Hydrobiologia **295**: 193–201, 1995.
Y. S. Wong & N. F. Y. Tam (eds), Asia-Pacific Symposium on Mangrove Ecosystems.

©1995. *Kluwer Academic Publishers. Printed in Belgium*

Community structure and standing crop biomass of a mangrove forest in Futian Nature Reserve, Shenzhen, China

N. F. Y. Tam[1], Y. S. Wong[2*], C. Y. Lan[3] & G. Z. Chen[3]
[1]*Department of Biology and Chemistry, City Polytechnic of Hong Kong, Tat Chee Avenue, Kowloon, Hong Kong*
[2]*Research Centre/Biology Department, Hong Kong University of Science and Technology, Clearwater Bay, Kowloon, Hong Kong*
[3]*Research Institute of Environmental Sciences, Zhongshan University, PRC*
(author for correspondence)*

Key words: mangrove forest, standing crop biomass, community structure, allometric regression

Abstract

The community structure and standing crop biomass of a mangrove forest in Futian Nature Reserve, Shenzhen, the People's Republic of China was studied. This mangrove, located towards the northern latitudinal limit of the mangrove development (22°N), had relatively simple structure and low diversity (the Shannon-Wiener index was 0.78). The three dominant species, namely *Aegiceras corniculatum*, *Kandelia candel* and *Avicennia marina*, possess importance values of 72, 19 and 9%, respectively. The average height of the mangrove community was 4.5 m with no vertical stratification. The values of tree density of *A. corniculatum* and *A. marina* were found to be 5290 and 260 ha^{-1}, respectively. The biomass of both *A. corniculatum* and *K. candel* was best estimated from regression equations using a combination of height and diameter at breast height as the independent variables. For *Avicennia marina*, there was no simple correlation between biomass and height or diameter. The regression models suggested by previous workers did not give satisfactory estimation of biomass of *A. marina* in this mangrove forest. The total biomass of this mangrove forest was 12.1 kg m^{-2}, with 73% of such production contributed by *A. corniculatum* and 8% by *A. marina*. Because of its small percentage, the inaccuracy in estimating biomass of *A. marina* did not affect the overall determination of biomass of the whole community. Average above-ground biomass was 8.7 kg m^{-2} (72% of the total biomass) and the major components were aerial woody tissues, stems and branches. The root:shoot ratio of this plant community was 0.4:1.

Introduction

Mangrove swamps are typical wetland ecosystems found in coastal deposits of mud and silt throughout the tropics and some distances into the subtropical latitudes. The total world-wide mangrove area, which is estimated at about 170 000 km^2, dominates approximately 75% of the world's coastline between latitudes 25 °N and 25 °S (McGill, 1958). Mangrove communities are normally characterized by high productivity, high biomass and litter production when compared to other terrestrial plant communities (Lugo & Snedaker, 1974; Mann, 1982). High rates of primary production and rapid decomposition of the mangrove litter result in an important food and energy source for a variety of aquatic organisms and have positive impacts on coastal productivity, including cultures of commercial shellfish such as oysters, clams, crabs, shrimps, and fishes (Chapman, 1983; Steinke & Ward, 1988).

The structure and productivity of mangrove ecosystems are significantly affected by climatic conditions resulting in geographical variations in biomass and primary production. Productivity appears to decrease with an increase in latitude but is enhanced with an increase in tidal amplitude (Woodroffe *et al.*, 1988). It has also been well-documented that mangrove swamps reach their greatest structural and floristic diversity in the tropics and decline with increasing latitude. Most of the previous studies on mangrove ecology focused on tropical mangroves with relatively few references on

sub-tropical regions. Mangroves in Shenzhen Special Economic Zone, the People's Republic of China, at 22°32′N, is located near the northern limits of the mangrove development. Its flora and fauna, the productivity and environmental factors are different from other mangrove stands located in the tropics. Despite their importance in the conservation and ecology of estuarine ecosystems, very little information is available on the community structure and standing crop biomass of the mangrove forests in this region. The present study therefore aims to (1) provide an acceptable method for the estimation of the above and below ground biomass of the mangrove community in Shenzhen, the PRC; and (2) determine the community structure and standing crop biomass of this mangrove forest.

Materials and methods

Study area

The study was carried out at the Futian Nature Reserve of Shenzhen Special Economic Zone, the PRC (22°31′N, 114°05′), which is contiguous with the Mai Po Nature Reserve of Hong Kong. Futian Reserve stretches 11 km from east to west, and covers an area of 304 hectares. Along the muddy shore of this reserve, 112 ha are mangrove forests dominated by *Aegiceras corniculatum* (L.) and *Kandelia candel* (L.) Blanco. The average height of these two dominant species are 4–5 m with no vertical stratification. Very few seedlings and almost no saplings are found on the forest ground. The forest is 20 to 22 years old. In addition to these two species, some *Avicennia marina* (Forsk.) Vierh and fewer individuals of *Excoecaria agallocha* are also found. At the gap or the open area of the mangrove forest, where more light reaches the forest ground, *Acanthus ilicifolius* Linn. are commonly found. The mangrove ecosystem is inundated by incoming tide twice a day and the largest tidal range, at high spring tides, is about 2.8 m. The climate of this area is humid, with mean annual relatively humidity of 80%. The mean annual air temperature is 22 °C, with the minimum and maximum temperatures at 0.2 and 38.7 °C, respectively. The lowest mean monthly temperature is 14.1 °C (in January) and the highest value is 28.1 °C (in July). Annual precipitation is 1926.7 mm and the rainy months are from May to September (78.4% falls in this wet season).

Harvesting for biomass estimation

Fifteen trees of *Aegiceras corniculatum* (2 to 12 cm DBH, diameter at breast height), nineteen trees of *Kandelia candel* (2 to 15 cm DBH) and 6 trees of *Avicennia marina* (8–15 cm DBH) were randomly chosen. The individual tree was felled and harvested, the height (HT) and diameter at breast height (DBH) were measured. The above-ground part was divided into stem (trunk), branch and twig, leaf, inflorescence and fruiting bodies. The fresh weight of these components was measured. Subsamples were then dried at 80 °C to determine their dry weights. Roots of three trees from each species were excavated manually to a depth of approximately 500 mm to give an estimate of below-ground biomass. All root materials were washed carefully under a jet of water to remove adhering mud. The fresh and oven-dried weight of the roots collected were determined. Various allometric regression equations using either tree diameter or height, or a combination of diameter and height as the independent variables, and the weight of the specific components as the dependent variable were developed (Table 1; Snedaker & Snedaker, 1984). The significance of the regression equation was assessed by the correlation coefficient value (r) and the t-tests on the slope or regression coefficient values (b).

Community structure and standing crop biomass of Futian mangrove forest

Two belt transects 100 m apart within the Futian mangrove forest were laid perpendicular to the shoreline to determine the structural feature and standing crop biomass of the mangrove plant communities. Transects A and B were 90 m × 10 m and 60 m × 10 m, respectively, and the total area covered was 1500 m^2. Fifteen quadrats, each of 10 m × 10 m, were sampled. Within each quadrat, all trees were identified and the number of trees of each species was recorded. The height (HT), DBH, maximum canopy width and length of each tree were measured. The relative density, frequency, dominance, basal area, average diameter and importance values were calculated for each species. The species diversity of the mangrove stand was determined in terms of Shannon-Wiener index and evenness. The biomass of each species and the plant community were estimated by the allometric regression equations formulated from the harvest data.

Table 1. Regression equations used to estimate the relationship between the dependent variable (weight of specific component, y) and the independent variables (height and/or diameter, x).

Regression equations	Independent variable (x)	Regression equations	Independent variable (x)
$y = ax^b$	$DBH^2 * HT$	$y^{1/3} = a + bx$	DBH
$y = ax^b$	DBH^2	$y^{1/3} = a + bx$	HT
$y = ax^b$	DBH	$y = a + bx_1 + cx_2$	x_1: DBH; x_2: HT
$y = ax^b$	HT	$y = a + bx_1 + cx_2$	x_1: DBH^2; x_2: HT
$y = a + bx$	$DBH^2 * HT$		
$y = a + bx$	DBH		
$y = a + bx$	HT		

DBH: Diameter at breast height (m); HT: Tree height (m); a, b and c are constants of the regression model.

Table 2. Harvest data of 15 individuals of *Aegiceras corniculatum* used to calculate the regression equations for biomass estimation.

DBH (cm)	HT (m)	Biomass (Oven-dry weight, kg)				
		Stem biomass	Branch biomass	Leaf biomass	Total aerial biomass	Root biomass
15.1	4.7	7.18	6.50	1.20	14.88	ND
20.2	4.3	7.38	6.64	1.35	15.82	ND
21.7	4.2	9.25	7.57	1.88	18.70	ND
15.8	4.2	6.13	5.53	1.02	12.68	ND
9.9	4.3	2.18	1.97	0.56	4.71	ND
24.6	4.7	10.38	6.60	1.20	18.18	ND
26.4	4.6	7.63	6.74	1.03	15.40	ND
11.3	4.0	3.18	2.49	0.43	6.10	ND
3.7	4.6	1.68	1.34	0.31	3.33	ND
11.9	4.0	3.50	3.03	0.41	6.94	ND
22.7	4.3	7.13	6.38	0.83	14.34	ND
7.1	4.7	3.38	2.26	0.30	5.94	ND
17.6	4.2	6.38	5.68	0.89	12.95	5.46
36.9	4.7	11.38	8.13	2.30	21.81	8.32
20.9	4.3	8.50	6.72	1.36	16.55	4.99

ND: Not determined.

Results

The dry weights of different components of *Aegiceras corniculatum*, *Kandelia candel* and *Avicennia marina* are recorded in Tables 2 to 4, respectively. The dry weight of the trees and their components were best estimated as a power function of the square of the diameter multiplied by tree height ($y = ax^b$ where y = biomass and $x = DBH^2 * HT$). The r values for *A. corniculatum* and *K. candel* were greater than 0.85 and 0.78, respectively (Table 5). In these two species, all other regression models listed in Table 1 were found to be less significant than this power function and the r values were less than 0.7. This indicates that plant biomass could not be satisfactorily estimated by only stem height or diameter. In the case of *A. marina*, none of the regression models being tested provided significant estimates of biomass, and the r values of the best

Table 3. Harvest data of 19 individuals of *Kandelia candel* used to calculate regression equations for biomass estimation.

DBH (cm)	HT (m)	Biomass (Oven-dry weight, kg)					
		Stem biomass	Branch biomass	Leaf biomass	Other biomass	Total aerial biomass	Root biomass
5.7	4.4	4.84	2.80	1.42	0.043	9.10	4.23
6.1	4.5	5.24	3.64	1.01	0.064	9.95	4.26
4.9	4.5	3.07	2.54	0.95	0.068	6.63	ND
6.9	4.5	7.09	5.96	2.17	0.240	15.46	ND
12.6	5.4	14.76	22.30	3.75	1.777	42.59	ND
4.6	4.5	2.13	1.75	0.45	0.054	4.38	ND
9.4	4.3	5.31	2.40	0.80	0.039	8.55	ND
6.0	5.1	4.96	3.87	0.74	0.204	9.77	ND
7.5	4.1	5.08	6.39	1.72	2.146	15.34	6.66
6.9	3.4	2.24	1.52	0.68	0.136	4.58	ND
6.9	3.4	2.01	1.37	0.68	0.036	4.09	ND
4.4	4.9	2.95	1.76	0.57	0.157	5.44	ND
7.6	4.8	4.96	4.93	1.67	0.261	11.82	ND
6.1	4.8	4.72	4.10	1.24	0.275	10.34	ND
7.4	5.2	8.27	8.45	2.14	ND	18.86	ND
9.4	4.8	15.45	22.32	4.31	ND	42.08	ND
7.6	4.7	8.79	17.01	3.38	ND	29.18	ND
5.4	5.1	4.02	2.00	0.94	ND	6.96	ND
8.1	5.5	7.37	8.16	2.88	ND	18.41	ND

ND: Not determined.

Table 4. Harvest data of 6 individuals of *Avicennia marina* used to calculate regression equations for biomass estimation.

DBH (cm)	HT (m)	Biomass (Oven-dry weight, kg)				
		Stem biomass	Branch biomass	Leaf biomass	Total aerial biomass	Root biomass
10.1	5.6	12.09	24.73	2.85	39.67	ND
12.7	3.1	3.29	6.95	1.81	12.05	ND
8.3	4.9	9.80	16.33	2.16	28.24	ND
12.5	5.0	12.49	18.77	2.14	33.40	4.28
14.3	4.7	12.70	22.15	2.68	37.53	5.89
9.9	4.8	9.86	11.88	1.54	23.28	3.62

ND: Not determined.

regression model (the same power function as the other two species) were less than 0.5 (Table 5). This suggests that the biomass of *A. marina* had no simple relationship with its diameter and tree height. This might be related to the unique structure and shape of this species in Futian. *A. marina* found in this mangrove stand was stunted, irregular in shape and started forking at very low level of the tree trunk.

The Futian mangrove community was rather simple with low species diversity. The Shannon-Wiener index and evenness were 0.78 and 48.98%, respectively, lower than that of the sub-tropical evergreen broad-leaf forest commonly found in the southern part

Table 5. Allometric regression equations, based on the harvest data shown in Tables 1-3, for estimating biomass of specific components of three dominant mangrove plant species.

Plant species	Plant components	Regression Equations	*r* value	F and significance of F value
Aegiceras corniculatum	Stem	$\text{Log } AS_W = 1.198 + 0.464 \text{ Log } (DBH^2 * HT)$	0.93	84.4, $P<0.0000$
	Branch	$\text{Log } AB_W = 1.110 + 0.463 \text{ Log } (DBH^2 * HT)$	0.93	87.0, $P<0.0000$
	Leaf	$\text{Log } AL_W = 0.393 + 0.475 \text{ Log } (DBH^2 * HT)$	0.88	43.2, $P<0.0000$
	Total aerial	$\text{Log } AT_W = 1.496 + 0.465 \text{ Log } (DBH^2 * HT)$	0.94	95.2, $P<0.0000$
	Root	$\text{Log } AR_W = 0.967 + 0.303 \text{ Log } (DBH^2 * HT)$	0.93	NC
Kandelia candel	Stem	$\text{Log } KS_W = 2.162 + 0.869 \text{ Log } (DBH^2 * HT)$	0.84	40.9, $P<0.0000$
	Branch	$\text{Log } KB_W = 2.741 + 1.253 \text{ Log } (DBH^2 * HT)$	0.80	30.4, $P<0.0000$
	Leaf	$\text{Log } KL_W = 1.706 + 0.943 \text{ Log } (DBH^2 * HT)$	0.78	26.9, $P = 0.0001$
	Total aerial	$\text{Log } KT_W = 2.814 + 1.053 \text{ Log } (DBH^2 * HT)$	0.83	38.8, $P<0.0000$
	Root	$\text{Log } KR_W = 2.433 + 0.990 \text{ Log } (DBH^2 * HT)$	0.95	NC
Avicennia marina	Stem	$\text{Log } VS_W = 1.643 + 0.544 \text{ Log } (DBH^2 * HT)$	0.39	0.75, $P = 0.44$
	Branch	$\text{Log } VB_W = 1.897 + 0.567 \text{ Log } (DBH^2 * HT)$	0.46	1.05, $P = 0.36$
	Leaf	$\text{Log } VL_W = 0.690 + 0.287 \text{ Log } (DBH^2 * HT)$	0.47	1.11, $P = 0.35$
	Total aerial	$\text{Log } VT_W = 2.092 + 0.529 \text{ Log } (DBH^2 * HT)$	0.45	1.02, $P = 0.37$
	Root	$\text{Log } VR_W = 1.361 + 0.615 \text{ Log } (DBH^2 * HT)$	0.92	NC

DBH: diameter at breast height (m); HT: Height (m); *r*: correlation coefficient between Log biomass and Log (DBH^2 * HT), NC: not calculated.

Table 6. Community structure of the mangrove forest in Futian Nature Reserve.

Plant species	Number of Individuals[a] (alive)	Number of Individuals[a] (dead)	Average DBH (cm)	Average Height (m)	Basal Area[b] (m^2)	Relative Density[c]	Relative Frequency[d]	Relative Dominance[e]	Importance Value[f]
Aegiceras corniculatum	794	99	19.56	3.85	1.219	84	42	89	71.67
Kandelia candel	117	0	7.76	4.20	0.163	12	36	9	19.00
Avicennia marina	39	6	13.63	4.35	0.042	4	22	2	9.33

[a] Number of individuals was measured based on a sampling plot size of 1500 m^2;
[b] Basal Area (m^2) = Σ ($DBH^2 * \pi$)/(4 * 10,000);
[c] Relative Density = (number of individuals of a species / total number of individuals) * 100;
[d] Relative Frequency = (frequency of a species / sum frequency of all species) * 100;
[e] Relative Dominance = (total basal area of a species / basal area of all species) * 100;
[f] Importance Value = (Relative Density + Relative Frequency + Relative Dominance) / 3.

of China (Zhang *et al.*, 1989). The mangrove forest was dominated by *A. corniculatum*, with an importance value of 71.67, which was much higher than *K. candel* and *A. marina* (Table 6). The tree density of *A. corniculatum* (5290 trees ha^{-1}) was also larger than the other two species, being 6 times higher than that of *K. candel* (780 trees ha^{-1}). The average tree density of this mangrove community was around 6000 ha^{-1}, and was within the documented values for mangroves reported elsewhere (1000 to 30 000 trees ha^{-1}, Day *et al.*, 1987; Komiyama *et al.*, 1987). However, in this mangrove stand, about 12.5% of the *A. corniculatum* trees were dead. Even for the living ones, a lot of them had dead lower branches and young leaves were found

Table 7. Total biomass and the partitioning of standing biomass in Futian mangrove forest.

Plant species	Stem		Branch		Leaf		Aerial sub-total		Root		Total	Dead material
	Biomass (kg m^{-2})	% of Total	Biomass (kg m^{-2})	% of Total	Biomass (kg m^{-2})	% of Total	Biomass (kg m^{-2})	% of Total	Biomass (kg m^{-2})	% of Total	Biomass (kg m^{-2})	Biomass (kg m^{-2})
Aegiceras corniculatum	3.434	35.95	2.745	28.73	0.527	5.52	6.807	71.26	2.746	28.74	9.553	0.849
Kandelia candel	0.464	28.77	0.429	26.59	0.124	7.69	1.058	65.59	0.555	34.41	1.613	ND
Avicennia marina	0.291	29.82	0.493	50.51	0.062	6.35	0.849	86.99	0.127	13.01	0.976	0.078
Total	4.189	34.50	3.667	30.20	0.713	5.87	8.714	71.77	3.428	28.23	12.142	0.927

ND: Not detected.

Table 8. Total and above-ground biomass (t ha^{-1}) of mangrove forests in the world.

Location	Latitude	Mangrove species	Structure or average height (m)	Above-ground biomass	Total biomass	Source of reference
Panama	9 °N	*Rhizophora brevistyla*	30-40	279.2	468.9	Golley *et al.*, 1975
Thailand	8 °N	*Rhizophora apiculata*	11	159.0	ND	Christensen, 1978
Malaysia	5 °N	*Rhizophora apiculata*	ND	185.3	202.5	Gong & Ong, 1990
Sri Lanka, Dutch Bay	8 °N	*Rhizophora mucronata* and *Avicennia marina*	4.5	71.0	ND	Amarasinghe & Balasubramaniam, 1992b
Sri Lanka, Puttalam lagoon	8 °N	*Avicennia marina*	7.3	201.7	ND	Amarasinghe & Balasubramaniam, 1992b
Puerto Rico	18 °N	*Rhizophora mangle*	8	62.9	112.9	Golley *et al.*, 1962
Philippines	12 °N	Mixed mangrove species	ND	45.9	ND	de la Cruz & Banaag, 1967
China, Hainan Island	19 °N	*Bruguiera sexaugula*	ND	248.5	420.3	Lin *et al.*, 1990
China, Fujian	24 °N	*Kandelia candel*	5	93.4	162.6	Lin, 1989
Hong Kong	22 °N	*Kandelia candel*	ND	129.6	ND	Lee, 1990
Taiwan	24 °N	*Kandelia candel*	ND	ND	143.9	Chen, 1982
USA, Florida	26 °N	*Rhizophora mangle*	fringe	118.9	ND	Lugo & Snedaker, 1974
		Rhizophora mangle	scrub	7.9	ND	Lugo & Snedaker, 1974
		Mixed species	island	49.0	57.0	Lugo & Snedaker, 1974
Japan	24 °N	*Rhizophora mucronata*	5-6	108.1	ND	Suzuki & Tagawa, 1983
		Bruguiera gymnorhiza	5-6	97.6	ND	Suzuki & Tagawa, 1983
Australia, Sydney	34 °S	*Avicennia marina*	6-8	128.3	ND	Briggs, 1977
Australia, Westernport Bay	38 °S	*Avicennia marina*	2-4	86.0	232.0	Clough & Attiwill, 1975
New Zealand	37 °S	*Avicennia marina*	2.5-4	104.1	ND	Woodroffe, 1985
		Avicennia marina	<1	6.8	ND	Woodroffe, 1985
China, Shenzhen	22 °N	*Aegiceras corniculatum* and *Kandelia candel*	4-5	87.1	121.4	This study

mainly at the top of the canopy. The average height of *A. corniculatum* was 3.9 m, slightly shorter than *K. candel* and *A. marina*.

The mean total biomass and the partitioning of biomass were calculated based on regression equations shown in Table 5. Table 7 reveals that *A. corniculatum* had the highest biomass (9.55 kg m^{-2}), 6 times of that found in *K. candel*. In both species, the aerial woody tissues (stem and branch) represented the greatest percentage of the biomass (64.7% and 55.4% for*A. corniculatum* and *K. candel*, respectively) while leaves made up 5.5 and 7.7%, respectively. A similar pattern was also found for *A. marina*. The mean total above-ground biomass contributed more than 65% of the total biomass. The root:shoot ratio of the community was 0.4:1. The highest root:shoot ratio was found *K. candel*, followed by *A. corniculatum* and *A. marina* had the lowest root:shoot ratio (Table 7).

Discussion

The mangrove stand in Futian Nature Reserve of the Shenzhen Special Economic Zone, the PRC had a relatively simple community structure with low species diversity. It was dominated by *Aegiceras corniculatum*, with few individuals of *Kandelia candel* and *Avicennia marina*. There was no zonation of species within this mangrove stand. It has been stated that mangroves are naturally stressed ecosystems. The survival of individual species and thus zonation within a mangrove stand depend on the following environmental factors: frequency of tidal flushing, soil type, soil salinity, drainage plant and animal interactions (Kenneally, 1982). In the present study, the mangrove had very flat topographic slopes and the frequency of tidal flushing in the upslope was low; the upper part of the shore was only flooded by tidal water during the very high spring tide. These created a condition similar to the mainland fringing habitat which was relatively unfavourable to support a large number of species. Amarasinghe and Balasubramaniam (1992a) reported that the mainland fringing mangrove stands had a simpler community structure and dominated by single species than the estuarine sites, the latter habitats had oscillating flushing conditions with more favourable nutrient balances which supported higher species diversity.

The present mangrove stand had a total biomass of 12.142 kg m^{-2} and about 72% of this was contributed by the above-ground portions. This value is comparable with those found in other mangroves of similar latitude such as Putero Rico (Golley *et al.*, 1962) and Japan (Suzuki & Tagawa, 1983), but much lower than those found in tropical regions (Table 8). In general, the species diversity, tree height and density, and the biomass increase with decrease in latitude. The tropical mangroves usually have higher standing crop biomass and more complicated structure than those in sub-tropical regions. However, the biomass of a mangrove forest is not only affected by the geographic location and the macro-climate. It is also related to the species composition, community structure, growth forms and the age of the plant community (Lugo & Snedaker, 1974; Knox, 1986). The biomass values of two geographically close mangrove forests could be very different. For instance, the biomass obtained in this study was significantly less than that reported in Mai Po, Hong Kong (Lee, 1990) although these two mangroves are contiguous to each other. The difference in biomass estimation of these two sites was mainly due to the fact that the other study took place in the tidal ponds (called '*gei wai*') where the mangrove forest was dominated by *Kandelia candel* (Lee, 1990). The enclosed situation and infrequent inundation in the tidal ponds restricted the dispersal of propagules and enhanced the retention of the majority of the nutrients for *in situ* recycling, therefore supporting larger tree density (51770 ha^{-1} in '*gei wai*' ponds and 6333 ha^{-1} in the present study) and higher biomass. Woodroffe (1985) concluded that the biomass depends very much on tree height and density. For the same *Avicennia* mangrove stands with a low and sparse population, the above-ground biomass was less than 2 t ha^{-1} while areas of tall dense trees had value of 104.13 t ha^{-1}. Moreover, *K candel*, at its mature stage, is taller and have more dense canopy cover than *A. corniculatum*. This explained the importance of factors other than macroclimate on the mangrove forest structure and productivity. Similarly, the biomass value of this mangrove stand was lower than those found in Taiwan (Chen, 1982) and Fujian, the PRC (Lin, 1989) with a location at even higher latitude (about 25 °N). These two mangrove stands were dominated by *Kandelia candel*, which had taller and more dense canopy cover than *A. corniculatum* at its mature stage. Furthermore, as discussed previously, a significant percentage of dead individuals of *A. corniculatum* was found in Futian mangrove stand, and most trees had dead leafless branches below the top canopy.

The mean root:shoot ratio of this community was 0.4:1, ranged from 0.53:1 in *K. candel* and 0.15:1 in *A. marina*. These values were similar to that report-

ed by previous researchers, including Golley *et al.* (1962; 0.44:1 and 1975; 0.68:1), Tamai *et al.* (1986; 0.44:1) and Silva *et al.* (1991; 0.25:1), but much lower than that of Briggs (1977; 1.02–1.28:1) and Clough & Attiwill (1975; 1.69:1). Mangrove communities were usually found to have high root:shoot ratios (Knox, 1986), and the community with taller trees tended to have a lower root:shoot ratio than the community of smaller trees (Briggs, 1977). In this study, the root biomass might have been underestimated especially for *A. marina* because of the following reasons. Firstly, the excavation for root biomass estimation was only limited to the top 50 cm and the deep roots might have been lost. Secondly, the root systems of the mangrove trees, in particular, *A. marina*, were very extensive and irregular so field collection of root material might be incomplete. Thirdly, the fine roots might have been missed during clearing of the adhering mud and soil. Lastly, only three trees were excavated and harvested for root biomass estimation, thus large error might have been generated. Actually, good root biomass data in mangroves studies are rare because of the difficulty in sampling roots quantitatively (Knox, 1986). More in-depth study on the root biomass production and its importance in the functioning, in particular, cycling of organic and inorganic material, of the mangrove ecosystem would be essential.

In the present study, the biomass of different components of *A. corniculatum* and *K. candel* were best estimated by power curves using a combination of tree height and diameter at breast height ($DBH^2 * HT$) as the independent variables. It was found that estimate of biomass based on only a single parameter, either height (HT) or diameter (DBH), as suggested by many researchers (Amarasinghe & Balasubramaniam, 1992b; Day *et al.*, 1987; Golley *et al.*, 1962; Woodroffe, 1985), was less significant. This implies that regression models developed by previous workers for estimating biomass could not be applied directly without modification for mangrove stands in Futian, PRC. Woodroffe (1985) found that the regression model and the importance of the tree height or diameter as the independent variable to estimate biomass value would vary between mangrove stands. Even for the same mangrove stand, the regression models would be different for areas of different tree height and density. In this study, there was no close relationship between height (and/or diameter) and biomass of *A. marina*, and none of the regression models suggested by previous workers was successful. Other parameters such as canopy diameter and width, which provide better description on the growth forms of *A. marina*, might need to be explored. The method developed by Briggs (1977), which calculated the mean tree biomass of *A. marina* from the mean volume and mean wood density, and the photosynthetic (leaf and petiole) biomass from the regression equation using stem diameter and non-photosynthetic biomass as independent variables, might be worthwhile for consideration. Nevertheless, *A. marina* was the least important species in Futian mangrove and it only contributed a small percentage to the total biomass value of the whole community (about 8% of total biomass). The unsatisfactory results in estimating biomass of this species from the harvest data would not affect the overall standing crop biomass values of this mangrove stand.

Acknowledgments

The authors wish to express their appreciation to all who assisted with field work, in particular, Dr M. S. Li and Mr S. H. Li. We would also like to thank the officers and technicians in the Futian Nature Reserve, the PRC, and the financial support from the Hong Kong University of Science and Technology, the Croucher Foundation and the Hong Kong Research Grant Council.

References

Amarasinghe, M. D. & S. Balasubramaniam, 1992a. Structural properties of two types of mangrove forest stands on the northwestern coast of Sri Lanka. Hydrobiol. 247: 17–27.

Amarasinghe, M. D. & S. Balasubramaniam, 1992b. Net primary productivity of two mangrove forest stands on the northwestern coast of Sri Lanka. Hydrobiol. 247: 37–47.

Briggs, S. V., 1977. Estimates of biomass in a temperate mangrove community. Aust. J. Ecol. 2: 369–373.

Chapman, V. J. 1983. Mangroves in New Zealand. In H. J. Teas (ed.), Biology and Ecology of Mangroves. Tasks for Vegetation Sciences Series Vol. 8, Dr W. Junk Publishers, Lancaster: 81–86.

Chen, M. Y., 1982. Ecological study of the mangroves of Tan-shui Estuary. Quart. J. Chinese Forestry 15: 17–25.

Christensen, B., 1978. Biomass and primary production of *Rhizophora apiculata* Bl. in a mangrove in southern Thailand. Aquat. Bot. 4: 43–52.

Clough, B. F. & P. M. Attiwill, 1975. Nutrient cycling in a community of *Avicennia marina* in a temperate region of Australia. In G. E. Walsh, S. C. Snedaker & H. J. Teas (eds.), Proceedings International Symposium on the Biology and Management of Mangroves, Honolulu Vol. 1, Univ. Florida, Gainesville: 137–146.

Day, Jr. J. W., W. H. Conner, F. L. Lou, R. H. Day & A. M. Navarro, 1987. The productivity and composition of mangrove forests, Laguna de Terminos, Mexico. Aquat. Bot. 27: 267–284.

Dela Cruz, A. A. & J. F. Banaag, 1967. The ecology of a small mangrove patch in Matabungkay Beach, Batangas Province. Nat. Appl. Sci. Bullet. 20: 486–494.

Gong, W. K. & J. E. Ong, 1990. Plant biomass and nutrient flux in a managed mangrove forest in Malaysia. Estuar. coast. Shelf Sci. 31: 519–530.

Golley, F. B., H. T. Odum & R. F. Wilson, 1992. The structure and metabolism of a Puerto Rican red mangrove forest in May. Ecology 43: 10–19.

Golley, F. B. J. T. McGinnis, R. G. Clements, G. I. Child & M. J. Duever, 1975. Mineral Cycling in a Tropical Moist Forest Ecosystem. Univ. Georgia Press, Athens Ga, 248 pp.

Kenneally, K. F., 1982. Mangroves of Western Australia. In. B. F. Clough (ed.), Mangrove Ecosystem in Australia: Structure, Function and Management, Australian Institute of Marine Sciences, Australia: 95–110.

Komiyama, A., K. Ogino, S. Adsornkoe & S. Sabhasri, 1987. Root biomass of a mangrove forest in southern Thailand, I. Estimation by the trench method and the zonal structure of root biomass. J. Trop. Ecol. 3: 97–108.

Knox, G. A., 1986. Estuarine Ecosystems: A System Approach, Vol. I. CRC Press Inc., Florida: 59–78.

Lee, S. Y., 1990. Primary productivity and particulate organic matter flow in a estuarine mangrove wetland in Hong Kong. Mar. Biol. 106: 453–463.

Lin, P., 1989. Biomass and element cycle of *Kandelia* forest in China. In P. Lin (ed.), Mangrove Research Papers (1980–1989), Xiamen Univ. Press, Xiamen: 143–149.

Lin, P., C. Y. Lu, G. L. Wang & H. X. Chen, 1990. Biomass and productivity of *Bruguiera sexangula* mangrove forest in Hainan Island, China. J. Xiamen Univ. (Nat. Sci.) 29: 209–213.

Lugo, A. E. & S. C. Snedaker, 1974. The ecology of mangroves. Annu. Rev. Ecol. Syst. 5: 39–64.

Silva, C. A. R., L. D. Lacerda, L. F. F. Silva & C. E. Rezenda, 1991. Forest structure and biomass distribution in a red mangrove stand in Sepetiba Bay, Rio de Janeiro. Revta Brasil. Bot. 14: 21–25.

Snedaker, S. C. & J. G. Snedaker, 1984. The Mangrove Ecosystem: Research Methods. UNESCO published, the Chaucer Press Ltd., U.K.

Steinke, T. D. & C. J. Ward, 1988. Litter production by mangroves, II. St. Lucia and Richards Bay. S. Afr. J. Bot. 54: 445–454.

Suzuki, E. & H. Tagawa, 1983. Biomass of a mangrove forest and a sedge marsh on Ishigaki Island, South Japan. Jpn. J. Ecol. 33: 231–234.

Tamai, S., T. Nakasuga, R. Tabuchi & K. Ogino, 1986. Standing biomass of mangrove forests in Southern Thailand. J. Jpn. For. Soc. 68: 384–388.

Woodroffe, C. D., 1985. Studies of a mangrove basin, Tuff Crater, New Zealand: I. Mangrove biomass and production of detritus. Estuar. coast. Shelf. Sci. 20: 265–280.

Woodroffe, C. D., K. N. Bardsley, P. J. Ward & J. R. Hanley, 1988. Production of mangrove litter in a Macrotidal Embayment, Darwin Harbour, N.T., Australia. Estuar. coast. Shelf Sci. 26: 581–598.

Zhang, H. D., B. S. Wang & Y. J. Hu, 1989. Hong Kong Vegetation. Suppl. ACTA Scientiarium Naturalium Universitatis Sunyatseni 8: 118–140.