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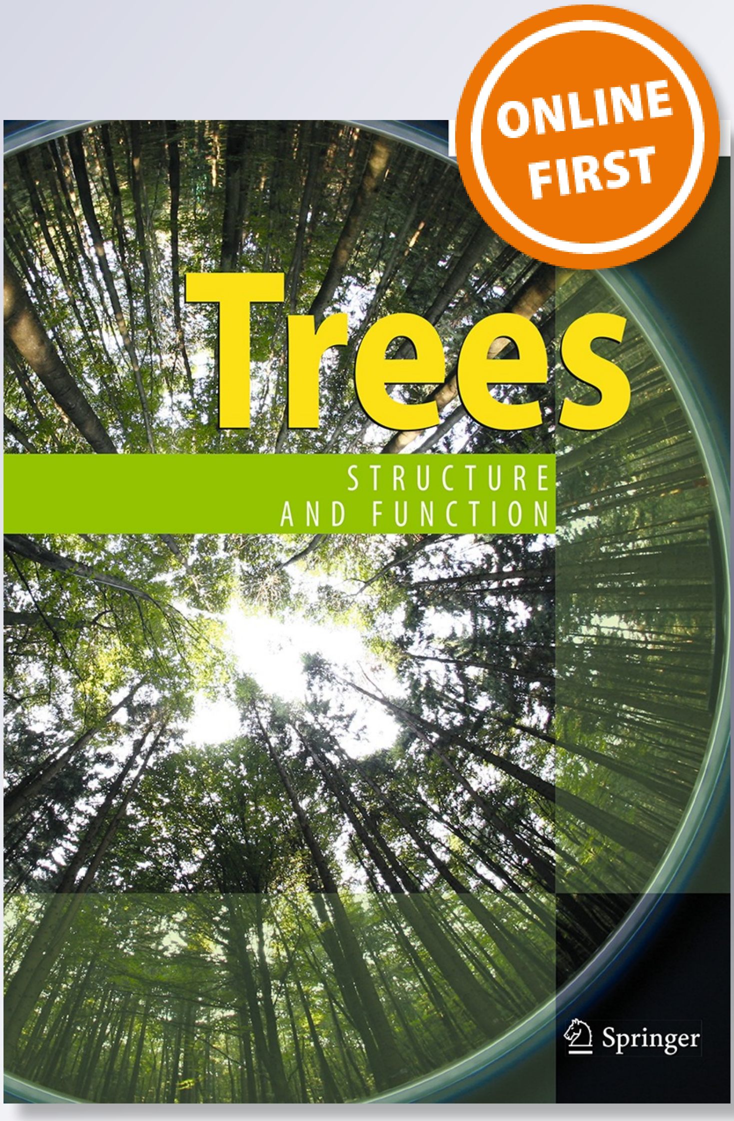

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ORIGINAL ARTICLE

Allometric biomass, nutrient and carbon stock models for *Kandelia candel* of the Sundarbans, Bangladesh

Mahmood Hossain[1] · Chameli Saha[1] · S. M. Rubaiot Abdullah[1] · Sanjoy Saha[2] · Mohammad Raqibul Hasan Siddique[1]

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Abstract

Key message **Present study recommends DBH as independent variable of the derived allometric models and Biomass = $a + b$ DBH^2 has been selected for total above-ground biomass, nutrients and carbon stock.**

Abstract *Kandelia candel* (L.) Druce is a shrub to small tree of the Sundarbans mangrove forest of Bangladesh. The aim of the study was to derive the allometric models for estimating above-ground biomass, nutrient and carbon stock in *K. candel*. A total of eight linear models with 64 regression equations were tested to derive the allometric models for biomass of each part of plant; and nutrients and carbon stock in total above-ground biomass. The best fitted allometric models were selected by considering the values of R^2, CV, R_{mse}, MS_{error}, S_a, S_b, F value, AICc and Furnival Index. The selected allometric models were Biomass $= 0.014$ DBH$^2 + 0.03$; $\sqrt{\text{Biomass}} = 0.29$ DBH $- 0.21$; $\sqrt{\text{Biomass}} = 0.66\sqrt{\text{DBH}} - 0.57$; $\sqrt{\text{Biomass}} = 1.19\sqrt{\text{DBH}} - 1.02$; Biomass $= 0.21$ DBH$^2 + 0.12$ for leaves, branches, bark, stem without bark and total above-ground biomass, respectively. The selected allometric models for Nitrogen, Phosphorous, Potassium and Carbon stock in total above-ground biomass were N $= 0.39$ DBH$^2 + 0.49$, P $= 0.77$ DBH$^2 + 0.14$, K $= 0.87$ DBH$^2 + 0.07$ and C $= 0.09$ DBH$^2 + 0.05$, respectively. The derived allometric models have included DBH as a single independent variable, which may give quick and accurate estimation of the above-ground biomass, nutrient and carbon stock in this species. This information may also contribute to a broader study of nutrient cycling, nutrient budgeting and carbon sequestration of the studied forest.

Keywords Allometry · Biomass · Carbon · *Kandelia candel* · Nutrient · Sundarbans

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✉ Mahmood Hossain
mahmoodhossain@hotmail.com

Chameli Saha
chamelifwt@gmail.com

S. M. Rubaiot Abdullah
rubaiot@yahoo.com

Sanjoy Saha
sanjoyfwt@yahoo.com

Mohammad Raqibul Hasan Siddique
raqibulhasanfwt@yahoo.com

[1] Forestry and Wood Technology Discipline, Khulna University, Khulna 9208, Bangladesh

[2] Centre for Integrated Studies on the Sundarbans, Khulna University, Khulna, Bangladesh

Introduction

Mangroves are distributed in the tropical and subtropical sheltered coastline (Field 1995) and act as a source of organic matter and nutrients to the aquatic ecosystem (Mazda et al. 1997; Alongi 2002; Mahmood et al. 2005, 2008; Mahmood 2014). The total area of the world mangroves is about 15 million hectares that are distributed in 100 countries and Bangladesh contributes about 4 % of the world mangroves (FAO 2003). The Sundarbans is the largest single continuous mangrove forest in the world that contributes about 95 % of the mangrove coverage of Bangladesh (Hoque and Datta 2005). Studies on stand structure, standing biomass, carbon stock, primary productivity and nutrient cycling are important for the proper management of mangroves (Tausch and Tueller 1988;

Komiyama et al. 2008; Mahmood 2014). Biomass of a stand can be estimated using three methods: the harvest method, the mean tree method and the allometric method. The harvest method requires destructive felling of trees and mean tree method is applicable for the plantation (Golley et al. 1975; Cintrón and Schaeffer-Novelli 1984; Ketterings et al. 2001). Allometric technique is a non-destructive and commonly used method of biomass estimation where whole or partial weight of a tree can be estimated from measureable tree dimension (stem diameter and height) and allometric equations (Ketterings et al. 2001; Komiyama et al. 2005). Many researchers have tried to develop generalized allometric model for different forests and tree species (Nelson et al. 1999; Montès et al. 2000; Komiyama et al. 2002, 2005; Chung-Wang and Ceulemans 2004; Chave et al. 2005; Navár 2009; Basuki et al. 2009). But, it is preferable to use species and site-specific allometric model for accurate estimation of biomass (Ketterings et al. 2001; Khan et al. 2005; Soares and Schaeffer-Novelli 2005; Smith and Whelan 2006; Kairo et al. 2009).

Kandelia candel (L.) Druce is an evergreen shrub to small tree. It shows a wide distribution from western and eastern India, Bangladesh and Myanmar to the South China Sea region (Spalding et al. 2010). This species occurs sporadically on the banks of tidal rivers and creeks of the Sundarbans at the moderate to high saline areas and has been used as fuel wood, poles, fodder, green manure and crud medicine (Das and Alam 2001). The present study aimed to develop the allometric models for estimating above-ground biomass, nutrient and carbon stock in *K. candel* of the Sundarbans which may contribute to assess the present stocking, scope of utilization and management of this species.

Materials and methods

Study area

Sundarbans mangrove forest of Bangladesh is located between latitudes 21°30′ and 22°30′N and longitude 89°00′ and 89°55′E that covers 600,386 hectares with 55 compartments. This forest has also been divided into three salinity zones, less saline (salinity <2 dS m^{-1}), moderate saline (2–4 dS m^{-1}) and high saline (>4 dS m^{-1}). Furthermore, there are 14, 30 and 11 compartments in the less saline, moderate saline and high saline zone, respectively (Siddiqi 2001). The present study was carried out at different compartments of moderate saline and high saline zone of this forest. The climate of the Sundarbans is humid subtropical and mean temperature for winter is 18–23 and 27–31 °C for the summer. The mean annual rainfall is 1980 mm/year; summer (May to September) contributes about 81 % of the annual rainfall while winter season contributes about 19 % of rainfall. Soil is clay and pH is around 7.9. *Kandelia candel* in the Sundarbans grows well at the moderate saline to high saline areas on the muddy banks of rivers and canals, and appears as understory with *Excoecaria agallocha, Xylocarpus moluccensis, Bruguiera sexangula, Rhizophora mucronata, Ceriops decandra* (Hussain and Acharya 1994).

Sample collection and processing

Twenty-five individuals of *K. candel* having DBH (Diameter at Breast Height) and TH (Total Height) ranging from 1.1 to 8 cm and 1.85 to 3.9 m, respectively, were selected subjectively (avoiding structural deformities and insect or disease infested trees) during June to December 2013. The selected individuals were felled at the ground level after measuring the Diameter at Breast Height (DBH) and grouped into 3 DBH classes as 1.1–3, 3.1–5 and 5.1 cm to above. Total height (TH) was measured from the felled trees as it is more convenient and less erroneous than the standing trees. The above-ground parts of the individuals were separated into leaves, branches, stem and bark, but all the sampled stems were not debarked in the field. Being a shrub species, a small section (50 cm in length) of the stem was collected from the base, middle and upper portion of randomly selected 5 sampled stems and thus a total of 15 sections were collected. Mass of these stem sections was recorded and then debarked in the field to get fresh mass ratio of bark and stem. Finally, the fresh mass of bark of a stem was estimated from the bark ratio and mass of stem with bark (Mahmood et al. 2004, 2012). Leaves, branches and stem of an individuals were weighted (fresh mass) separately in the field and recorded. Ten sub samples (100 g) from each part (leaves, branches, stem and bark) were brought back to the laboratory and oven dried at 80 °C until constant mass to get fresh mass to oven-dry mass conversion ratio. The oven-dried mass of different parts of *K. candel* individual was calculated from the derived conversion ratio and fresh mass of the corresponding plant part. Mean biomass proportion of each part (leaf, branch, bark and stem) was also estimated in accordance with the DBH classes.

Nutrients and carbon in plant part

Ten samples (about 100 gm) of plant parts (leaf, branch, bark and stem) were collected randomly from the sampled trees. The collected samples were oven dried at 80 °C until constant weight, processed and stored accordingly. Micro Kjeldahl digestion for Nitrogen and tri-acid (H_2SO_4, $HClO_4$ and HNO_3) digestion for Phosphorus and Potassium was applied to the processed samples (Allen 1989). Nitrogen and Phosphorus in the sample extract were measured calorimetrically according to the Baethgen and Alley (1989) and Timothy et al. (1984), respectively, using

UV–visible Recording Spectrophotometer (HITACHI, U-2910, Japan). Potassium concentration in sample's extract was measured by Flame Photometer (PFP7, Jenway LTD, England). Organic carbon in samples was determined by ignition method (Allen 1989). Nutrients and carbon concentration in plant parts were compared by one-way analysis of variance (ANOVA) followed by Duncan Multiple Range using SAS (6.12) statistical software. The amount of nutrients and carbon in each part of individual tree was estimated from their concentration and oven-dried biomass of the respective plant parts.

Allometric models

A total of eight linear models ($y = a + \mathrm{b}X$, $\sqrt{y} = a + b\sqrt{X}$, $y = a + b$ Log X, Log $y = a + \mathrm{b}X$, Log $y = a + b$ Log X, $y = a + b \ln X$, Ln $y = a + \mathrm{b}X$ and Ln $y = a + b \ln X$) with 64 regression equations were tested to derive the allometric model for biomass of each plant part, and nutrients and carbon stock in total aboveground biomass (Soares and Schaeffer-Novelli 2005; Mahmood et al. 2015). Significant test of regression equations was tested using SAS (6.12) statistical software. The best fitted regression equations were selected considering the highest R^2 and F value, with the lowest value of CV, R_{mse}, MS_{error}, S_a, S_b, AICc and FI (where R^2 = coefficient of determination; CV = coefficient of variation, R_{mse} = root mean square error; MS_{error} = mean square error; S_a = standard error of intercept ''a''; S_b = standard error of regression coefficient ''b'' and AICc = akaike's information criterion corrected; FI = furnival index).

Results

The mean biomass proportion of plant parts was varied with DBH classes. Comparatively, higher proportion (11.88 ± 2.66 %) of leaf biomass was observed at the lowest DBH class of 1.1–3 cm, while higher proportion (29.16 ± 12.31 %) of branch biomass was detected at the highest DBH class of 5.1 cm to above. But, almost similar proportion of stem (49.32 ± 10.32–51.54 ± 5.00 %) and bark (15.26 ± 3.19–15.94 ± 1.55 %) biomass was observed for all DBH classes (Table 1).

Leaf contained significantly ($p < 0.05$) higher concentration (8.42 ± 0.75 mg/g) of nitrogen followed by bark (2.91 ± 0.08 mg/g) and lower nitrogen concentration (1.08 ± 0.12–1.21 ± 0.13 mg/g) was observed in branches and stem. Similar concentration (4.23 ± 0.39–4.74 ± 0.02 mg/g) of phosphorus was observed in leaves, branches and bark, while lowest concentration (2.74 ± 0.14 mg/g) was detected in stem. Highest concentration (11.09 ± 0.19 mg/g) of potassium was observed in leaves and lower concentration (2.59 ± 0.04–4.80 ± 0.08 mg/g) was found in stem and branches. Conversely, higher concentration (45.25 ± 0.23–45.53 ± 1.60 %) of carbon was detected in woody parts (stem and branches) of *K. candel* compared to leaves and bark (Table 2).

This study tested a total of 8 linear models along with 64 regression equations in combination with DBH and TH as independent variables, which yield a total of 240 equations for leaves, bark, branch, stem and total biomass. Most of the equations were significant ($p < 0.05$) but 217 regression equations were excluded considering the value of co-

Table 1 Biomass proportions (mean ± SE) in plant parts according to DBH classes of *Kandelia candel*

DBH class (cm)	Height limit (m)	Biomass proportion (%)			
		Leaf	Branch	Bark	Stem without bark
1.1–3 (9)	1.85–2.90	11.88 ± 2.66	20.63 ± 4.07	15.94 ± 1.55	51.54 ± 5.00
3.1–5 (13)	2.95–3.80	7.72 ± 0.47	25.06 ± 1.72	15.88 ± 0.47	51.35 ± 1.52
5.1–above (3)	3.50–3.90	6.28 ± 1.20	29.16 ± 12.31	15.26 ± 3.19	49.32 ± 10.32

Values within parenthesis indicate the number of replicates

Table 2 Nutrients and carbon concentration (mean ± SE) in different parts of *Kandelia candel*

Plant components	Nitrogen (mg/g)	Phosphorus (mg/g)	Potassium (mg/g)	Carbon (%)
Leaf (9)	8.42 ± 0.75^{A}	4.74 ± 0.02^{A}	11.09 ± 0.19^{A}	43.27 ± 0.20^{AB}
Branch (9)	1.21 ± 0.13^{C}	4.23 ± 0.39^{A}	4.80 ± 0.08^{B}	45.25 ± 1.60^{A}
Bark (9)	2.91 ± 0.08^{B}	4.53 ± 0.40^{A}	3.80 ± 0.35^{C}	41.72 ± 0.13^{B}
Stem (9)	1.08 ± 0.12^{C}	2.74 ± 0.14^{B}	2.59 ± 0.04^{D}	45.53 ± 0.23^{A}

Values within parenthesis indicate the number of replicates

Similar alphabet along the column is not significantly ($p > 0.05$) different

Table 3 Best fit models for plant parts and total above-ground biomass (kg) of *Kandelia candel*

Plant part	Equation	R^2	*a*	*b*	Sa	Sb	CV	R_{mse}	MS error	*F*	AICc	FI
Leaf	Biomass = a DBH^2 + b	0.89	0.014	0.03	0.001	0.02	28.46	0.06	0.004	180.98	−133.53	0.063
	Biomass = a DBH^2 × TH + b	0.87	0.004	0.05	0.0003	0.02	30.97	0.66	0.004	149.18	−128.04	0.063
	$\sqrt{\text{Biomass}} = a$ DBH + b	0.82	0.11	0.08	0.01	0.04	16.51	0.07	0.01	102.47	−126.34	0.081
Branch	Biomass = a DBH^2 + b	0.91	0.08	−0.28	0.005	0.09	41.24	0.31	0.1	220.1	−52.725	0.316
	Biomass = a DBH^2 × TH + b	0.88	0.02	−0.18	0.002	0.1	46.22	0.35	0.12	170.53	−44.201	0.346
	$\sqrt{\text{Biomass}} = a$ DBH + b	0.87	0.29	−0.21	0.02	0.09	20.84	0.16	0.03	153.46	−86.947	0.230
	$\sqrt{\text{Biomass}} = a \sqrt{\text{DBH}^2 \times \text{TH}} + b$	0.86	0.14	−0.09	0.01	0.08	21.92	0.17	0.03	136.54	−81.241	0.230
Bark	Biomass = a DBH + b	0.87	0.24	−0.37	0.02	0.07	30.07	0.13	0.02	150.84	−95.017	0.141
	$\sqrt{\text{Biomass}} = a \sqrt{\text{DBH}} + b$	0.86	0.66	−0.57	0.05	0.1	16.3	0.1	0.01	138.19	−110.07	0.111
	$\sqrt{\text{Biomass}} = a$ DBH + b	0.85	0.17	0.3	0.01	0.05	16.65	0.1	0.01	131.45	−109.01	0.111
	$\sqrt{\text{Biomass}} = a \sqrt{\text{DBH}^2 \times \text{TH}} + b$	0.86	0.09	0.1	0.01	0.05	16.1	0.1	0.01	142.19	−107.21	0.111
	$\sqrt{\text{Biomass}} = a \sqrt{\text{DBH}^2 \times \text{TH}^2} + b$	0.86	0.04	0.16	0.004	0.04	16.24	0.1	0.01	139.45	−107.21	0.111
Stem	Biomass = a DBH + b	0.87	0.79	−1.19	0.06	0.23	30.07	0.43	0.19	150.84	−36.632	0.435
	$\sqrt{\text{Biomass}} = a \sqrt{\text{DBH}} + b$	0.86	1.19	−1.02	0.1	0.18	16.3	0.18	0.03	138.19	−80.521	0.345
	$\sqrt{\text{Biomass}} = a \sqrt{\text{DBH}^2 \times \text{TH}} + b$	0.86	0.15	0.18	0.01	0.09	16.1	0.18	0.03	142.19	−77.664	0.345
	$\sqrt{\text{Biomass}} = a \sqrt{\text{DBH}^2 \times \text{TH}^2} + b$	0.86	0.08	0.28	0.01	0.08	16.24	0.18	0.03	139.45	−77.664	0.345
Total above-ground-biomass	Biomass = a DBH + b	0.91	1.78	−3.1	0.12	0.42	27.59	0.79	0.63	232.32	−6.631	0.793
	Biomass = a DBH^2 + b	0.94	0.21	0.12	0.01	0.19	21.6	0.62	0.38	393.73	−18.875	0.616
	Biomass = a DBH^2 × TH + b	0.94	0.06	0.36	0.003	0.18	21.76	0.62	0.39	387.59	−15.653	0.624
	Biomass = a DBH^2 × TH^2 + b	0.93	0.02	0.56	0.001	0.19	24.2	0.69	0.48	308.93	−10.343	0.692
	$\sqrt{\text{Biomass}} = a$ DBH + b	0.92	0.47	−0.03	0.03	0.11	12.79	0.2	0.04	258.71	−75.687	0.565
	$\sqrt{\text{Biomass}} = a \sqrt{\text{DBH}^2 \times \text{TH}} + b$	0.92	0.23	0.17	0.01	0.1	12.78	0.2	0.04	259.06	−72.83	0.565
	$\sqrt{\text{Biomass}} = a \sqrt{\text{DBH}^2 \times \text{TH}^2} + b$	0.91	0.11	0.32	0.01	0.09	13.6	0.21	0.04	225.87	−69.733	0.565

R^2 coefficient of determination, S_a standard error of regression coefficient "*a*", S_b standard error of intercept "*b*", *CV* coefficient of variation, R_{mse} root mean square error, MS_{error} mean square error, *AICc* akaike's information criterion corrected, *FI* furnival index

efficient of determination (R^2) <0.80 for leaves, 0.85 for branch, bark, and stem without bark; R^2 value <0.90 was also excluded for total above-ground biomass. The preliminary selected equations were compared to get the best fit equation or model considering the parameters of estimation such as CV, R_{mse}, MS_{error}, S_a, S_b, F value, AICc and furnival index (Table 3). The selected allometric models were Biomass = 0.014 DBH^2 + 0.03; $\sqrt{\text{Biomass}}$ = 0.29 DBH − 0.21; $\sqrt{\text{Biomass}}$ = 0.66 $\sqrt{\text{DBH}}$ − 0.57; $\sqrt{\text{Biomass}}$ = 1.19 $\sqrt{\text{DBH}}$ − 1.02; Biomass = 0.21 DBH^2 + 0.12 for leaves, branches, bark, stem without bark and total above-ground biomass, respectively (Fig. 1). Irrespectively, allometric models for nutrients (N, P and K) and carbon stock in the above-ground biomass were also selected by considering the same principle as followed for the biomass equations. The selected allometric models for

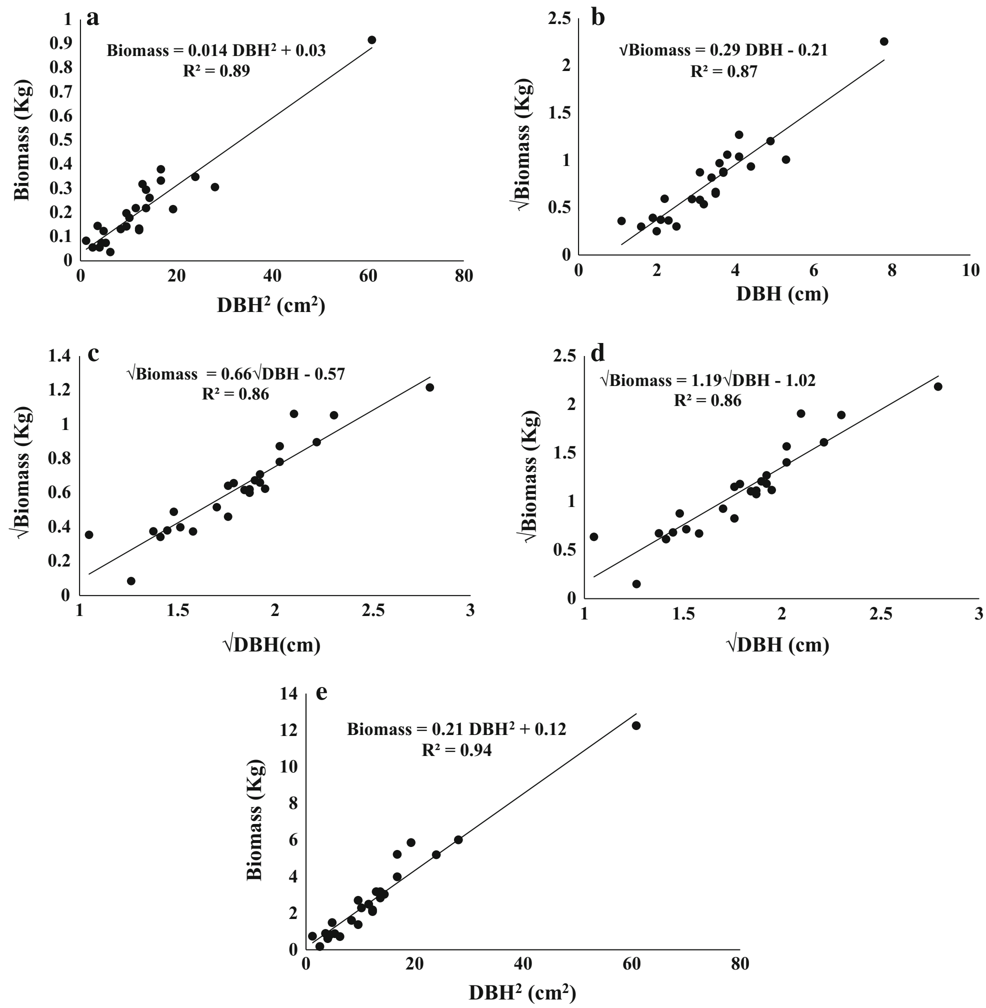

Fig. 1 Graphical representation of the best fit models for leaf (**a**), branch (**b**), bark (**c**), stem without bark (**d**) and total above-ground biomass (**e**) of *Kandelia candel*

Nitrogen, Phosphorous, Potassium and Carbon were $N = 0.39\ DBH^2 + 0.49$, $P = 0.77\ DBH^2 + 0.14$, $K = 0.87\ DBH^2 + 0.07$ and $C = 0.09\ DBH^2 + 0.05$ (Fig. 2).

Discussion

Higher biomass proportions for branches were found at higher DBH classes of the *K. candel*. Similar findings of higher biomass proportion of branch were observed with lower DBH classes of *B. parviflora* in Malaysia (Mahmood et al. 2004), *Rhizophora apicuata* and *R. stylosa* in north-eastern Australia (Clough 1992). Different mangrove species showed different proportions of biomass allocation to their parts and this proportion of biomass allocation depends on species-specific architecture at different stages (seedlings, saplings and trees), stand structure, regional climate and environmental factors (Steinke et al. 1995; Tam et al. 1995; Clough et al. 1997; Mahmood et al. 2004). Close range of height (1.85–3.9 m) and overlapping height limits among the DBH classes of the sampled *K. candel* may be responsible for observing almost similar proportion of stem and bark biomass for all DBH classes (Table 1). Moreover, plant size (height and DBH) and age have significant influence on partitioning of above-ground biomass into various parts of a species (Clough et al. 1997; Peichl and Arain 2007).

Higher concentration of nutrients was observed in leaves, but highest concentration of carbon was detected in woody parts of the *K. candel.* The trend of nitrogen, phosphorus and potassium concentration in plant parts of the studied species was similar to that of *C. decandra* (Mahmood et al. 2012), *R. apiculata* (Ong et al. 1984), *Avicennia* spp., *Bruguiera* spp. and *Ceriops spp.* (Aksornkoae and Khemnark 1984) and *B. parviflora* (Mahmood et al. 2006). Leaves and green parts of plants contain higher concentration of nutrients than woody parts (Binkley 1986; Mahmood 2014). The variation of nutrients and carbon concentration in plant parts also related to the

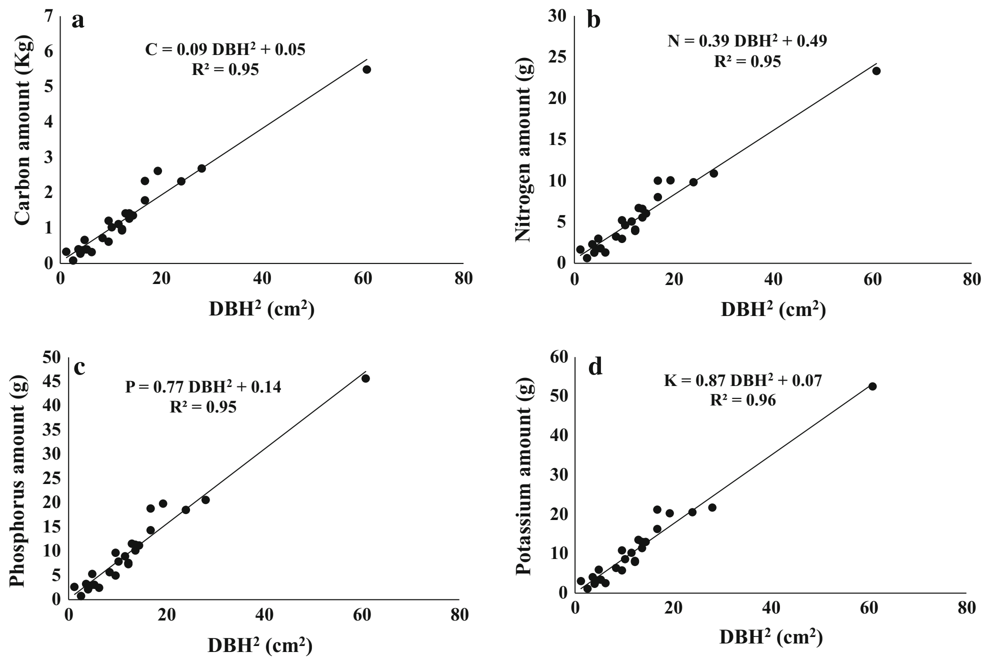

Fig. 2 Allometric relationship between diameter at breast height (DBH) and amount of Carbon (**a**), nitrogen (**b**), phosphorus (**c**) and potassium (**d**) in total above-ground biomass

structural component of plant cell (Kaakinen et al. 2004). Plant species, physiological age of the tissue, position of the tissue in plant, available form of nutrients in the substrate, concentration of other nutrients, climatic and soil edaphic factors may be the reason for variation in nutrient concentration in plant parts (Mahmood 2004).

The allometric models for biomass estimation are developed from the relationship between physical parameters of the trees (e.g., diameter at breast height, height of the tree trunk, total height of the tree and crown diameter) and tree biomass. DBH and height are commonly used variables in allometric models to estimate the above-ground biomass of mangrove species (Saintilan 1997; Komiyama et al. 2002; Xiao and Ceulemans 2004; Cienciala et al. 2006). The present study tested linear regression equations with different transformation (Log, ln, and Square root) of independent (DBH and TH) and dependent (biomass) variables to get best fitted one for biomass estimation. But, the selection of best regression equation is the key to allometric modeling in biomass estimation (Steinke et al. 1995; Tam et al. 1995). The use of R^2 value gives a general assessment for selecting the best fit equation, but this will give misleading result for models with different set of variables (West and Wells 1990; Zar 1996; Parresol 1999). Moreover, root mean square error (R_{mse}) is not a logical parameter to compare the equations with transformed variables. But, Furnival Index is one of the recommended parameters to compare equations with transformed variables (Furnival 1961; Jarayaman 1999). Therefore, the precise selection can be obtained by considering R^2 and FI along with the other parameters of estimation values, such as CV, MS_{error}, S_a, S_b, F value and AIC_c (Slim and Gwada 1993; Ibrahima 1995; Zar 1996; Chave et al. 2005; Soares and Schaeffer-Novelli 2005; Basuki et al. 2009; Siddique et al. 2012).

Kandelia is a genus of Rhizophoracea family, which has long been regarded as a monotypic genus with a single species *Kandelia candel* (L.) Druce. But, Sheue et al. (2003) has identified *K. obovata* Sheue, Liu & Yong as a new species, which was previously reported as *K. candel* (L.) Druce (Khan et al. 2005; Cuc and Ninomiya 2007). This two species are distributed within two distinct geographical regions. *Kandelia obovata* is distributed in the Gulf of Tonkin northeastward to Kwangtung, Fukien, Taiwan, the Ryukyus, southern Japan and northern Vietnam. Whereas, *K. candel* ranges from western India and the Ganges Delta of eastern India, Burma, Thailand, Malay Peninsula, Sumatra to northern Borneo and southern Vietnam (Sheue et al. 2003). In a comparison, the biomass models of *K. obovata* in Japan (Suwa et al. 2008; Hoque et al. 2011), mistakenly recognized *K. obovata* as *K. candel* in Japan (Khan et al. 2005) and Vietnam (Cuc and Ninomiya 2007), and *Bruguiera gymnorrhiza* in Japan (Deshar et al. 2012) recommended $D_{0.1}^2H$ ($D_{0.1}$, stem diameter at a height of H/10; H, tree height) as independent variables for the best fitted models. Stem diameter at a height of H/10

($D_{0.1}$) and total height (H) are complicated independent variables in terms of measurement in the field and this complication may reduce the applicability of the allometric models (Overman et al. 1994). But, the present study recommends DBH as independent variable which easily measurable and more acceptable physical parameter of trees (Komiyama et al. 2002; Ong et al. 2004; Comley and McGuinness 2005). This study showed the best fitted allometric model with $R^2 = 0.94$ for the total above-ground biomass which is similar to the study of Cuc and Ninomiya (2007) and Suwa et al. 2008, but lower than Khan et al. (2005) ($R^2 = 0.958$) and Hoque et al. (2011) ($R^2 = 0.975$). In case of leaf biomass, Suwa et al. (2008) observed highest R^2 value (0.945) than Khan et al. (2005) ($R^2 = 0.729$), Cuc and Ninomiya (2007) ($R^2 = 0.92$) and this study. The forest structure of the study site of Japan (Khan et al. 2005; Suwa et al. 2008; Hoque et al. 2011), Vietnam (Cuc and Ninomiya 2007) and Bangladesh (present study) was monospecific to closed canopy, plantation and natural mixed mangroves, respectively. Therefore, the variation in independent variables and R^2 values of the allometric models may vary with species, sample size, stand type and stand structure (Steinke et al. 1995; Tam et al. 1995; Komiyama et al. 2008; Alemayehu et al. 2014). The developed allometric models for *K. candel* in the Sundarbans will be useful in estimating biomass, nutrient and carbon stock which may contribute to a broader study of nutrient cycling, nutrient budgeting and carbon sequestration of this forest. Moreover, the findings of this study can contribute to planning for utilization and management of this species in the Sundarbans.

Author contribution statement Mahmood Hossain: principle investigator of this research project, overall supervision of the research work and preparation of manuscript; Chameli Saha: field work, statistical analysis and manuscript preparation; S. M. Rubaiot Abdullah: field work and laboratory analysis; Sanjoy Saha: field work and laboratory analysis; Mohammad Raqibul Hasan Siddique: compilation of field data.

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Compliance with ethical standards

Conflict of interest There is no conflict of interest.

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