Socio-Ecosystem Studies on Mangrove Forests— Charcoal Industry and Primary Productivity of Secondary Stands

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Abstract. In Ranong province, southern Thailand, the biomass and net primary production of secondary mangrove forest stands were estimated and compared with the amount of mangrove wood used for the charcoal industry. Using the naturally regenerated mangrove stands, the net primary production was calculated by the allometric equation and the summation method. The wood amount used for the charcoal factory in Ranong province was calculated from the kiln volume, the burning frequency, and the wood packing capacity of the kilns. The balance between the biological production and the human utilization is discussed concerning the secondary mangrove forests.

Key words: mangroves / socio-ecosystem / primary production / charcoal industry / Southern Thailand

The mangroves give rich and various kinds of daily necessities for the tropical coastal people, *i.e.* the wood for buildings and fuels, the bark for extracting tannins, some fruits for foods and even for local medicines, etc. (Walsh, 1974; Watson, 1928).

In these several decades, the social condition of tropical world has been changed by the progress of monetary economics and industrialization. The utilization of mangrove resources has been done on an industrial basis (Ogino, 1989). Charcoal burning, aqua-culture, tin-mining, and so on have been extensively conducted (Aksornkoae & Kongsangchai, 1982). Undoubtedly, this is a result of increasing demands of coastal people to get monetary benefits from mangrove resources. These human activities became more and more destructive to the mangrove ecosystems, compared with earlier exploitations when people used the forests rather moderately.

In Thailand, Aksornkoae & Kongsangchai (1982) mentioned that 90% of the total mangrove wood is utilized for charcoal. In Ranong province, most of the concessionaires are said to be the owners of charcoal factories. The charcoal industry has given a considerable effect on the mangrove forests. The tannin extractions had been one of main industries in the mangrove areas. Now, it becomes rare because of the spreading of chemical products used for fishing net.

In Thailand, it is reported that the area of the mangrove forests accounted for 287, 308 ha, which are directly under control of the Royal Forest Department (RFD). The RFD adopts a

Fig. 1. Study sites and vegetation.
(Symbols see text)

concession system to manage the mangrove forests. The system comprises the annual felling plan of each provincial mangrove forest, dividing into several management units.

The method of estimating the primary productivity of forest ecosystems has been elucidated in the light of a series of IBP studies, and the primary productivities of various typed forest ecosystems were summarized (Reichle, 1981; Kira & Shidei, 1967). A mangrove ecosystem basically lives on its own biological primary productivity, which depends on environmental, spatial, and temporal factors of the stand concerned.

The authors studied the biomass and net primary production (NPP) of secondary mangrove forests in Ranong, southern Thailand. In the present study, the biomass and NPP estimates were compared with that of wood volume consumed by the charcoal industry. The balance between biological production and utilization is discussed with a view to build a proper socio-ecosystem model.

STUDY SITE AND METHOD

Study sites were selected in mangrove forests near the Mangrove Forest Research Center (MFRC) at Banglang village, Ranong ($9^{\circ} 58' \text{N}$, $98^{\circ} 38' \text{E}$). Fig. 1 shows the location of eight study plots. The plots TP-1-4 were situated in the concession area for wood production, and the plots RP-1-4 in the reserved area controlled by the MFRC for research. The sizes of study plots are listed in Table 1.

The plots TP-1-4 established in 1989 were young mangrove stands consisting mainly of regenerated *Rhizophora apiculata*, *R. mucronata*, *Bruguiera cylindrica*, *B. parviflora*, *Avicennia officinalis* and *A. marina*. The plots had passed 0, 8, 14, and 20 years since the latest felling. The plots RP-1-4 were established in the so-called Hatsuikhaio plot, where the biomass of a mature natural forest was intensively studied (Komiya *et al.*, 1987, Ogino 1985, Tamai *et al.* 1986). This natural forest at Hatsuikhaio was unfortunately disturbed by local people, and big trees have been selectively cut since 1983. The plots RP-1-4, established in 1988, had passed at least 6 years after the disturbance mentioned above. The RP-1 was *Sonneratia alba* dominated stand mixed with some *R. mucronata*, and the RP-2-4 were *R. apiculata* and *B. gymnorhiza* mixed stands. In these plots, some big remnant trees escaped

Table 1. Study plots and results of biomass (t ha⁻¹) and NPP (t ha⁻¹yr⁻¹) estimations.

Plot	Stem	Branch	Leaf	Fruit	Root	Top	Total
TP-2 (8 years stand, 10m×100m)							
Biomass	1.82	0.56	0.24	0.00	4.40	2.62	7.02
Increment	0.80	0.24	0.07	0.00	0.00	1.11	1.11
Sloughed part amount	(0.20)		0.20	0.00	0.01	0.40	0.41
NPP	1.24		0.27	0.00	0.01	1.51	1.52
TP-3 (14 years stand, 20m×20m)							
Biomass	8.86	2.78	1.30	0.01	16.79	12.95	29.74
Increment	3.41	0.95	0.34	0.00	0.00	4.70	4.70
Sloughed part amount	(1.00)		1.00	0.01	0.02	2.01	2.03
NPP	5.36		1.34	0.01	0.02	6.71	6.73
TP-4 (20 years stand, 20m×10m)							
Biomass	13.69	4.34	2.17	0.02	18.97	20.22	39.19
Increment	4.40	1.24	0.47	0.00	0.00	6.11	6.11
Sloughed part amount	(1.60)		1.60	0.02	0.02	3.22	3.24
NPP	7.24		2.07	0.02	0.02	9.33	9.35
RP-1 (6 years stand, 30m×30m)							
Biomass	62.07	14.31	2.61	0.19	14.64	79.18	93.82
Increment	2.28	0.49	0.09	0.00	0.00	2.86	2.86
Sloughed part amount	(3.23)		3.23	0.19	0.15	6.65	6.80
NPP	6.00		3.32	0.19	0.15	9.51	9.66
RP-2 (6 years stand, 30m×30m)							
Biomass	36.80	9.10	2.39	0.03	25.73	48.32	74.05
Increment	4.62	1.07	0.30	0.00	0.00	5.99	5.99
Sloughed part amount	(1.78)		1.78	0.03	0.06	3.59	3.65
NPP	7.47		2.08	0.03	0.06	9.58	9.64
RP-3 (6 years stand, 30m × 30m)							
Biomass	14.06	4.36	1.56	0.03	21.44	20.01	41.45
Increment	2.80	0.81	0.23	0.00	0.00	3.84	3.84
Sloughed part amount	(1.24)		1.24	0.03	0.03	2.51	2.54
NPP	4.85		1.47	0.03	0.03	6.35	6.38
RP-4 (6 years stand, 30m × 30m)							
Biomass	82.27	15.39	3.74	0.13	57.02	101.53	158.55
Increment	5.97	1.23	0.33	0.01	0.00	7.54	7.54
Sloughed part amount	(2.76)		2.76	0.13	0.13	5.65	5.78
NPP	9.96		3.09	0.14	0.13	13.19	13.32

from cutting still remained. Diameter (D) and height (H) of trees of D > 4 cm were measured during 1988-1989 (for RP-1-4) and in 1989 (for TP-1-4).

The biomass of each plot was estimated by the allometric equations developed by Komiyama *et al.* (in preparation, see Table 2). The root biomass was estimated by the root density distribution model (Komiyama *et al.*, 1987) using the obtained root density in each plot.

The net primary production (NPP) was calculated by the summation method (Ogawa, 1967):

$$\text{NPP} = (\text{biomass increment}) + (\text{sloughed part amount}) + (\text{grazed part amount}).$$

The biomass increment was calculated using the relative growth rate of diameter obtained in RP-1-4 during 1988-1989 (Table 3). Few individual trees died of natural mortality during the period. The grazed part amount was unknown. Judging from small number of arboreal

Table 2. Parameters of allometric equations.

Species	Stem	Branch	Leaf	Fruit	Prop root
<i>Rhizophora</i> (A)	0.05740	0.02867	0.03307	1.974 (E-6)	0.003625
(h)	0.9282	0.8197	0.6385	1.329	1.0623
<i>Bruguiera</i> (A)	0.05902	0.03534	0.06544	7.479 (E-4)	—
(h)	0.9158	0.8326	0.5985	0.6833	—
Others (A)	0.04004	0.02217	0.00667	3.100 (E-5)	—
(h)	0.9143	0.8377	0.7897	1.0362	—

$$W_x = A (D^2 H)^h \quad (x: \text{each organ})$$

(after Komiyama *et al.* in preparation)

Table 3. Annual relative growth rate of diameter (yr⁻¹).

Species	Diameter size (cm)				
	0-5	5-10	10-15	15-20	20-30
<i>Rhizophora</i>	0.1286	0.1010	0.05439	0.02308	0.01616
<i>Bruguiera</i>	0.1506	0.08361	0.07637	0.06135	0.02357
Others	0.2610	0.1170	0.05501	0.06111	0.01487

arthropods (Abe, 1988), it should be relatively small.

The sloughed part amount of leaf was estimated by the turnover rate assuming a dynamic equilibrium state of leaf biomass. Including the data of the present study site, Moriya *et al.* (1986, 1988) gave the annual turnover rate of leaf as 0.738 for the *Rhizophora apiculata* and *R. mucronata*, 0.734 for the *Bruguiera gymnorrhiza*, and 1.29 for other species like the *Sonneratia alba* and *Avicennia officinalis*.

The sloughed part amount of woody organs was estimated by Kira's empirical method (Kira & Shidei, 1967); this amount was assumed to be equivalent to that of leaves. The sloughed root part was calculated from the annual dead amount of fine root ($D < 2$ mm), assuming the annual turnover rate of fine root as 0.0578 (Jordan & Escalante, 1980).

In November 1990, the Mangrove Management staffs of the Unit - 1, 2, 3 (RFD) in Ranong, and the managers of three selected charcoal factories were interviewed. The area of concession forests, the annual felling area, the expected wood harvest, and the kiln volume were investigated. In the charcoal factories, the period of burning in kiln, the burning frequency in a year, and the wood packing capacity of a kiln were investigated.

RESULTS

Biomass and Net Primary Production of Secondary Mangrove Stands

The coastal vegetations in the study site are illustrated in Fig. 1 by observations from boats. All the coasts were covered by mangroves, except the rocky area of north-west Ko Lao island. The vegetation was classified into two types.

One type was dominated by *Sonneratia alba*, *Avicennia officinalis* and *A. marina* (shown by dots in Fig. 1), distributed mainly along the coasts where the soil had been remarkably accumulated ("+"). The other type occupied the banks where the soil had been eroded by water currents (" - "). *Rhizophora apiculata* or *R. mucronata* dominated the vegetation accompanied with *Bruguiera parviflora*, *B. cylindrica* and *B. gymnorrhiza*. Most of inland parts were occupied by this vegetation type.

The mean height (shown by "H=" in Fig. 1) of *Rhizophora* spp. and *Bruguiera* spp. was usually not more than 8 m, except in the Hatsaikhao plot where some remnant trees exceeded 30 m in height. The stand height of the *Sonneratia alba* and *Avicennia* spp. was about 10 m. It was obvious from the observation that almost all the study sites were occupied by small secondary mangrove species.

Results of the biomass and NPP calculations are summarized in Table 1. The largest biomass was 158.55 t ha⁻¹ of RP-4, but the large portion of this biomass accounted for the remnant trees of the Hatsaikhao plot mentioned above. The large biomasses, 93.82 t ha⁻¹ of RP-1 and 74.05 t ha⁻¹ of RP-2, were also due to the remnant trees. The biomass of TP-1 was assumed to be zero because this plot was clear-cut just two months before. The biomass of the oldest TP-4 (20 years stand) was 39.19 t ha⁻¹. The smaller biomass was estimated from the plots TP-2 and TP-3.

The largest NPP was 13.32 t ha⁻¹yr⁻¹ of RP-4. The smallest was 1.52 t ha⁻¹yr⁻¹ of TP-2. The NPP of other plots was in the range of 6.38 - 9.66 t ha⁻¹yr⁻¹. In all the plots, the stem and leaf accounted for very large portion of the NPP. In small mangroves, only the stems can be used for charcoal. The stem biomass and annual growth increment were 13.69 t ha⁻¹ and 4.40 t ha⁻¹yr⁻¹ in 20 years stand of TP-4. Those of younger plots TP-2 and TP-3 showed smaller values of 0.82-3.41 t ha⁻¹yr⁻¹.

Mangrove Wood Utilization for Charcoal Industry in Ranong

In Table 4, results of the interviews in the three Mangrove Management Units (RFD) are summarized. In Ranong province, there were 19,573.0 ha of concession forests supervised by the three Units (RFD). In 1990, 1,234.1 ha of area had been slated to be felled. The felled

Table 4. Area of concession forests, expected wood harvest, and kiln volume in Ranong province in 1990.

Place	Total area (ha)	Felled area in 1990 (ha)	Expected harvest		Kiln volume		
			(m ³)	(t ha ⁻¹)	(N)	(m ³)	Mean
Unit No.1							
1. Lad Sang	875.6	52.9 (6.0%)	3390	49.28	4	962	241
2. Kaokum	769.4	56.2 (7.3%)	4031	55.16	4	1006	252
3. Tum	777.2	55.6 (7.2%)	4775	66.04	6	1788	298
4. La Ong	1128.0	—	—	—	—	—	—
5. Saikhao	741.8	45.8 (6.2%)	3935	66.07	7	1586	227
6. Kunkhachon	1004.8	70.4 (7.0%)	4459	48.71	5	1126	225
7. Ko Sam	1300.9	92.0 (7.1%)	5691	47.57	8	2172	272
8. Kum Puan	1130.8	67.2 (5.9%)	4492	51.40	6	1505	251
9. Lao Non	1476.9	83.5 (5.7%)	5079	46.78	6	1345	224
10. Ko Mu	602.0	38.0 (6.3%)	4055	82.06	5	1495	299
11. Lad Khao	828.6	57.6 (7.0%)	4347	58.04	4	1348	337
12. Ngao	832.0	63.8 (7.7%)	3942	47.51	4	1239	310
Total	11468.0	683.0 (6.0%)	48196	54.26	59	15572	264
Unit No.2							
Total	4419.0	305.8 (6.9%)	30887	77.67	35	9234	(264)
Unit No.3							
Total	3686.0	245.3 (6.7%)	20513	64.31	45	11878	(264)
Whole area	19573.0	1234.1 (6.3%)	99596	62.06	139	36687	(264)

area corresponds to 6.3% of total area of the concessions on an average. The alternative strip method was adopted in 15 year-rotation, in which a stand was divided into felled/reserved strips of 40 m width each. From all the felled area in Ranong province, the RFD expected to harvest 99,596 m³ of mangrove wood for the charcoal industry in 1990. According to the RFD statistics, the charcoal kilns in Ranong province were 139 and 36,687 m³ in total kiln number and volume, respectively (in the Unit 2 and 3, the total kiln volume was temporally estimated by the mean kiln volume at the Unit 1 area).

At the Unit 1 in the Ranong city, the total area of 11,468.0 ha was divided into the 12 concession areas (Table 4). In total, 683.0 ha of the forest (6.0% of the total area) had been slated to be felled in 1990. The RFD's expected harvest was 48,196 m³ in total. There were 59 kilns and total volume of them was 15,572 m³.

In the respective 12 concessions, the felled area differed from 38.0 to 83.5 ha, which corresponds to 5.7-7.7% of the total area. The RFD's expected wood harvests were in the range of 3,390 - 5,691 m³. The total kiln volume also differed from 962 to 2,172 m³. The total kiln volume was larger where the high wood harvests were expected. The mean volume of a kiln was more or less similar by area.

The procedure of charcoal burning was investigated in the three factories at Banglang, Kapoe, and Laun districts. All the factories were located on small rivers, by which boats could bring the mangrove wood to the factories. They had more than nine big kilns of hemispheric shape in a building 30 m in width and 120 m in length. Each factory employed about 50 workers.

The mangrove wood's bark was removed, and then loaded into the charcoal kiln. The *Rhizophora apiculata*, *R. mucronata*, *Bruguiera gymnorrhiza*, *B. parviflora*, and *B. cylindrica* were used for the charcoal materials, and the *Sonneratia alba*, *Xylocarpus granatum*, *Avicennia officinalis*, and *A. marina* for fuel. After burning in the kilns, the charcoal was allowed to cool and then unloaded from the kilns.

According to the investigations in the factory at Laun district, the mangrove wood was once stocked in an open space at riverside. The logs for charcoal materials were piled up in the space as blocks sized 1.5 m (Length) × 1.5 m (Height) × 0.6 m (Width). The 50-60 blocks of logs (67.5-81.0 m³ as gross mass containing vacant space among piled logs) were said to be loaded into a kiln (82.1 m³). To burn these charcoal materials, other 4-6 blocks of fuel wood (5.4 - 8.1 m³ as gross mass) were necessary. In the other factories investigated, the ratio between the charcoal materials and the fuel wood was 70:16 in volume.

The period for burning/cooling was around 40 days in a kiln (D=12 m, H=6 m). The period should be shorter in smaller kilns or longer in larger kilns. In Ranong, the burning frequency in a kiln was said to be between two and six times per year.

DISCUSSION

The utilizations by the charcoal industry give important impacts on the mangrove ecosystem in Thailand as mentioned above. The mangrove resources are to be sustainable when the human demands balance to the forest productivity.

The amount of mangrove wood used for the charcoal industry can be estimated by a simple model using the three parameters; the kiln volume, the burning frequency, and the wood packing capacity of a kiln (Fig. 2). For example, in the area supervised by the

Fig. 2. Burnt wood volume in relation to burning frequency and packing capacity of a kiln. (Symbols see text)

Mangrove Management Unit 1 at Ranong, if all kilns are used only one time per year and completely packed with the mangrove wood materials, the total kiln volume 15,572 m³ (Table 4) should be equivalent to the amount of *Rhizophora* spp. and *Bruguiera* spp. wood harvested from mangrove forests for charcoal. Actually in the process, some fuel wood of the *Sonneratia alba* and other species are also used. In the factories investigated, the ratio of fuel wood to the charcoal materials was around 20% in volume. Assuming the ratio as 20%, the total wood amount used there should increase to 18,686 m³.

As for the annual frequency of burning in a kiln, an upper limit exists because of the working procedure. For the hemispheric shaped kiln (D=12 m, H=6 m) mentioned above, 8 burnings should be the limit per year, taking into account the burning/cooling period (about 40 days) and the loading/unloading of wood materials. The size of the kilns were more or less similar in the area under the Unit 1, but the burning frequency was said rather in the wide range of 2-6 times per year. The authors considered that 4-6 burnings per year as a relevant estimation, because most kilns were working all the year round.

As for the estimation of the wood packing capacity of the kilns, the information in the factory at Laun shows 67.5-81.0 m³ of gross wood-mass was packed in a kiln of 82.1 m³ volume. This amount corresponds to 82%-99% of the kiln volume. The vacant space among the piled logs was estimated at around 30% in volume by means of photographic analysis. The net wood packing capacity of a kiln should be around 50-70%.

In Japanese black charcoal kilns of 7-8 m³ volume, usually 4.6 m³ of oak wood is packed (Kuriyama, 1968). The wood packing capacity was in the range of 58-66% in volume. So-called Miura's kiln, which is a standard type of kiln of 4.9 m³ volume in Japan, produces 600 kg of black charcoal (Kishimoto, 1976). The packing capacity of Miura's kiln was estimated to be around 60% in wood volume.

Based on the data about the burning frequency and the wood packing capacity of a kiln, the wood amount used for the charcoal industry can be estimated in the area under the Unit 1

for 1990. The result is shown by closed circles in Fig. 2. The estimated burnt volume differed in the range of 37,373 m³ to 78,483 m³. If the charcoal factories moderately operate the kilns, these values coincided fairly with the expected wood harvest supervised by the RFD (48,196 m³, shown by a broken line in Fig. 2). Although, if the factory operates them more often, the used amount should be larger than the expected harvest.

Thus, the charcoal factories in Ranong had enough capacities to dispose all the expected wood harvests supervised by the RFD. Whether the expected wood harvest balanced to the primary productivity of secondary mangrove stands or not is next question.

The RFD's expectation of wood harvests, 48,196 m³ from 683.0 ha of the concession area, could be converted to the stem weight of 54 t ha⁻¹ using the apparent volume-weight ratio, 0.769 of *Rhizophora apiculata* (Komiya, 1988). The stem biomass in a stand should be double of this amount, 108 t ha⁻¹, because of the alternative strip method used. In this method, trees should be cut in a 30 year-rotation on an average.

In the present study, the stem biomass and its increment of a 20 years stand were estimated at 13.69 t ha⁻¹ and 4.40 t ha⁻¹yr⁻¹, respectively. The present results were far smaller than the expected 108 t ha⁻¹, even if the stand maintains the same growth increments for next 10 years. The net primary production estimated in the study plots was 13.32 t ha⁻¹yr⁻¹ at the maximum. The matured tropical rain forests are said to reach to 20-25 t ha⁻¹yr⁻¹ in the NPP (Kira & Shidei, 1967).

Larger stem biomass was reported from a well-managed 14 year-old *Rhizophora apiculata* stand in Thailand as 135.9 t ha⁻¹ (Aksornkoe, 1975). From young *R. apiculata* and *R. mucronata* plantations in Thailand, the growth increments of stem biomass were reported as high as 9.78-20.92 t ha⁻¹yr⁻¹ (Kongsangchai *et al.*, 1990). In Malaysia, the total biomass of a 28 year-old *R. apiculata* plantation was estimated at 211 t ha⁻¹ (Ong *et al.*, 1982). Golley *et al.* (1962) estimated the net primary production of a *R. mangle* stand in Puerto Rico at around 20 t C ha⁻¹yr⁻¹.

The stem productivity in the present study site was smaller, compared with those estimates from other well-managed stands mentioned above. One of the reason is the incessant utilization of mangrove wood by local inhabitants. For example, the fishermen cut the mangrove trees continuously from young stands nearby, as the slender stems of mangroves such as *Rhizophora apiculata*, *R. mucronata*, *Bruguiera cylindrica*, *B. parviflora* are very useful. In the plots TP-1-4, 34% of sample trees were cut or taken by them during 1989-1990. Probably, these traditional exploitations have been repeatedly occurring before the establishment of our plots in 1989. The stand biomass will not easily increase with the progress of time.

In the study area, it is considered that the primary productivity of secondary mangrove stands can not support the current wood demands from the charcoal industry. The mangrove ecosystem will be deteriorated if this condition lasts long.

The social demands to the mangrove resources can be classified into two types of form, *i.e.* traditional and industrial. Both demands impacted significantly the mangrove forests. The former was demands of local people to get daily necessities from the forest, and it should be a vested right of them. This kind of utilizations occurred rather disorderly from place to place, and therefore it makes the estimation of forest growth difficult.

Though the primary productivity of forest ecosystems has biological limits, the human demands to the ecosystem seems to be limitless. Now, mangrove ecosystems are standing in

an unbalanced condition between the limited biological production and the vast human demands. The re-adjustment of the social demands will be necessary to establish a sustainable management plan of mangrove ecosystems.

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マングローブ林社会生態系の研究 — 製炭産業と二次林の一次生産量

タイ国のラノン県を対象地域として、マングローブ二次林の一次生産量と製炭産業で使用されたマングローブ材量の比較を行った。その結果、つぎのことが明らかとなった。

王室森林局の1990年における計画伐採量は、調査した683 haあたり年4.8万m³で、これを持続するためには、30年経過した林分で幹108 t ha⁻¹のマングローブ材の蓄積が必要である。

炭焼き産業で使用されたマングローブ材量は、年3.7~7.8万m³と推定される。炭焼き窯の使用頻度が少ない場合にのみ、使用材量は計画伐採量と均衡する。すなわち、各業者は、材の割当量を完全に消費している、もしくは処理する十分な能力を持つ。

マングローブ二次林における幹の現存量は、20年経過林分で14 t ha⁻¹程度にすぎず、年成長量は4 t ha⁻¹ yr⁻¹程度であった。これらの林分は計画伐採後そのまま放置されておらず、しばしば住民が生活材を収穫していた。マングローブ林に対する計画外の圧力として、このような住民の既得権による、潜在的・伝統的な圧力が存在した。

以上のことより、現在のマングローブ二次林には、産業的圧力と住民の伝統的圧力が同時にかけられており、産業伐採量は現実の森林の成長量を超えている可能性が指摘された。