Litter Production and Decomposition of a Mangrove Forest at Ohura Bay, Okinawa

By

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沖縄県大浦湾のマングローブ林のリターフォール及びその分解

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Abstract

The litter production and decomposition of a mangrove forest at Ohura Bay, Okinawa were studied with the use of littertraps and litterbags. The litter production of the *Kandelia candel* community (P1), the *Kandelia candel* and *Bruguiera gymnorrhiza* community (P2) and the *Bruguiera gymnorrhiza* community (P3) was 8.72, 10.74 and 7.73 ton/ha/year, respectively. Litterfall rates were seasonal in the three communities. The first peak of litterfall in P1 and P2 was in May (spring) as a result of the *K. candel* mature fruit fall, while that in P3 was in February as a result of the *B. gymnorrhiza* leaf fall. Due to typhoons, remarkable increases occurred during July and August (summer) and all communities showed great peaks at that time. Afterward, the amount of litterfall in the three communities decreased greatly.

Leaves of *K. candel* decomposed slightly faster than those of *B. gymnorrhiza*. In both species, the early decomposition (after 1 and 2 months) was great, followed by a slower decrease in dry mass for the remaining period of the experiment. The dry mass of twigs showed a much slower decrease compared with that of the leaves. The decrease in twig mass of the two species was almost entirely the result of bark loss which flaked from the wood. After 6 months decomposition, the woody materials remained generally firm and hard without obvious signs of breakdown.

Key words: Mangrove forest, *Kandelia candel* (L.) Druce, *Bruguiera gymnorrhiza* (L.) Lamk., Litterfall, Decomposition.

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1. Introduction

Mangroves form a transition from land to sea, sheltering tropical shores with trees and bushes growing below the level of spring tides. Relatively few species of woody plants are able to thrive under such physiologically adverse conditions. Mangrove forests have very low floristic diversity ; only 90 species are known to exist in the world, of which 55 are, in general, restricted to mangrove swamps. The mangrove forest of the Indo-Pacific areas have a richer flora than those of American and West African areas, with 63 species, widely distributed (CHRISTENSEN, 1983).

In the wet tropics, mangrove forests reach their greatest luxuriance and floristic richness (RICHARD, 1975). In the equatorial part of the Far East, mangrove forests are more floristically rich than anywhere else in the tropics (WHITMORE, 1984). In Indonesia, mangroves cover an area approximately 3.6 million hectares (SUGIARTO, 1984), which are composed of about 30 tree species from 15 familiees (KARTAWINATA et al., 1984). More than 27 genera of trees and other plants are commonly found amongst the mangroves at Amphoe Khlung, Thailand (AKSORNKOAE, 1979). At least 33 mangrove species belonging to 16 families have been recorded in North-Eastern Queensland, Australia (WELLS, 1983).

At the northern and southern global limits of their occurrence, mangroves become diminished in structure and poor in species (WHITMORE, 1984). There are only 6 species belonging to 5 families at Fujian in the sub-tropical zone of China (PENG and XIN-MEN, 1983). In Victoria, Australia, the southernmost occurrence of mangrove in the world, only *Avicennia marina* var. *australasica* remains (WELLS, 1983), while in New Zealand only *Avicennia marina* var. *resinifera* is found (CHAPMAN, 1983).

In Japan, mangrove forests are at their northern limits, and are distributed from Yaeyama Islands in the sub-tropical zone to southern parts of Kyushu Island in the warm-temperate zone, and therefore they are poor in species. Only 7 species are recognized, namely *Kandelia candel*, *Bruguiera gymnorrhiza*, *Rhizophora stylosa* (Rhizophoraceae), *Avicennia marina* (Avicenniaceae), *Sonneratia alba* (Sonneratiaceae), *Lumnitzera racemosa* (Combretaceae) and *Nypa fructicans* (Palmae) (NAKASUGA, 1979).

Only 2 species are found in the study area, namely *Kandelia candel* (L.) Druce and *Bruguiera gymnorrhiza* (L.) Lamk. Mean tree height of the *K. candel* in a *K. candel* community (P1), *K. candel* and *B. gymnorrhiza* community (P2), and *B. gymnorrhiza* community was 4.95, 6.60, and 4.43 m, respectively, while that of *B. gymnorrhiza* was 4.58, 6.46, and 4.55 m, respectively. Mean tree diameter at breast height of *K. candel* in the P1, P2, and P3 was 4.73, 6.49, and 4.90 cm, and that of *B. gymnorrhiza* was 5.75, 8.78, and 7.03 cm, respectively. *K. candel* started flowering in June, leading to a maximum in July and August, and followed by a sharp decrease in September. *B. gymnorrhiza* kept flowering in all seasons, but the maximum of flowering was in August, September, and October. The peak of mature fruits falling of *K. candel* was in April and May (HARDIWINOTO, 1988). NAKASUGA and ITOO (1983) stated that the optimum period of collecting fruits of *K. candel* in Okinawa was from March to May, and that of *B. gymnorrhiza* was from October to May.

There is generally an import of inorganic nutrients from the land to the mangroves and an export of organic matter from the mangroves to the sea (CHRISTENSEN, 1983). Litter-fall records are valuable as an indicator of the mangrove productivity, and the decomposition process studies are necessary to estimate the contribution of the mangroves toward nutrient recycling in the forest ecosystems.

In recent years many researchers have attempted to quantify the rate of litterfall and decomposition process in various forest ecosystems. Litterfall and decomposition studies in mangrove forests have been carried out in many parts of the world, among them are in Ranong, Thailand (AKSORNKOAE et. al, 1982), Rookery Bay and Estero Bay, Southwest Florida (TWILLEY et. al, 1986), Mgeni Estuary, South Africa (STEINKE et. al, 1983, STEINKE and CHARLES, 1984), and on Iriomote Island, Japan (KISHIMOTO et. al, 1987).

STEINKE and CHARLES (1984) reported that the litter production in a sub-tropical mangrove community of South Africa was low in comparison with results obtained in tropical mangrove communities, though it compared favorably with data obtained in sub-tropical mangroves in South Florida, Puerto Rico and New South Wales. In this study attempts were made to obtain data on litter production and decomposition of a mangrove forest which lies in the sub-tropical zone. The obtained data are complementary to the earlier ones in order to gain further insight into litterfall and decomposition process in mangrove ecosystems.

2. Study Area, Materials and Methods

2.1 Study Area

This study was carried out in a mangrove forest which is located at Ohura Bay, Nago City, on the eastern coast of Okinawa Island. It is situated approximately at N26°31′, E128°5′ (Fig. 1). The study area lies in the subtropical zone with the following general climatic conditions. Annual mean temperature was 21.5°C, with the coldest mean monthly in January (14.9°C), while the warmest was in July (27.8°C). Annual mean precipitation was

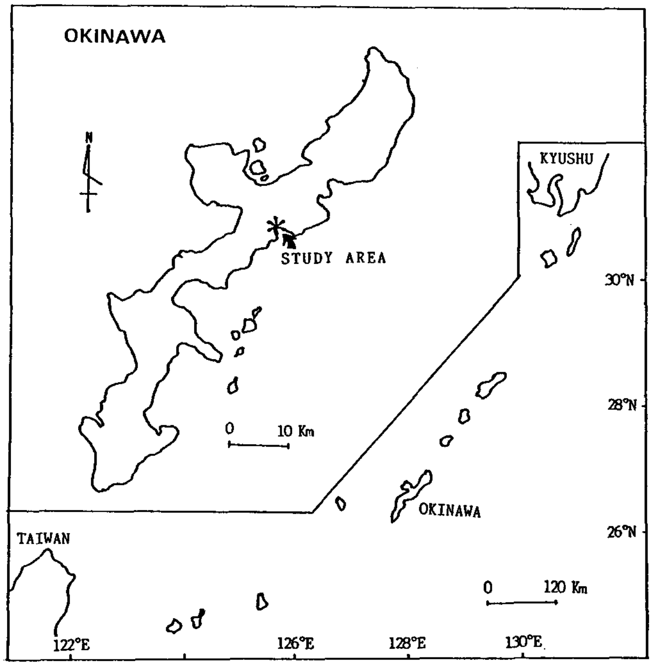

Fig. 1. Map of the Ryukyu Islands, showing location of the study area.

Photo 1. View of the study area (the Ohura mangrove forest).

Photo 2. Inside view of the mangrove stand during the high tide.

Photo 3. Flowers of *Kandelia candel* in the study area (July, 1987).

Photo 4. Fruits of *Bruguiera gymnorrhiza* in the study area (July, 1987).

2,412.9 mm, with the lowest mean monthly in November (119.9 mm), and the highest in June (395.4 mm). Annual mean wind speed was 2.9 m/s (NAGO-CITY, 1984).

2.2 Materials and Methods

Three permanent plots, P1, P2 and P3 (each 10 m × 10 m in size) which were supposed to be representative samples of the forest were established in December 1986. The stand structure of the study plots was reported previously (HARDIWINOTO et. al., 1988). The P1, P2 and P3 were a *Kandelia candel* community, *Kandelia candel* and *Bruguiera gymnorrhiza* community and *Bruguiera gymnorrhiza* community, respectively. In order to catch litter-fall, 15 littertraps in the three plots (5 traps in each plot) were placed at the end of December, 1986. The traps were made from nylon net bags, supported by a round frame of plastic pipe (the mouth of every trap was 1 m^2 in area). The mouth was then supported horizontally by perpendicular plastic poles at about 1.2 m above ground surface.

All organic materials (litterfall) accumulating in the traps were collected monthly, at the end of every month. The materials were separated into leaves, branches, stipules, flowers, fruits and other materials. The leaves, flowers and fruits were further sorted by species. Before weighing, the sorted materials were oven-dried at 80°C for 48 hours.

Old leaves and dead twigs of *K. candel* and *B. gymnorrhiza* were picked from parent trees prior to abscission, taken to the laboratory, and to be air dried. The twigs of both species which had a diameter less than 1cm were cut into lengths of 10-15 cm. The leaves and the twigs of each species were weighed to equal weight, then put into 50 cm × 50 cm nylon mesh bags (the mesh of the bags was irregular and about 1 mm in size). The bags were transferred and placed on the floor of the Ohura mangrove forest. In order to protect the bags from being floated and washed away by the tides, they were secured with

Photo 5. One of the littertraps in the Plot 3.

wire.

The leaf litter, in the bags, was placed on July 1, 1987, and collected at monthly intervals, over a period of 6 months. For each of these collections, 4 bags from each species were removed. The twig litter bags were placed on June 1, 1988 and harvested every two months over a period of a half year. Two bags from each species were collected at every removal.

The remaining litter in the bags was rinsed in water to remove the accmulation of soil. The litter was transferred into paper bags to be oven-dried at 80°C for 48 hours before weighing. Litter losses during the decomposition time were calculated by subtracting the remaining litter from the initial weight.

3. Results

3.1 Litter Production

Table 1 illustrates the litterfall of the *K. candel*community (P1). It was 72.77 g/m²/mo or 8.72 ton/ha/year, composed of leaves (54.1 %), branches (18.9 %), reproductive organs (flowers and fruits = 16.7 %), stipules (6.6 %) and other materials (3.7 %). The litterfall of *K. candel* and *B. gymnorrhiza* community (P2) is shown in Table 2. The amount was 89.49 g/m²/mo or 10.74 ton/ha/year. It consisted of leaves (64.3 %), branches (11.3 %), reproductive organs (14.9 %), stipules (6.3 %) and other materials (3.2 %). In Table 3, litterfall of the *B.gymnorrhiza* community (P3) is presented. It was 64.40 g/m²/mo or 7.73 ton/ha/year, composed of leaves (73.3 %), branches (10.8 %), reproductive

Table 1. Monthly changes of litterfall in *Kandelia candel* community (P1) in 1987 (grams per square meter)

	Leaves		Branches	Stipules	Flowers		Fruits		Other mate-rials	Total	%
	K.c	B.g			K.c	B.g	K.c	B.g			
Jan.	5.48	11.14	0.33	2.73	–	0.38	0.69	–	0.54	21.29	2.4
Feb.	7.74	13.94	0.38	2.29	–	0.16	1.48	0.40	0.50	26.89	3.1
Mar.	17.63	19.25	0.40	4.06	–	–	1.79	–	0.90	44.03	5.0
Apr.	22.05	7.58	0.27	5.28	–	–	19.04	0.09	2.03	56.34	6.5
May	21.43	7.59	1.28	7.41	–	0.09	98.27	0.38	2.23	138.68	15.9
Jun.	24.87	8.97	6.92	7.74	0.09	0.02	2.88	1.69	1.86	55.04	6.3
Jul.	49.97	18.07	31.06	10.94	0.69	0.20	0.82	5.04	4.56	121.35	13.9
Aug.	36.89 (83.20)	9.30 (48.55)	123.10	6.22	0.50 (0.26)	1.12 (2.03)	–	–	14.96	192.09 (134.04)	37.3
Sep.	7.73	5.35	0.14	3.44	0.03	2.23	–	–	2.21	21.13	2.4
Oct.	12.43	3.82	0.06	2.60	–	1.36	–	–	1.53	21.80	2.5
Nov.	9.81	4.46	0.58	2.71	–	1.92	–	0.32	0.72	20.52	2.4
Dec.	5.91	9.26	0.53	2.31	–	0.88	–	0.63	0.55	20.07	2.3
Tot	305.14	167.28	165.05	57.73	1.57	10.39	124.97	8.55	32.59	872.27	100.0
%	34.9	19.2	18.9	6.6	0.2	1.2	14.3	1.0	3.7	100.0	

K.c = *Kandelia candel* B.g = *Bruguiera gymnorrhiza.*
Numbers in parenthesis are expected to be fallen by typhoon.

Table 2. Monthly changes of litterfall in *Kandelia candel* and *Bruguiera gymnorrhiza* community (P2) in 1987 (grams per square meter)

	Leaves		Branches	Stipules	Flowers		Fruits		Other mate-rials	Total	%
	K.c	B.g			K.c	B.g	K.c	B.g			
Jan.	3.58	38.78	0.40	2.27	–	1.03	0.38	–	0.40	46.85	4.3
Feb.	5.27	57.51	0.34	2.17	–	0.89	0.63	1.19	0.46	68.46	6.4
Mar.	8.97	47.72	0.34	3.12	–	0.11	2.30	1.00	0.77	64.33	6.0
Apr.	9.67	13.62	0.57	4.34	–	0.07	48.14	1.40	1.07	78.88	7.3
May	8.65	22.45	0.36	7.10	–	0.31	41.21	1.72	1.39	83.19	7.7
Jun.	9.41	34.54	1.23	9.59	–	0.35	1.31	2.76	1.17	60.36	5.6
Jul.	23.11	63.80	20.10	14.08	0.22	2.27	0.69	5.27	4.46	134.00	12.5
Aug.	15.42 (38.64)	26.88 (147.27)	94.51	8.92	0.29 (0.24)	8.69 (8.72)	–	–	16.20	170.91 (194.87)	34.1
Sep.	5.32	17.83	0.38	5.16	0.03	14.18	–	–	5.47	48.37	4.5
Oct.	8.09	12.14	0.82	4.13	–	6.48	–	–	2.35	34.01	3.2
Nov.	7.04	16.46	1.76	3.82	–	4.21	–	1.34	0.52	35.15	3.3
Dec.	3.72	44.01	0.49	2.83	–	1.40	–	1.34	0.71	54.50	5.1
Tot	146.89	543.01	121.30	67.53	0.78	48.71	94.66	16.02	34.97	1073.87	100.00
%	13.7	50.6	11.3	6.3	0.1	4.5	8.8	1.5	3.2	100.0	

K.c = *Kandelia candel* B.g = *Bruguiera gymnorrhiza*
Numbers in parenthesis are expected to be fallen by typhoon.

Table 3. Monthly changes of litterfall in *Bruguiera gymnorrhiza* community (P3) in 1987 (grams per square meter)

	Leaves		Branches	Stipules	Flowers		Fruits		Other mate-rials	Total	%
	K.c	B.g			K.c	B.g	K.c	B.g			
Jan.	1.03	34.55	0.34	1.45	–	1.03	–	–	0.25	38.65	5.0
Feb.	1.46	55.56	0.26	1.33	–	0.47	0.14	0.96	0.13	62.69	8.1
Mar.	2.17	57.61	0.16	1.77	–	0.21	–	–	0.26	62.18	8.1
Apr.	3.00	15.81	–	2.11	–	0.07	–	–	0.19	21.18	2.7
May	2.60	26.34	–	3.68	–	0.17	7.06	0.41	0.82	41.08	5.3
Jun.	1.95	45.59	0.03	6.19	–	0.12	0.45	–	0.73	55.06	7.1
Jul.	3.97	85.37	4.48	10.69	0.32	1.28	–	1.30	2.86	110.27	14.3
Aug.	3.78 (3.96)	29.61 (115.21)	69.56	6.84	0.14 (0.04)	4.13 (7.37)	– –	– –	8.98	123.04 126.58	32.3
Sep.	2.40	14.77	0.55	4.28	–	12.36	–	–	3.86	38.22	5.0
Oct.	2.59	12.95	5.05	2.56	–	12.01	–	–	2.25	37.41	4.8
Nov.	2.68	18.24	1.07	2.07	–	4.59	–	0.60	0.61	29.86	3.9
Dec.	1.16	22.21	–	1.19	–	1.10	–	0.61	0.31	26.58	3.4
Tot.	32.75	533.85	83.88	44.16	0.50	44.91	7.65	3.88	21.25	772.80	100.0
%	4.2	69.1	10.8	5.7	0.1	5.8	1.0	0.5	2.7	100.0	

K.c = *Kandelia candel* B.g = *Bruguiera gymnorrhiza*
Numbers in parenthesis are expected to be fallen by typhoon.

organs (7.4 %), stipules (5.7 %) and other materials (2.7 %).

Rates of litterfall were seasonal in the three communities (Fig. 2). During winter months (January and February), the litterfall amount of P1 was low, increased during March and April, and the first peak occurred in May (Spring). The amount of litterfall of P2 in January was also low, but it started to increase in February, and the first peak was also reached in May. A sharp increase of litterfall in P1 and P2 during May was attributable to the fall of the mature *K. candel* fruits. In January, litterfall in P3 was not so low, with a low peak appearing in February as a result of the *B. gymnorrhiza* leaf fall. Remarkable increases of litterfall occurred in July and August, with all communites showing great peaks at that time. These were appparently due to the typhoons which not only made the leaves fall, but also caused branches and twigs to break off.

Photo 6. Litterfall in the forest floor after the typhoon attack at the end of August 1987.

Fig. 3 shows the seasonal changes of the leaf fall of the two species. The lowest leaf fall of *K. candel* was in January and February (winter), and increased gradually in warmer months (spring). Unlike *K. candel*, the *B. gymnorrhiza* leaf fall was not low during the winter, and even in February the first low peak appeared. The lowest leaf fall was in April and May (spring). In the beginning of summer, the leaf fall of both species tended to rise. Large increases occurred in July and August due to the typhoons. Thereafter, the rates decreased remarkably in September and October (autumn) in both species. In December, the leaf fall rates of *K. candel* became lower and, in contrast, *B. gymnorrhiza* showed sharp increases at this time.

Branch litter in the three communities showed uncertain parterns (Table 4). Generally the litter was very low except in July and August when there were typhoons which not

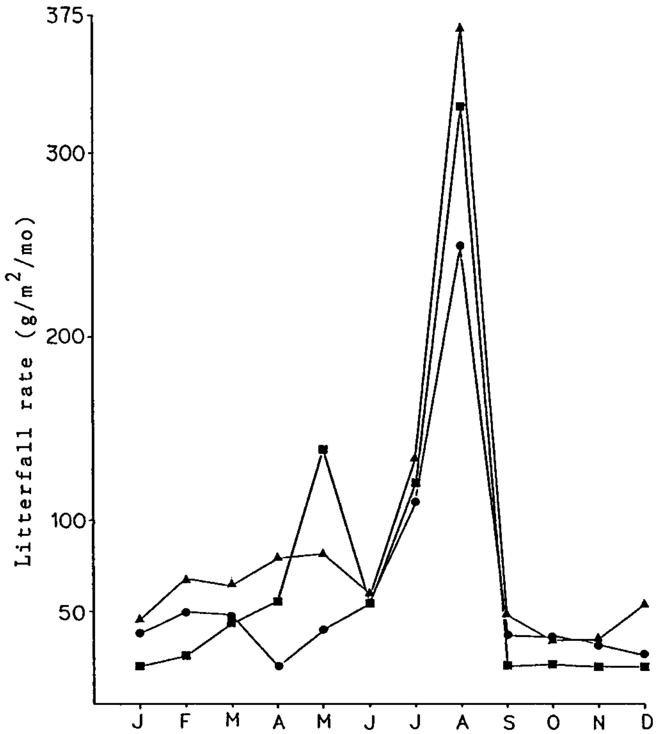

Fig. 2. Monthly changes of litterfall in the three communities in 1987. Squares, triangles and circles, respectively refer to P1, P2 and P3.

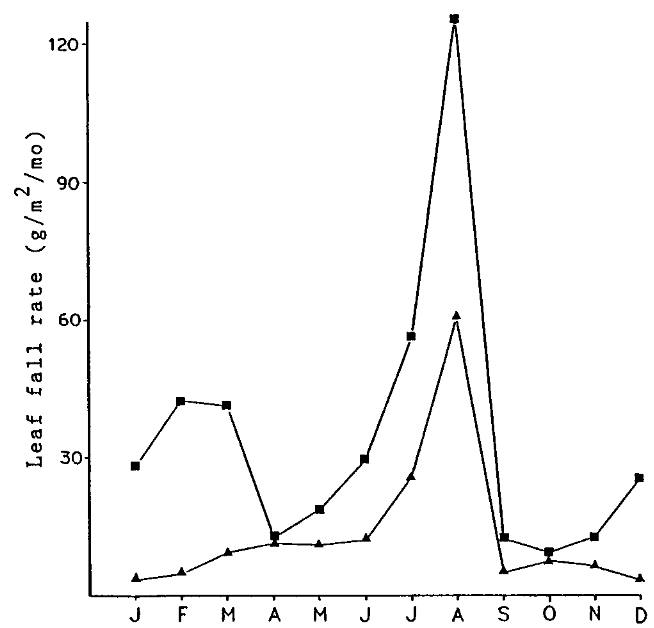

Fig. 3. Seasonal trends of *K. candel* (triangels) and *B. gymnorrhiza* (squares) leaf fall.

Table 4. Monthly trends of branch litter in the three communities (g/m²)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
P1	0.33	0.38	0.40	0.27	1.28	6.92	31.06	123.10	0.14	0.06	0.58	0.53
%	0.2	0.2	0.2	0.2	0.8	4.2	18.8	74.6	0.1	0.0	0.4	0.3
P2	0.40	0.34	0.34	0.57	0.36	1.23	20.10	94.51	0.38	0.82	1.76	0.49
%	0.3	0.3	0.3	0.5	0.3	1.0	16.6	77.9	0.3	0.7	1.4	0.4
P3	0.34	2.64	0.16	0.00	0.00	0.03	4.48	69.56	0.55	5.05	1.07	0.00
%	0.4	3.1	0.2	0.0	0.0	0.0	5.4	82.9	0.7	6.0	1.3	0.0
Mean	0.36	1.12	0.30	0.28	0.55	2.73	18.55	95.72	0.36	1.98	1.14	0.34
%	0.3	0.9	0.2	0.2	0.5	2.2	15.0	77.6	0.3	1.6	0.9	0.3

Table 5. Seasonal trends of flower/calyx litter in the three communities (grams per m²)

		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
K.c.	P1						0.09	0.69	0.50(0.26)	0.03			
	P2						–	0.22	0.29(0.24)	0.03			
	P3						–	0.32	0.14(0.04)	–			
Mean							0.03	0.41	0.31(0.18)	0.02			
%							3.2	43.2	32.6 (18.9)	2.1			
B.g.	P1	0.38	0.16	–	–	0.09	0.02	0.20	1.12(2.03)	2.23	1.36	1.92	0.88
	P2	1.03	0.89	0.11	0.07	0.31	0.35	2.27	8.69(8.72)	14.18	6.48	4.21	1.40
	P3	1.03	0.47	0.21	0.07	0.17	0.12	1.28	4.13(7.37)	12.36	12.01	4.59	1.10
Mean		0.81	0.51	0.11	0.05	0.19	0.16	1.25	4.65(6.04)	9.59	6.62	3.57	1.13
%		2.3	1.5	0.3	0.1	0.6	0.5	3.6	13.4 (17.4)	27.7	19.1	10.3	3.2

K.c. = *Kandelia candel* B.g. = *Bruguiera gymnorrhiza*
Numbers in parenthesis are expected to be fallen by typhoon.

only made dead branches fall but also broke living ones; about 93 % of the mean annual branch litter occurred in these months. Stipula litter in the three communities had a similar pattern. The lowest rate was during the winter months, increasing progressively in warmer months (Spring), reaching their peaks in July (summer), and thereafter, decreasing gradually during the cooler months (autumn).

Flower litter in the three communities is shown in Table 5. Presence of *K. candel* flower litter in the traps was from June to September, with the maximum in July and August. Flower litter of *B. gymnorrhiza* was recorded in every month, with a high fall in July, August, September and October. The fruit litter of *K. candel* was recorded from January to July, and that of *B. gymnorrhiza* was from February to July, and from November to December. The contribution of *K. candel* fruit litter to the total annual litter in that year was much higher (75.76 g/m²/year) than *B. gymnorrhiza* (7.87 g/m²/year). The high fruit fall of *K. candel* was in April and May when the mature fruits were falling,

Table 6. Seasonal changes of fruit litter in the three communities (g/m²)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
K.c. P1	0.69	1.48	1.79	19.04	98.27	2.88	0.82					
P2	0.38	0.63	2.30	48.14	41.21	1.31	0.69					
P3	–	0.14	–	–	7.06	0.45	–					
Mean	0.36	0.75	1.36	22.39	48.85	1.55	0.50					
%	0.5	1.0	1.8	29.5	64.5	2.0	0.7					
B.g. P1		0.40	–	0.09	0.38	1.69	5.04				0.32	0.63
P2		1.19	1.00	1.40	1.72	2.76	5.27				1.34	1.13
P3		0.96	–	–	0.41	–	1.30				0.60	0.62
Mean		0.85	0.33	0.50	0.84	1.48	3.87				0.75	0.79
%		9.0	3.5	5.2	8.8	15.6	40.8				8.0	9.1

K.c. = *Kandelia candel* B.g. = *Bruguiera gymnorrhiza*

and that of *B. gymnorrhiza* was in July (Table 6). Other litter material was mainly composed of very small particles which were difficult to be identified. Besides these materials, insects and bird feathers were sometimes observed. As usual, the litter was very low, except when typhoons beat leaves, branches and other parts of trees into small fractions.

3.2 Litter decomposition

In Table 7, dry mass loss of the mangrove leaves during the decomposition is present-

Table 7. Dry mass decrease of mangrove leaves during the decomposition (grams of dry weight)

Dt	0	1 mo	2 mo	3 mo	4 mo	5 mo	6 mo
KL 1	38.61	23.22	4.49	1.32	1.02	0.61	0.52
2	38.58	22.68	3.69	1.76	1.30	0.74	0.49
3	38.70	20.05	2.30	1.37	0.71	0.34	0.18
4	38.87	21.53	2.71	1.29	0.82	0.44	0.39
Mean	38.69	21.87	3.30	1.43	0.96	0.53	0.39
%	100	56.5	8.5	3.7	2.5	1.4	1.0
% loss		43.5	91.5	96.3	97.5	98.6	99.0
BL 1	37.96	21.58	6.72	3.85	1.71	1.32	1.26
2	37.35	21.64	6.10	2.72	1.68	1.73	1.03
3	37.69	21.47	5.54	2.08	1.15	0.91	0.78
4	37.86	21.17	4.77	2.24	1.93	0.95	0.82
Mean	37.71	21.46	5.78	2.72	1.62	1.23	0.97
%	100.00	56.9	15.3	7.2	4.3	3.2	2.6
% loss	0.00	43.1	84.7	92.8	95.7	96.8	97.4

Dt = decomposition time KL 1 = sample number 1 of *K. candel* leaves
BL 1 = sample number 1 of *B. gymnorrhiza* leaves

Table 8. Dry mass loss of mangrove twigs during the decomposition (grams of dry weight)

Dt	0 mo	2 mo	4 mo	6 mo
BK 1	144.39	138.18	132.04	118.67
2	143.81	138.52	131.12	120.41
Mean	144.10	138.35	131.58	119.54
%	100.0	96.0	91.3	83.0
% loss	0.0	4.0	8.7	17.0
BB 1	196.79	180.46	168.34	161.41
2	191.75	180.65	162.71	155.06
Mean	194.27	180.55	165.25	158.23
%	100.0	92.9	85.2	81.5
% loss	0.0	7.1	14.8	18.5

Dt = decomposition time BK 1 = sample number 1 of *K. candel* twigs
BB 1 = sample number 1 of *B. gymnorrhiza*

ed. After 1, 2, 3, 4, 5 and 6 months, the dry mass losses of *K. candel* leaves were 43.5, 91. 5, 96.3, 97.5, 98.6 and 99.0 %, and those of *B. gymnorrhiza* were 43.1, 84.7, 92.8, 95.7, 96.8 and 97.4 %, respectively. Decreases in dry mass of *K. candel* twigs after 2, 4 and 6 months were 4.0, 8.7 and 17.0 %, and those of *B. gymnorrhiza* were 7.1, 14.8 and 18.5, respectively (Table 8). The dry mass losses (%) of the mangrove leaves and twigs during the decomposition are shown in Fig. 4.

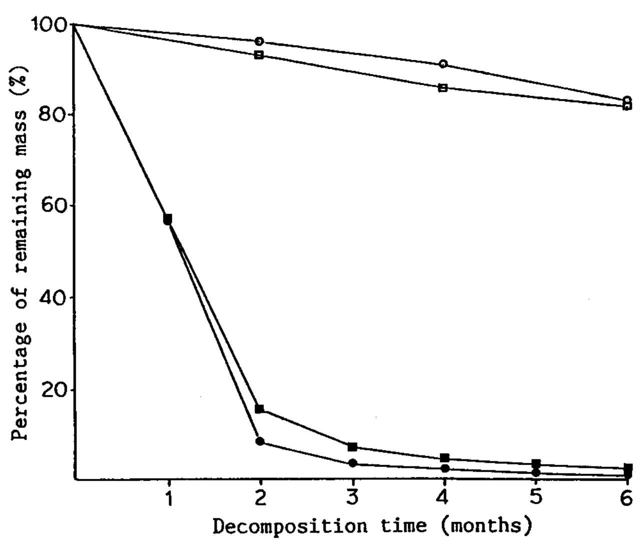

Fig. 4. Dry mass losses (%) of mangrove leaves (closed marks) and twigs (open marks) during the decomposition. Squares and circles, respectively refer to *B. gymnorrhiza* and *K. candel*.

4. Discussion

Total annual litterfall was 8.72, 10.74 and 7.73 ton/ha/year in P1, P2 and P3, respectively. STEINKE and CHARLES (1984) reported that the total annual litterfall of a mangrove forest in the Mgeni estuary was 8.61 ton/ha/year in the *Bruguiera gymnorrhiza* community and 7.15 ton/ha/year in the *Avicennia marina* community. Litterfall of a mixed forest of *Avicennia germinans*, *Rhizophora mangle* and *Laguncularia racemosa* in South Florida was 8.68 ton/ha/year (in Fort Myers) and 7.51 ton/ha/year (at Rookery Bay), and that of monospecific stands of *A. germinans* was 3.51 ton/ha/year in Fort Myers, 5.38 and 4.69 ton/ha/year at Rookery Bay (TWILLEY et al., 1986). KISHIMOTO et al. (1986) reported that the litterfall of mangrove stands on Iriomote Island, Japan, was 7.5 and 8.8 ton/ha/year in *Rhizophora stylosa-Bruguiera gymnorrhiza* community and *Bruguiera gymnorrhiza* community, respectively. In general, compared with these subtropical obtained results, the mean annual litterfall of the Ohura mangrove stand (9.07 ton/ha/year) was higher. It is supposed that the typhoons during the period of the experiment (on July 16 and August 29, 1987), which made the total litterfall in these months remarkably higher than other months, were responsible for the high litterfall yield. The litterfall was high in P2, P1 and the lowest was in P3 which had a mean tree height 6.53, 4.76 and 4.49 m, respectively. There was an apparent indication that the total annual litterfall positively correlated with the mean tree height, with a high co-efficient of correlation, (r) = 0.98.

In a warm temperate evergreen broadleaved forest of Minamata, Kyushu, the litterfall amounted to 5.78 ton/ha/year (NISHIOKA and KIRITA, 1978). Total annual litterfall of *Chamaesiparis obtusa* stands on Mt. Hiei, Shiga Prefecture was 5.1, 3.4, 2.9 and 3.5 ton/ha/year in P1, P2, P3 and P4, respectively (TSUTSUMI et al., 1983). In an *Abies firma* forest of the Aobayama hill in the western part of Sendai City, the total annual litterfall amounted to 7.27 ton/ha/year (HIRABUKI, 1985). SIMARANGKIR (1987) reported that the litterfall of a subarctic forest in Northern Hokkaido amounted to 3.0 ton/ha/year. Compared with these obtained results, the value of litterfall in the present study is obviously greater. This fact suggests that the mangrove forest has a very important role in producing organic materials.

The peak of the *Rhizophora mangle* and *Avicennia germinans* leaf fall in South Florida was in July and Ocotober, respectively (TWILLEY et al., 1986). It was reported by STEINKE and CHARLES (1984) that the leaf fall of the *B. gymnorrhiza* community was high during the cool, dry months than during the warmer months. The leaf fall of *B. gymnorrhiza* in the Ohura mangrove stand also showed a high yield during the winter months, though it had a tendency to increase in the beginning of summer (June). In contrast, the leaf fall of *K. candel* was low during the winter months. The seasonal trends of the leaf fall were in contrast with those of temperate deciduous forests, where all the leaves fall during the autumn. They were also different from those of the warm-temperate forests in Kyushu (NISHIOKA and KIRITA, 1978) and those of a subarctic forest in Northern Hokkaido (SIMARANGKIR, 1987).

Leaf appearance, as measured by the number of fallen stipules, is presented in Table 9. It can be easily seen from the table that the communities had a similar pattern in their leaf appearance. During the cool months (winter), leaf appearance was the lowest, increased progressively in warmer months, peaking in July (summer). This fact supports the finding

Table 9. Seasonal trends of fallen stipules in the three communities (n/m²)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
P1	91	68	139	172	216	236	332	287	178	138	135	90
%	4.4	3.3	6.7	8.3	10.4	11.3	15.9	13.8	8.5	6.6	6.5	4.3
P2	6	62	100	137	209	298	373	299	201	169	158	94
%	3.0	2.9	4.6	6.3	9.7	13.8	17.2	13.8	9.3	7.8	7.3	4.3
P3	41	36	55	68	94	183	249	184	132	86	75	37
%	3.3	2.9	4.4	5.5	7.6	14.8	20.1	14.8	10.7	6.9	6.0	3.0
Mean	76	55	98	126	173	239	318	257	170	131	123	74
%	4.1	3.0	5.2	6.9	9.4	13.0	17.3	14.0	9.3	7.1	6.7	4.0

of STEINKE and CHARLES (1984) in the *B. gymnorrhiza* community of Mgeni mangrove. NAKAGOSHI and NEHIRA (1986) also reported the cumulative temperature was directly proportinal to the number of leaves and the rate of leaf production on mangrove seedlings transplanted to Hiroshima.

Leaves of *Avicennia marina* in South Africa decomposed faster than those of *B. gymnorrhiza*. STEINKE et al. (1983) supposed that the slower decomposition of the *B. gymnorrhiza* leaves was attributable to the fact that the leaves were more buoyant than *A. marina* leaves, and both surfaces covered with a thick cuticle. In the Ohura mangrove, *B. gymnorrhiza* leaves also showed a slightly slower decomposition in comparison with *K. candel* leaves. Dry mass losses of the twigs showed a much slower decrease than those of the leaves. The decrease in twig mass of the two species was almost entirely the result of bark loss which flaked from the wood. The bark apparently decomposed only partially. Most of the bark material still remained after a half year decomposition, while the woody materials remained generally firm and hard without obvious signs of breakdown.

The effects of the typhoons during the period of the experiment (in July and August), which made the amount of litterfall in these months remarkably high, are interesting, with 4.4 ton/ha or about 48.1 % of the total annual litterfall occuring in these months. The litterfall was mainly composed of green leaves and branches. In consequence of the typhoons, the total annual litterfall of the Ohura mangrove was higher in comparison with results obtained in other subtropical mangroves.

MIYAGI and SHIMABUKU (1984) reported that most of damaged *Sonneratia alba* and *Kandelia candel* trees in a mangrove forest on Iriomote Island recovered soon after a typhoon. In the case of typhoons in the Ohura mangrove forest, no obvious effects on the leaf appearance of the forest were found. A great amount of fallen leaves and branches, caused by the typhoons, has possibly opened the canopy of the forest and even resulted in gap areas. This is capable of stimulating the seedlings growth. It is assumed that the typhoons will be able to accelerate the regeneration process of the forest.

Okinawa Island is located in a typhoon zone. According to OYAMA (1978), mean annual typhoon occurrence on Okinawa Island was 7 times/year, with the average of 4.2 typhoons/year having a typhoon center of less than 300 km. Therefore, the typhoon attacks during the period of the experiment were not accidental events, and should be recognized as a special environmental factor with unique effects on the character of the forest.

Some information on litter production and decomposition has been obtained from this study, but more questions appeared. Results obtained in many forest ecosystems showed that the annual litterfall rates fluctuated widely from year to year. It can be seen from this study that the mangrove twig litter was resistant to decomposition, while the decomposition process of the flower, fruit, stipula and other material litter,nutrient concentration in the litterfall and nutrient release during the decomposition process have not yet been investigated. Therefore, longer term and more detailed studies are necessary before a fairly reliable estimation of the contribution of the mangrove forest toward nutrient recycling can be formulated.

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摘　要

この研究は沖縄県名護市の大浦湾（北緯26度31分，東経128度５分）にあるマングローブ林で行った。1986年12月に，10ｍ×10ｍの方形調査区，Ｐ１，Ｐ２及びＰ３を設定した。Ｐ１はメヒルギ（*Kandelia candel*）優勢林，Ｐ２はメヒルギとオヒルギ混交林，Ｐ３はオヒルギ（*Bruguiera gymnorrhiza*）優勢林であった。

１年間のリターフォール量はＰ１では8.73 ton/haで，葉（54.1％），枝（18.9％），生殖

器官(16.7％)，托葉(6.6％)，その他(3.7％)であった。P 2では10.74 ton/haで，葉(64.3％)，枝(11.3％)，生殖器官(14.9％)，托葉(6.3％)，その他(3.2％)，P 3では7.72 ton/haで，葉(73.3％)，枝(10.8％)，生殖器官(7.4％)，托葉(5.7％)，その他(2.7％)であった。

P 1とP 2のリターフォール量は冬期に少なく，春期に多かった。5月には成熟した種子が落下したのでピークが認められた。P 3では2月にはオヒルギの落葉が多く，そのためにリターフォール量に小さいピークが現われた。8月にに台風によって大量のリターフォールが生じ，全プロットで大きなピークが認められた。

メヒルギの葉の分解はオヒルギの葉より少し早かった。両種の葉の分解は最初の2ヵ月間に非常に多く，91.5％のメヒルギの葉及び84.7％のオヒルギの葉が分解した。枝の分解は葉の分解よりかなり遅かった。枝の分解は樹皮から起こり，木部は半年経過後でもまだ分解していなかった。