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Biomass and Energy Flow of *Sonneratia apetala* Community in Leizhou Peninsula, China
无瓣海桑人工林的生物量与能量研究*

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Abstract Mangrove *Sonneratia apetala* has been introduced and planted in large areas of mudflats in South China in order to meet the ecological services. To probe into its growth and ecological characteristics, the plot survey, wood growth analysis of the standard trees, litter fall net collection, in-site decomposing experiments of litter-leaves in net bags and gross caloric value tests of dry samples in the restored mangrove *S. apetala* communities in Lanbei, Fuchen, Leizhou, were carried out. The results were as follows. In the seven-year old Lanbei community, average single wood volume was 101.415 dm^3; stand biomass was 25.016 kg/m^2 with underground parts to aboveground parts ratio 0.32; current year stand biomass was 8.154 $kg \cdot m^{-2} \cdot a^{-1}$; annual litter fall was1.895 $kg \cdot m^{-2} \cdot a^{-1}$ during the period between Feb. 2001 and Jan. 2002; current year productivity was 10.040 kg/m^2; stand energy fixed amount(EFA) was 443.483 MJ/m^2; average single stand EFA was 1847.849 MJ; current year stand EFA was 144.132 MJ/m^2; current year energy return amount was 34.152 $MJ \cdot m^{-2} \cdot a^{-1}$; current year net EFA was 179.474 $MJ \cdot m^{-2} \cdot a^{-1}$; solar energy fixed rate was 8.10%. The litter leaf decomposition trials revealed that the high decomposition rate of *S. apetala* litter leaves with half dry mass decomposed was 11 days in the dry-cold season and 7 days in the rain season. The biomass and energy data of the above parts showed that the *S. apetala* community was the highest in productivity among mangroves in China as indicated by the ratio of solar energy fixing efficiency which was close to its upmost ecosystem productivity level. Therefore, *S. apetala* is suggested to be planted in the open coastal mudflats of southern China in order to obtain faster forestation and better coastal sheltering and other ecological benefits. But for the national mangrove reserves, the strong ecological invasion of *S. apetala* communities should be watched out.

Key words Mangrove, *Sonneratia apetala*, biomass, energy

摘要 为了认识引进红树林树种无瓣海桑(*Sonneratia apetala*)的生长与生态特征,对雷州附城镇岚北无瓣海桑生态恢复林地进行样方调查与树干生长分析、凋落物收集网收集、干重热值实验分析和网袋就地凋落叶分解试验。结果表明:岚北7a生无瓣海桑群落平均单株无瓣海桑材积为101.415 dm^3;群落现存生物量为25.016 kg/m^2,地下部分现存生物量与地上部分现存生物量比例为0.32;当年现存生物量为8.154 $kg \cdot m^{-2} \cdot a^{-1}$;2001年2月至2002年1月凋落物总量为1.895 $kg \cdot m^{-2} \cdot a^{-1}$;当年群落生产力为10.040 kg/m^2;群落能量现存量为443.483 MJ/m^2;单株能量固定量为1847.849 MJ;当年能量固定量为144.132 MJ/m^2,当年年能量归还量34.152 $MJ \cdot m^{-2} \cdot a^{-1}$(2001年),当年能量净固定量为179.474 $MJ \cdot m^{-2} \cdot a^{-1}$,当年光能转化率为8.10%。同一季节的落叶分解速率相同,半分解期干冷季节为11d,湿热季节为7d,表现出较高的分解速率。无瓣海桑群落具有显著的高生物量与能量积累和归还量特性,其生产力水平处于我国红树林群落中的最高值,其对太阳能的利用形成生物量的水平接近该生态系统最适条件下的水平。因此,对裸滩宜林地选择无瓣海桑进行红树林生态恢复造林,具有成林快、景观和防护等生态效益明显的特点,适合的华南沿海滩涂推广。但是对红树林保护区而言,人工无瓣海桑群落的上述快速生长特性则表现为极强的入侵性,应引起各沿海红树林保护区高度重视和警惕。

关键词 红树林 无瓣海桑 生物量 能量
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1 Introduction

Mangroves are woody plant communities of inter-tide areas of tropical and subtropical coastlines, with particular ecological services in coastal protection, commercial use of the forest resources, near-shore fishery and environmental maintenance, animal habitats, recreation, education and scientific researches, etc[1~9].

The slow growth of native mangroves suppresses the eager of restoration of mangrove resources in the coastlines of Leizhou Peninsula, the southernmost continental tip of China, as the native forestation tree species *Kandelia candel*, *Avicennia marina*, *Rhizophora stylosa* have less contribution toward coastal protection than the introduced *Sonneratia apetala* which has been promoted for large area reforestation on mudflats in South China by several academic institutes and local authorities[10~12]. The aim of this article is to reveal the biomass and energy status of *S. apetala* after seven years of restoration in the inter-tide environment.

2 Plot situation

S. apetala was introduced from Dongzhai Harbour, Hainan Province, south to Leizhou Peninsula in 1993, and the planting trials were carried out by local forestry stations under the guidance of Zhanjiang Forestry Bureau. The results of planting trials showed that the individuals of *S. apetala* grew best at the middle to high inter-tide sites with year round freshwater input[13~14] and also grew well in a fresh water pond[15].

Two plots of the seven-year old *S. apetala* plantations in Lanbei, latitude 20° 50′ N, longitude 110° 20′ E, were selected for biomass study. The climate is characterized as the most southern subtropical monsoon, with average annual temperature of 22.9℃ and average annual rainfall of 1711 mm. The trees were planted at the most landward sides of the inter-tide, with surrounding land reclaimed as fishponds. Irregular tides affect the stands, and the ground surface is about 1.5 m under water at high tides, and 0.6 to 1.2 m above water at low tides. A freshwater channel goes through the edge of the woodland and provides freshwater year-round from drainage in a sea-dyke. The forest soil is mangrove acid. It is dark with lots of organic materials at a depth of 0 to 10 cm, gray at a depth of 10 to 40 cm, and mixed color or yellow at a depth below 40 cm. The pH values were 6.8 at ground level, 5.8 at a depth of 20 cm, 4.5 to 5.0 at a depth of 40 cm, and 6.0 at a depth of 60 cm. The *S. apetala* seedlings were introduced from Dongzhai Harbour, Hainan Province, and planted in Lanbei in August 1995. The seedlings were planted in space of 2 m × 2 m for 166 seedlings per 0.67 hm^2 area (2500 plants/hm^2). This was the first trial for *S. apetala* in the Peninsula. The fresh water drainage kept the fertile soil in low salt content between 4.45 to 5.82 g/kg in order to let the plantation grew vigorously. Other species such as *Kandelia candel*, *Aegiceras corniculatum*, *Avicennia marina*, *Clerodendron inerme*, *Acrostichum aureum*, *Pluchea indica* etc. were only found at the edge of the pure *S. apetala* plantation. The Leaf Area Index (LAI) of 8.6, plant density of 2500 plants/hm^2, and tree crown coverage around 0.9 were recorded in the field work of this biomass study in Jan. 2002.

3 Research methods

Two plots of 5 m × 5 m were set up. Two standard trees were selected in each plot and cut down for biomass and annual growth measurement. A pit of 1 m × 1 m × 1 m was excavated in each plot for root collection. These roots were sorted out in order of large root with diameter $d \geqslant 1.5$ cm, middle root with diameter $1.5\ \text{cm} > d \geqslant 0.2$ cm, and fine root $d \leqslant 0.2$ cm. Biomass was measured in dry weight (105℃). Plant samples were examined for gross carolic value (GCV) with WGG-1G computer carolic detector. Litter fall production was measured through a year round collection between Feb. 2001 and Jan. 2002, with 6 sets of one-square-meter nets hanged under the tree crown at 2 m high above soil surface. The yearly biomass productivity is the product of the current year biomass productivity rate (P_A) multiplied by the total biomass of the plantation. P_A comes from the following formula:

$$P_A = \frac{V_{2001}}{V_0} \quad (1)$$

Where, V_{2001} is wood volume increase; P_A is current year wood volume productivity; V_0 is total volume.

In 2001, we had litter leaf decomposition trials in *S. apetala* communities in two plots (Lanbei and Shaoshan) in dry (July-August) and wet (February-March) seasons. These two plots are 6 km away from each other. In each plot, the fresh dropped leaves were collected and mixed, and then evenly put into 13 nylon bags with apertures 1 mm × 2 mm and dimension 20 cm × 30 cm. One of the bags was taken back to lab for measurement and others were fixed onto the plot

ground. Two bags were collected each week for dry weight measurement.

4 Results

The biomass and energy data of *S. apetala* plantation surveyed are showed in Table 1.

Table 1 The biomass and energy accumulation of *S. apetala* plantation

Parts of tree	Biomass (kg/m^2)	GCV	Single plant's energy (MJ)	Plantation's energy (MJ/m^2)
Trunk	12.779	18.478	983.875	236.130
Bark	0.836	17.057	59.417	14.260
Old branches	2.703	17.868	201.238	48.297
Young branches	1.425	17.198	102.113	24.507
Dead branches	0.087	18.386	6.667	1.600
Leaves	1.107	18.433	85.021	20.405
Flowers and fruits	- 19.573	-	-	
Above ground parts subtotal	18.937	-	1438.331	345.199
Aerial roots	0.303	14.413	7.988	1.917
Underground trunk	2.732	17.191	195.692	46.966
Raw roots	2.285	16.794	159.892	38.374
Middle roots	0.579	13.886	33.500	8.040
Fine roots	0.225	13.275	12.446	2.987
Underground parts subtotal	6.124	-	409.518	98.284
Total	25.061	-	1847.849	443.483

4.1 Biomass

4.1.1 Underground part biomass

The plot investigation showed that the underground part biomass of *S. apetala* was 6.124 kg/m^2. There was 92.91% root biomass distributed at the depth of 0~ 40 cm, and only 1.04% root biomass below the depth of 60 cm (see Table 2). The underground trunk biomass was 2.732 kg/m^2, accounting for 44.61% of the total underground part biomass.

4.1.2 Above ground part biomass

Above ground part biomass was 18.937 kg/m^2, see Table 1. The above ground part biomass of the single plant of *S. apetala* was 78.902 kg, see Table 3.

Table 2 The root distribution of *S. apetala* communities (Dry weight, kg/m^2)

Depth (cm)	Large root	Middle root	Fine root	Total	Per (%)
0~ 20	1.416	0.338	0.182	4.170	62.67
20~ 40	0.733	0.172	0.029	1.480	30.24
40~ 60	0.123	0.056	0.008	0.299	6.05
60~ 80	0.013	0.013	0.006	0.032	1.048
0~ 100	0	0	0	0	0
Total	2.285	0.579	0.225	3.089	
%	73.93	18.74	7.28		100.00

4.1.3 Total biomass

Total biomass was 25.061 kg/m^2, the ratio of the underground part biomass to the above ground part biomass was 0.32 and P_A was 0.325. The current year biomass was 8.145 $kg \cdot m^{-2} \cdot a^{-1}$ in 2001. In comparison with productivity of mangroves in different regions and productivity of Eucalyptus plantations in the same region (Table 4), *S. apetala* plantation was obviously one of the fastest growing forests.

4.2 Trunk wood volume growth

The single plant trunk wood volume was 101.415 dm^3, and the current year trunk wood volume growth was 32.986 dm^3 (Table 5). According to Formula 1, the current year wood volume productivity was 0.325, and f_{2001} was 0.43. The growth characteristics of this species in the plots indicated no certain slower growth time to be expected.

4.3 Litter fall and its monthly allocation

According to litter fall collection in the period from Feb. 1 2001 to Jan. 31 2002, a total of 11.368kg dry litter fall was collected in six nets, with monthly litter fall 1.895 $kg \cdot m^{-2} \cdot a^{-1}$ (Table 6). It is the largest records in mangroves in China[6, 8, 22].

Table 3 Above ground part biomass and its vertical distribution in Lanbei plot

Height (m)	Trunk (kg)	Bark (kg)	Leaves (kg)	Old branches (kg)	Young branches (kg)	Dead branches (kg)	Total (kg)	Per (%)
12~ 13.05	0	0	0.220	0	0.218	0	0.438	0.56
10~ 12	2.196	0.181	2.309	0.692	2.353	0	7.731	9.80
8~ 10	5.058	0.317	0.862	2.957	1.231	0	10.425	13.21
6~ 8	7.864	0.548	0.258	0	0.171	0	8.841	11.21
4~ 6	9.780	0.640	0.387	2.223	0.842	0.027	13.899	17.62
2~ 4	10.788	0.687	0.014	0.692	0.156	0.141	12.478	15.81
0~ 2	17.560	1.111	0.562	4.697	0.966	0.194	25.09	31.80
Total	53.246	3.484	4.612	11.261	5.937	0.362	78.902	
%	55.59	4.48	8.41	22.40	7.93	0.44		100.00

Table 4 Comparison of productivity of mangrove communities in different regions

Location	Community*	Age (a)	Biomass ($t\ hm^{-2}$)	Productivity ($t\ hm^{-2}\cdot a^{-1}$)	Data Cited
Longhai	KC	20	162.63	23.46	[8]
Beihai	AM	30	52.72		[16]
Qiongshan	SC-KC	6	38.53	4.701**	[17]
Qiongshan	BS	55	420.30	29.5	[8]
Wenchang	SC	5	47.23	3.807**	[18]
Futian	SA+ SC	6	65.71	36.40	[19]
Gaojiao	AM	5	16.37		[20]
Gaojiao	KC	5	62.64		[20]
Gaojiao	AC	5	5.55		[20]
Gaojiao	RM	30	96.10		[20]
Gaojiao	BG	10	41.38		[20]
Leizhou	Eucalypt-	3.5	39.596		[21]
	UsCV `Lei-	4.5	56.456		[21]
	lin `No1	6.5	62.671		[21]
Leizhou	SA	6	229.55	100.40	[13]
Leizhou	SA	7	250.61		This article

*: KC= *Kandelia candel*, AM= *Avicennia marina*, SC= *Sonneratia caseolaris*, BS= *Bruguiera sexangula*, SA= *Sonneratia apetala*, AC = *Aegiceras corniculatum*, BG = *Bruguiera gymnorrhiza*, RM = *Rhizophora stylosa*. **: Aboveground biomass only.

The total and monthly litter fall are listed in Table 6. Most of the litter fall was collected in July and August (37.63% of the total litter fall was collected in these two months), since there was 3 Typhoons and the trees were bearing lots of fruits in these two months as well.

4.4 Energy

In order to compare the energy status of plantations, the gross caloric value (GCV) which means the total caloric value of one gram sample was detected for energy characteristics analysis of the plantation. The GCV and energy accumulation of plant show the plant's nutrients and transfer potential of sunlight, and are regarded as important ecological data[8,23].

4.4.1 GCV

The gross caloric values(GCV) of *S. apetala* were listed in Table 1, which range from 12.275 to 19.573 kJ/g. The average energy stored of single plant of seven years old *S. apetala* plantation was 1847.849MJ (Table 1).

4.4.2 Current year energy stored in the plantation

The current year energy stored in the plantation was 443.483 MJ/m^2. The current year energy fixed was 144.132 $MJ\ m^{-2}\cdot a^{-1}$ upon the P_A.

The underground part biomass energy was 98.284 MJ/m^2 accounting for 22.2% of the total energy stored in the stand. The above ground part biomass energy was 345.199 MJ/m^2 (77.8% of the total). The energy stored in different parts of trees was in the following order: trunk, old branches, underground trunk, large roots, young branches, leaves, bark, middle roots, fine roots, dead branches.

According to the data published, the stored energy of the 70 a (in 1989) *Rhizophora stylosa* community in Hainan was 520.372 MJ/m^2[16] and the

Table 5 Wood growth of the standard trees of *S. apetala* community in Lanbei plot

Entry	Height (m)	DBH (cm)	Wood volume (dm^3)	Yearly growth (dm^3)	Mean yearly growth (dm^3)	f (wood shape index)
Year 1(1995)	1.80	0.98	0.410	0.410	0.410	-
Year 2(1996)	3.20	2.84	2.778	2.368	1.389	-
Year 3(1997)	5.10	5.71	8.955	6.177	2.985	0.69
Year 4(1998)	7.00	8.07	21.062	12.107	5.266	0.59
Year 5(1999)	9.00	10.37	41.404	20.342	8.281	0.54
Year 6(2000)	11.00	13.09	68.429	48.087	11.405	0.46
Year 7(2001)	13.05	15.23	101.415	32.986	14.488	0.43

Table 6 The year-round litter fall collection in the *S. apetala* communities in Lanbei, Fuchen, Leizhou

	Litter fall(g/m^2)													Per (%)
	Feb 2001	Mar 2001	Apr 2001	May 2001	Jun 2001	Jul 2001	Aug 2001	Sep 2001	Oct 2001	Nov 2001	Dec 2001	Jan 2002	Total	
Leaves	40.38	77.90	118.88	158.77	142.22	169.62	83.02	65.65	88.63	58.98	42.95	29.83	1076.83	56.84
Branches	4.85	9.15	11.02	29.22	12.67	82.07	63.83	19.10	21.28	14.77	28.75	5.12	301.82	15.93
Flowers	0.03	0.12	0.37	8.48	5.85	9.85	6.50	3.73	1.50	0.30	0.00	0.03	36.77	1.94
Fruits	0.22	0.23	3.45	0.00	19.20	207.52	90.62	43.12	43.75	53.10	16.90	1.12	479.22	25.29
Total in a month	45.48	87.40	133.72	196.47	179.93	469.05	243.97	131.60	155.17	127.15	88.60	36.10	1894.63	100.00
Per(%)	2.40	4.61	7.06	10.37	9.50	24.76	12.87	6.94	8.19	6.71	4.68	1.91	100.00	

stored energy of the 20 a(in 1989) *Kandelia candel* community in Fujian was 746.186 MJ/m^2[24]. Comparing to the above data, the community's energy studied was accumulated in a pretty high speed.

4.4.3 Yearly energy return in the community

The community's yearly energy return was 35.342 MJ $m^{-2}\cdot a^{-1}$, in which 56.16% was in form of leaves, 28.58% in form of flowers and fruits and 15.26% in form of branches(Table 8).

4.4.4 The yearly net energy production in the community

The yearly energy production in the *S. apetala* community equals the total of the yearly stored energy in the stand and the energy in litter fall in the same year, and the result showed that it was 179.474 MJ $m^{-2}\cdot a^{-1}$ [It equals 144.132 MJ $m^{-2}\cdot a^{-1}$ as stored energy in the stand in 2001 added 35.342 MJ $m^{-2}\cdot a^{-1}$]as the energy in litter fall in 2001. The yearly net energy production was 34.276 MJ $m^{-2}\cdot a^{-1}$ in the tropical rain forests[25], 27.302 MJ $m^{-2}\cdot a^{-1}$ in the 70 a(in 1989) *Rhizophora stylosa* community, 56.040 MJ $m^{-2}\cdot a^{-1}$ in the 55 a(in 1984) *Bruguiera sexangula* community, 44.305 MJ $m^{-2}\cdot a^{-1}$ in the 20 a(in 1983) *Kandelia candel* community[8,24]. Based on the data above, it showed that the *S. apetala* community has much higher yearly net energy production.

Table 8 The energy return of *S. apetala* communities

Parts of tree	Yearly litter fall ($g\ m^{-2}\cdot a^{-1}$)	Return Energy ($MJ\ m^{-2}\cdot a^{-1}$)
Leaves	1076.8	19.849(56.16)
Branches	301.8	5.393(15.26)
Flowers and fruits	516.0	10.100(28.58)
Total	1894.6	35.342(100.00)

Value in brackets were percentage

4.4.5 The yearly solar energy utilization ratio

The ratio of the fixed energy in the dry materials in the community to the solar energy reached onto the surface of the community in one year indicates the community's highest efficiency of utilization of solar energy when it is in normal CO_2 and suitable environment (water, temperature and nutrients et al.)[25]. The data 4711.7 MJ $m^{-2}\cdot a^{-1}$ of mean yearly ground solar energy recorded by the local Haikang metrology station was used as the solar energy reached on the *S. apetala* community's crown surface in 2001. Since the fixed energy of the dry materials in the community was 179.474 MJ $m^{-2}\cdot a^{-1}$, the yearly solar energy utilization ratio was 8.10%. The yearly solar energy utilization ratio in the 55 a(in 1984) *Bruguiera sexangula* community was 3.01%, and 2.01% in the 20 a(in 1983) *Kandelia candel* community[24]. Based on the data above, it showed that the *S. apetala* community has much higher efficiency in yearly solar energy utilization in mangrove communities in China[8,26].

4.5 Litter leaf decomposition rate

The litter leaf decomposition trials in the two plots in dry and wet seasons in 2001 showed that there was not obvious difference between these two plots. But the litter leaves in wet season decomposed faster than that in dry season, with half decomposition period of 7 days (July–August) and 11 days(February–March) respectively. It is similar to the trial results of litter leaf decomposition in Avicennia marina community(its litter leaf half decomposition rates were 6 days in summer and 11 days in autumn) in Jiulong River[27]. In the trials we found that 90% of the litter leaves were diluted into its community's environment within 42 days, and the community had pretty higher decomposition rate compared with 6 to 71 days in the mangroves around the world[8]. It had highly contribution to the productivity of the near shore fishery[28,29].

5 Discussion

Plant biomass and energy are indicators of plant and plant community productivity and represent their solar utilization status[25]. This research showed that the *S. apetala* community in Leizhou had very high biomass and energy accumulation and high litter leaf decomposition rate, and was recorded as the highest among mangrove communities in China[30-31]. This characteristics of the community is the result of the fast growth rate of the species (better than local *Eucalyptus cultivars*) in the suitable inter-tide sites in Leizhou, in which there was year round freshwater input, fertile soil, and lots of activity of mudcrabs which provide soil air and few pest interference. The community has great value to the protection of coastal geography and biodiversity and the sustainability of its nearshore fishery. Therefore, these outstanding quick restoration characteristics of *S. apetala* promote the application of itself in mangrove restoration in open coastal mudflats of southern China in order to obtain faster forestation, better coastal sheltering and other ecological benefits. But for the conservational sake of the national mangrove reserves, a higher attention should be paind to the strong ecological invation of *S. apetala* communities.

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