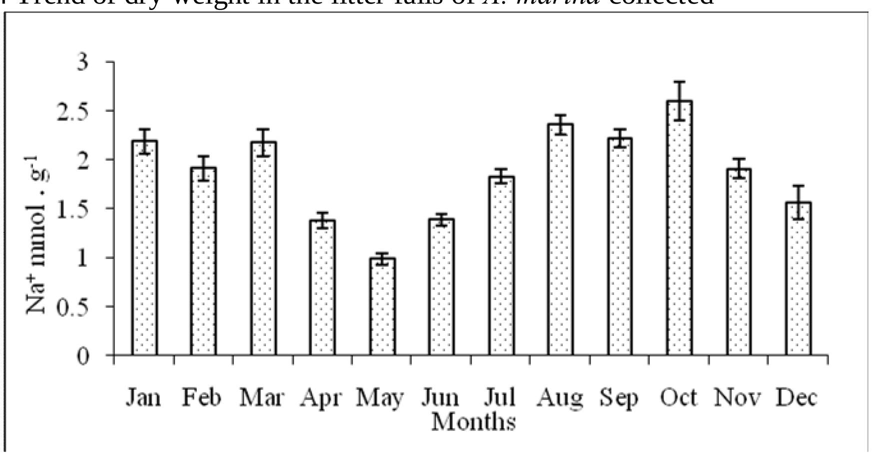

Fig. 5 Trend of Sodium (Na^{+}) content mean weight in the litter falls of *A. marina*

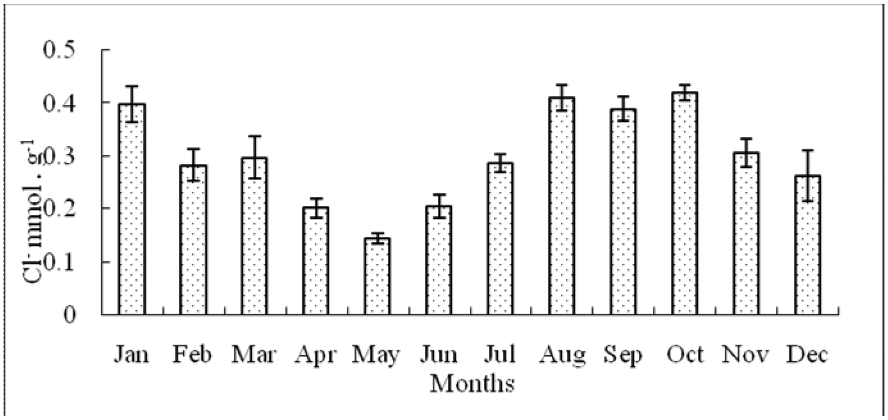

Fig. 6 Trend of Chlorine (Cl^-) content mean weight in the litter falls of *A. marina*

CONCLUSION

The baseline studies results reported in this paper showed that the Mangroves particularly *A. marina* has the tendency of accumulating inorganic ions at extreme salinity during dry season. This is then used as the main osmotic adjustment mechanism under salinity treatment. This associates the uptake of ions with the compartmentations of ions in the vacuoles causing high shoot concentration of Na^+ without any effects to the mangroves. So the high productivity of leaf litter was highly determined by the accumulation of the inorganic ions, in which the inorganic ions accumulate due to the extreme salinity in dry season.

Therefore, growth and survival of *A. marina* in saline environment is affected by the occurrence of inorganic ions which causes the high productivity of leaf litter which is of great importance to the ecosystem. The wet season facilitate the spread of new colony of *A. marina* by the propagules organs. The different seasons have a great effect on the productivity, growth and survival of *A. marina* which in turn protect the coast communities, stabilize the coastline, serves as a filter for upland runoff, habitat for marine organisms and contributes in soil formation.

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