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FLORAL DIVERSITY OF SIX MANGROVE FORESTS ALONG THE NORTHWESTERN COASTLINE OF WET, INTERMEDIATE AND DRY CLIMATE ZONES OF SRI LANKA

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ABSTRACT - Although the primary role of mangrove vegetations as photosynthetic primary producers, they are the basis of a complex and productive ecosystem. The mangrove forests in the tropics are threatened due to the immense human pressure especially through infrastructure development and aquaculture. Therefore information on the change of mangrove species diversity in different climate conditions and in the location of the forest is useful for restoration and identifying the conservation needs. The species diversity of six mangrove forests of three different climate regions was examined in this study. Species diversity in bottom, hydromorphic fringe, non-hydromorphic fringe and upland segments of each forest was also studied. There was no clear species difference in different climate regions. The highest diversity was reported in Negombo Lagoon of wet zone followed by Chilaw Lagoon of dry zone. *Avicennia marina, Excoecaria agallocha, Lumnitzera recemosa* and *Rhizophora mucronata* were found in all six forests. *Aegicereas corniculatum, Bruigera gymnorrhiza* and *B. sexangula* were found only in wet and intermediate zones. The lowest species diversity was identified in the bottom segments having *R. mucronata, R. apiculata, Acanthus ilicifolius* and *Scyphiphora hydrophyllacea.* The highest diversity was recorded in the non-hydromorphic fringe segment where 14 out of 15 totally recorded species were found in that region. Several threats to the mangrove forests, especially due to infrastructure developments and shrimp farming were also identified.

KEY WORDS : Climatic zones; Diversity indices; Mangrove; *Scyphiphora hydrophyllacea*; Species diversity

INTRODUCTION

Mangroves are unique and highly productive ecosystems distributed along the inter-tidal coastlines, mudflats and riverbanks in association with the brackish water margin between the land and sea in tropical and subtropical areas (Barbier, 2000; Hogarth, 2007; Nagelkerken et al., 2008). Therefore mangrove ecosystem plays a key role by providing the link between marine and terrestrial ecosystems (Cannici et al., 2008). The above link will provide and maintain the stability, not only to the mangrove habitats itself, but also to the other related coastal ecosystems such as sea grass beds and coral reefs (Ewel et al., 1998). It also plays a significant role in replenishing various fish populations for the coastal and lagoon fish industry (Primavera, 2005). The nutrients given to the lagoon as a detritus from the mangrove ecosystem is carried into the coastal waters by the tidal currents (Chanda et al., 2013) and become food for marine micro-organisms, which is the first step of the marine food chain. Numerous invertebrate and vertebrate fauna are abundant in mangrove ecosystems and therefore they provide suitable breeding and nursery areas for a large number of fish, shrimps, crayfish, clams, and other aquatic organisms (Primavera, 2005;

Krauss et al., 2008). Moreover, those are used as feeding, breeding, and resting places for many species of birds, amphibians, reptiles, and terrestrial and aquatic mammals (Baba, 2004; Krauss et al., 2008). Mangrove vegetations also act as effective CO2 sinks (Chanda et al., 2013).

Depending on the distribution, mangroves are divided as true and mangrove associates. True mangrove species are absolutely bound to brackish water areas while mangrove associates can grow in similar areas as well as in aquatic environments and coastal backwaters with saline soil. True mangroves comprise some 55 species in 20 genera, belonging to 16 families which are taxonomically diverse (Hogarth, 2007). However, mangrove associates comprise a large number of (Hogarth, 2007). Although true mangrove species bear many adaptations such as prop and stilt roots, xenomorphic leaves, vivipary etc. to adapt to the saline/brackish water, such special adaptations cannot be observed in mangrove associates.

The bio-geographic distribution of mangroves is generally confined to the tropical and subtropical regions and the largest percentage of mangroves is found between 5° N and 5° S latitude (Giri et al., 2011). The largest extent of mangroves is found in Asia (42%) followed by Africa (20%), North and Central America (15%), Oceania (12%) and South America (11%). Approximately 75% of world's mangroves are found in 15 countries, and only 6.9% are protected under the existing protected areas network (IUCN, 2006).

Out of 65,610 km2 of total land area of Sri Lanka, 24% encompasses coastal land area excluding inland water. With the coastline of about 1,739.3 km, Sri Lanka is rich in highly productive coastal ecosystems such as coral reefs, sea grasses, mangrove forests, lagoons, estuaries, salt marshes, mudflats, sand dunes and beaches. However, the mangrove cover is about 12,000 ha which is as little as 0.1-0.2% of the total land area (Karunathilake, 2003). There are extensive mangrove areas around some lagoons and estuaries and sometimes they extend for a few kilometres towards the inland from the tidal level and transform into an inland plant community gradually (Liyanage, 1997).

Northwest coastline which covers about 20% of the entire coastline of Sri Lanka bears six main mangrove forest patches named Negombo Lagoon, Anankalliya, Chilaw Lagoon, Mundal Lake, Puttlam Lagoon and Kalaoya Estuary. These locations are different due to the climate difference and also due to their functions.

Negombo Lagoon which is used as a large fishery harbour is multi-functional and threatened by accelerated unplanned infrastructure developments. 51 out of the total of 108 ha of this mangrove forest has been demarcated as a National Biosphere Reserve under the Man and Biosphere (MAB) Programme of UNESCO (IUCN, 2006).

Anankalliya bears a large, relatively undisturbed mangrove forest and acts as a tourist attraction mainly due to the presence of hotels in the surrounding. However, it is also under a threat due to the extensive shrimp farming in the adjacent lands.

Chilaw Lagoon, also a fishery harbour, is considered as one of the most diverse mangrove forests in the northwest coastline of Sri Lanka. Shrimp farming is one of the main income generation methods of the people in the surrounding which can be considered as a threat to the mangrove vegetation.

Mundal is a shallow, brackish coastal lake with fringing mangrove swamps and brackish marshes, separated from the sea by a sandy ridge. The lake is completely cut off from the sea by a narrow sandbar. Shrimp farms are the most conspicuous developments around the lake while a small-scale subsistence fishery can also be found. Once considered as a very important wetland for a wide variety of water birds, has been threatened due to the mangrove destruction occurred at a rapid rate (IUCN, 2006).

Puttlam Lagoon is very rich in biodiversity, as it contains a range of habitats including mudflats, mangroves, saltpans, salt marshes, sea grass beds and coral reefs. 245 ha of Puttlam Lagoon have been demarcated as a National Biosphere Reserve under the Man and Biosphere Programme of UNESCO. The major threats of the mangrove vegetation are the

expansion of aquaculture schemes and saltpans in the area.

Kalaoya is a bay estuary and it harbours the largest tract of intact riverine mangrove in Sri Lanka. Mangrove forest in this estuary is the least disturbed (Mahaweli Authority of Sri Lanka, 2005) compared with the other mangrove forests listed above. From the inland side, it borders to one of the important and largest national wildlife parks of Sri Lanka named Wilpattu which is famous for wild elephants, sloth bears and leopards.

Human pressure on coastal ecosystems is often high, with land competition for aquaculture, agriculture, infrastructure and tourism. At the regional level, Asia suffered the largest net mangrove loss, more than 1.9 million hectares since 1980, mainly due to landuse changes. North and Central America and Africa also contributed significantly to the decrease in mangrove area at the global level, with losses of about 690,000 and 510,000 ha respectively over during 1980-2005 (FAO, 2007).

The objectives of this study were to identify the species difference of mangrove vegetations of different climate zones and to identify the species distribution from the bottom of the vegetation towards the land. The findings are highly useful in selecting the most appropriate species for the mangrove rehabilitation programs and for the identification of the conservation needs for future use.

METHODOLOGY

1. Study sites

This study was conducted in all six major mangrove forests (Table 1) located along the coastline runs through Gampaha and Puttlam administrative districts of Sri Lanka. This is also known as the northwest coastline (Figure 1) of Sri Lanka which extends from Hendala (6°58'20"N; 79°52'29"E) of Gampaha district to Modaragam Aru, Kudremalai of Puttlam district (8o34'15"N; 79o55'13"E). The most significant fact of this coastline is that it runs through all three major climate zones, viz. wet, intermediate and dry of Sri Lanka.

2. Data collection

Data were collected using 52 sample plots from all six mangrove forests. Samples were demarcated from the bottom of the vegetation to its end at the land side. The width of each sample plot was 20 m and the length varied from 20 to 45 m depending on the distribution of mangrove species from the bottom of the vegetation to the inland. Each sample plot was divided into four segments, viz. bottom, hydromorphic fringe, non-hydromorphic fringe and upland. True mangrove species (Table 2) were identified from each segment recorded. Species identification was done using the field guides (Pinto, 1986) and using the preserved specimens at the National Herbarium of Sri Lanka.

3. Species diversity determination

The relative abundance (%) of each mangrove species was calculated by dividing the number of individuals of the particular species by the total number of individuals of all species. Mangrove species diversity of each site was measured by using Simpson and Shannon indices.

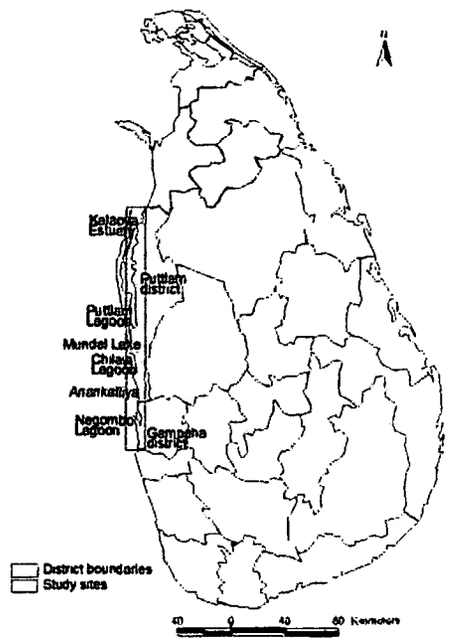


Fig. 1: Northwest coastline of Sri Lanka showing the study sites.

Table 1: Details of the mangrove forests selected for the present study.

Characteristic	Negombo Lagoon	Anankalliya	Chilaw Lagoon	Mundal Lake	Puttlam Lagoon	Kalaoya Estuary
Total extent, ha	3,164	181	2,000	3,600	32,750	316
Forest, ha	108	181	568	34	777	316
District	Gampaha	Puttlam	Puttlam	Puttlam	Puttlam	Puttlam
Climate zone	Wet	Intermediate	Intermediate	Dry	Dry	Dry
Ann. rainfall, mm	>2,000	>1,500	>1,500	>1,000	>1,000	>500
No of dry months	$3^1/_2$	5	5	7	7	7

Table 2: True mangrove species of Sri Lanka (Jayatissa et al., 2002).

Family	Scientific name
Acanthaceae	*Acanthus ilicifolius*
Avicenniaceae	*Avicennia marina*
	A. officinalis
Combretaceae	*Lumnitzera littorea*
	L. racemosa
Euphorbiaceae	*Excoecaria agallocha*
	E. indica
Lythraceae	*Pemphis acidula*
Meliaceae	*Xylocarpus granatum*
Myrsinaceae	*Aegiceras corniculatum*
Palmae	*Nypa fruticans*
Rhizophoraceae	*Bruguiera cylindrica*
	B. gymnorrhiza
	B. sexangula
	Ceriops tagal
	Rhizophora annamalayana
	R. apiculata
	R. mucronata
	Sonneratia alba
	S. caseolaris
Rubiaceae	*Scyphiphora hydrophyllacea*
Sterculiaceae	*Heritiera littoralis*

RESULTS

1. Mangrove species distribution and diversity

The highest number of mangrove species (14) was recorded from Negombo Lagoon (Figure 2) followed by Chilaw Lagoon (13 species). Ten, nine and six species were recorded from Puttlam Lagoon, Kalaoya Estuary and Anankalliya respectively. The lowest number of mangrove species (5) was recorded in Mundal Lake (Figure 2).

Rhizophora apiculata had the highest relative abundance in Negombo Lagoon followed by *Avicennia marina* (Figure 2). *Lumnitzera racemosa* had the highest relative abundance in Anankalliya while *Excoecaria agallocha* was the highest in Chilaw Lagoon (Figure 2). In Mundal Lake, *A. marina* reported the highest relative abundance and *R. mucronata* was the highest in both Puttlam Lagoon and Kalaoya Estuary (Figure 2).

R. apiculata and *R. mucronata* were present in all four zones, i.e., bottom, hydromorphic fringe, non-hydromorphic fringe and upland of Negombo Lagoon and those two species were the most abundant in the bottom (Figure 3). Considering all four zones, the non-hydromorphic fringe of Negombo Lagoon was the most diverse in terms of the highest number of mangrove species present. 13 out of the 14 recorded mangrove species of the Negombo Lagoon were found in that zone.

Although only six species were recorded in Anankalliya (Figure 2), the mangrove vegeta-

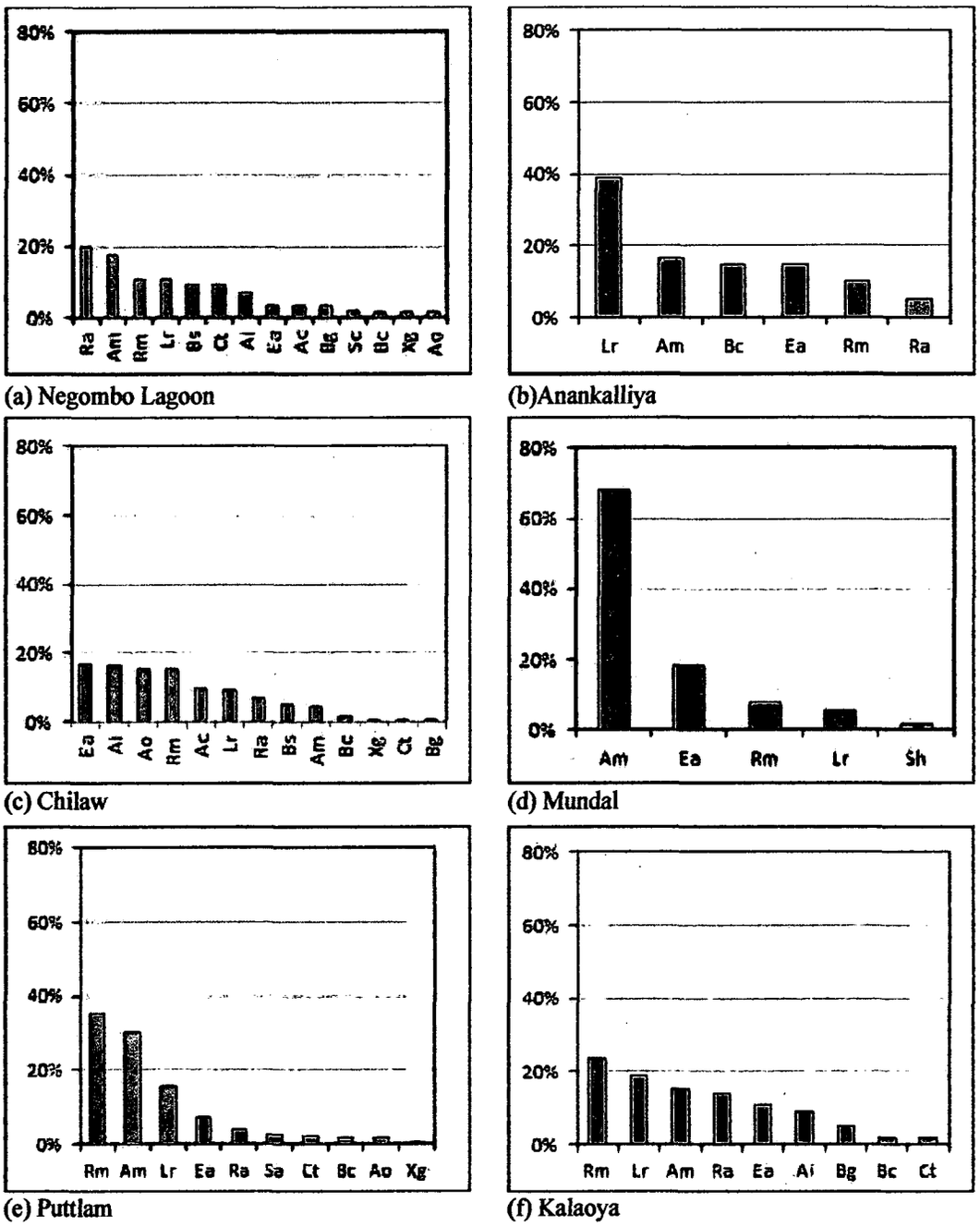
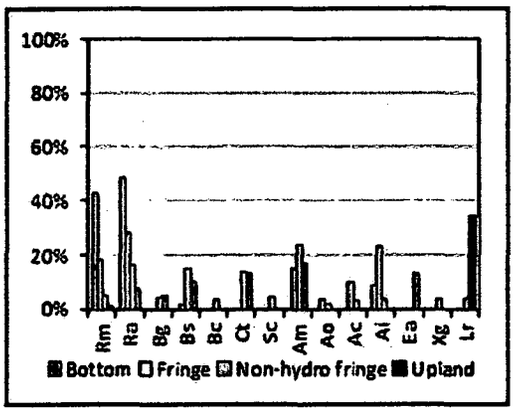


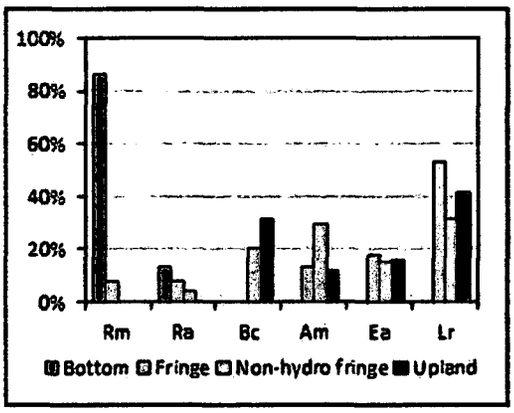
Fig. 2: Relative abundance of mangrove species in the selected six locations.

tion was highly dense. However, none of the recorded species were common in all four zones (Figure 3). Only *R. apiculata* and *R. mucronata* occupied the bottom. *L. racemosa* were dominant in both hydromorphic and non-hydromorphic fringes as well as in the upland.

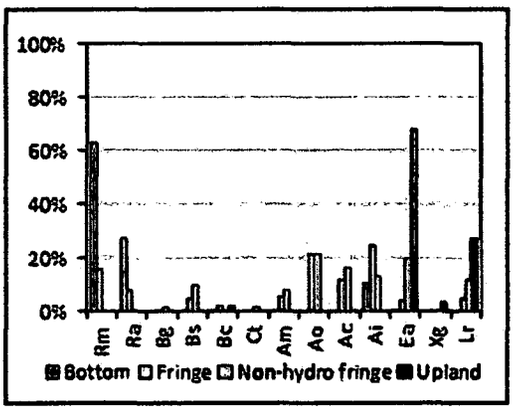
Similar to Negombo Lagoon, mangrove species showed more evenness in the Chilaw Lagoon compared to other areas (Figure 2). *R. mucronata* dominated the bottom occupying 62.5% of the total species while *E. agallocha* accounted for 67.8% of the total species count at the upland (Figure 3).



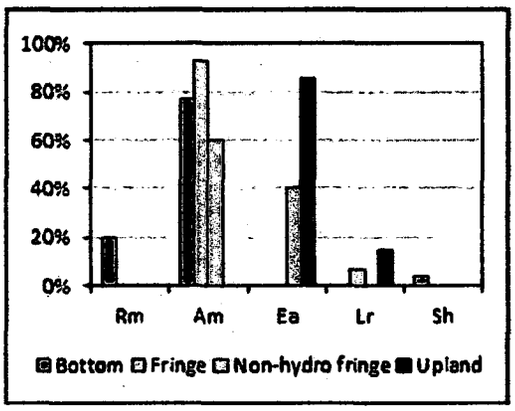
(a) Negombo Lagoon



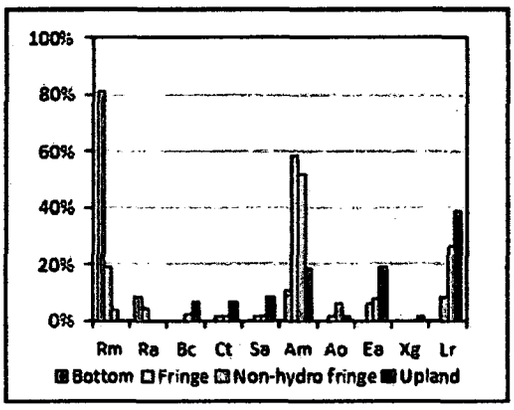
(b)Anankalliya



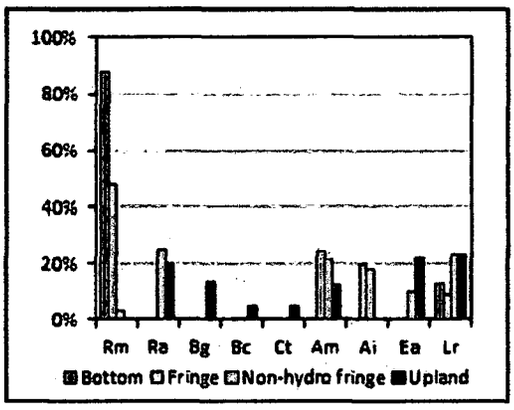
(c) Chilaw



(d) Mundal



(e) Puttlam



(f) Kalaoya

Fig. 3: Relative abundance in the bottom, hydro and non-hydromorphic fringe and land.

Out of the four species recorded (Figure 2), *A. marina* was the dominant species in the bottom, hydromorphic and non-hydromorphic fringes in the Mundal Lake (Figure 3) while E. agallocha was dominant in the upland.

Out of the 10 species recorded, *A. marina* was the only species found in all four zones in Puttlam Lagoon (Figure 3). Abundance of *R. apiculata* was very low in compared with *R. mucronata* in Puttlam Lagoon. *L. racemosa* was found in high abundance in hydromorphic fringe, non-hydromorphic fringe and upland areas although it was not recorded in the bottom.

R. mucronata, L. racemosa, A. marina and *R. apiculata* were the most abundant species in the Kalaoya Estuary (Figure 2). Both the bottom and the hydromorphic fringe were dominated by *R. mucronata* (Figure 3) while the non-hydromorphic fringe and upland mangrove vegetations showed comparatively high evenness.

2. Species variation along climate differences

A. marina, E. agallocha, L. racemosa and *R. mucronanta* were recorded in all six sites (Figure 2) located under different climate conditions. *B. cylindrica* and *R. apiculata* were recorded in all sites other than Mundal Lake. It was interesting to observe the presence of *Sonneratia alba* only in Puttlam Lagoon of the dry zone while *S. caseolaris* was recorded only in Negombo Lagoon of the wet zone. *Scyphiphora hydrophyllacea* was only recorded in Mundal Lake of the dry zone. *Aegiceras corniculatum, B. gymnorrhiza* and *B. sexangula* were recorded only from the wet and intermediate zones (Figure 2).

3. Variation of mangrove diversity indices

Simpson and Shannon indices together confirmed that Negombo and Chilaw Lagoons were the most diverse among the mangrove forests located along the northwest coastline of Sri Lanka (Table 3). Those two lagoons recorded the highest values (0.88) for Simpson index. However, Negombo Lagoon recorded a higher value (2.32) for the Shannon index than Chilaw Lagoon (2.18) confirming that Negombo Lagoon has the highest mangrove diversity. Mundal Lake showed the lowest diversity values for both indices making it the least diverse.

4. Species distribution from bottom to the upland

The least species diversity was identified in this study in the bottom segment of the forests. *R. mucronata* was the only species found in this region of all six forests while *R. apiculata* was found in the bottom segments of four forests other than in Mundal Lake and Kalaoya. In addition, only two other species viz., *A. ilicifolius* (in Negombo and Chilaw Lagoons) and *S. hydrophyllacea* (in Mundal Lake) were found in the bottom segments. In comparison, the highest species diversity was found in the non-hydromorphic fringe segment where all species identified in this study were reported except *S. hydrophyllacea.*

5. Identification of new habitat of Scyphiphora hydrophyllacea

One of the major findings of the study was the locating a new habitat for *Scyphiphora hydrophyllacea* which has been considered as vulnerable for the extinction (National Red List, 2012). In this study it was recorded for the first time at the point called Udappuwa

Table 3: Mangrove species diversity in the selected six locations.

Index	Negombo Lagoon	Anankalliya	Chilaw Lagoon	Mundal Lake	Puttlam Lagoon	Kalaoya Estuary
Simpson	0.88	0.77	0.88	0.49	0.76	0.85
Shannon	0.32	1.61	2.18	0.92	1.67	1.97

(7o43'55.99"N; 79o42'34.98"E) of Mundal Lake where it has never been recorded previously.

DISCUSSION

In this study we considered 22 true-mangrove species of 11 families listed by Jayatissa et al. (2002) and found 15 mangrove species of 10 genera belonged to seven families. However, *Lumnitzera citlora, Excoecaria indica, Pemphis acidula, Nypa fruticans, Rhizophora annamalayana* listed by Jayatissa et al. (2002) were not recorded in any of the sites used in this study. Liyanage (1997) and Amarasinghe (1996) mentioned higher number of true mangrove species in their studies. However, according to Jayatissa et al. (2002), the reason of listing a higher number of mangrove species could be due to misidentification.

Mangrove species present in Sri Lanka can be categorised into most common, common and rare (IUCN, 2006). The most common species of Sri Lankan mangroves are *Avicennia marina, Bruguiera gymnorrhiza, Excoecaria agallocha, Lumnitzera racemosa, Rhizophora mucronata, R. apiculata* and *Sonneratia caseolaris* (IUCN, 2006). These species grow under a wide range of soil and hydrological conditions and are widely distributed in Sri Lanka. The common category of mangrove species include *Aegiceras corniculatum, A. officinalis, B. cylindrica, B. sexangula, Ceriops tagal, Heritiera littoralis, Pemphis acidula, Sonneratia alba, Nypa fruticans*. Although these species are widely distributed in Sri Lanka, they are low in abundance. Rare species of mangroves that are few in numbers restricted to a few locations in Sri Lanka include *L. littorea, Xylocarpus granatum* and *Scyphiphora hydrophyllacea* (IUCN, 2006). In this study, from the most common mangrove species listed above, we also identified *A. marina, L. racemosa, E. agallocha* and *R. mucronata* commonly in all six sites while *R. apiculata* was not recorded only in one study site, viz. Mundal Lake. Similarly we also could not observe *L. littorea* in any of the study sites, Only one individual of *S. hydrophyllacea* was observed only in Mundal Lake. Although mentioned as rare, we recorded *X. granatum* from three sites but in low numbers. However, *S. caseolaris* was recorded only in Negombo Lagoon although this species was listed in very common category (IUCN, 2006).

Karunathilake (2003) stated that *R. mucronata* and *A. marina* were the most predominant true mangrove species in Sri Lanka which are extensively growing in Kalaoya Delta and Puttlam Lagoon. Our findings in both locations were similar to the above. In addition, we commonly found *A. marina, L. racemosa, E. agallocha* and *B. cylindrica* both in Puttlam Lagoon and Kalaoya Estuary.

In Bangladesh, Gupta and Ghose (2014) found that sites having diurnal inundation were dominated by *Avicennia alba, A. marina* and *A. ilicifolius*. However, Wah et al. (2011) found that *R. mucronata* as the most dominant species in undisturbed mangrove ecosystems in Semporna of Malaysia followed by *R. apiculata* and *Sonneratia caseolaris*. The bottom and hydromorphic fringe segments are subjected to the diurnal inundation of the coastal zone. In those areas, we found *R. mucronata* and *R. apiculata* as the dominant species. In addition, *A. marina* was commonly found in the inundation area of Mundal Lake, Puttlam Lagoon and Kalaoya Estuary.

The global average annual rate of mangrove loss is about 2.1%, exceeding the rate of loss of tropical rainforests (0.8%) (Wells et al., 2006). The cumulative effects of natural and anthropogenic pressures make mangrove wetlands one of the most threatened natural communities worldwide (IUCN, 1989; Valiela *et al.*, 2001; Gilman et al., 2006). Major reasons for this destruction are urban development, aquaculture, mining and over-exploitation for timber, fish, crustaceans and shellfish (Alongi, 2002). The destruction of mangroves is also positively related to human population density (Alongi, 2008). During the data collection period, we also found the destruction of existing mangrove species due to infrastructure development activities and shrimp farming in Negombo, Chilaw and Puttlam Lagoons and Mundal Lake which can be a major issue unless appropriate control measures are taken.

Among the six forests studied, we found that Negombo Lagoon has the highest

mangrove diversity followed by Chilaw Lagoon. There was no clear pattern of species diversity change with the climate differences. However, *B. gymnorrhiza, B. sexangula* and *A. corniculatum* were found only in the wet and intermediate zones. The most dominant species were *R. apiculata* and *A. marina* in Negombo Lagoon, *L. racemosa* in Anankalliya, *E. agallocha* in Chilaw Lagoon, *A. marina* in Mundal Lake and *R. mucronata* in Puttlam Lagoon and Kalaoya Estuary. The species diversity was the lowest in the bottom region which was dominated by *R. apiculata* and *R. mucronata.*

S. hydrophyllacea which is categorised as a vulnerable for extinction (National Red List, 2012) belongs to family Rubiaceae was recorded for the first time in Sri Lanka by Abeywickrema (1960). Jayatissa et al. (2002) also recorded a few trees which were restricted to one locality on the Kalpitiya Peninsula of the dry zone.

In addition to enhancing degraded mangroves by removing stresses that caused their decline, restoring areas where mangrove habitat previously existed and creating new mangrove habitat will also contribute to offsetting anticipated reductions in mangrove area and health and increase resistance and resilience to climate change effects (Hansen and Biringer, 2003; Ellison, 2004). Therefore the findings of this study can effectively be used in such rehabilitation activities.

CONCLUSION

The highest diversity was recorded in the Negombo Lagoon followed Chilaw Lagoon. *A. marina, E. agallocha, L. racemosa* and *R. apiculata* were found in all six sites. *A. corniculatum, B. gymnorrhiza* and *B. sexangula* were recorded in wet and intermediate zones. The lowest mangrove diversity was found in the bottom region and the highest diversity was recorded in the non-hydromorphic fringe region.

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