

Floral Distribution, Diversity and Ecology of Mangrove Forests in Mandaitivu and Arali, Sri Lanka

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Abstract Mangroves in the Northern parts of Sri Lanka has been understudied and often ignored by the ecologists due to several reasons. This paper contributes to the assessment of floristic diversity and community structure of mangrove forests in two sites in the Northern Province; Mandaitivu and Arali. Vegetation studies were undertaken with the use of 10m wide belt transect laid across the water-land gradient, within which, 5-7 quadrats were placed for floral identification ($n_{\text{Mandaitivu}}=67$, $n_{\text{Arali}}=44$). Subsurface water samples ($n=57$) from adjacent estuarine region were taken to assess environmental parameters. Ten true mangrove species of six families were identified altogether in both sites. *Bruguiera cylindrica*, *Lumnitzera racemosa*, *Excoecaria agallocha* and *Avicennia marina* showed higher niche width. Zonation exhibited Rhizophora in the fringing zone, Avicennia landward and the others in the mixed zone. Salinity in both areas were relatively high and showed a significantly positive correlation with mangrove abundance along with conductivity, tidal regime and pH. Despite of their important role in coastal dynamics, mangroves have been degraded due to anthropogenic activities, thus demanding actions for conservation in the future.

Keywords: mangroves, diversity, Arali, Mandaitivu, distribution, conservation

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1. Introduction

Mangroves are a diversified group of predominantly tropical trees and shrubs growing in the marine intertidal zone where conditions are usually harsh, restrictive and dynamic; such as rhythms of tides and seasons or long-term changes of climate and sea level. They are dominant coastal vegetation system comprising chiefly angiosperms uniquely adapted to marine and estuarine tidal conditions; densely structured with closed canopies cloaking coastal margins and estuaries of equatorial, tropical and subtropical regions around the world. As a group, they share several highly specialized and collectively well known for their morphological and physiological adaptations coping with salt, saturated soils and regular tidal inundation, notably with specialized attributes [1]. Mangroves define the landscape and participate directly or indirectly in the ecological processes that take place within the ecosystems [2]. Mangrove forests play a critical role in multiple ways within coastal landscapes, particularly where the communities depend on the richness of the aquatic resources their habitat supports [3]. They provide a huge range of highly valuable ecosystem services, including support of biodiversity and fisheries, coastal protection,

carbon sequestration and nutrient processing [4]. Despite their ecological and economic importance, mangroves have been destroyed from their motherlands i.e. wetlands due to rapid urban and industrial developments including constructions, agriculture, aquaculture etc.

Sri Lankan mangroves are confined to a narrow strip since the tidal amplitude is low (less than 75cm) and they appear throughout the coastal belt more as a forest patch. There are ambiguities regarding the total mangrove extent of the country, due to lack of scientific data on the topic, yet latest research reports an extent of about 15,670 ha widely distributed along the coastal districts [5] occupying the inter-tidal coastlines, mudflats and riverbanks in association with the brackish water margin thus establishing a link between the land and the ocean [6].

The northern part of the island and their mangrove extent has been addressed rarely on literature, even though they have a wide range of mangrove forest reported by the Forest Department of Sri Lanka. According to available literature [7]; Jaffna peninsula holds the second largest mangrove forest of the island yet they are underreported in terms of diversity and abundance. The forest structure, the three dimensional arrangement of the individual tress, has a significant effect on the ecosystems services they provide. Analyzing the structural attributes of the existing mangroves is relevant to further studies based on their

economic viability, carbon sequestration, forest plantation programs and so on. Considering these facts, this study is undertaken in order to report the mangrove vegetation cover of two mangrove patches in the Jaffna peninsula, namely Mandaitivu and Arali, to assess the ecological status and analyze the mangrove structure in relation to the environmental parameters. The results of this paper is expected to aid in assessment of mangrove health and promoting replanting activities in the regions aforementioned.

2. Materials and Methods

2.1. Study Area

Jaffna peninsula located in the northern-most part of Sri Lanka; extends from 9° 49' 17" to 9° 28' 13" N latitude and 79° 38' 41" to 80° 34' 56" E longitude; bounded by the sea on the west, north and east and by Jaffna lagoon in the south. The topography of Jaffna is almost flat with wide ranging soil types including calcic red-yellow laterols, regosols and solodized solonetz and solonchaks. It holds the second largest mangrove forest (2505 hectares) ever reported in the island [5]. It belongs to the dry zone with uniformly high temperature all year around (range 26°C - 33°C) and an annual precipitation that rang between 696mm to 1125mm [8]. The highest elevation is 15.3 meters above sea level (masl), with a median being 2.72m and the average tidal amplitude is between 0.115 and 0.17 m. Of the several mangrove patches two of them Mandaitivu and Arali were selected for this study purpose (Figure 1).

2.2. Floristic Survey

Floristic survey and field sampling was carried out on December 2019, from the aforesaid areas. The stations were selected primarily based on the mangrove floral density and accessibility. Both sites selected were naturally available mangrove sites and both were observed to be human-impacted.

2.3. Species Composition and Nomenclature

The present study followed Pinto (1986) for species identification and nomenclature, which was derived from Tomlinson (1986) and Duke (1992).

2.4. Structural Analysis

Fixed plot measurement was used for the characterization of the structural attributes of true mangroves based on the methods suggested by Snedaker, [9]. Mangrove floral vegetation was studied using 10m wide belt transects in randomly selected points. Quadrat method was used for the structural analysis of true mangrove flora. Twelve transects in Mandaitivu and seven in Arali were laid perpendicular to the High Tide Line (HTL); from the estuarine zone towards the landward margin. All the plots were installed more than 20m away from adjacent plot to avoid spatial autocorrelation. Within each transect, 5-7 quadrats (5 x 5m) were laid for the purpose of species identification ($n_{\text{Mandaitivu}}=67$, $n_{\text{Arali}}=44$). Each species in the quadrat were identified, enumerated and then recorded. Zonation pattern of each species was also examined along the transects (10m width) across the land-water margin.

2.5. Environmental Parameters

Subsurface water samples were collected from the selected two sites at the points of the transects. A minimum of 3 samples were taken from each transect line and hence 57 samples altogether. The water temperature were recorded in the field using a standard degree centigrade thermometer. The water pH was measured with digital pH probe (Voniry make, Model No. 8541957750), electric conductivity by laboratory Eh meter ((ECscan20 conductivity tester), dissolve oxygen with a digital DO meter (JPB-607A dissolved oxygen meter/Analyzer) and salinity by a portable refractometer (BIOBASE make, Model No. Bk-Pr32) [10].

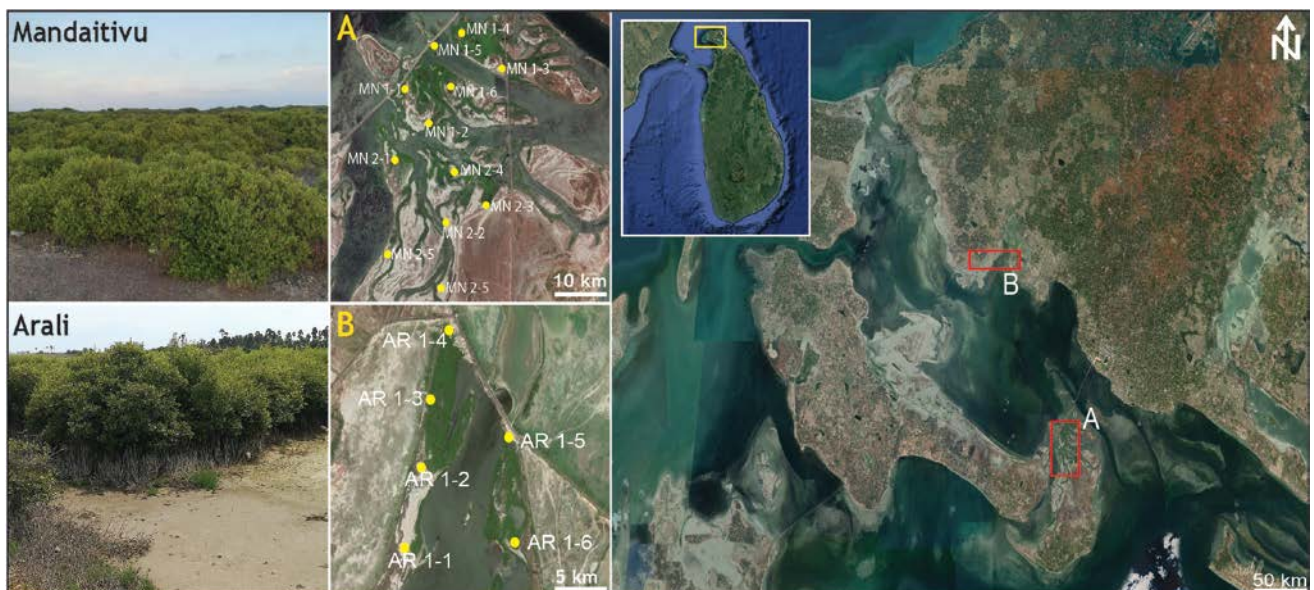


Figure 1. Map of the study area

2.6. Statistical Analysis

Biodiversity of both mangrove stands were analyzed with the use of various indices including Shannon diversity (H'), Pielou's evenness (J'), Simpson's dominance index (λ') [11] Margalef species richness (d') [12]. Total phylogenetic diversity index (sPhi+), taxonomic diversity (Δ), average taxonomic distinctness index ($\Delta+$) and variation in taxonomic distinctness index ($\Delta+$) [10] were also calculated for comparing the biodiversity among sites. Cluster analysis and similarity percentage (SIMPER) were performed based on Bray-Curtis dissimilarity matrix. Apart from these indices niche width was also calculated [13]. Multiple response permutation procedure was applied to check for significant difference between the clusters. Multi-Dimensional Scaling (MDS) and Principal Component Analysis (PCA) were performed to clarify the relationship of environmental factors on the plant community. Pearson's correlation coefficients were calculated to assess environmental parameters and stand characteristics. Community structure was analyzed with PRIMER V6 [14] whilst other quantitative data were analyzed using SPSS 17.0.

3. Results

3.1. Species Composition and Distribution

A sum of ten true-mangrove species representing six families were identified from the selected sites of Mandaitivu and Arali (Figure 2). Niche width measures the degree of specialization of a species and its ability to

exploit an environmental range in space and also to maintain its population in different environments [15]. The species with wider niches can be considered as generalists (utilize a wide range of resources) and narrow niche as specialists, exploit a specific set of resources [16]. Highest niche width was exhibited by *Bruguiera cylindrica* (2.99) followed by *Lumnitzera racemosa* (2.86), *Excoecaria agallocha* (2.75) and *Avicennia marina* (2.74) which reveals their capability to adapt to the environmental conditions in Mandaitivu and Arali (Table 1). However, *Aegiceras corniculatum* (1.88), *Bruguiera gymnorrhiza* (1.91) and *Acanthus ilicifolius* (1.92) have shown narrow niche width, were found restricted to few parts of the area sampled. Highest density over the sites sampled was exhibited by *Avicennia marina* (653) followed by *Lumnitzera racemosa* (578) and *Excoecaria agallocha* (507). Amongst these, *Avicennia marina* has extensively dominated over the sites sampled. Whilst lower density have been shown by *Pemphis acidula* (17).

3.2. Diversity Analysis

The Shannon diversity Index for Mandaitivu and Arali were 2.02 and 1.79 respectively whereas Simpson index for Mandaitivu and Arali were 0.84 and 0.82 respectively. Shannon diversity ranged from 1.79 to 2.02 with the highest species richness exhibited in Mandaitivu. (2.02). However, the taxonomic diversity index was in a range of 80 to 84 although total phylogenetic diversity index ranged 650 to 950. Among the study sites, Mandaitivu has shown exclusively higher species richness and diversity (Table 2) but Arali showed the highest variation in taxonomic distinctness index (113.38).

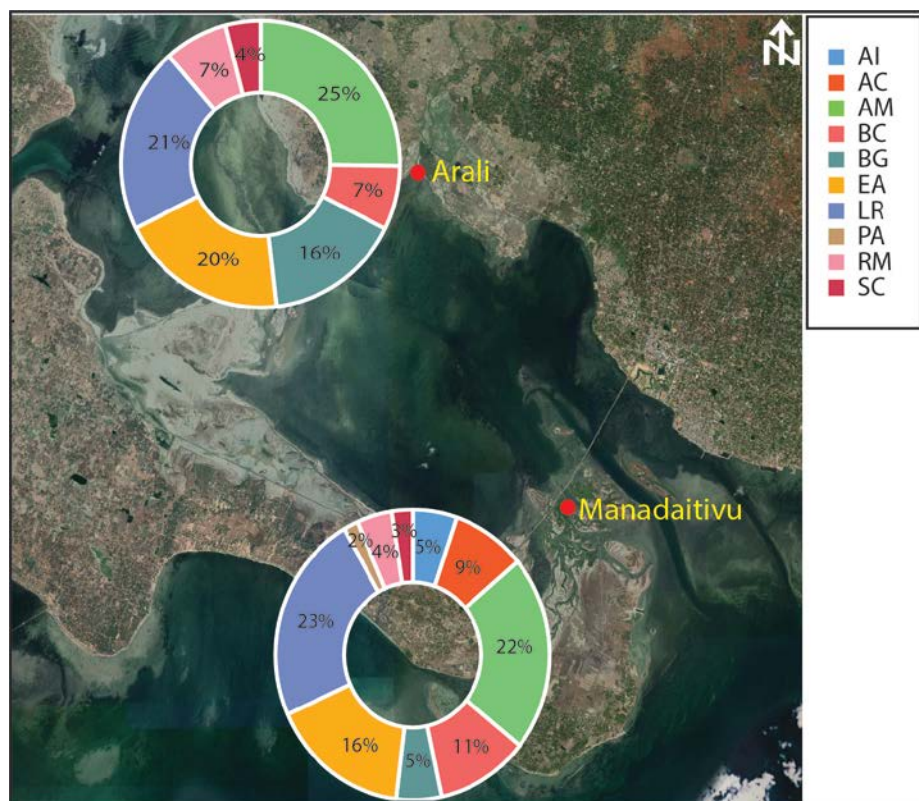


Figure 2. Species composition in the selected sites (AI: *Acanthus ilicifolius*, AC: *Aegiceras corniculatum*, AM: *Avicennia marina*, BC: *Bruguiera cylindrica*, BG: *Bruguiera gymnorrhiza*, EA: *Excoecaria agallocha*, LR: *Lumnitzera racemosa*, PA: *Pemphis acidula*, RM: *Rhizophora mucronata*, SC: *Sonneratia caseolaris*)

Table 1. Species composition, distribution and structural attributes of true mangroves from selected sites

Family	Species	Niche width	Distribution*		Density (no ha ⁻¹)	
			Mandaitivu	Arali	MND	Arali
Acanthaceae	<i>Acanthus ilicifolius</i> L.	1.92	Rare	-	23	0
Primulaceae	<i>Aegiceras corniculatum</i> (L.) Blanco	1.88	Occasional	-	38	0
Acanthaceae	<i>Avicennia marina</i> (Forssk.) Vierh.	2.74	Abundant	Abundant	94	424
Rhizophoraceae	<i>Bruguiera cylindrica</i> (Linnaeus) Blume	2.99	Occasional	Occasional	47	122
Rhizophoraceae	<i>Bruguiera gymnorhiza</i> (L.) Lamk.	1.91	Rare	Frequent	23	264
Euphorbiaceae	<i>Excoecaria agallocha</i> L.	2.75	Common	Common	71	328
Combretaceae	<i>Lumnitzera racemosa</i> Willd.	2.86	Abundant	Abundant	101	353
Lythraceae	<i>Pemphis acidula</i> Forst.	2.00	Rare	-	8	0
Rhizophoraceae	<i>Rhizophora mucronata</i> Lamk.	2.17	Rare	Occasional	18	124
Lythraceae	<i>Sonneratia caseolaris</i> (L.) Engler	2.47	Rare	Rare	11	69

*'Abundant': frequency more than 80%, 'Common': frequency between 61 and 80%, 'Frequent': frequency between 41 and 60%, 'Occasional': frequency between 21 and 40, 'Rare': frequency less than 20.

Table 2. Forest structural indices of true mangrove flora from Mandaitivu and Arali

	S	N	d	J'	H'	1-Lambda	Δ	Δ+	λ+	sPhi+
Mandaitivu	10	14426	0.94	0.88	2.02	0.84	83.69	99.27	54.32	950
Arali	7	23990	0.594	0.92	1.79	0.82	80.62	98.62	113.38	650

S-Total species, N-Total individuals, d- Species richness (Margalef), J'-Pielou's evenness, H'-Shannon, 1-Lambda- Simpson, Δ - Taxonomic diversity, Δ+ - Average taxonomic distinctness index, λ+ - Variation in taxonomic distinctness index, sPhi+ - Total phylogenetic diversity index.

3.3. Environmental Parameters

Water quality parameters displayed a tidal fluctuation along with least freshwater input and increased evaporation [17] in these regions. This have resulted in an extremely high salinity and lower dissolved oxygen (Table 3). Salinity ranges between 25 and 27 ppt whilst pH showed a slight alkalinity with a variation from 7.05 (+ 0.19) to 7.4 (+ 0.1). The soil water content varied between 24 and 26% showing a critical dryness of the region sampled.

3.4. Spatial Variability: Mandaitivu versus Arali

Relatively higher species diversity and abundance has been noted in Mandaitivu (H'=2.02) than Arali (H'=1.79) (Table 2). A sum of ten species have been recorded from Mandaitivu whereas seven species were recorded from Arali. Yet it could be observed that the evenness in Arali (J'=0.92) is quite higher than that of Mandaitivu (J'=0.88). *Avicennia marina*, *Lumnitzera racemosa* and *Excoecaria*

agallocha were predominantly observed in both sites at large numbers. However, rare occurrences of *Acanthus ilicifolius*, *Aegiceras corniculatum* and *Pemphis acidula* recorded in Mandaitivu were not observed in Arali.

3.5. Zonation Pattern

It was not easy enough to observe a clear zonation pattern in the areas selected for the mangrove survey. Yet with the available data, a rough representation of the zonation pattern has been created. Zonation in both areas consisted of *Rhizophora* in the fringing zone and *Avicennia* in the landward zone. In Mandaitivu, *Sonneratia* and *Bruguiera* was observed in the mixed zone towards fringing zone whilst *Lumnitzera*, *P. acidula* and *Excoecaria* were in another mixed group landwards (Figure 3). *Aegiceras* and *Acanthus* was observed toward the land zone. In Arali, a similar mixed zone was observed comprising of *Sonneratia* and *Bruguiera* toward the fringing zone (Figure 4). However, singular zones of *Excoecaria* and *Lumnitzera* were observed landward.

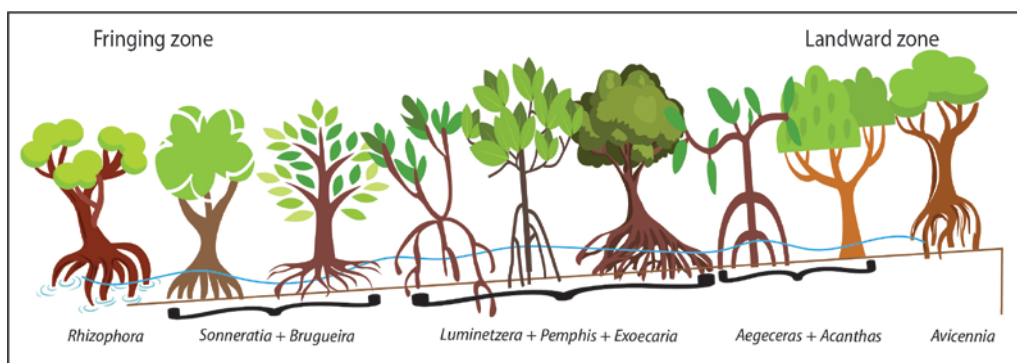


Figure 3. Zonation pattern of mangroves in Mandaitivu

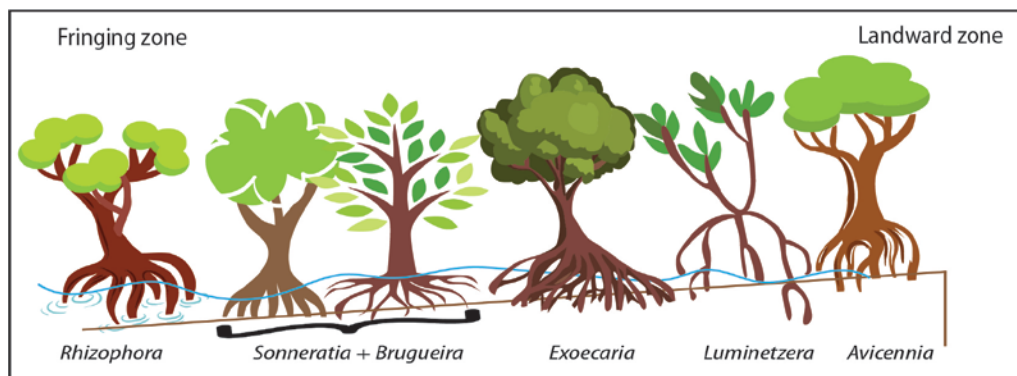


Figure 4. Zonation pattern of mangroves in Arali

3.6. Cluster Analysis and Community Structure

Form the species cluster analyses (Bray-Curtis similarity: 80%) and multidimensional scaling plots based on mangrove abundance and salinity in both sites; Mandaitivu was classified into three clusters; the first cluster included *A. corniculatum*, *A. ilicifolius*, *Brugueira spp.* whilst *L. racemosa*, *A. marina* and *E. agallocha* were observed on the second cluster. *S. caseolaris*, *R. mucronata* and *P. acidula* were included in the third cluster (Figure 5). On contrary, species composition in Arali were categorized into two clusters where *R. mucronata*, *B. cylindrica* and *S. caseolaris* included in the first cluster while *L. racemosa*, *A. marina* and *E. agallocha* *B. gymnorrhiza* were encompassed into the second cluster. On the other hand, 2D Multi-Dimensional Scaling plots have revealed that the similarity of the sites sampled in Mandaitivu comprised more than 80% except for *P. acidula* whereas all the species recorded in Arali showed more than 80% resemblance (Figure 5).

Table 3. Environmental parameters in the surveyed site

	Mandaitivu		Arali	
	Mean	SE	Mean	SE
Salinity (ppt)	26.67	0.89	27.58	0.95
pH	7.05	0.19	7.4	0.1
Conductivity (μS^{-1})	784.17	48.44	873	27.69
Elevation	7.97	0.1	8.06	0.07
Soil water content (%)	23.84	0.95	26.29	0.65
DO (ppm)	6.24	0.28	6.85	0.24
Tidal inundation (m)	0.16	0.04	0.15	0.03
Sediment type	Clayey sand		Clay	

SE- Standard error.

3.7. Environment-plant Interactions

Amidst the several environmental parameters checked mangrove abundance showed a positive correlation (Pearson) with salinity and electric conductivity. Highly significant positive correlation was observed between salinity and mangrove abundance and salinity (0.969, $p=0.000$ in Mandaitivu and 0.938, $p=0.002$ in Arali)

whilst electric conductivity had a fairly strong correlation (0.669, $p=0.017$ in Mandaitivu and 0.663, $p=0.105$ in Arali). However, positive but weak correlation by pH and tidal amplitude in both sites.

Principal Component Analysis (PCA) of Mandaitivu revealed a strong impact of salinity, tidal amplitude, pH and electric conductivity on the sampling points. At the same time, PCA in Arali revealed such an influence is strongly given by salinity, tidal amplitude and conductivity. Hence, this study suggests, that salinity, tidal amplitude and electric conductivity and pH are the key factors swaying the mangrove vegetation and community structure (Figure 6).

4. Discussion

4.1. Species Composition

Altogether ten mangrove species have been identified from the selected sites of Mandaitivu and Arali. It should be noted that there have not been any previous studies reported in this study area thus this paper contributes to report the floral diversity for the very first time. For the past 30 years, the northern parts of Sri Lanka were not accessible due to the civil war conditions prevailed in the country. The areas were allowed for survey only after the end of the war by 2009. However, there is a lack of enthusiasm in many researchers in accessing the areas for research purposes and study the mangrove ecology.

Of the ten species reported the respective site, the mangrove forest is typically dominated by *Avicennia marina*, *Luminetzeria racemosa* and *Excoecaria agallocha* representing a 'high saline' mangrove ecosystem. Noteworthy domination has been observed in Arali by *A. marina* (25%) even though the species diversity is reported low there. Nevertheless, past studies taken in other Sri Lankan dry zone forests have revealed that *A. marina* has a resistance towards extreme environmental conditions thus have a tendency to be widespread throughout the country's mangrove ecosystems [6,18,19].

4.2. Diversity Analysis and Community Structure

High Shannon index means there is a more amiable

environment that facilitates abundance due to the presence of larger number of species or uniform distribution of a number of species in a quadrat [10]. Hence, the mangrove forests in both sites looked healthy status, in terms of Shannon index since it was near two (2). On contrast, Simpson index was observed lower as <1 in both sites surveyed. β diversity value was found to be 3 which is as much as low, indicating a high homogeneity of mangrove species between the two mangrove forests in Mandaitivu and Arali. Figure 5 represents the Cluster analysis and 2D Multi-Dimensional Scaling (MDS) on an unambiguous scale in Mandaitivu and Arali, respectively.

4.3. Zonation Pattern

Mangrove species respond to various tidal regimes, where they occupy a convenient space on the mangrove forest, which forms a distinct zone of unique species. Yet the low tidal amplitude in the seas around Sri Lanka and the coastal geomorphology restricts the inter-tidal zone into narrow strips [20]. Generally, *A. marina* could survive very high salinities yet are more common around the Sri Lankan mangrove forests, especially in the dry zones. Silva & Silva, [21], specifically refers such a type of mangroves as ‘high saline’ and they occupy the river estuaries typically in the dry zones.

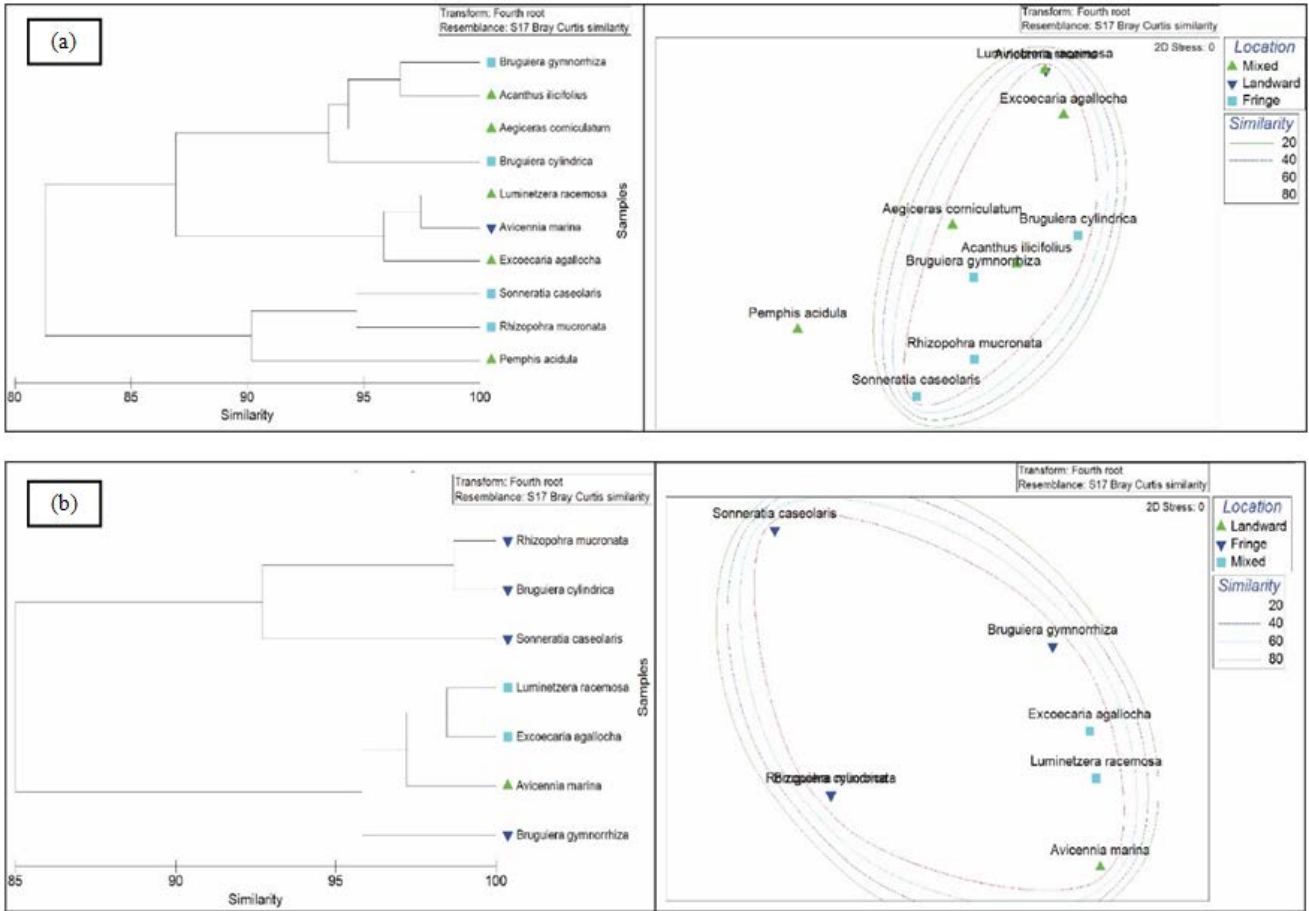


Figure 1. Cluster analysis and 2D- Multi Dimensional Scaling of Community structure in (a) Mandaitivu and (b) Arali

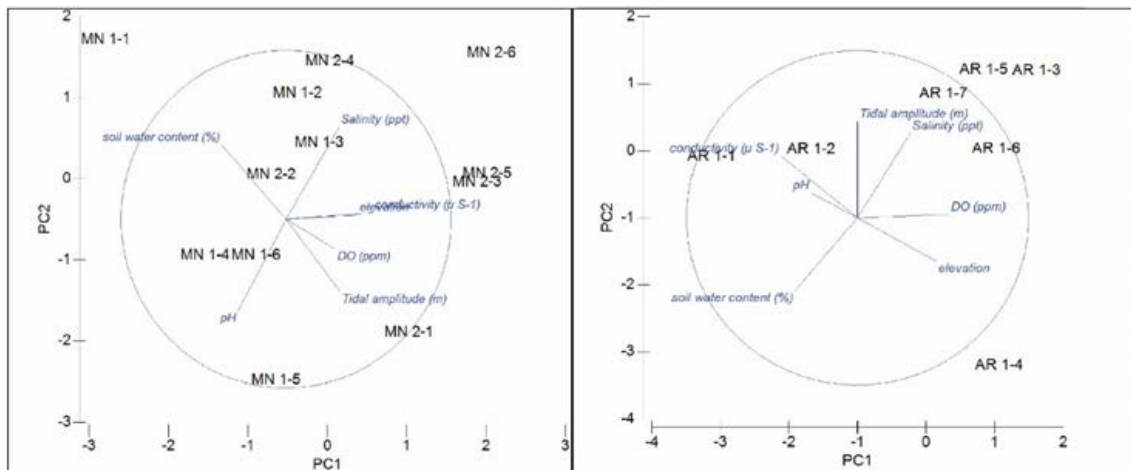


Figure 6. Principal Component Analysis (PCA) depicting the influence of environmental factors over the sites sampled in (a) Mandaitivu and (b) Arali

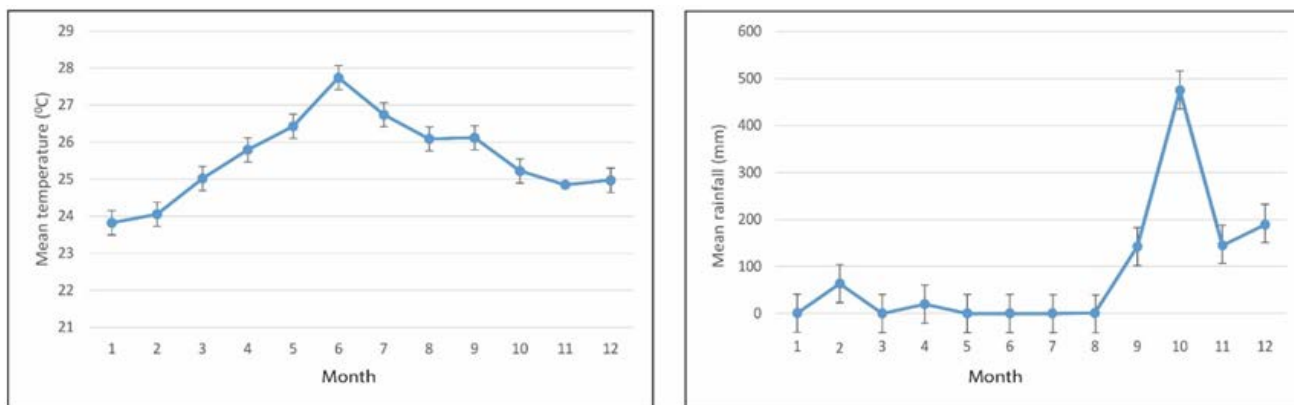


Figure 7. Summary of hydrographic factors from a long term monitoring record (Source: Meteorological Department of Sri Lanka)

4.4. Environment - Plant Relations

Long-term monitoring data of hydrographic parameters and temperature in Jaffna region have shown year round mean temperature over 24°C and the hottest months are observed during May - July, whilst peak rainfall could be observed throughout October, November and December (Figure 7). This makes Jaffna a dry zone and gives a reason for the increases salinity observed throughout the sites surveyed. In addition, the seas around Sri Lanka are micro-tidal and semi-diurnal in which rise and fall is between 0.7m and 0.05, spring and neap tides respectively. Especially the influence of tides is less in the northern parts of the country [22]. Hence, logical evidences lack to analyze the role of environmental factors excluding salinity to have a prominent influence over the mangrove distribution and zonation observed in the sites surveyed, even though PCA analyses show a promising result.

5. Conclusion

The assessment of the forest composition and structure of Mandaitivu and Arali have revealed a sum of ten true mangrove species, distributed throughout the estuarine areas, occurring in homogeneous and intricate mixtures with the dominance of by *Avicennia marina*, *Lumnitzera racemosa* and *Excoecaria agallocha* representing a 'high saline' mangrove ecosystem. Even though proper structural development has not observed in the mangrove forests, they tend to show a zonation involving *Rhizophora* in the waterfront and *Avicennia* towards the landward margin. Mangrove strands showed a significant correlation with the edaphic factors especially with salinity, conductivity, tidal regime and pH. Lack of knowledge and awareness and negligence have resulted in poor management and degradation of these mangrove forests in the Northern Province of Sri Lanka. Further research and knowledge development is recommended in these and adjacent areas for the productivity, dynamics and sustainability of the mangrove forests.

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