American Journal of Marine Science, 2013, Vol. 1, No. 1, 7-15
Available online at http://pubs.sciepub.com/marine/1/1/2

DOI:10.12691/marine-1-1-2

Vegetation Structure and Species Distribution of Mangroves along a Soil Salinity Gradient in a Micro Tidal Estuary on the North-western Coast of Sri Lanka

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Received July 23, 2013; Revised August 15, 2013; Accepted August 17, 2013

Abstract Soil salinity in both coastal and inland, is known to affect vegetation structure and functions. Mangrove vegetation at Kala Oya estuary on the north western coast of Sri Lanka was selected to study the effect of soil salinity on structure, potential gross primary productivity and plant biomass of the ecosystems. Five belt-transects were laid perpendicular to the shoreline, covering 3.5 km upstream and approximately at 750 m intervals to collect data for the purpose. Vegetation structure was determined using data collected on plant species diversity, density, basal area, leaf area index and tree height. Biomass (total of above and below ground) of mangrove trees was estimated by allometric methods and potential gross primary productivity was calculated using leaf area index measured with terrestrial radiation sensor. Total of eight (8) true mangrove species were encountered in the area and highest density was recorded for *Rhizophora mucronata* (528 trees/ha), followed by *Excoecaria agallocha* (447 trees/ha) and *Lumnitzera racemosa* (405 trees/ha). Vegetation complexity index (CI), basal area, total tree biomass leaf area index and potential gross primary productivity measurements revealed an inverse correlation with soil salinity. Mangrove species were observed to possess varying salinity tolerance levels and *Avicennia marina* was the most salinity tolerant species, followed by *Rhizophora mucronata, Ceriops tagal and Lumnitzera racemosa*. *Excoecaria agallocha* was the least salt tolerant species in the area. Mangrove areas located around 2 km from the estuary mouth, where the soil salinity ranged from 8-12 mg/l, was observed to be with the highest species richness and diversity, indicating its' ecological and conservation significance that may be considered in mangrove management decision-making for the area. Presence of a few species of terrestrial and freshwater plants among the mangroves indicates salinity changes that would have taken place due to trans-basin diversion of water to the area for irrigation purposes.

Keywords: *mangroves, soil salinity, species distribution, micro-tidal estuary*

Cite This Article: K. A. R. S Perera, M. D. Amarasinghe, and S. Somaratna, "Vegetation Structure and Species Distribution of Mangroves along a Soil Salinity Gradient in a Micro Tidal Estuary on the North-western Coast of Sri Lanka." *American Journal of Marine Science* 1, no. 1 (2013): 7-15. doi: 10.12691/marine-1-1-2.

1. Introduction

Mangroves are associated with tropical coastal environments and they are comprised with woody halophytes that are well adapted to intertidal conditions. Many factors strongly influence the occurrence and growth of mangroves and these include geographical latitude, wave action, rainfall, freshwater runoff, erosion/sedimentation rates, aridity, salinity, nutrient inputs and soil quality [1]. Complex environmental factors determine the distribution of plants in nature. Several studies have attempted to correlate salinity with the standing biomass of mangroves and productivity [2,3,4] and local pattern of tidal inundation further influences the soil characteristics that control species zonation of mangroves [5].

Mangroves are salt tolerant and relative tolerance varies among the species. In general, mangrove vegetation is more luxuriant in lower salinities [6] 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 [7,8].

Coastline of Sri Lanka is approximately 1600 km long and the total extent brackish water areas, including estuaries and lagoons, is about 158016 ha [9]. Puttalam lagoon and Dutch bay, along with Portugal bay form the largest brackish water area (approximately 32,700 ha) in Sri Lanka and it accounts for 20% of total brackish waters in the country. Kala Oya estuary supports the largest and least disturbed mangroves in Sri Lanka, which extends over 1837 ha [10] and comprises nearly 65% of the mangroves in Dutch bay.

Kala Oya basin has undergone considerable changes in its hydrology with the diversion of water from Mahaweli river basin, for irrigation. Shifting Water table towards surface, increased volume of freshwater in Kala Oya and declined salinity in estuarine waters are the salient among changes. Increased presence of freshwater plant species such as *Typha anguistifolia*, *Nymphea* sp. and terrestrial plants such as *Diospyros* sp., *Terminalia arjuna* and *Manilkara hexandra* among mangrove plants provide testimony to this change.

Present study therefore was undertaken to investigate the effect of soil salinity gradient along the estuary on complexity of vegetation structure, especially in relation to species distribution as well as on potential gross primary production and carbon retention by mangrove plants.

2. Materials and Method

2.1. Study Area and Sites

Kala Oya estuary is located on the north western coast of Sri Lanka ($8^0$17' N; $79^0$50' E). A dry climate prevails in the area, where annual rainfall is 1000 -1100 mm and mean atmospheric temperature is 29-30 ^{0}C. Belt transects of 10 m wide were laid perpendicular to the shoreline, up to varying lengths inland, depending on the width of the mangrove area and the locations are depicted in Figure 1 with distance from the river mouth (place where the river meets Dutch bay) and area of the transects are given in Table 1.

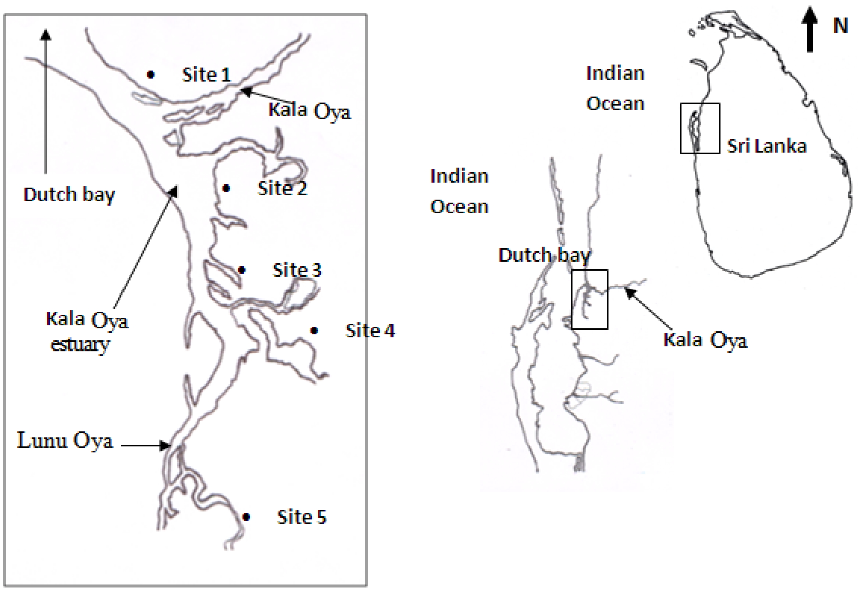

Figure 1. Study sites located at Oya estuary

Table 1. Basic information about the study sites at Kala Oya estuary

Study site	location	Area of the transect (m^2)	Distance from estuary mouth (m)
1	$8^0$17' 41.44" N; $79^0$50' 26.17 E	400	813
2	$8^0$17' 11.31" N; $79^0$50' 45.65 E	500	1533
3	$8^0$17' 24.50" N; $79^0$50' 42.51 E	400	2143
4	$8^0$17' 05.95" N; $79^0$50' 51.48 E	400	2408
5	$8^0$16' 43.38" N; $79^0$50' 50.04 E	400	3430

2.2. Vegetation Structure

Data on mangrove vegetation structure i.e. species diversity, tree diameter at breast height (dbh) and tree height were collected using standard methods [1,11] from each sub-plot (100 m^2) in the belt transects. Plants with less than 2.5 cm in girth at breast height (gbh) were excluded.

Complexity of index [12,13] which has taken into account the number of species, stand density, stand basal area, and stand height, was modified and leaf area index too was added to the equation.

$$Complexity\ of\ index(CI) = number\ of\ species \times stand\ basal \times leaf\ area\ index\ stand\ height \times 10^{-5}$$

Relative contribution of each constituent species to the mangrove vegetation structure was assesses by calculating the importance value for each species.

$$Importance\ value(IVI) = Relative\ density \times Relative\ frequency\ of\ occurence \times Relative\ dominance(basal\ area) \quad [11]$$

2.3. Potential Gross Primary Productivity (GPP)

Leaf area index was determined by measuring the difference between photon flux density beneath the mangrove canopy and top of the canopy, by using LI-COR Terrestrial radiation sensor (LI-191SA Line Quantum sensor) and following the method described by [11,12].

$$I = I_0 e^{-kLI}$$

$$L^I = \frac{\log e(I/I_0)}{-k}$$

$$L = L^I \times \cos(\theta \times 3.141593/180)$$

I = photon flux density beneath the canopy
I_o = photon flux density incident on the top of the canopy or fully exposed position outside the canopy
L^I = Leaf area index correction; L = Leaf area index; θ = zenith angle
k= canopy light extinction coefficient.

Clough (1997) and English et al (1997) reported that k commonly lies between 0.40 and 0.65 in a variety of mangrove canopies and hence the average value, i.e. 0.5 was used for calculations.

Approximately 50 readings were taken beneath the canopy (I) from each sub plot and accordingly 200-250 readings were obtained from each transect/study site during 08.00 and 14.00. Zenith angle (angle of the sun from the vertical) at the time of measurement was obtained from the Metrological Dept. of Sri Lanka.

Potential gross primary productivity (GPP) of the canopy per unit area was calculated according to the method proposed as below [10].

$$P_N = A \cdot d \cdot L$$

P_N = Potential gross primary productivity of the canopy per unit area
d = day length in hours; L = leaf area index
A= Average rate of photosynthesis, the value for dry season was taken as 0.216 g C m^{-2} hr^{-1} and for the wet season as 0.432 g C m^{-2} hr^{-1}

Since the rate of photosynthesis varies from dry to wet season [14,15,16], and therefore the present study, the average rate for dry season was taken as 0.216 g C m^{-2} hr^{-1} while that for the wet period was considered as 0.648 g C m^{-2} hr^{-1} [17].

2.4. Soil Salinity

Soil was collected from the first 5 cm from the surface and water was obtained by pressing soil with a plastic syringes to obtain interstitial water and its salinity was measured using a potable refractometer (iuchi IS-Mill-E). Mean salinity was calculated with salinity measurements made at 4 randomly selected localities in each sub-plot.

2.5. Mangrove Biomass of Mangrove Plants

Above ground and below ground biomass of mangrove species in the sub-plots was determined by allometric equations derived for individual species [18,19,20]. Table 2 includes the allometric equations used for the purpose.

Table 2. Summary of the used allometric equations for determine above and belowground biomass in mangroves

Mangrove species	Above ground biomass (AGB)	Below ground biomass (BGB)
Bruguiera gymnorrhiza	AGB= 0.289 $(dbh)^{2.327}$ (Perera & Amarasinghe, 2012)	BGB= 0.100 $(dbh)^{2.364}$ (Perera & Amarasinghe, 2012)
Lumnitzera racemosa	AGB= 0.114 $(dbh)^{2.523}$ (Perera & Amarasinghe, 2012)	BGB= 0.118 $(dbh)^{2.063}$ (Perera & Amarasinghe, 2012)
Rhizophora mucronata	$\log_e$(AGB)= 6.247+2.64 $\log_e$(dbh) (Amarasinghe & Balasubramaniam, 1992)	BGB= 0.199 $\rho^{0.899}$ $dbh^{2.46}$ (Komiyama et al., 2005)
Avicennia marina	$\log_e$(AGB)= 5.551+2.153$\log_e$(dbh) (Amarasinghe & Balasubramaniam, 1992)	
Bruguiera cylindrica	AGB= 0.251 ρ $dbh^{2.46}$ (Komiyama et al., 2005)	
Excoecaria agallocha		
Ceriops tagal		
Aegiceras corniculatum		

AGB- Above ground biomass, BGB- below ground biomass, dbh- diameter at breast height (1.3 m), ρ – density of wood (http://www.worldagroforestrycenter.org).

3. Results

3.1. Relative Contribution of Constituent Mangrove Species to Vegetation Structure

Rhizophora mucronata was the most abundant (528 trees/ha) mangrove species in Kala Oya estuary. *Lumnitzera racemosa* retains the highest biomass (1.27 t/ha) while *Aegiceras corniculatum* population retains less than 0.5 ton of biomass per ha. The mean tree size (as indicated by mean *Excoecaria agallocha*, and *Lumnitzera racemosa* (as indicated by mean dbh, basal area and height) are the most dominant and it is corroborated by the importance value index (IVI). Structural data on constituent species of mangrove areas at Kala oya estuary are presented in Table 3.

Table 3. Structural data of constituent species of Kala Oya estuarine mangroves

Species	Density (No. Trees per ha)	Mean basal area(m^2)	Mean height (m)	Total biomass (t/ha)	IVI
Rhizophora mucronata	528(4.847)	0.016(0.000)	7.19(0.286)	0.73(0.056)	52.05(0.481)
Bruguiera gymnorrhiza	48(1.000)	0.008(0.003)	7.28(1.475)	0.51(0.233)	7.84(0.162)
Bruguiera cylindrica	338(8.057)	0.009(0.001)	7.40(0.545)	0.611(0.124)	36.87(0.887)
Avicennia marina	414(8.039)	0.011(0.001)	6.58(0.338)	0.579(0.073)	46.27(0.887)
Lumnitzera racemosa	405(5.284)	0.019(0.002)	9.56(0.516)	1.273(0.214)	61.05(0.783)
Excoecaria agallocha	447(5.572)	0.025(0.024)	8.92(0.361)	0.958(0.108)	69.32(0.865)
Ceriops tagal	152(1.788)	0.004(0.000)	6.74(2.104)	0.263(0.060)	23.81(0.280)
Aegiceras corniculatum	10(0.547)	0.001(0.000)	3.25(0.250)	0.042(0.010)	2.78(0.152)

*****(Std. error of mean)

3.2. Mangrove Vegetation (Plant Community) Structure

Highest stand density (3375 trees/ha) was revealed from the sampling site that is situated 2.1 km from the estuarine mouth where the soil salinity is 13.25 mg l^{-1} (Table 4). The highest basal area (48.25 m^2 per ha) and leaf area index (6.52) were recorded from the study site located 3.5 km from the estuary mouth where the soil salinity is 8 mg l^{-1}. Highest species richness occurs at the study site located 2.4 km from the estuary mouth where the soil salinity is 13 mg/ l.

Table 4. Summary of mangrove vegetation structural parameters and soil salinity recorded in each study sites at Kala Oya estuary. Standard error of the mean is given in the parantheses

Sampling site	Species richness	Stand density (Per ha)	Basal area (m^2 per ha)	Stand height (m)	Species diversity	Leaf area index	Complexity Index (CI)	Soil salinity (mg/l)
1	6	2350 (373.11)	27.1 (0.031)	5.35 (0.196)	1.58	4.30 (0.069)	12.88 (0.594)	23.00
2	4	1340 (178.88)	33.27 (0.073)	11.38 (0.528)	1.34	4.62 (0.036)	16.46 (0.927)	18.00
3	7	3375 (637.59)	34.30 (0.028)	5.62 (0.168)	1.76	5.26 (0.024)	48.59 (2.57)	13.25
4	8	1900 (469.59)	30.98 (0.042)	10.76 (0.910)	1.54	5.33 (0.032)	55.66 (4.34)	13.00
5	6	3000 (726.57)	48.25 (0.045)	8.39 (0.377)	1.48	6.52 (0.034)	80.60 (4.04)	8.00

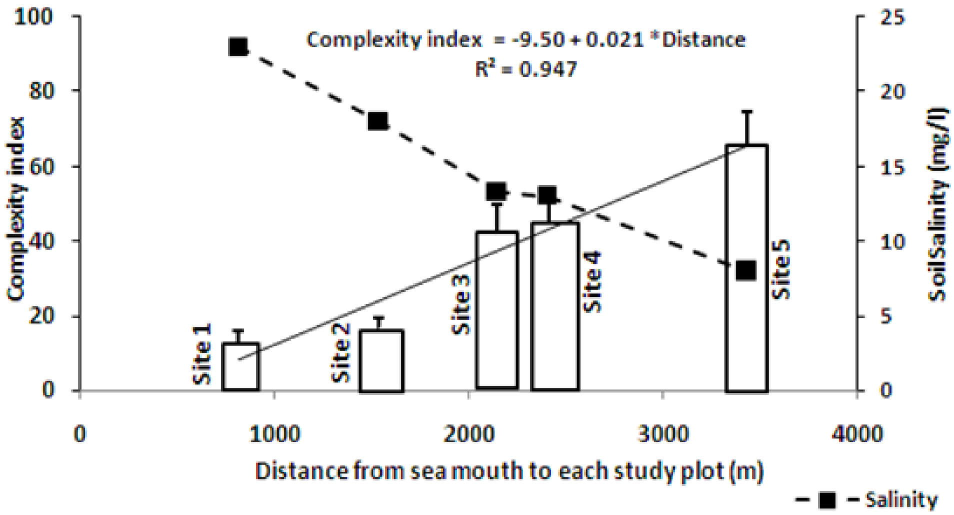

Figure 2. The relationship between vegetation structure in terms of complexity index (CI) with distance upstream from sea mouth of Kala Oya estuary

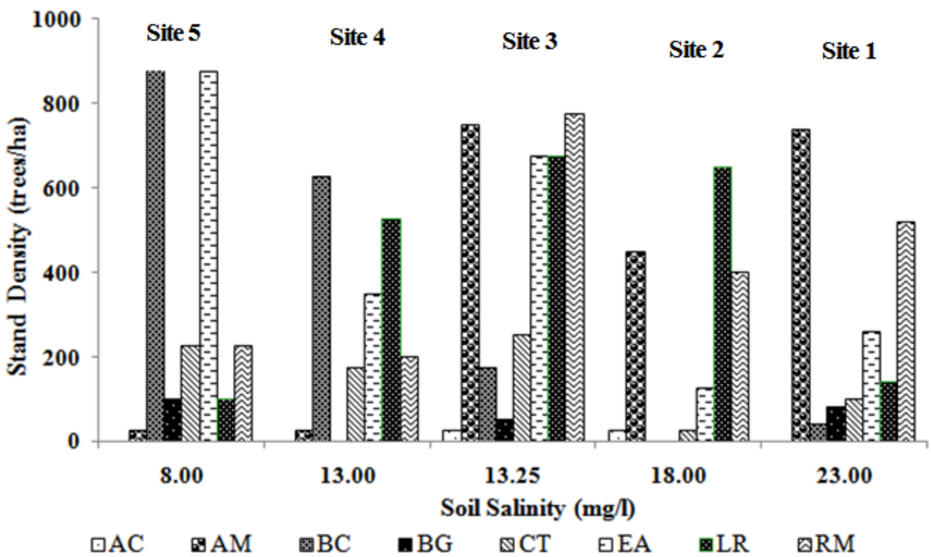

Figure 3. Density of constituent plant species of mangrove stands occupying areas with varying soil salinities distributed within a distance of 3.5 km at Kal Oya estuary

AC- Aegiceras corniculatum, AM- Avicennia marina, BC- Bruguiera cylindrica, BG- B. gymnorrhiza, CT- Ceriops tagal, EA- Excoecaria agallocha, -LR- Lumnitzera racemosa RM- Rhizophora mucronata.

Complexity of index (CI) that represents the structural complexity of mangrove communities at each site shows a statistically significant positive correlation with distance from the estuary mouth and s oil salinity (Figure 2).

Along the 3.5 km length of Kala Oya estuary, *Avicennia marina* was observed to be most abundant in high salinity areas (13.25-23 mg/ l) near the estuary mouth and it gradually declines along the salinity gradient. *L. racemosa* occurs in low dominance in estuarine mouth (high salinity areas), and it increases at 2000- 2500 m upstream, nevertheless showing a decrease in the areas of low salinity (8 mg/l) about 3000-3500 m upstream from estuary mouth. *E. agallocha* and *Bruguiera cylindrica* recorded low occurrence in 850-1000 m area with high salinity (18-23 mg/l) and become highly dominant in low salinity (8 mg/l) around 3000-3500 m upstream from estuarine mouth (Figure 3).

A highly positive correlation was revealed between salinity and density of *A. marina* (0.730) (Table 5). This implies that density of *A. marina* increases with salinity. Nevertheless, a statistically significant linearly relationship was not found among salinity and density of *A. corniculatum*, *B. gymnorrhiza* and *L. racemosa*. Plant density of *B. cylindrical* (r = -0.843), *E. agallocha* (r = -0.747) and *C. tagal* (r = -0.647) showed a decrease in density with increasing salinity.

Table 5. Correlation between salinity and distribution of species density at Kala Oya estuary

		Species							
		AC	AM	BC	BG	CT	EA	LR	RM
Salinity	Pearson Correlation Coefficient (r)	0.049	0.730	-.843	.000	-.647	-.747	-.013	.457
	Sig. (2-tailed)	.937	.161	.073	1.000	.238	.146	.984	.439
	No. of transects (n)	5	5	5	5	5	5	5	5

* Correlation is significant at the 0.05 level (2-tailed).

3.3. Mangrove Plant Biomass

A statistically significant positive relationship was revealed between total tree biomass and embedded total organic carbon (TOC) content with distance from sea mouth of the estuary where a salinity gradient exists (Figure 4).

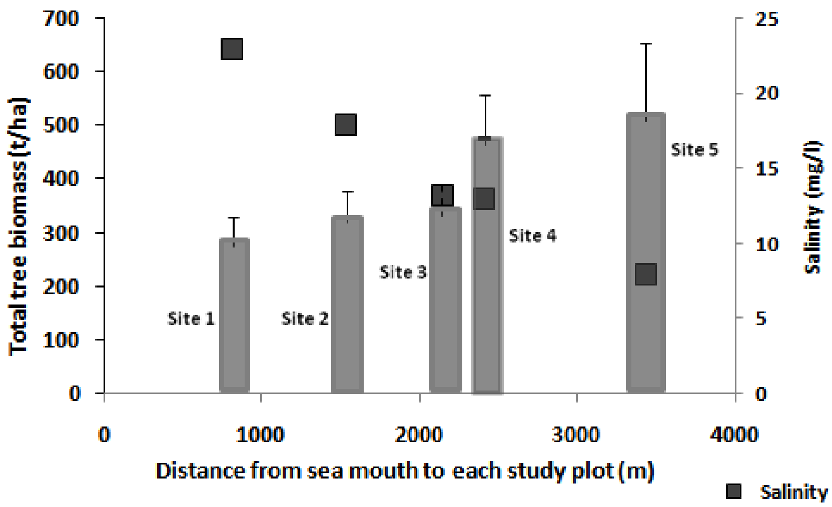

Figure 4. Variation of total tree biomass and total organic carbon content with soil salinity along a distance of 3.5 km in Kala Oya estuary

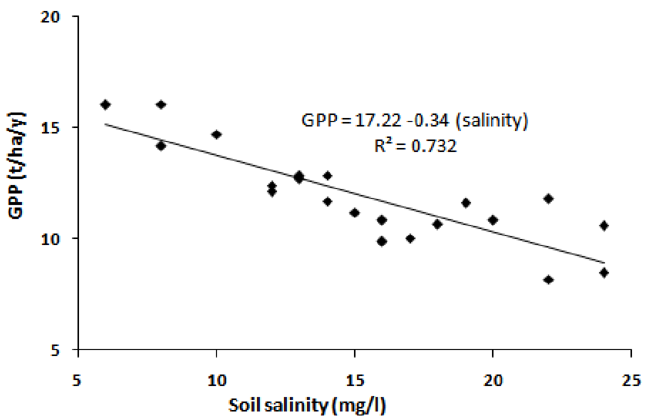

Figure 5. Relationship between potential gross primary productivity and soil salinity of Kala Oya estuary

3.4. Potential Gross Primary Productivity (GPP)

A statistically negative correlation was revealed between GPP and soil salinity of the study sites at Kala Oya estuary. Pearson correlation (-0.849) revealed that the correlation is significant at the 0.01 level (2-tailed) (Figure 5).

3.5. Species Diversity

Species diversity (Shannon-Wienner index) calculated for each study plot at Kala Oya estuary showed that a highly negative correlation exists between salinity and species diversity(Pearson correlation = -0.797) and it was significant at the 0.01 level (2-tailed). The highest plant species diversity occurs in relatively low salinity range between 6 -12 mg/l.

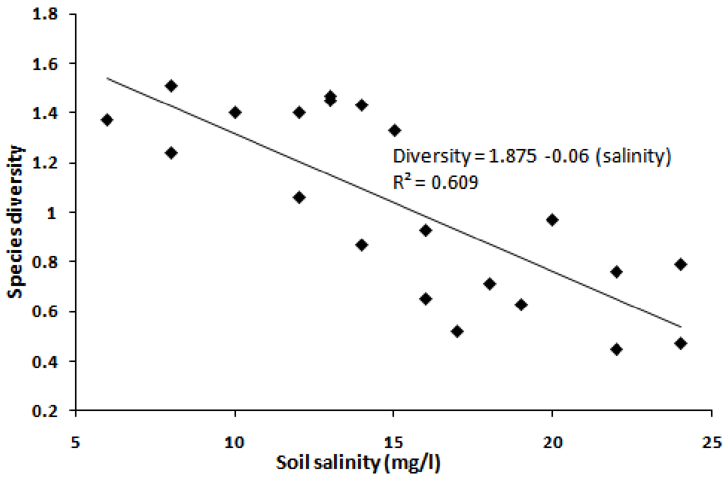

Figure 6. Relationship between mangrove species diversity and soil salinity of Kala Oya estuary

Table 6. Summary of the extraction of principal component analysis of 12 parameters at 21 study plots along the Kala Oya estuary

	PC 1	PC 2	PC 3
% of variance explained	57.180	29.118	8.417
Cumulative %	57.180	86.298	94.715
Total biomass	0.994	0.008	0.098
Aboveground biomass	0.994	0.008	0.095
Root organic carbon	0.990	0.004	0.112
Basal area	0.936	0.032	0.146
Tree height	0.276	0.066	0.958
Salinity	0.002	-0.967	-0.045
Distance from sea mouth	0.031	0.960	0.085
Gross primary productivity (GPP)	0.018	0.930	0.008
Species diversity	-0.013	0.876	-0.035

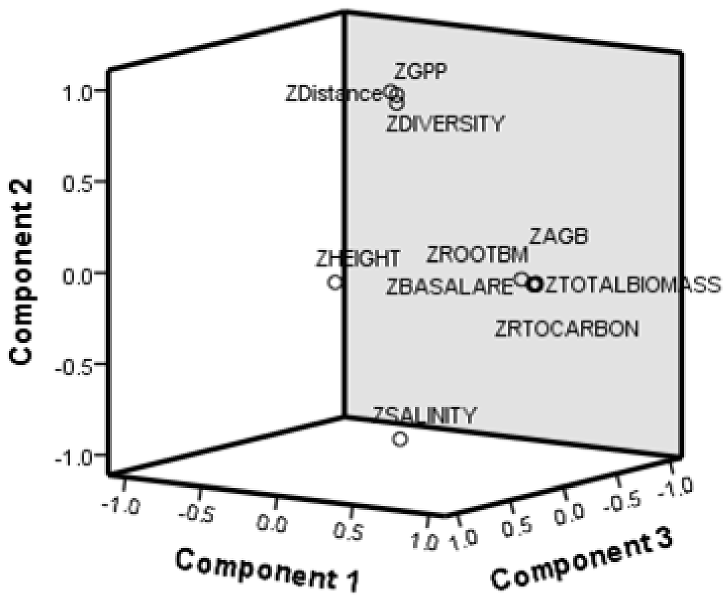

Figure 7. Final results of the extraction of principal components plot in rotated space

Data collected from 21 study plots were subjected for Principal component analysis (PCA). The PCA of the results suggested that three components together were able to explain 94.71% of the total variance in the data. The three PCs individually accounted for 57.18%, 29.11% and 8.41% of the variance respectively. The components loading indicated in Table 4, shows that structural parameters except for tree height, highly load along the first PC (> 94 %). The second component is loaded with environmental and physical parameters of the study area. The salinity of the sites indicated a strong negative contribution to the second PC. The tree height highly loaded in the third PC with value of 0.958. Overall extraction of principal components plot in rotated space is depicted in Figure 7.

The PCA scores derived for PC1 and PC2 were used to plot to observe the pattern reflected from the sites included in the study (Figure 8). The sampling plots of site 1 clustered into one group with certain amount of overlapping were with the plots of site 2. Similarly, the plots of site 3 and site 4 fall into a single cluster. The plots of the site 5, were well separated from the rest of the sites. The general pattern reflected from the study was that the salinity variation between sites seems to be contributed much to the species occurrence reflected in the Figure 8.

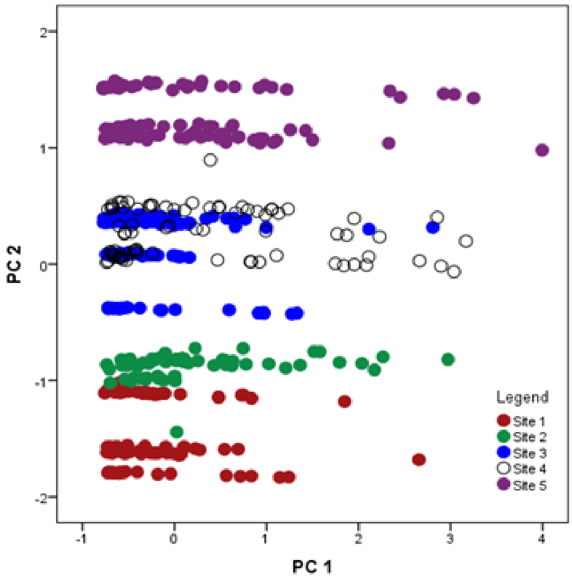

Figure 8. Distribution pattern of each sampling plot in study sites

4. Discussion

Nearly one third of the true mangrove species (8 species) that have been recorded from Sri Lanka occurs in the five study sites that covered 2100 m^2 in extent at Kala Oya estuary (Table 3). Although most of the species occur in all the study sites, their relative densities differ markedly. With a relative density (RD) of 22.5, *R. mucronata* was revealed to be the most abundant species in Kala Oya mangrove areas and it corroborates with previous observations [18,21]. *A. corniculatum* was the least abundant (RD = 0.4) and its distribution is sporadic along the salinity gradient. Relative density of *A. marina* declines from 39 to 23 when soil salinity decreases. On contrary, *A. agallocha* and *B. cylindrica* were more abundant in the low salinity areas in the upstream of the estuary, indicating their low salinity. Despite high density, *R. mucronata* contains relatively low amounts of biomass and total organic carbon and thus low importance value index, due the small size of the stems (Table 3). The heavy propagules of *R. mucronata* that could not get dispersed efficiently by the weak tidal currents appear to establish themselves near the water-front areas making this zone dominated by this species. Distribution of *L. racemosa* was predominant around 2000 – 2500 m away from the river mouth where the soil salinity is about 15 mg/ l, indicating its narrow range of salinity tolerance.

Maximum vegetation structural complexity (CI) has been reported from mangrove areas in least saline zones of Lothian island of the western Sundarabans [22]. In the present study too, the highest complexity values were recorded from the study site located in the most landward (upstream) area, 3.5 km away from estuary mouth where the soil salinity (8 mg/l) was lowest.

Mangroves are adapted to tolerate anoxia and salt in the intertidal substrate [23], and salinity plays a vital role in the distribution of species, their growth and productivity. Some species such as *A. marina* do not grow in fresh water and may be obligate halophytes. Others, such as *E. agallocha*, survive well in fresh water and may not have obligatory requirement for salt beyond trace amount [24]. Under natural conditions, mangroves exhibit clear tolerance differences among species. Findings of the present study are comparable with already documented [24] relative tolerance levels of 36 mangrove species [24].

Distribution of mangrove species towards the upstream of Kala Oya estuary along the soil salinity gradient (Figure 3) revealed that, area around 2000 m away from river mouth, with soil salinity of 13 mg/l, supports highest species richness (study site 3 and 4) of the area. This might be the most favorable salinity regime for the majority of mangrove species of Kala Oya estuary, and thus would be the most important area with respect to conservation and management of mangrove ecosystems in Kala Oya estuary.

Potential gross primary productivity (GPP) revealed to possess a negative relationship with soil salinity. High salinity of interstitial water reported to result in reduced leaf area, thus increasing the leaf area/ leaf weight ratio which in turn leads to decrease in total nitrogen, potassium and phosphate content with the plant [25]. It has also shown that a simple rise of salinity in the soils may have a significant negative effect on photosynthesis and growth of mangroves [26]. Evidently, hyper-salinity has led salt marshes to invade into mangrove areas in Senegal [27]. In Kala Oya estuary, the mangrove areas in the low-salinity upstream areas therefore contribute most to the total mangrove productivity of this estuarine system.

Total tree biomass too was revealed to possess a negative correlation with soil salinity (Figure 4). Hydroponically grown *Bruguiera gymnorrhiza* has proven that the mangrove tree biomass reduces with increasing salinity [28]. Denaturing of terminal buds of *Rhizophora mangle* seedlings also has been reported at high soil salinities [29] and such adversaries, among others may produce less biomass in highly saline areas. Besides, as plants growing in high saline soils spare more energy to exclude salt, they naturally perform inferiorly to those inhabit in low-saline soils [18]. Since approximately half the tree mangrove biomass is composed of organic carbon, [30,31] capacity of carbon sequestration by mangrove stands increases with decreasing soil salinities. Contribution of mangrove plants in the low-salinity inter-tidal areas of Kala Oya estuary therefore is of high ecological significance with respect to carbon-sink function of this estuary.

Results of the principle component analysis (PCA) revealed that salinity is one of the major factors that affect distribution of mangrove species, gross primary production (GPP), total biomass (above and below ground), and total carbon retention in mangrove ecosystems in Kala Oya estuary. Hydrology of the river basin and input of freshwater plays a major role in maintaining the salinity levels in the estuary. During the last twenty years, upstream of Kala Oya has received increasing amounts of freshwater through spilling of Rajanganaya reservoir and the paddy fields that it irrigates. Irrigation waters that pass through crop fields not only change the salinity levels, but also may provide plant nutrients for the down streams. Changes in quality and quantity of fresh water input may affect growth and structure of mangrove vegetation as well as other ecosystems that depend directly or indirectly on them. A few freshwater plant species (*Nymphaea lotus*) that were found growing close to mangrove plants along Kala Oya and Lunu Oya distributaries, about 2000 m from estuary mouth, indicate presence of permanent pockets of freshwater in the estuary, where the water should otherwise be brackish. Terrestrial tree species such as *Manilkara hexandra* and *Diospyros* species that were observed within the mangrove areas (although they were not encountered in the sampling plots) of Kala Oya estuary too indicate declined salinity conditions that prevail over extensive periods. Previous studies at Kala Oya estuary [18,32] did not record the occurrence of terrestrial or freshwater plant species within the mangroves, corroborating the fact that changes in salinity and other physical and chemical conditions of the estuary may have occurred during the last twenty years with more irrigation water reaching Kala oya basin as a result of diversion of river water from Mahaweli river basin. Anticipated climate change may not only affect the mangrove ecosystem structure and function through inundation but also through altered salinity regimes due to changing rainfall patterns and freshwater input to these inter-tidal areas.

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