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Density, Storage and Distribution of Carbon in Mangrove Ecosystem in Guangdong's Coastal Areas

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Abstract Using the mangrove plants and sediment of the typical mangrove areas in Guangdong's coastal areas, P. R. China as the research object, the density, storage and spatial distribution of carbon are studied. The study method is the combination of the wild field analysis and laboratory testing method. The results show that the carbon density of the sediment will gradually decrease because of the increased depth, and has nothing to do with the difference of the area and tree species. The average carbon density of 50cm sediment is 0.007gC/g. The carbon density is obviously different in different components of different mangrove species in different regions. The total carbon storage in different regions is in the following order: Zhuhai > Gaoqiao > Shenzhen > Shuidong Bay > Guanghai Bay > Raoping > Daya Bay > Chenghai. The carbon density and carbon storage are obviously higher in mangrove covered area than blank area. It shows that mangroves have very strong carbon sink function.

Key words Mangrove, Carbon density, Carbon storage, Distribution characteristics, Guangdong's coastal areas

In recent years, the CO_2 concentrations continue to grow in atmosphere, and the resulting global warming and other issues have made the carbon cycle become a global research focus[1]. The current studies are mainly focused on the carbon cycle of forests, grasslands and other terrestrial forest ecosystems[2-6]. There are few studies on carbon storage and carbon cycle of the coastal wetland ecosystem. The global wetland ecosystem accounts for only 1% of the earth's surface area, but its carbon storage occupies 15% of the earth's total terrestrial carbon[7], so the carbon cycle of wetland ecosystem plays an important role in the global carbon cycle. The mangrove ecosystem occupies an important position in the common wetland ecosystems due to short carbon cycle and high primary productivity. Mangroves are various large and extensive types of trees up to medium height and shrubs that grow in saline coastal sediment habitats in the tropics and subtropics-mainly between latitudes 25°N and 25°S. The mangrove ecosystem is one of the important types of Chinese coastal wetland ecosystems. In recent years, due to rapid economic development and human activities, the mangrove habitat has been severely damaged, therefore, studying the carbon density, storage and spatial distribution of mangrove can help to accurately understand the carbon cycle of mangrove wetlands in China's coastal areas, and it can also provide a scientific basis for mangrove conservation, restoration and development. In this study, we select the mangrove plants in the typical coastal mangrove areas of Guangdong Province as the research object, and use field and laboratory analysis to research the carbon density, storage and spatial distribution characteristics of mangrove, in order to provide some basic data for accurately evaluating the role of mangrove wetland ecosystems in the global carbon balance.

1 Materials and methods

1.1 Overview of the experimental sites Guangdong is a province with the largest mangrove distribution area in China[8], and this study selects 8 typical coastal mangrove areas as experimental sites: Huizhou Daya Bay Mangrove Park; Zhuhai Qi'aodao Mangrove Nature Reserve; Shenzhen Futian Mangrove Nature Reserve; Chenghai Chengraowei Mangrove Area; Raoping Fushicun Mangrove Area; Maoming Shuidong Bay Mangrove Area; Jiangmen Guanghai Bay Mangrove Area; Lianjiang Gaoqiao Mangrove Tourist Area. The common species of mangrove are mostly native species, and only *Sonneratia apetala* is the introduced species.

1.2 Experimental materials The common mangrove species and the base sediments are collected from various experimental sites as experimental materials, to conduct various tests and analysis.

1.3 Experimental methods In November 2012, the sampling points were set in the typical dominant species forest stands with consistent environmental conditions in various regions, respectively, and the plant and sediment samples were collected from each sampling point. The average wood harvesting method was used to measure the plant biomass, and the plant samples were labeled and frozen according to different components. The plant samples were rinsed with distilled water, and dried to constant weight in the laboratory at 60 ℃ (>72 h). In each sampling point, after

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being dried for 1 h, a PVC tube with diameter of 5 cm was vertically thrusted into the sediments at depth of 50 cm, and the sampling tube was horizontally laid after being taken out. 3 tubes of the same samples were taken. According to the characteristics of mangrove roots and sediment, we described the sediment characteristics and conducted stratified sampling (upper layer 5 cm; middle layer 5 – 20 cm; lower layer 20 – 50 cm). Samples collected were immediately frozen[9]. Sediment samples in the laboratory were divided into two parts. One part was naturally aired and the other part was dried at 80 – 100 ℃. The plant and sediment samples processed as described above were ground to be sifted through 0.25 mm-mesh sieve for determination. The carbon of each sample was determined using potassium dichromate oxidation - reduction volumetric method.

1.4 Statistical analysis Excel and SPSS19.0 are used for the statistical analysis of experimental data.

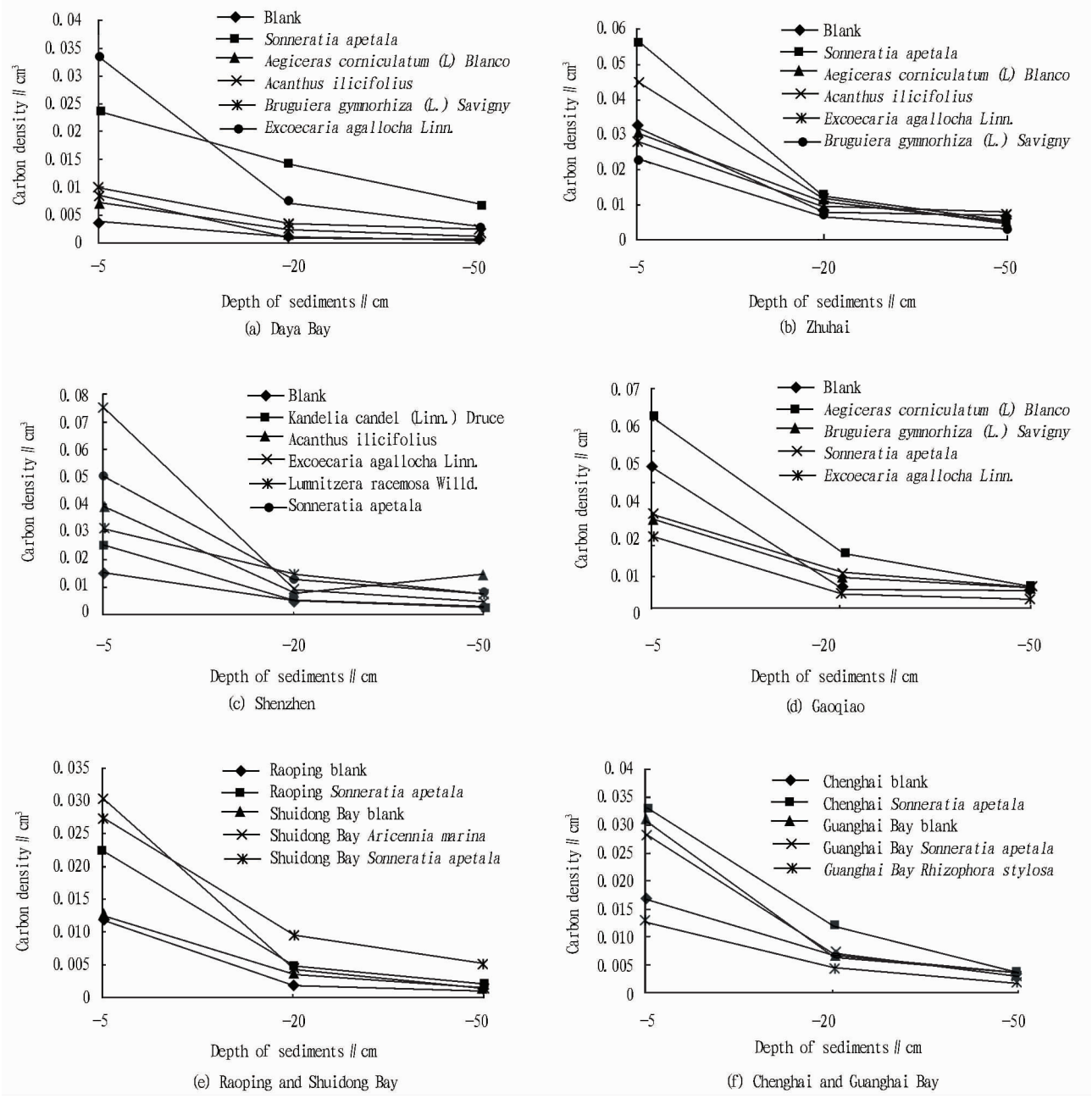

Fig. 1 The vertical distribution of sediment carbon density for different species of tree in different regions

2 Results and analysis

2.1 The vertical distribution of sediment carbon density for different species of tree in different regions As can be seen from Fig. 1, the sediment carbon density gradually decreases with increasing depth, and it has nothing to do with differences in region and species. The carbon density of sediments in the upper

layer ranges from 0.0016 to 0.0758g/cm^3; the carbon density of sediments in the middle layer ranges from 0.0010 to 0.0177 g/cm^3; the carbon density of sediments in the lower layer ranges from 0.0007 to 0.0149 g/cm^3. The average carbon density of sediments in the upper layer is 0.0387 g/cm^3; the average carbon density of sediments in the middle layer is 0.0094 g/cm^3; the average carbon density of sediments in the lower layer is 0.0187 g/cm^3.

2.2 The carbon density distribution of different components for different species of mangrove plants in different regions

As can be seen from Table 1, there are evident differences in the carbon density of different components for different mangrove species in different regions, and the carbon density of leaves for most plants is larger than that of roots. The carbon density value of different components for all plants in Daya Bay, Zhuhai, Shenzhen, Gaoqiao, Shuidong Bay, Guanghai Bay, Raoping and Chenghai, is 0.04 – 0.31, 0.02 – 0.24, 0.05 – 0.48, 0.006 – 0.130, 0.03 – 0.13, 0.09 – 0.25, 0.09 – 0.17 and 0.04 – 0.12 gC/g, respectively. The average value is 0.175, 0.130, 0.265, 0.068, 0.080, 0.170, 0.130, and 0.080 gC/g, respectively. The carbon density value of different components for *Sonneratia apetala*, *Rhizophora stylosa*, *Aegiceras corniculatum* (*L*) *Blanco*, *Acanthus ilicifolius L.*, *Bruguiera gymnorhiza* (*L.*) *Savigny*, *Excoecaria agallocha Linn.*, *Kandelia candel* (*Linn.*) *Druce*, *Heritiera littoralis Dryand.*, *Acrostichum aureum Linn.*, *Lumnitzera racemosa Willd.* and *Aricennia marina* in different regions, is 0.006 – 0.25, 0.1 0 – 0.19, 0.02 – 0.16, 0.11 – 0.48, 0.01 – 0.15, 0.02 – 0.37, 0.05 – 0.24, 0.03 – 0.09, 0.02 – 0.17, 0.06 – 0.19, and 0.03 – 0.12 gC/g, respectively. From Table 1, it can be found that the carbon density of the underground part concerning different mangrove species in different regions accounts for 11% to 35% of the carbon density of whole plant. The proportion of carbon density of different components concerning *Sonneratia apetala*, *Aegiceras corniculatum* (*L*) *Blanco*, *Acanthus ilicifolius L.*, *Bruguiera gymnorhiza* (*L.*) *Savigny*, *Excoecaria agallocha Linn.*, *and Kandelia candel* (*Linn.*) *Druce* in different regions, is 15% – 33%, 16% – 21%, 12% – 35%, 10% – 20%, 11% – 27% and 11% – 12%, respectively.

Table 1 The carbon density distribution of different components for different mangrove species in different regions (gC/g)

Serial number	Regions	Species of tree	Roots	Trunk	Branch	Defoliated branch	Tree leaf	Flowers and fruits	Dry branches
1	Daya Bay	*Sonneratia apetala*	0.12(21)	0.08		0.13	0.25		
		Aegiceras corniculatum (L) Blanco	0.12(16)	0.10	0.13	0.09	0.16	0.15	
		Acanthus ilicifolius L.	0.31(35)	0.28		0.11	0.20		
		Bruguiera gymnorhiza (L.) Savigny	0.07(20)	0.06		0.15	0.05		
		Excoecaria agallocha Linn.	0.09(12)	0.05	0.06	0.15	0.09	0.25	0.04
2	Zhuhai	*Kandelia candel* (Linn.) Druce	0.11(12)	0.09	0.06	0.12	0.24	0.22	0.07
		Acanthus ilicifolius L.	0.12(12)	0.17		0.22	0.22		0.25
		Heritiera littoralis Dryand.	0.09(24)	0.06		0.07	0.09	0.03	0.04
		Sonneratia apetala	0.13(15)	0.08	0.02	0.15	0.23	0.21	0.07
		Acrostichum aureum Linn.	0.15(28)	0.17		0.17	0.03		0.02
3	Shenzhen	*Kandelia candel* (Linn.) Druce	0.07(11)	0.06	0.05	0.09	0.19	0.15	0.08
		Acanthus ilicifolius L.	0.23(20)	0.12		0.3	0.48		
		Excoecaria agallocha Linn.	0.10(11)	0.09		0.22	0.37		0.09
		Lumnitzera racemosa Willd.	0.12(18)	0.10	0.06	0.13	0.19		0.06
		Sonneratia apetala	0.24(20)	0.22	0.11	0.14	0.21	0.25	
4	Gaoqiao	*Aegiceras corniculatum* (L) Blanco	0.04(21)	0.02	0.03	0.03	0.06		
		Bruguiera gymnorhiza (L.) Savigny	0.04(10)	0.03	0.01	0.08	0.1	0.06	0.06
		Sonneratia apetala	0.03(33)	0.03	0.01	0.02	0.006		
		Excoecaria agallocha Linn.	0.09(27)	0.05	0.02	0.03	0.13		
5	*Shuidong Bay*	Aricennia marina	0.12(23)	0.08	0.03	0.08	0.12		0.08
		Sonneratia apetala	0.13(30)	0.05		0.06	0.09		0.09
6	Guanghai Bay	*Sonneratia apetala*	0.13(17)	0.09		0.15	0.25	0.19	
		Rhizophora stylosa	0.13(19)	0.10		0.10	0.14	0.19	
7	Raoping	*Sonneratia apetala*	0.12(17)	0.09		0.16	0.17	0.17	
8	Chenghai	*Sonneratia apetala*	0.10(19)	0.06	0.04	0.08	0.12	0.11	

Note: The imperfect data are invalid data and are not calculated, and the data within brackets are the proportion of carbon density of underground part to whole plant carbon density.

2.3 The carbon storage of different mangrove ecosystems in different regions Carbon storage is the product of carbon density and biomass, and carbon storage of mangrove ecosystem is the sum of total plant carbon storage and total sediment carbon storage. As can be seen from Table 2, most organic carbon in mangrove ecosystem is stored in the sediments and the organic carbon content is low in the mangrove plants. The total carbon storage in Zhuhai, Shenzhen, Gaoqiao and Shuidong Bay is much higher

than in several other areas, which has a close relationship with the total area and tree age. Zhuhai Qi'ao Island Mangrove Nature Reserve and Lianjiang Gaoqiao Mangrove Tourist Area are the conservation zones with a large area and old trees, and the carbon sink function is also particularly significant. The size of total carbon storage is in the following order: Zhuhai > Gaoqiao > Shenzhen > Shuidong Bay > Guanghai Bay > Raoping > Daya Bay > Chenghai.

3 Conclusion and discussions

3.1 The carbon density distribution characteristics of mangrove The results of the study show that the sediment carbon density gradually decreases with increasing depth, which is consistent with the findings of Xu Fanghong et al. [9] on the soil carbon pool of 3 natural mangrove forests in Gaoqiao of Guangdong Province. The average carbon density of 50 cm sediments is 0.0187 g/cm^3, about 0.518 times that of freshwater marsh system[10], and 46.51 times that of tidal flat soil system of Yellow River Estuary[11]. There are also differences in the carbon density of different components and sediments for the same species of mangrove in different regions, such as *Sonneratia apetala*, which may be related to temperature, soil pH, tides[12], demersal species[13] and other factors, so there is a need to perform the further analysis.

Table 2 The carbon storage of different mangrove systems in different regions

Serial number	Regions	Tree species	Blank area t	Sediment t	Mangrove t	The sum of the tree species // t	The sum of the areas // t	Carbon storage t/hm^2
1	Daya Bay	*Sonneratia apetala*	108.07	96.40	4.64	101.05	323.12	45.72
		Aegiceras corniculatum (L) Blanco		13.88	1.25	15.13		12.01
		Acanthus ilicifolius L.		12.06	0.06	12.12		7.87
		Bruguiera gymnorhiza (L.) Savigny		16.27	0.10	16.37		17.60
		Excoecaria agallocha Linn.		62.37	8.02	70.39		40.69
2	Zhuhai	*Kandelia candel* (Linn.) Druce	221 802.87	5 092.88	52.97	5 145.84	239 052.82	65.14
		Acanthus ilicifolius L.		4 445.72	2.67	4 448.39		46.83
		Heritiera littoralis Dryand.		3 885.19	16.01	3 901.20		54.95
		Sonneratia apetala		2 744.65	62.39	2 807.04		32.26
		Acrostichum aureum Linn.		931.91	15.57	947.48		52.64
3	Shenzhen	*Kandelia candel* (Linn.) Druce	6 858.50	440.98	84.51	525.49	10 235.60	35.75
		Acanthus ilicifolius L.		805.23	18.33	823.56		78.43
		Excoecaria agallocha Linn.		276.86	25.69	302.55		72.04
		Lumnitzera racemosa Willd.		383.88	1.94	385.82		60.28
		Sonneratia apetala		1 305.60	34.08	1 339.67		69.41
4	Gaoqiao	*Aegiceras corniculatum* (L) Blanco	42 937.00	11 028.79	84.18	11 112.98	67 499.68	78.26
		Bruguiera gymnorhiza (L.) Savigny		6677.98	80.35	6758.32		49.33
		Sonneratia apetala		4 446.61	121.62	4568.23		52.51
		Excoecaria agallocha Linn.		2 060.21	62.94	2123.15		26.88
5	Shuidong Bay	*Aricennia marina*	1 645.90	1137.77	57.71	1 195.47	5 661.23	27.17
		Sonneratia apetala		2 783.70	36.15	2819.86		44.76
6	Guanghai Bay	*Sonneratia apetala*	1 102.58	469.58	11.51	481.09	1 741.40	34.36
		Rhizophora stylosa		142.95	14.78	157.73		19.72
7	Raoping	*Sonneratia apetala*	323.28	794.95	112.63	907.58	1 230.86	28.36
8	Chenghai	*Sonneratia apetala*	135.50	227.23	17.79	245.02	380.52	49.00

3.2 The carbon sink function of mangrove In most of the areas surveyed in this study, both the carbon density and carbon storage in the areas covered with mangrove are significantly higher than in the areas without mangrove coverage, indicating that mangrove has a strong carbon sink function[14]. There are few studies on the carbon storage of mangrove ecosystem, and most of them focus on the carbon storage of vegetation. Lin Peng et al. [15] estimate the vegetation carbon density of 56-year-old *Aricennia marina* forest in Shenzhen Futian at about 83 t/hm^2. Cao Qingxian[16] estimates the vegetation carbon storage of coastal mangrove in Beibu Gulf, and the carbon storage of *Bruguiera gymnorhiza* (L.) *Savigny*, *Aricennia marina* and *Aegiceras corniculatum* (L) *Blanco* is 251.2, 130.9 and 15.7 t/hm^2, respectively. Mao Zilong *et al.* [17] conduct detailed study of vegetation carbon storage of *Kandelia candel* (*Linn.*) Druce mangrove ecosystem in Shenzhen Futian. However, the existing studies rarely touch upon the soil carbon storage, and the study of Xu Fanghong *et al.* [9] on the soil carbon pool of 3 natural mangrove forests in Gaoqiao of Guangdong Province shows that the 100 cm soil carbon pool of *Aegiceras corniculatum* (*L*) *Blanco* communities is 673.2 t/hm^2. In this study, we estimate the carbon storage of 11 kinds of common mangrove in 8 typical mangrove areas in Guangdong Province, and the results can provide a reference for the future study on carbon sink function

(To page 73)

mental status in the study area from the spatio-temporal aspects.

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(From page 65)

of mangrove ecosystem in Guangdong Province. However, due to constraints of sampling time, methods, technology and funds, the study results are not accurate enough, and there is a need to carry out more accurate follow-up study.

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