Biomass of Coarse Woody Debris in Subtropical Evergreen Broad-leaved Forest on Northern Okinawa Island, Japan

Takashi MASUNO and Tsuneo NAKASUGA

Abstract Coarse woody debris (CWD), including logs (fallen trees) and branches and snags (standing dead trees), of butt diameter or diameter at breast height (DBH) □ 2.5 cm were measured and its biomass estimated in subtropical evergreen broad-leaved forest on northern Okinawa Island in 2001. Two study plots (plots A and B) were designated. Plot A had a total plot area of 0.12 ha, basal area 49 m^2/ha, tree density 5017 trees/ha and estimated biomass 182 t/ha. Plot B had a total plot area of 0.16 ha, basal area 59 m^2/ha, tree density 3094/ha and estimated biomass 240 t/ha. *Castanopsis cuspidata* was the dominant species in both plots. The volume of logs and branches, and standing snags in plot A were 9.62 and 14.56 m^3/ha, respectively and in plot B were 24.9 and 3.82 m^3/ha, respectively. Snags caused by the density effect were an important source of CWD in plot A, whereas fallen trees and large branches were an important source of CWD in plot B. The biomasses of CWD in plots A and B, considering the degree of decay, were estimated at 7.4 and 8.5 t/ha, respectively.

Key words: Carbon sink, *Castanopsis cuspidata*, CWD, Litter, Ryukyu archipelago

I Introduction

Coarse woody debris (CWD) is large tree litter which includes logs (fallen trees) and branches as well as snags (standing dead trees). CWD is regarded as incapable of utilization from the standpoint of silviculture in Japan. Recently, however, CWD has gradually become recognized as an essential element of the forest ecosystem from the standpoint of forest ecology, as it offers a habitat for small animals, provides a food source, and maintains biodiversity (*1*). In addition, as global warming has become a matter of international concern, forests are attracting attention as an important carbon sink. Much of the carbon is stocked in live plant body and plant litter in the forest. But plant litter, especially CWD has seldom been measured.

It has been pointed out that climate, types of forest vegetation, and human impact on forests all affect the amount of CWD biomass (*2*). As CWD exists in all kinds of forests, it is an important task to figure out CWD biomasses for all types of forest vegetation. The biomass and decomposition rate of CWD in temperate evergreen forest have already been reported (*3*). Recently, intensive research has also been carried out on the decomposition rate of temperate broad-leaved forest (*4*). The biomass of CWD in subtropical evergreen broad-leaved forest, however, has not yet been reported.

The objective of this research was to calculate the biomass of CWD in subtropical evergreen broad-leaved forest dominated by *Castanopsis cuspidata*. Specifically, stand structures in two plots of forest were first analyzed. The size and extent of decay of CWD were then measured and the biomass of CWD was estimated.

II Materials and methods

1. Study site

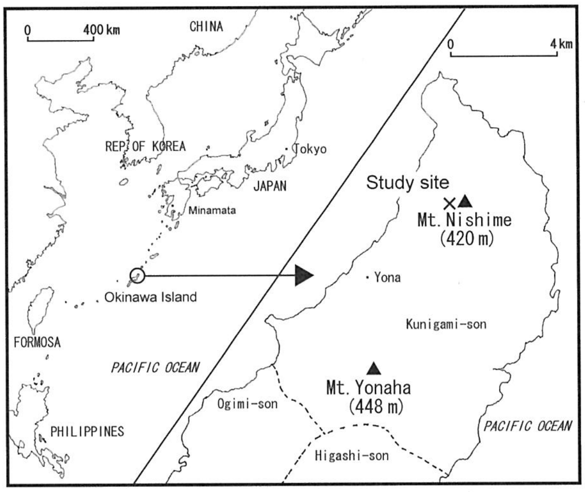

Fig. 1 Study site

The research was conducted on the hillsides of Mt. Nishime, located in the northern part of Okinawa Island, Japan (Fig. 1). Okinawa Island has a subtropical climate. Its average annual temperature and average annual rainfall are about 21℃ and 2200 mm, respectively. A wildlife sanctuary has been established around Mt. Nishime, and the area is covered in evergreen broad-leaved forest. This area has been impacted by human activity, such as clear cutting and selective cutting of good trees, from the 1940s to the 1960s. Since then forest

Takashi MASUNO (HCAS, SOKENDAI. Shonan Village, Kanagawa, 240-0193 Japan. E-mail: masuno_takashi@goo.jp)
Tsuneo NAKASUGA (Fuc. Agr. Univ. of the Ryukyus. 1 Senbaru, Nishihara, Okinawa, 903-0213 Japan)

vegetation has naturally recovered. The field survey was conducted from October to December 2001.

2. Forest stand structure Two research plots (plots A and B) were established on the hillside of Mt. Nishime. The altitude and total area of plot A were about 330 m and 0.12 ha, respectively, and those of plot B were 370 m and 0.16 ha. Although both plots are secondary forest, their forest structures are not the same. The trees in plot A are younger than those in plot B. Plot A has a higher tree density than plot B and has a maximum diameter of 35 cm at breast height (DBH). On the other hand, plot B has old, large diameter trees which have a maximum 87 cm DBH. The plot A seemed to be impacted by clear cutting and plot B by selective cutting of good trees.

Tree DBH and tree height were measured and the species of each tree identified in each plot. Trees of DBH ≥ 2.5 cm were studied. The above-ground tree biomass was estimated by using the regression formula of Kawanabe et al. (*5*).

3. Measurement of CWD CWD consisting of fallen trees and branches and snags with butt diameter or DBH ≥ 2.5 cm was measured. The diameter and length of fallen trees and branches was measured. Diameters were measured at the butt, each 50 cm from butt and tip. Branches that formed part of CWD were also measured. Snags were measured at the base, breast height, and tip. The tip diameters of snags taller than 2 m were estimated by the eye. The volume of CWD was calculated according to mensuration by division using the Smalian formula (*6*). The surface area of land covered by CWD was also calculated from the width and length of CWD and then its proportion against the flat land surface area was calculated.

As decay proceeds, the bulk density of CWD becomes smaller. The four decay classes (sound, slightly decayed, moderately decayed, and advanced decay) of each CWD were identified by the method described in Lambert et al (*7*). The extent of decay (other than sound) was determined as follows. A pointed metal rod 0.5 cm in diameter was pushed firmly into the wood. Decay classes were defined as: "slightly decayed" (penetration < 0.5 cm), "moderately decayed" (penetration 0.5 cm to the radius of the bole), or "advanced decay" (penetration through the bole). Since decay state varied along an individual bole, classification was determined by the decay state of > 50% of the bole.

4. Estimation of coarse woody debris biomass The bulk density of *C. cuspidata* is reported to be 497-501 kg/m^3 (*8*). Although the study plots included more than 40 species, the bulk density of *C. cuspidata* (500 kg/m^3) was used for estimation of CWD biomass to avoid complicated calculations.

To take decay status of CWD into account, we used relative bulk densities according to the decay classes. The relative bulk densities were calculated from 136 samples of *C. cuspidata*. The samples were collected from the research plots and brought back to the laboratory. The volume of each sample was calculated, after which it was dried in drying machine and weighed. The relative bulk densities of samples of different decay classes against sound *C. cuspidata* (500 kg/m^3) were calculated (Table 1).

Table 1 Relative bulk densities of sampled *Castanopsis cuspidata* according to decay class

Decay class	Relative bulk density		
	Average	Standard deviation	n
1. Sound	1.00		
2. Slightly decayed	0.73	0.20	37
3. Moderately decayed	0.55	0.12	34
4. Advanced decay	0.31	0.10	65

III Results

1. Stand structure The number of species, tree density and basal area in plot A were 46 species, 5017 trees/ha, and 49 m^2/ha, respectively (Table 2) and in plot B were 49 species, 3094 trees/ha, and 59 m^2/ha, respectively (Table 3). Thirty-five species were common to plots A and B.

Table 2 Dominant species and basal areas in plot A (0.12 ha)

Species	Tree density (/ha)	Basal area (m^2/ha)	Relative basal area (%)
Castanopsis cuspidata	683	22.6	46.1
Schima superba	233	4.3	8.8
Daphniphyllum teijsmanni	317	2.9	6.0
Machilus thunbergii	108	2.4	4.9
Elaeocarpus japonicus	342	2.0	4.1
Other 41 species	3334	14.8	30.2
Total: 46	5017	49.0	100.0

Table 3 Dominant species and basal areas in plot B (0.16 ha)

Species	Tree density (/ha)	Basal area (m^2/ha)	Relative basal area (%)
Castanopsis cuspidata	194	24.7	41.8
Distylium racemosum	244	6.7	11.3
Quercus salicina	56	4.5	7.6
Styrax japonicus	100	3.3	5.7
Schefflera octophylla	163	3.1	5.2
Other 44 species	2337	16.7	28.4
Total: 49	3094	59.0	100.0

Both plots are dominated by *C. cuspidata*, which accounted for more than 40% of the basal area of both plots A and B. The basal area of plot A is smaller than that of plot B. The basal area of plot A (49 m^2/ha) is regarded as a restored *C. cuspidata* stand on Okinawa Island.

From the standpoint of DBH size, the biggest tree in plot A was a 34.9cm *C. cuspidata* (Fig. 3) and in plot B an 86.8cm *C. cuspidata* (Fig. 4). The tree size of plot B was larger than that of plot A, and the biggest tree in both plots was a *C. cuspidata*. Plot B included four *C. cuspidata* trees with DBH ≥ 60 cm, and all those trees were of large hollows (Fig. 4).

The above-ground tree biomass in plots A and B were estimated at 182 t/ha and 240 t/ha, respectively. The tree biomass of plot A was 76% of that plot B.

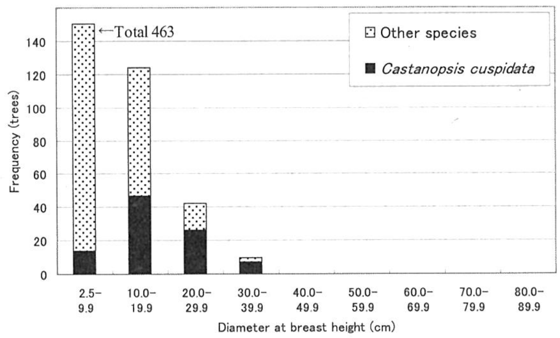

Fig. 3 Frequency distribution of DBH of trees in plot A

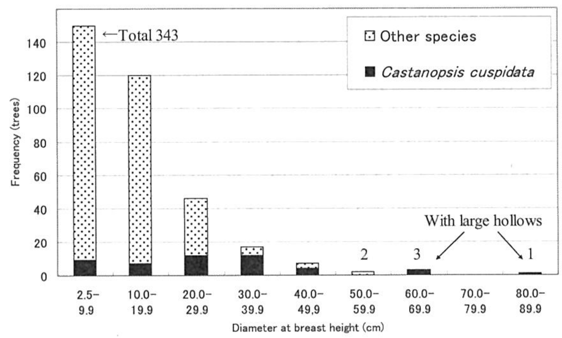

Fig. 4 Frequency distribution of DBH of trees in plot B

2. Diameters and volume of CWD The size of CWD in plot A ranged from 2.5 cm to ≥ 20 cm (Fig. 5). Only one individual fallen tree or branch had a butt diameter of ≥ 20 cm, measuring 20.8 cm in diameter. The biggest snag in plot A had a diameter of 23.1 cm at the base of the tree. Snags of base diameter between 10.0 cm and 19.9 cm formed the majority of CWD volume in plot A.

The size of CWD in plot B ranged from 2.5 cm to ≥ 20 cm (Fig. 6). Eleven individual fallen trees and branches had a butt diameter of ≥ 20 cm. The biggest individual had a butt diameter of 43.8 cm. Three individual snags had base diameters of ≥ 20 cm, of which the biggest measured 24.0 cm.

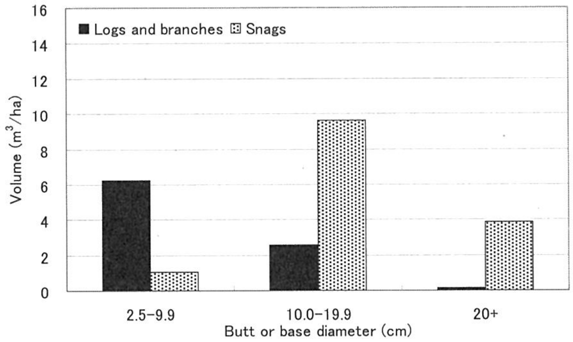

Fig. 5 Frequency distribution of butt diameter and volume of CWD in plot A

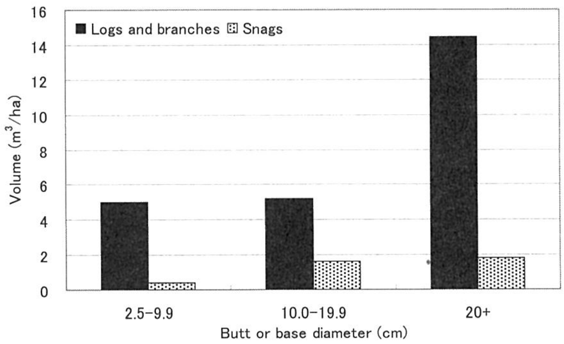

Fig. 6 Frequency distribution of butt diameter and volume of CWD in plot B

The volume of CWD in plot A was 24.2 m^3/ha, and the CWD of snags accounted for 60% of the total (Table 4). The volume of CWD in plot B was 28.7 m^3/ha, and the CWD of fallen trees and branches accounted for 87% of the total. The land surface areas covered by CWD in plots A and B were 2.04% and 2.71%, respectively (Table 4).

Table 4 CWD volume and CWD covered land surface area in plots A and B

Plot	Volume (m^3/ha)			Land surface area covered by CWD (%)		
	Logs and branches	Snags	Total	Logs and branches	Snags	Total
A	9.6	14.6	24.2	2.01	0.03	2.04
B	24.9	3.8	28.7	2.70	0.01	2.71

3. Estimated biomass of CWD The CWD biomasses, ignoring the decay class and assuming all CWD is sound, in plots A and B were estimated at 12.1 t/ha and 14.4 t/ha, respectively (Table 5). When decay class is taken into account, the CWD biomass in plot A was estimated at 7.4 t/ha and that of plot B was 8.5 t/ha.

Table 5 Biomass of CWD in plots A and B

Plot	Decay class ignored (t/ha)			Decay class considered (t/ha)		
	Logs and branches	Snags	Total	Logs and branches	Snags	Total
A	4.8	7.3	12.1	2.6	4.8	7.4
B	12.5	1.9	14.4	7.3	1.1	8.5

IV Discussion

We first discuss the difference in CWD types between plot A and B. In plot A, CWD biomass originating from snags was larger than that from fallen trees and branches. This is because the trees in plot A were still growing rapidly, and many trees had died owing to the density effect. On the other hand, in plot B the CWD biomass originating from fallen trees and branches was larger than that from snags. Plot B had four *C. cuspidata* trees of diameter ≥ 60 cm, all of which had large hollows and decaying branches. This made these aged trees a source of CWD consisting of fallen trees and branches.

Secondly, we discuss the relationship between above-ground tree biomass and CWD biomass. The above-ground tree biomasses in plots A and B were estimated at 182 t/ha and 240 t/ha, respectively. Ignoring decay class, the CWD biomasses in plots A and B were estimated at 6.6% and 6.0% of the above-ground tree biomass. When decay class was considered, the CWD biomasses of plots A and B were estimated at 4.1% and 3.5% of above-ground tree biomass. Thus about 4% of above-ground tree biomass could be expected to be CWD biomass.

Finally, we compare the present study with previous work on CWD biomass. The total wood litter in temperate evergreen broad-leaved forest at Minamata, Kumamoto Prefecture, Japan has been reported as 9.5 t/ha (*3*). In *Quercus prinus* stands in other temperate regions, the biomass of logs has been reported as 11-22 t/ha (*2*). In a forest in the tropical region of Paso, Malaysia, CWD biomass was 35.7 t/ha (*3*). The CWD biomass estimated in our research (7.4-8.5 t/ha) is smaller than that of tropical regions, because tropical forests have a larger tree biomass than does the subtropical forest of our study. The CWD biomass estimated in our research is also smaller than that of temperate evergreen broad-leaved forest. The stand structure and forest size of the subtropical evergreen forest we studied and the temperate evergreen broad-leaved forest at Minamata are very similar. There is a high possibility that various human disturbances have affected the CWD biomass in the study plots. Due to the selective cutting of good trees, commercially useless tees which are characterized by the large trees with decay part or large cavities remain at plot B. These useless trees seem to supply the much amount of CWD advancing decay. The decomposition rate usually increases with increasing temperature. In subtropical regions, a faster decay rate of CWD is to be expected than that in temperate regions, explaining why the CWD biomass estimated in our research is smaller than that of temperate evergreen broad-leaved forest.

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