Carbon retention capacity of two mangrove species, Bruguiera gymnorrhiza (L.) Lamk. and Lumnitzera racemosa Willd. in Negombo estuary, Sri Lanka

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Abstract

Carbon accumulation/sequestration by plants is a major function that contributes to removal of carbon dioxide from the atmosphere and capacity to perform it depends on the plant species and environmental conditions under which they live. Carbon retention by natural ecosystems such as mangroves therefore, is considered a crucial ecological service, and valued highly under the current global context of continued increase in greenhouse gas emission and associated climate change, on which marginal effort has hitherto been spared over its quantification. The Present study was conducted to characterize two true Sri Lankan mangrove species, i.e. *Bruguiera gymnorrhiza* (L.) and *Lumnitzera racemosa* Willd.,. with respect to their carbon retention capacity, and to develop allometric relationships between biomass of plant components and stem diameter at breast height (dbh) of the two species with a view to assisting quantification of carbon-sink function of mangrove ecosystems. Fourteen trees of *B. gymnorrhiza,* and ten trees of *L. racemosa* that represented the range of dbh distribution in the mangrove area at Kadolkele in Negombo estuary were selected, harvested and dry weights (biomass) were obtained of the components based on wet:dry weight. Organic carbon in samples taken from each plant component of the two species was determined using dichromate oxidation and colorimetry using spectrophotometer. Partitioning of biomass between above (A) and below (B) ground components is approximately 3:1, revealing that the pattern resembles more of that of terrestrial plants (A/B = 3.9-4.5) than mangrove species in higher latitudes (A/B = 2-3). A positive correlation ($p<0.01$) and non-linear relationship (linear log-log relationship) was revealed between dbh and biomass (component and total) of the two species and allometric equations were derived that could be used to quantify carbon-sink function of mangrove ecosystems comprised of these species and the potential of mangroves in carbon mitigation programmes with financial incentives for mangrove conservation. The average amount of carbon retained by an individual was 9.16 kg per tree and thus the total organic carbon retained by *L. racemosa* in the mangrove ecosystem in Kadolkele was 9.44 t/ha while that of *B. gymnorrhiza*, was 5.6 t/ha, despite its greater capacity of individual carbon retention (13.76 kg per tree) due to its relatively low density and basal area. *L. racemosa* contains higher percentage of carbon in the stems, branches and roots than *B. gymnorrhiza*, revealing its superior contribution to carbon-sink function of mangrove ecosystems.

Keywords: Mangroves, Biomass, Allometry, Organic carbon retention

Introduction

Mangroves are coastal wetlands that essentially occur in tropical inter-tidal areas and their primary productivity is characteristically high when compared to other terrestrial plant communities (Lugo & Snedaker, 1974; Khan *et al*, 2009; Suratman, 2008). Part of the gross primary production or the atmospheric carbon assimilated through photosynthesis is accumulated in the plants themselves and it is measured as net primary production, the portion that is available for other heterotrophs in the ecosystem as a source of energy. Carbon that is accumulated in the above-ground components such as leaves, smaller branches and non-woody aerial roots that decompose rapidly is considered labile carbon, as it readily moves back into the atmosphere. Carbon that remains away from atmosphere within plants for considerably a long time, i.e. carbon in wood (of stems and large branches) and woody roots, both below-ground and aerial, is the sequestered carbon that contributes to carbon sequestration function of mangrove ecosystems. Carbon sequestration capacity of mangrove plants depends on biomass/carbon partitioning pattern which is characteristic to the species. Contribution of mangrove plant species for carbon sequestration may vary from species to species, for their inherent capacities of primary production, storage and environmental conditions such as soil salinity, nutrient availability and location/latitude which determine the amount of photosynthetically active radiation (PAR) available for photosynthesis (Twilley *et al*, 1992).

Allometry is a powerful tool for estimating tree weight from independent variables such as trunk diameter, tree height that are easily quantifiable in the field. The growth rate of one part of the tree is proportional to that of others, which is the basic theory of allometric relationships and therefore the trunk diameter of a tree is highly correlated with trunk weight (Komiyama, Ong, & Poungparn, 2008). If a range of tree sizes is measured, a regression equation can be derived for predicting tree weight. Although allometric equations have been developed for a number of mangrove species, hardly any literature is available for estimating mangrove root biomass and it may be due to complete extraction of mangrove roots being a difficult and tedious process. Accurate estimates of biomass and carbon contents are important for describing the current state of mangrove forests and for predicting the consequences of change such as age-size structure, species composition and carbon assimilation capacity. Further, such estimates are of considerable practical significance for modeling the potential consequences of climate changes, carbon sequestration capacity and for national and international carbon accounting and monitoring requirements.

Mangroves in Negombo estuary, however, are constantly under human pressure and being located in the vicinity of populous areas, mangroves are removed for human settlements, roads and public utility areas and in the process, carbon sink function is lost irreversibly. Although *Avicennia marina* (density- 2470 trees/ ha) and *Rhizophora mucronata* (405 trees/ ha) appear to dominate Negombo estuarine mangroves superficially, *L. racemosa* ranks second in abundance (620 trees/ha) in these mangrove areas and determining its contribution to C-sequestration function is important to calculate the total sequestration capacity of the mangrove area in performing this function. *B. gymnorrhiza* ranks fourth in abundance (80 trees/ ha) and its contribution is too significant to disregard in total sequestration capacity calculations. Although allometric relationships have been developed for *A. marina* and *R. mucronata* (Amarasinghe & Balasubramaniam, 1992) absence of the same for the latter species under local environmental circumstances was the prime reason for selecting these two species for the characterization under the present study. Development of allometric relationships between dbh and biomass/organic carbon content enables quantification of carbon-sequestration capacity of plants in this mangrove area.

The Present study therefore was conducted with *Bruguiera gymnorrhiza* (L.) Lamk. and *Lumnitzera racemosa* Willd., with the objectives of developing allometric relationships between biomass of stems, leaves, below and above ground roots with easily measured variables such as girth/ diameter at breast height (gbh/dbh) of trees that assist to estimate the total organic carbon retaining capacity of the two species.

Methodology

Determination of Biomass

Fourteen trees of *Bruguiera gymnorrhiza*, dbh of which falls within 2.18 -13.33 cm, and ten trees of *Lumnitzera racemosa* (dbh range 4.20 – 15.43cm) were harvested from Kadolkele mangrove area (7011’42.18”- 7011’50.48” N; 790 50’32.08”– 790 50’47.50” E) at Negombo estuary and to measure biomass. Each sample tree was cut at ground level using a chainsaw and separated manually into trunk, branches, leaf fractions and reproductive parts. For all sample trees, the trunk diameter at ground level (D_0), at dbh level ($D_{1.3}$) and at each 1m interval between the above two levels, were recorded. Roots of each sample tree were excavated using mechanical devices and washed with pressurised water. (Comely & McGuinnes, 2005, Komiyama, Poungparn & Kata, 2005).

Fresh weight of each sample trunk, branches, leaves, reproductive parts and roots were recorded with electronic balance with 1.0 g accuracy in the field. Fresh weight (0.1 g accuracy) of sub-samples from each component was obtained by oven drying at 65^0C to constant weight. Fresh to dry ratio of samples was used to calculate total dry weight of each biomass component.

Accuracy of developed equations for biomass estimation was tested with actual biomass data and the percentage difference between estimated and actual values was calculated to determine the extent of accuracy of the calculated biomass using the equations.

Determination of Total Organic Carbon Content

Total organic carbon content in wood in stem, leaves and roots of the two species were oven dried at 60^0 C until constant weight, ground with an electrical grinder and sieved through 150 µm mesh. Wet oxidation (using potassium dichromate) method without external heating procedure was used (Anderson & Ingram, 1998) to determine the total carbon content.UV-visible spectrophotometer (Spectro UV-VIS Double Beam UVD-3000) under 600 nm was used to measure absorbance by chromic solution.

Relationship between dbh of trees and biomass of components was analyzed with SPSS Ver.16.

Results

Distribution of Biomass

Biomass of the above ground plant components is nearly three times greater than that of the below-ground components in both the mangrove species (Table 1).

Table 1: Biomass of plant components of *Bruguiera gymnorrhiza* and *Lumnitzera racemosa* trees sampled at Negombo estuary, Sri Lanka. Percentage distribution of biomass among above and below-ground plant components are given within parentheses.

Species	Biomass (dry weight)/plant (kg/plant)							Ratio of above to below ground biomass
	Above-ground					Below-ground	Total/plant	
	Stem	Leaves	Branches	Roots	Total	Roots		
Bruguiera gymnorrhiza (n=14)	10.62 ± 4.35 (32%)	5.30 ± 1.95 (16%)	7.91 ± 2.93 (24%)	1.52 ± 0.56 (5%)	25.35 ± 9.43 (77%)	7.54 ± 2.83 (23%)	32.89 ± 13.08	3.36
Lumnitzera racemosa (n=10)	15.10 ± 4.36 (32%)	1.80 ± 0.47 (4%)	18.07 ± 5.94 (38%)	0.81 ± 0.42 (2%)	35.78 ± 11.44 (76%)	11.35 ± 2.88 (24%)	47.13 ± 14.58	3.15

Allometric Relationship between dbh and Biomass

Among others, Power curve was determined the most fit for the data sets of the two species and therefore allometric equations were derived from power curve (Fig 1). A strong positive correlation ($p<0.01$) and a high coefficient of determination (r2>0.80) with non-linear relationships were observed (except leaves) for all plant components with tree dbh of two species (Table 2).

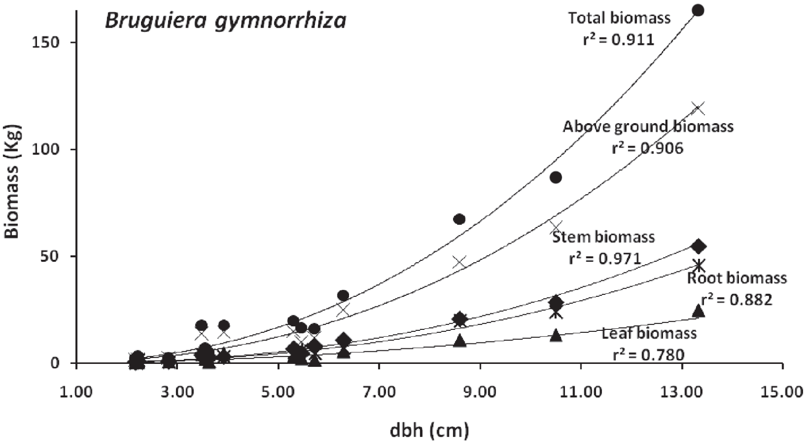

Fig.1: Relationship between dbh and biomass of plant components of *Bruguiera gymnorrhiza* (r^2 - Coefficient of determination)

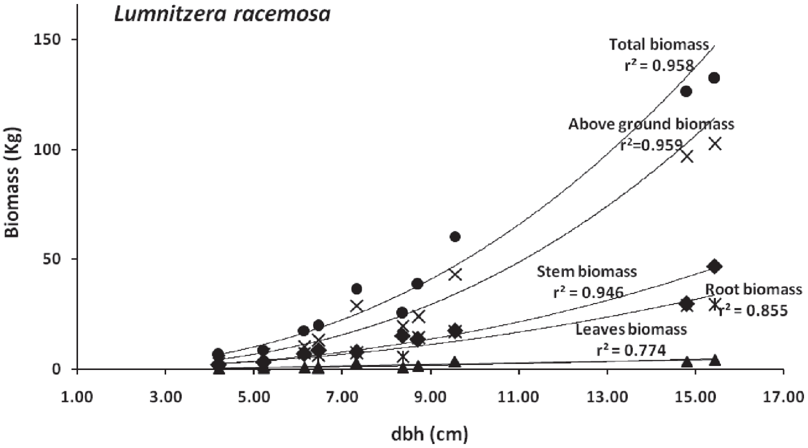

Fig.2: Relationship between dbh and biomass of plant components of Lumnitzera racemosa (r^2 - Coefficient of determination)

Table 2: Regression results for data fit to the power curve in each tree component with dbh (D1.3) for the two species

Species	***Component***	B_0	B_1	r^2	MS_{error}	***n***
B.gymnorrhiza	Stem	0.115	2.386	0.972	4.041	14
	Leaves	0.114	2.017	0.780	1.811	14
	Root	0.100	2.366	0.882	3.397	14
	Total AGB	0.289	2.328	0.906	8.756	14
	Total Biomass	0.405	2.321	0.911	12.140	14
L. racemosa	Stem	0.099	2.243	0.946	4.363	10
	Leaves	0.019	2.014	0.762	0.474	10
	Root	0.118	2.063	0.856	3.227	10
	Total AGB	0.114	2.524	0.960	11.436	10
	Total Biomass	0.220	2.377	0.958	14.575	10

B_0 and B_1 are the regression coefficients , MS_{error} is the mean stand error, n is the number of individuals and AGB is the aboveground biomass, r^2 is the coefficient of determination.

Allometric equations were developed between dbh with biomass of stem, leaves, roots, total above ground biomass and total biomass (above and belowground biomass) ($p<0.01$) of *Lumnitzera racemosa* and *Bruguiera gymnorrhiza* species (Tables 3).

Table 3: Developed Allometric equations for determination of biomass of each plant component of *B. gymnorrhiza*

Species	***Component***	***Allometric equation***
Bruguiera gymnorrhiza	Stem	$0.115\ (\mathrm{dbh})^{2.386}$
	Leaves	$0.114\ (\mathrm{dbh})^{2.014}$
	Root	$0.100\ (\mathrm{dbh})^{2.364}$
	Above-ground biomass	$0.289\ (\mathrm{dbh})^{2.327}$
	Total biomass (above+below)	$0.405\ (\mathrm{dbh})^{2.320}$
Lumnitzera racemosa	Stem	$0.098\ (\mathrm{dbh})^{2.244}$
	Leaves	$0.019\ (\mathrm{dbh})^{2.011}$
	Root	$0.118\ (\mathrm{dbh})^{2.063}$
	Above-ground biomass	$0.114\ (\mathrm{dbh})^{2.523}$
	Total biomass (above+below)	$0.220\ (\mathrm{dbh})^{2.376}$

Accuracy of Biomass Estimation Using Allometric Equations

Estimated values of biomass using the allometric equations were compared with actual data and the percentage differences between actual and estimated were found to be low (*B. gymnorrhiza* for all components less than 2.1% (except for leaves), *L. racemosa* for all components the difference was less than 4 % (except for stems), indicating the high reliability of using the developed allometric relationships to estimate biomass of these plant species (Table 4).

Table 4: Accuracy of estimated biomass of each plant component of *B. gymnorrhiza* and *L. racemosa* using the derived allometric equations.

	Biomass (Kg)		
Component	***Actual biomass***	***Estimated biomass***	***% Difference***
Bruguiera gymnorrhiza			
Stem	10.62	10.64	-0.18
Leaves	5.30	4.61	-13.01
Root	9.06	8.86	-2.09
Above-ground	23.83	23.63	-0.83
Total tree	32.89	32.50	-1.18
Lumnitzera racemosa			
Stem	15.10	16.08	6.50
Leaves	3.01	3.04	0.69
Root	11.32	11.41	0.79
Above-ground	32.83	34.12	3.93
Total tree	52.26	52.81	1.05

Total Organic Carbon Content

Except in the leaves of *L. racemosa*, approximately 50% of the biomass in all components of *L. racemosa* and *B. gymnorrhiza* were composed of carbon Table 5.

Table 5: Organic carbon content in biomass of wood, leaves and roots of *B. gymnorrhiza* and *L. racemosa*

Mangrove Species	**Percentage Carbon in biomass**		
	Wood	leaf	Roots
Bruguiera gymnorrhiza	54.90 ± 0.370	51.21 ± 0.219	52.91 ± 0.303
Lumnitzera racemosa	55.75 ± 0.172	44.13 ± 0.267	54.35 ± 0.322

Total Organic Carbon (TOC) Retention by Mangrove Plant Species

Organic carbon retained by *L. racemosa* and *B. gymnorrhiza* in Negombo estuary reveals that it depends not only on species but also on the structural characteristics of the mangrove ecosystems in relation to the species. Higher carbon retention capacity was recorded for *L. racemosa* (9.4 t/ha) than for *B. gymnorrhiza* (5.6 t/ha) (Table 6).

Table 6: Total organic carbon (TOC) retention capacity and related structural data of *L. racemosa* and *B. gymnorrhiza.*

	Bruguiera gymnorrhiza	*Lumnitzera racemosa*
Plant density (trees/ha)	80	620
Average dbh (cm)	5.00	4.65
Above ground TOC content (t/ha)	4.53	7.55
Below ground TOC content (t/ha)	1.07	1.88
Total organic carbon retention capacity (t/ha)	5.60	9.44
Average TOC retention	13.75	9.16

Discussion

Distribution of Biomass among the Plant Components

Although a greater average biomass was observed to be retained in stems of *L. racemosa* (15.1±4.36 kg) than in *B. gymnorrhiza* (10.62±4.35 kg), reflecting their inherent differences, both species retain 32% of total biomass in their stems (Table 1). Comley & McGuinness (2005) too, have observed that biomass retention by stems may vary from 14 – 40%, depending on the species of mangroves. Leaves are the plant appendages that contain least percentage of biomass (4 – 16%) and the leaves of *L. racemosa* contain more water as manifested by greater weight loss when dried. Profuse branching in *L. racemosa* may contribute to greater biomass (twice as much as that of stem) in them relative to *B. gymnorrhiza*.

Accumulation of biomass in knee roots (20-30 cm above ground) in *B. gymnorrhiza* accounted for 5% of total biomass, and it is greater than that observed to be accumulated in the slender knee roots (4-5 cm above ground) of *L. racemosa* (2% of total biomass) which are confined to trees growing in areas inundated for comparatively long periods. Development of knee roots of *L. racemosa* therefore appears to be a response to stress conditions created by anaerobic conditions due to prolonged inundation.

Biomass Distribution among Above and Below- ground Plant Components

Nearly quarter of the total plant biomass in both the species are stored in underground roots, with *L. racemosa* having higher below-ground root biomass than *B. gymnorrhiza*. The former species produces a larger/deeper below ground root-ball while the latter produces a spongy (with larger air spaces in the root cortex) near-surface network of roots which does not produce a significant pool of biomass. This observation contradicts that of Ong *et al*., (2004) who reported that 30% - 90% of the total biomass of *Rhizophora spp*. in a Malaysian mangroves to be retained in below ground roots and thus resulting a low above (A):below (B) ratio. Ong *et al*., (2004) also reported that mangrove plants maintain bottom-heavy tree forms and low A:B which appear useful to keep the plant upright in unconsolidated inter-tidal soils.

The A:B was revealed to be approximately similar for *B. gymnorrhiza* (3.36) and *L .racemosa* (3.15) (Table 1) and these values are lower than that for terrestrial trees, which range 4 - 4.5 (Cairns *et al*., 1997). Generally, this ratio lies between 2.0 and 3.0 for the mangroves (Komiyama *et al*.,2008). This appears to be evidence that mangrove plants accumulate more organic carbon in their root systems compared to terrestrial plants/trees. This ratio was recorded to be 1.1 with *Ceriops tagal* in Thailand and 4.4 for *Sonneratia* stands in Indonesia (Komiyama *et al*., 2008), indicating that the *Sonneratia* plants in Indonesia where the tidal range is above 3m possess extensive pneumatophore systems, accumulate relatively low amount of biomass in below-ground roots than in *Ceriops tagal*, which does not produce aerial roots such as prop, stilt and knee roots or pneumatophores, despite living in a similar tidal environment. *B. gymnorrhiza* is a mangrove species that produces characteristic knee roots and they originate from radial underground roots. In the present study, although *B. gymnorrhiza* was revealed to account for an A:B of 3.36, when all root biomass (above and below ground) is considered together, the A:B reduces to 2.6 which then falls in the range hitherto reported for mangrove species (Komiyama *et al*., 2008) and this applies to *L. racemosa* too. Comley and McGuinness (2005) reported the A:B of four mangrove species, *Avicennia marina* (1.08), *Bruguiera exaristata* (0.75), *Ceriops australis* (2.44) and *Rhizophora stylosa* (2.12) growing in macro-tidal Darwin Harbour, Australia, where the tidal amplitude is 8m. They also highlight that it is difficult to distinguish between the above and below-ground roots when sediment accumulates near the roots and thus inclusion of biomass of part of the above ground roots in the below-ground components, contributing to lower A:B is not an unlikely error that would associate in measuring biomass of below-ground roots. Mangroves being plants living in an environment subjected to the effect of tides that enhance the instability of substratum, diversion of part of the root biomass to appendages such as the variety of aerial roots that they possess appear to be not only an adaptation to cope with the anaerobic conditions prevailing in mangrove soils, but also a measure of rendering the plant, enhanced stability to remain upright in an unstable substratum. The radial roots, although not penetrated deep into soil, are extended over a wide area, rendering stability to the plant in anchoring itself in the unstable inter-tidal substratum.

Observations on the presence of pneumatophores of *L. racemosa* revealed that they are present only in the plants located close to puddles and creeks that are inundated for relatively long periods and pneumatophores were absent in other localities where the plant/root system is exposed, thus resulting in a very low mean biomass value for above ground knee roots (0.81 ± 0.42). This observation reveals that *L. racemosa* spares some of its below-ground biomass to develop pneumatophores when the plant is under stress due to anaerobic conditions in the root zone. These two mangrove species with low below ground biomass in comparison to that of other mangroves reported, represents a condition that prevails with plants in terrestrial forests, where the A:B is between 3.96 and 4.52 (Cairns *et al*., 1997). This indicates that the intertidal environment where the above mangrove species occur does not impose anaerobic conditions that can result in high environmental stress on plants/roots. Being a micro-tidal estuary, with less than 50 cm of average tidal amplitude and located in the wet zone of Sri Lanka where opportunities are marginal for development of high soil salinities and prolonged periods of inundation, *B. gymnorrhiza* and *L. racemosa* that naturally occur in Negombo estuary, may manifest a within plant biomass distribution that represents more of terrestrial plants than of semi-aquatic plants that exist under severe environmental stress, especially due to anaerobic soil conditions under inundation.

Below-ground to above ground biomass ratio (B/A) was observed to vary with tree height (Fig, 1). With increasing the tree height of *B. gymnorrhiza*, more biomass was accumulated in below ground portions and this observation was common to other terrestrial forests (Fromard *et al*. 1998). Similar observations were also recorded by Alongi, 2009 with data from Matsui, 1998, with *Rhizophora stylosa* stands in Iriomote island, Japan. A contradictory observation was recorded with *L. racemosa* in this study: more biomass was accumulated in below ground portion in smaller trees and B/A ratio decline with increasing tree height. This may be specific to the species, especially in tree architecture, unlike mature trees of *Bruguiera* spp. and *Rhizophora* spp., without harsh environmental conditions *L. racemosa* did not observe special types of roots such as knee roots or prop roots.

Allometric Relationship between dbh and Biomass

The strong positive correlation ($p<0.01$) and coefficient of determination ($r^2>0.80$) assures that a dbh can be used to determine the biomass of various components (except for leaves) of these two mangrove plant species (Figs. 1 & 2, Table 2). These results (Table 3) are comparable with allometric relationships developed for other mangroves species using power curves (Amarasinghe and Balasubramaniam, 1992, Comley & McGuinness, 2005 and Komiyama *et al*., 2005). The high reliability of the relationships developed for *B. gymnorrhiza* and *L. racemosa* through the present study (Table 4) can be used to estimate the total organic carbon content in these species for which no allometric relationships, based on empirical data, are available hitherto.

Comparison of biomass accumulation by individuals of *B. gymnorrhiza* with the same dbh in Australian mangroves (Twilley *et al*, 1992) reveals that, above ground biomass per tree in Negombo estuary is approximately twice as that has been estimated for individuals in Australian mangroves areas, that highlights the significance of mangroves in lower latitudes such as in Negombo estuary in global carbon-sink scenario and thus its conservation.

Organic carbon content in plant components

Estimating organic carbon content in mangrove plants reflects their significance as carbon sequestraters and the role of ecosystems in reducing global warming. Results of the present study (Table 5) reveal that percentage organic carbon content in the wood (stem and branches) of *B. gymnorrhiza* (54.9%) and *L. racemosa* (55.75%) is slightly higher than the value (49%) that has been recorded by IPCC 2006 for tropical and subtropical wood which includes plants of tropical rainforests. Besides, as revealed in the present study, *L. racemosa* accumulates more sequestered carbon in the stems and branches when compared to *B. gymnorrhiza*, thus it is relatively superior in terms of carbon sequestration. The total retention capacity of carbon by an ecosystem depends on its vegetation structure, i.e. plant species diversity, density of each species and average size of plants. Contribution of individual plant species to reduction of atmospheric carbon, therefore, depends on the environmental factors that affect their survival and growth (Clough *et al*, 1997; Tam *et al*, 1995; Ong, *et al*, 2004). Although the carbon retention capacity of *B. gymnorrhiza* (13.75 kg per tree) is greater than that of *L. racemosa* (9.16 kg per tree), because of its relatively high density in the mangrove stands at Kaldolkele in Negombo estuary (Table 6) it qualifies it as superior in performing carbon retaining functions. Although *L. racemosa* is not popular as a species for mangrove plantations or for rehabilitating degraded mangrove areas, it can be recommended as a species suitable for the purpose, which can enhance the ecological value of such endeavours.

Carbon sequestration function of natural ecosystems has drawn massive attention with the necessity to address global environmental issue of climate change. Carbon retention by natural ecosystems has not been given its due recognition hitherto, nevertheless, rapid development of market-based management mechanisms such as carbon foot printing and trading to reduce climate change as well as carbon mitigation programmes such as REDD +, a mechanism to reduce global greenhouse gasses by compensating countries for avoiding deforestation or forest degradation and conservation of ecosystems contributing to carbon sequestration, demands calculating realistic values of natural vegetation types in removing CO_2 from the atmosphere. This paper presents the findings of the first ever research performed with Sri Lankan mangrove species, and the knowledge generated on the allometric relationship between biomass and organic carbon content in the two species under study has expanded the knowledge base required to generate realistic estimates of this important ecological function and thus the conservation value of these hitherto unknown ecological services of mangrove ecosystems for the welfare of humanity.

Conclusion

Quantification of sequestered carbon in mangrove plant species could be determined by allometry of biomass and stem diameter of plants and organic carbon content in samples of plant components. High accuracy of the allometric equations derived for determination of biomass of *B. gymnorrhiza* and *L. racemosa* provides a pragmatic tool to calculate plant biomass and sequestered carbon and in turn, its relative contribution to carbon-sink function of mangrove ecosystems.

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