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論　文（Original article）

Basic densities as a parameter for estimating the amount of carbon removal by forests and their variation

FUJIWARA Takeshi [1)*], YAMASHITA Kana [1)], KURODA Katsushi [1)]

Abstract

Basic densities of wood from 10 species (572 trees) of softwoods and 50 species (440 trees) of hardwoods were measured as parameters for estimating the amount of carbon removal by forests following the guidelines described in the Kyoto Protocol and Marrakesh Accord. The basic densities of individual trees were averaged for each species and 95% confidence limits were calculated for quality control. Furthermore, variations in the mean basic densities within species were assessed by analysis of variation and the effects of stand ages or tree ages on the basic densities were also evaluated. The average and 95% confidence limits of the basic densities in most species that were collected for a certain number of sample trees converged and most species showed low uncertainty up to 5 %. Some species, such as *Larix kaempferi*, *Picea jezoensis* and *Picea glehnii*, showed significant differences among plots, while other species, such as *Chamaecyparis obtusa* and *Abies sachalinensis* did not. When the basic densities were averaged for regional groups, the regional mean did not show significant difference. Thus, the differences found between plots might not have been caused by regional variation. Moreover, neither the tree age nor the stand age showed significant correlation with the basic densities; the basic densities of younger stands (younger than 20 years old) did not differ from those of the older stands. These results suggest that using basic densities as a parameter for estimating carbon removal by forests does not require the preparation of values for districts or age classes.

Key words : basic density, Kyoto Protocol, softwoods, hardwoods, uncertainty

Introduction

The increase of greenhouse gases in the atmosphere is considered to be one cause of global warming. In order to reduce the amount of greenhouse gases, the 3rd Conference of the United Nations Framework Convention on Climate Change (COP3) ratified the Kyoto Protocol and it went into effect in February 2005. While the protocol forces signatory nations to reduce greenhouse gases, the carbon removed by forests planted after 1990 can be counted toward the reduction target (UNFCCC, 1998). Furthermore, at COP7 held at Marrakesh in 2001, it was agreed that carbon removed by forests planted before 1990 could be countable as carbon removal by forests (UNFCCC, 2002). The Kyoto Protocol states that reports have to be compiled in a transparent and verifiable manner and that parameters used in calculations must be established using transparent and verifiable methods. Parameters such as volume and basic density should be established for calculating the amount of carbon in forests. The total oven-dried biomass of an individual trunk can be calculated as the product of the volume and the basic density, because the basic density is oven-dried weight in unit green volume.

The measurement of basic density has a long history in wood research because it is one of the most fundamental parameters of wood properties (e.g. Miyajima, 1958; Miyajima, 1985; Fujisawa, 1998; Fujiwara *et al.*, 2004). Few studies, however, have been published on the average basic density of individual species. The average basic densities of each species compiled in the Mokuzai Kogyo Handbook (FFPRI, 2004) cited data from FFPRI (unpublished), in which the average basic densities were calculated from only a few naturally grown trees of each species. Thus, the data may not be applicable to the basic density of plantation trees. Furthermore, the national report following the Kyoto Protocol requires quality control of parameters to ensure the transparency and verifiability of the parameters. To control the quality of the parameters, the parameters have to be assessed for variation and uncertainty, which are defined in Good Practice Guidance (IPCC, 2003b). When the 95% confidence limit of the parameters is to be calculated, certain numbers of sample trees of each species are required.

Many authors have reported that the basic density varied within an individual tree (Fukazawa, 1967; Fujiwara & Iwagami, 1986; Minato *et al.*, 1989; Hishinuma *et al.*, 1992; Fujiwara *et al.*, 2004). Although the basic density might vary

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* Department of Wood Properties, Forestry and Forest Products Research Institute (FFPRI), 1 Matsunosato, Tsukuba, Ibaraki, 305-8687 Japan; e-mail: fujiwara@ffpri.affrc.go.jp.
1) Department of Wood Properties, Forestry and Forest Products Research Institute (FFPRI)

within a tree, Yahata *et al*. (1987) and Fujiwara *et al*. (2004) reported that the average density at breast height had a distinct positive correlation with the average density of trunks. Thus, they concluded that the density measured at breast height could represent the mean density of the individual trees (Yahata *et al*., 1987; Fujiwara *et al*., 2004). Therefore, measuring the basic density at breast height is sufficient for calculating species average. The basic densities of major species in Japan are still insufficient as parameters, but the basic densities for the Kyoto Protocol parameters have been published in 6 major softwood species: *Cryptomeria japonica*, *Chamaecyparis obtusa*, *Larix kaempferi*, *Abies sachalinensis*, *Picea jezoensis*, and *Picea glehnii* (Fujiwara *et al*., 2004). However, the basic density has to be measured for hardwoods as well because the volume of hardwood species can not be ignored, and the variation should be considered to determine whether regional variation and/or stand age influence the basic density. In the present research, the average of the basic densities of each target species and their variation were investigated in addition to the data reported in a previous work (Fujiwara *et al*., 2004).

Materials and Methods

Sample trees and specimens

Good Practice Guidance for Land Use, and Land-Use Changes and Forestry (IPCC, 2003a) divides districts in Japan into 2 climate zones, cold temperate wet and warm temperate wet. The northern districts of Hokkaido and Tohoku, and mountainous regions of central Japan are classified as cold temperate wet and the other districts are categorized as warm temperate wet (Fig. 1). With the exception of *Larix kaempferi*, all softwood samples were obtained from planted forests that were located within the range of the natural distribution of the species. Although the natural distribution of *Larix kaempferi* is limited to the high altitude regions of central Japan, it is a major commercial species planted in cold temperate zones such as Hokkaido and Tohoku. All species examined in this work are listed in Tables 1 and 2. The tables also indicate the number of trees of each species that were measured for basic density in each species. Although number of the trees in each plot was generally 4 softwood trees or 8 hardwood trees, number of trees for one species did not reach such number of trees and sample trees consist of several species when the forests were mixed forests. Discs for measuring the basic density were obtained at 1.2 m and 1.5 m above ground from softwoods and hardwoods, respectively. The discs were split into two fan-shaped specimens without barks for measuring the basic densities.

Measurement procedure

The basic density of the specimens was measured using the floating method. The floating method derives the volume of specimens as a function of their buoyancy, which is calculated from the difference between their weight in air and in water. The green specimens were vacuum-saturated with water in order to measure the stable weight of the specimens in water. The weight

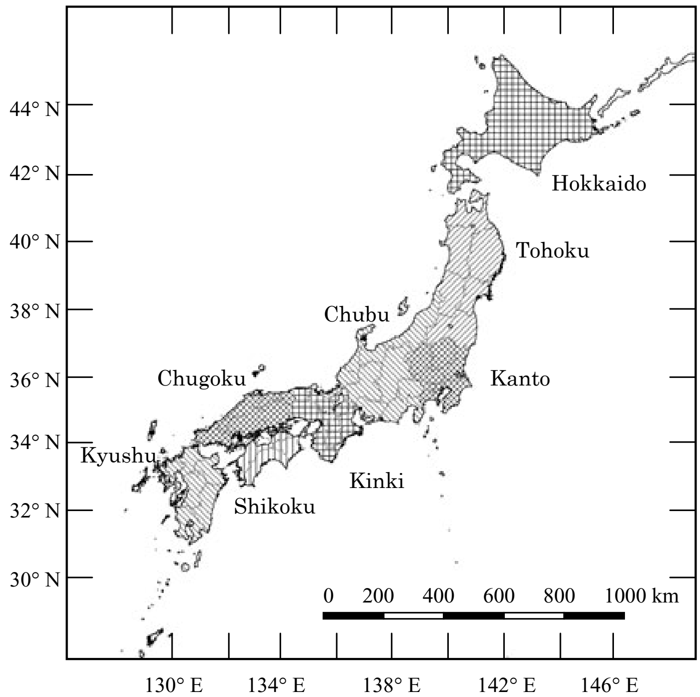

Fig. 1. Geographical location of Japan and each district.
Note: The climatic zone of northern Japan (Hokkaido and Tohoku districts) and mountainous regions in central Japan are classified as cold temperate wet and the others are classified as warm temperate wet.

of the specimens being water saturated was measured with a balance scale (Mettler Toledo, PR503DR), and the weight of the specimens in water was measured by suspending them with a fishing line and a hook from the balance scale into a water bath placed below the balance scale. The specimens were air dried for 2 days after measuring the weight of water- saturated specimens in air and in water. Then, they were dried in a drying oven with fan (Yamato Scientific, DN600) at 60 ºC for 24 hours and 102 ºC for 2-3 days, and the oven-dried weight of the specimens was measured. The basic density (BD, kg/m^3) was calculated from the oven-dried weight (W_0, g), water saturated weight (W_s, g) and weight of the water saturated specimens in water (W_w, g), as follows:

$$BD=W_0/(W_s-W_w)\times1000$$

The balance scale used in the present work had enough resolution for calculating the basic density within 1 kg/m^3 accuracy because it measured the weight of the specimens in 1 mg units and 10 mg units when the weight was less than 100 g and 100 g or more, respectively. The average of the basic density by weighted radius was the mean basic density of the trees. Species and plot averages, standard deviations, 95 % confidence limit and uncertainty were calculated on the mean basic density of the individual trees. The uncertainty (%) was calculated according to following equation:

$$uncertainty=\frac{1/2\times\text{(95\%confidence interval width)}}{\mu}\times100$$

where μ is the mean of the distribution (IPCC, 2003b).

Assessment of variation in basic density

Variations in the basic density were analyzed using analysis of variance (ANOVA) by one-way classification of the plots. The software JMP5.1 (SAS Institute Inc.) was used to assess the variation between the plots for each species by ANOVA.

Results and Discussion

Basic densities of softwoods and their variation between plots

The basic densities of 567 trees from 10 softwood species were measured, and the mean basic densities with standard deviations and 95% confidence limits for each species were calculated (Table 1). The species shown in Table 1 cover almost all softwood species planted in Japan. The major species are *Cryptomeria japonica*, *Chamaecyparis obtusa*, *Larix kaempferi*, *Abies sachalinensis*, *Picea jezoensis*, *Picea glehnii* and *Thujopsis dolabrata* var. *hondae* because of their stocks and planted area. The basic densities of all of the listed species were measured using a certain number of trees from many sites. Variation of the basic densities was analyzed for all species but 2 *Pinus* species and *Abies homolepis*, which were excluded because of an insufficient number of sample trees.

The average basic density of 64 *Cryptomeria japonica* trees from 17 plots was 314 kg/m^3 with 32 kg/m^3 of standard deviation and 8 kg/m^3 of the 95% confidence limit (Table 1). Analysis of variance (ANOVA) by one-way classification of plots indicated that the average basic densities of the plots were significantly different at the 5% level (Table 3). The average basic density of 111 *Chamaecyparis obtusa* trees from 28 plots was 407 kg/m^3 with 36 kg/m^3 of standard deviation and 7 kg/m^3 of the 95% confidence limit (Table 1). ANOVA indicated that there ware no significant differences in the average basic densities among the plots (Table 3). Thus, the basic density of *Chamaecyparis obtusa* did not have much variation among plots and this resulted in lower 95 % confidence limits than the

Table 1. Basic density, standard deviation and 95% confidence limit of major softwoods.

Species	P a)	N b)	Age c)	BD d) (kg/m^3)	SD e) (kg/m^3)	CL f) (kg/m^3)	UC g) (%)
Cupressaceae							
Chamaecyparis obtusa Endl.	28	111	7-74	407	36	7	1.7
Thujopsis dolabrata var. *hondae* Makino	11	44	7-49	412	56	16	4.0
Pinaceae							
Abies homolepis Sieb. et Zucc.	1	4	41	359	33	33	9.1
Abies sachalinensis (Fr. Schm.) Mast.	14	56	10-59	318	29	8	2.4
Larix kaempferi (Lamb.) Carr.	14	56	11-56	404	39	10	2.5
Picea jezoensis (Sieb. et Zucc.) Carr.	28	112	3-68	357	41	8	2.3
Picea glehnii (Fr. Schm.) Mast.	26	104	7-69	362	56	11	3.0
Pinus densiflora Sieb. et Zucc.	4	16	8-56	451	66	32	7.2
Pinus thunbergii Parl.	1	4	8	464	20	19	4.2
Taxodiaceae							
Cryptomeria japonica D.Don	17	64	8-72	314	32	8	2.5
Total		572		371	57	5	1.3

a) Number of plots, b) number of trees, c) range of stand age, d) basic density, e) standard deviation, f) 95% confidence limit, g) percentage uncertainty

Table 2. Basic density, standard deviation and 95% confidence limit of hardwoods.

Species	P [a)]	N [b)]	BD [c)] (kg/m^3)	SD [d)] (kg/m^3)	CL [e)] (kg/m^3)	UC [f)] (%)
Acearaceae						
Acer mono Maxim.	1	1	601	-	-	-
Aquifolicaceae						
Ilex chinensis Sims	1	2	548	20	27	5.0
Ilex integra Thunb.	1	1	579	-	-	-
Ilex macropoda Miq.	1	2	548	25	34	6.3
Ilex pendunculosa Miq.	1	7	541	19	14	2.6
Araliaceae						
Acanthopanax sciadophylloides Fr. st Sav.	1	1	397	-	-	-
Betulaceae						
Alnus hirsute (Spach.) Rupur.	1	4	419	14	14	3.3
Alnus japonica (Thunb.) Steud.	1	8	454	20	14	3.1
Betula ermanii Cham.	1	8	510	32	22	4.3
Betula maximowicziana Regel	1	8	499	39	27	6.0
Betula pentaphylla var. *japonica* (Miq.) Hara	1	8	434	22	16	5.4
Carpinus tshonoskii Maxim.	1	1	563	-	-	-
Cercidiphyllaceae						
Cercidiphyllum japonicum Sieb. et Zucc.	3	16	454	30	20	5.1
Clethraceae						
Clethra barbinervis Sieb. et Zucc.	2	8	544	19	13	2.4
Cornaceae						
Cornus controversa Hemsley	2	10	491	24	15	3.0
Ebenaceae						
Diospyros kaki L.f.	1	1	621	-	-	-
Euphorbiaceae						
Bischofia javanica Bl.	1	8	470	55	38	8.1
Mallotus japonicus (Thunb.) Muell.	2	2	413	25	35	8.5
Fagaceae						
Castanea crenata Sieb. et Zucc.	5	17	419	25	12	2.8
Castanopsis cuspidata (Makino) Nakai	4	10	431	30	19	4.3
C. cuspidata var. *sieboldii* (Makino) Nakai	7	13	497	37	20	4.1
Fagus crenata Bl.	1	2	571	30	41	7.2
Lithocarpus edulis (Makino) Nakai	1	6	599	18	15	2.5
Lithocarpus glabra (Thunb.) Nakai	3	5	531	36	32	6.0
Quercus crispula Bl.	4	27	607	37	14	2.3
Quercus serrata Murray	9	51	633	30	8	1.3
Quercus acutissima Carrth.	10	77	668	44	10	1.5
Quercus glauca Thunb.	6	30	646	40	14	2.2
Quercus salicina Bl.	3	3	629	12	13	2.1
Quercus gilva Bl.	1	1	618	-	-	-
Quercus myrsinaefolia Bl.	1	1	724	-	-	-
Hamamelidaceae						
Distylium recemosum Sieb. et Zucc.	4	8	652	18	12	1.9
Juglandaceae						
Juglans sieboldiana Maxim.	1	2	519	11	15	3.0
Lauraceae						
Cinamomum japonicum Sieb. ex. Zucc.	1	1	427	-	-	-
Machilus thunbergii Sieb. et Zucc.	5	6	485	36	29	6.0
Neolitsea sericea (Bl.) Koidz.	4	6	467	31	25	5.3
Leguminosae						
Albizia julibrissin (Willd.) Durazz.	1	1	575	-	-	-
Magnoliaceae						
Magnolia obovata Thunb.	2	9	386	30	20	5.1

Table 2. Basic density, standard deviation and 95% confidence limit of hardwoods.(Continued)

Species	P a)	N b)	BD c) (kg/m^3)	SD d) (kg/m^3)	CL e) (kg/m^3)	UC f) (%)
Oleaceae						
Fraxinus lanuginose Koidz.	2	16	566	28	14	2.5
Fraxinus mandshurica var. *japonica* Maxim.	3	24	540	25	17	1.8
Ligustrum japonicum Thunb.	1	1	639	-	-	-
Rosaceae						
Prunus grayana Maxim.	1	2	505	26	35	7.0
Prunus sargentii Rehd.	1	1	575	-	-	-
Sorbus alnifolia (Sieb. et Zucc.) C.Koch	1	1	540	-	-	-
Styracaceae						
Styrax japonica Sieb. et Zucc.	2	5	501	20	18	3.5
Symplocaceae						
Symplocos lucida Sieb. et Zucc.	1	1	535	-	-	-
Theaceae						
Camelia japonica L.	2	2	626	35	48	7.6
Eurya japonica Thunb.	2	2	519	11	15	3.0
Ulmaceae						
Ulmus davidiana var. *japonica* (Rehd.) Nakai	1	1	558	-	-	-
Zelkova serrata Makino	2	10	611	28	12	2.8
Total		440	566	93	9	1.5

a) Number of plots, b) number of trees, c) basic density, d) standard deviation, e) 95% confidence limit, f) percentage uncertainty

Table 3. Analysis of variance of the basic densities of 7 softwood species.

Species and sources of variance	d.f. a)	SS b)	MS c)	F-value
Cryptomeria japonica				
Plot	16	25,985.4	1,624.1	2.05*
Error	47	37,299.9	793.6	
Total	63	63,285.4		
Chamaecyparis obtusa				
Plot	27	47,937.4	1,775.5	1.53
Error	83	96,029.3	1,157.0	
Total	110	143,966.8		
Larix kaempferi				
Plot	13	45,717.7	3,516.8	4.03**
Error	42	36,686.3	873.5	
Total	55	82,404.0		
Abies sachalinensis				
Plot	13	10,708.6	823.7	0.98
Error	42	35,213.3	838.4	
Total	55	45,921.8		
Picea jezoensis				
Plot	27	91,101.0	3,374.1	2.93**
Error	84	96,681.8	1,151.0	
Total	111	187,782.8		
Picea glehnii				
Plot	25	220,291.0	8,811.6	6.90**
Error	78	99,677.8	1,277.9	
Total	103	319,968.8		
Thujopsis dolabrata var. *hondae*				
Plot	10	69,663.6	6,966.4	3.61**
Error	33	63,624.0	1,928.0	
Total	43	133,287.6		

Note: a) degrees of freedom, b) sum of squares, c) mean of squares.
Asterisks, * and **, indicate that the F-value is significant at the 5% and 1% level, respectively.

other species. The mean basic density of *Abies sachalinensis* was 318 kg/m^3 and standard deviation was 29 kg/m^3 (Table 1). *Abies sachalinensis* also showed no significant difference among the plots (Table 3). Neither species seems to require regional and other variations due to stand age to be taken into consideration. On the other hand, *Larix kaempferi*, *Picea jezoensis*, *Picea glehnii* and *Thujopsis dolabrata* var. *hondae* showed larger standard deviation than the previous 3 species (Table 1). The standard deviation of these latter species varied from 39 kg/m^3 to 56 kg/m^3. ANOVA indicated that there were significant differences at the 1% level among the plots. The species for which significant differences were found in their mean basic densities among plots might require further analysis of the variation in their basic densities.

The basic densities of the major softwood species were measured and the mean basic density of each species was obtained (Table 1), but the basic densities of the minor species were not derived. To improve the accuracy of the estimation of carbon removal, more data should be acquired on the basic densities of the minor softwood species.

Relation between stand age and basic density in softwoods

The basic density in softwoods may be influenced by tree age, because the densities in juvenile woods formed around pith differ from those in mature woods. The density of juvenile woods can be higher or lower than that of mature woods, depending on the species (e.g. Fukazawa, 1967; Fujiwara *et al*. 2004). In order to assess the effects of stand ages on the basic densities, the relation between stand age and the mean basic density of the stands was examined (Figs. 2-8). Most species did not show a significant correlation between stand age and the mean basic density, while the mean basic densities in the younger stands were higher in *Chamaecyparis obtusa*, *Cryptomeria japonica* and *Picea glehnii*, and lower in the other species (Figs. 2-7). The only exception was *Thujopsis dolabrata* var. *hondae* (Fig. 8). The basic densities of younger stands were markedly higher than those of older stands and the correlation between the stand age and the basic density was significant at the 5% level. This finding indicates that much has to be taken into consideration to determine the basic density of such species.

Statistical confirmation of the basic density of younger

Table 4. Analysis of variance of the basic densities of major hardwood species.

Species and sources of variance	d.f. a)	SS b)	MS c)	F-value
Quercus crispula				
Plot	3	18,301.6	6,100.5	7.86**
Error	23	17,846.0	775.9	
Total	26	36,147.6		
Quercus serrata				
Plot	8	4,428.5	553.6	0.62
Error	41	36,480.4	889.8	
Total	49	40,908.9		
Quercus acutissima				
Plot	9	48,952.3	5,439.1	3.67**
Error	66	97,600.4	1,478.8	
Total	75	146,552.6		
Quercus glauca				
Plot	5	15,385.9	3,077.2	2.61
Error	16	18,849.9	1,178.1	
Total	21	34,235.8		
Castanopsis cuspidata				
Plot	2	4,567.2	2,283.6	3.26
Error	5	3,505.7	701.1	
Total	7	8,072.9		
C. cuspidate var. *sieboldii*				
Plot	3	4,917.7	1,639.2	1.39
Error	7	8,234.5	1,176.4	
Total	10	13,152.2		
Fraxinus mandshurica d)				
Plot	3	4,221.8	1,407.3	2.03
Error	28	19,458.6	695.0	
Total	31	23,680.5		

Note: a) degrees of freedom, b) sum of squares, c) mean of squares, d) *Fraxinus mandshurica* var. *japonica.* Asterisks, **, indicate that the F-value is significant at the 1% level.

stands and older stands might be necessary, although stand age did not correlate to the basic density for most species. For this purpose, the mean basic densities of younger stands (up to 20

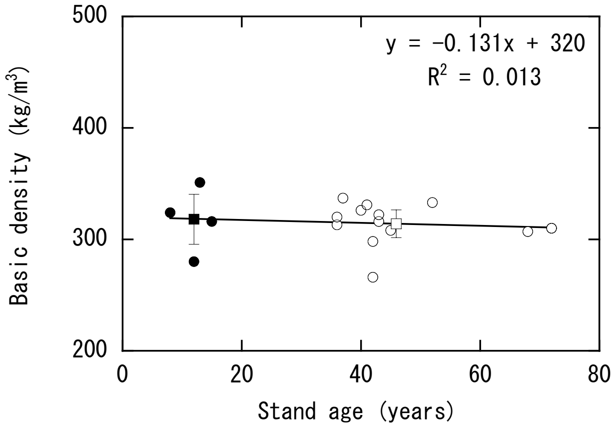

Fig. 2. Relation between stand age and basic density in *Cryptomeria japonica*.
Legend: ●: basic densities in younger stands; ○: basic densities in older stands; ■: mean basic density of younger stands; □: mean basic density of older stands. Note: error bars indicate 95% confidence limits of the mean basic densities.

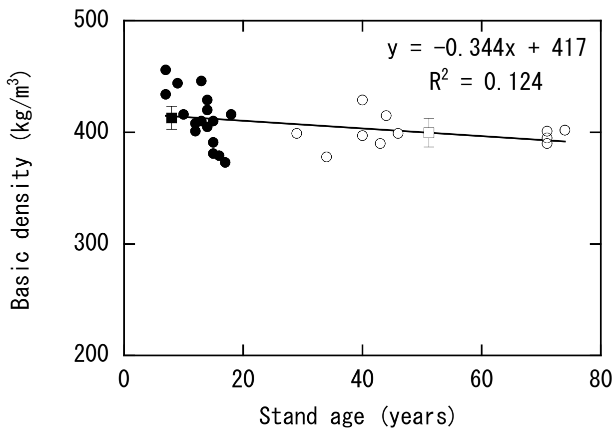

Fig. 3. Relation between stand age and basic density in *Chamaecyparis obtusa*.
Legend and note: refer to Fig. 2.

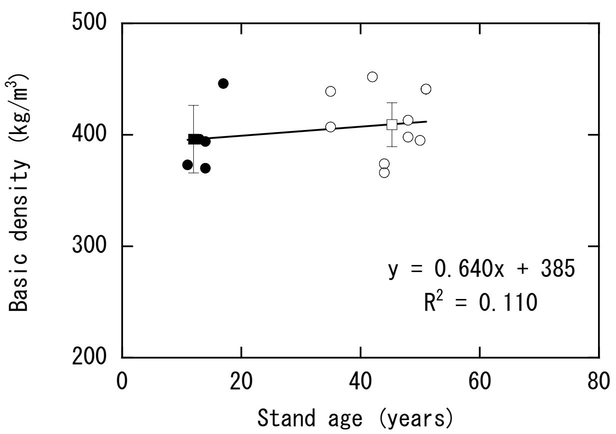

Fig. 4. Relation between stand age and basic density in *Larix keampferi*.
Legend and note: refer to Fig. 2.

years) and older stands (over 20 years) were compared (Figs. 2-8). The boundary, 20 years old, between younger stands and older stands, corresponds with the boundary of the biomass expansion factor (Greenhouse Gas Inventory Office of Japan *et al*., 2006). The mean basic densities of younger stands and older stands are shown with 95 % confidence limits in Figs. 2-8. The 6 species did not show significant differences in the basic densities between the younger stands and older stands at the 5 % level (Figs. 2-7). The younger stands, however, showed significantly higher basic density than the older stands in *Thujopsis dolabrata* var. *hondae* (Fig. 8). Because *Thujopsis dolabrata* var. *hondae* showed a significant correlation between stand age and basic density and a significant difference between younger stands and older stands, further analysis might be required.

Some of the young stands of *Picea jezoensis* and *Picea glehnii* showed extremely high basic densities (Figs. 6 and 7). The sample discs from a plot showing extremely high density in *Picea jezoensis* had only 3 annual rings and were a mere 1.6 cm in diameter. Three plots of *Picea glehnii* also showed much higher density than the other plots (Fig. 7). Their stand ages were 10, 11 and 18 years and they were not the youngest stands.

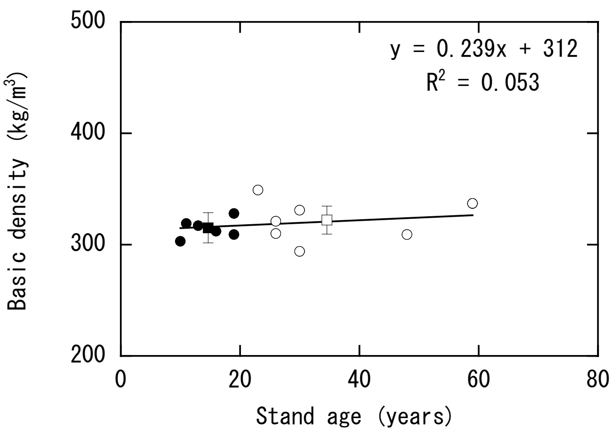

Fig. 5. Relation between stand age and basic density in *Abies sachalinensis*.
Legend and note: refer to Fig. 2.

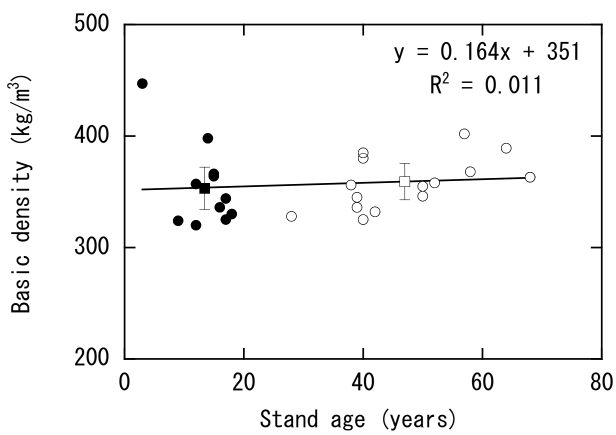

Fig. 6. Relation between stand age and basic density in *Picea jezoensis*.
Legend and note: refer to Fig. 2.

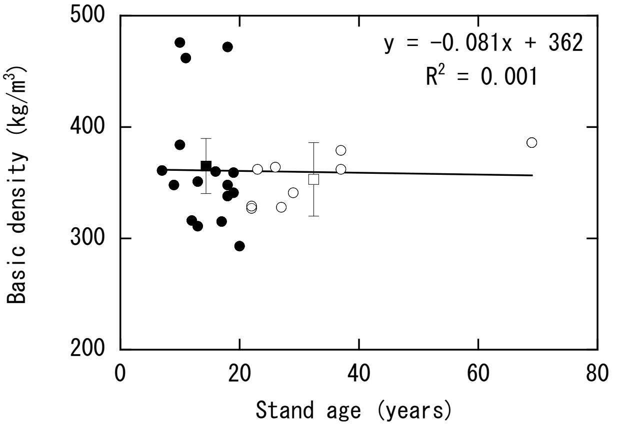

Fig. 7. Relation between stand age and basic density in *Picea glehnii*.
Legend and note: refer to Fig. 2.

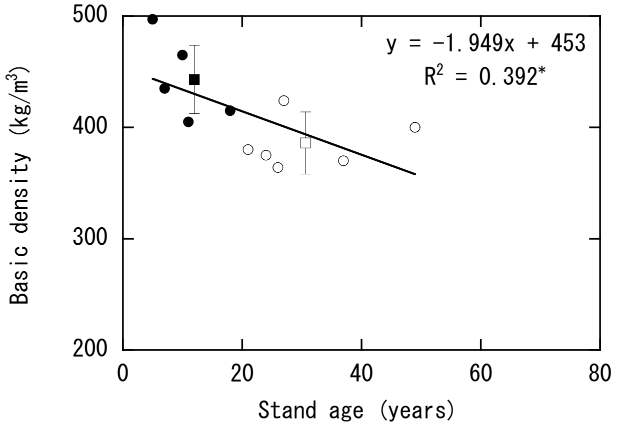

Fig. 8. Relation between stand age and basic density in *Thujopsis dolabrata* var. *hondae*.
Legend and note: refer to Fig. 2. Asterisk indicates that the correlation coefficient is significant at the 5% level.

The diameters of sample discs of the plots, however, were 2.5, 5.1 and 6.0 cm and their growth rates were smallest with 1.2, 2.3, 1.7 mm/year, respectively. Because the basic density of *Picea glehnii* was reported to be high around pith (Akutsu, 1997; Iizuka *et al*., 1999), narrow stems might have higher density than thick stems. In addition, younger plots of *Chamaecyparis obtusa* tended to show higher density as shown in Fig. 3. The higher density if the inner stem might cause the higher density of the younger plots.

Regional variation of basic densities in several softwoods

Some of the species, i.e., *Cryptomeria japonica*, *Chamaecyparis obtusa* and *Larix kaempferi*, account for a large proportion of Japanese plantation forests and they are widely distributed. On the other hand, forest stands of *Thujopsis dolabrata* var. *hondae* do not occupy so much area and most of them are concentrated in 2 prefectures, Aomori and Ishikawa. It might be possible to compare the regional mean basic densities of these 4 species, because Zovel and van Buijtenen (1989) pointed out that the basic density of southern pines (*Pinus elliottii* Englem., *P. palustris* Mill. and *P. taeda* L.) had a geographic trend in the USA. If the basic density of any species shows a geographic trend, the average basic density must calculated for each corresponding region.

In order to determine whether or not the variation in *Cryptomeria japonica* between plots was caused by a geographic trend, the average basic density between regional groups was categorized by districts such as Tohoku (TH, 1 plot), Kanto (KT, 4 plots), Chubu (CB, 8 plots), and Shikoku (SK, 4 plots) from north to south (Figs. 1 and 9). The sample trees of *C. japonica* from Kyushu district were not included in this work while *C. japonica* is main species in the district, because *C. japonica* in the district is mixture of various cultivars and the cultivars have genetic diversity in the basic density between them (Yahata *et al*., 1987; Fujisawa, 1998) that might cause to bias the mean basic density of the species. No geographic trend from north to south appeared in the average basic density and ANOVA indicated no significant difference between the groups ($F = 0.71$, $p = 0.59$). The basic density of *Chamaecyparis obtusa* also showed no significant differences between groups such as Kanto (KT, 4 plots), Chubu (CB, 18 plots), Kinki (KK, 2 plots), Shikoku (SK, 1 plot), Kyushu (KS, 3 plots) (Figs. 1 and 10) as well as no significant difference among the plots. These findings suggest that variation among plots was smaller than within plots, and it was concluded that for the basic densities for *Cryptomeria japonica* and *Chamaecyparis obtusa*, one value for each (314 kg/m^3 and 407 kg/m3, respectively) was sufficient for all the regions where these species are planted in Japan.

Because *Larix kaempferi* grows well under cold temperate climate, it is a major species that has been widely planted in the northern and mountainous regions of Japan. Original distribution of *Larix kaempferi*, however, is isolated and restricted to central Japan. The previous report (Fujiwara *et al*, 2004) also indicated that *Larix kaempferi* had wide diversity in its density variation and suggested that the diversity might be caused by differences in provenances from which the seedlings planted in the stands had originated, because the wood density of *Larix kaempferi* planted in provenance test stands varied with the provenances of the seeds (Nakagawa, 1963; Koizumi *et al*., 1990). Therefore, the genetic background of the seedlings might be considered when examining the variation of the basic density in *Larix kaempferi*. The regional averages of the basic density calculated for 2 regions, central Japan (7 plots) which is the original habitat, and the Hokkaido and Tohoku districts (7 plots) where it was introduced, did not show significant difference (Fig. 11). Thus, the difference found among plots was considered to be not caused by regional variation or stand age, but by one or more unspecified factors.

The distribution of the planted *Thujopsis dolabrata* var.

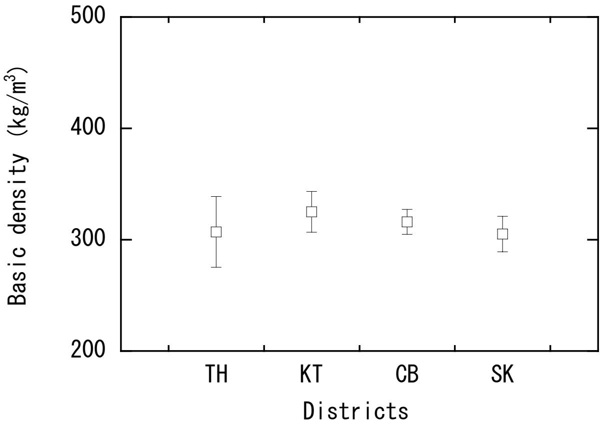

Fig. 9. Mean basic densities of *Cryptomeria japonica* in each district.
Note: bars indicate 95% confidence limits of the mean basic densities. TH, KT, CB, KK and SK denote the Tohoku, Kanto, Chubu, Kinki and Shikoku districts, respectively.

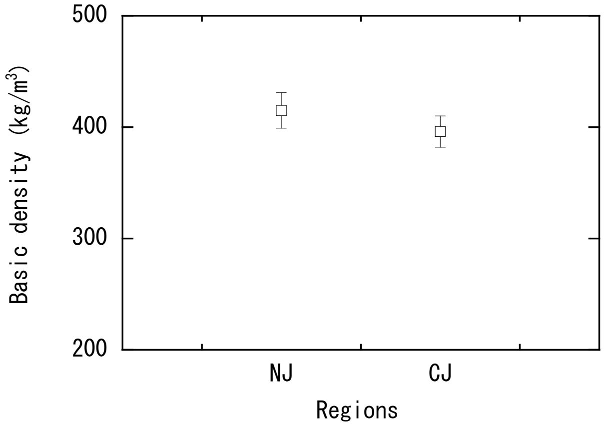

Fig. 11. Mean basic densities of Larix keampferi in central and northern Japan.
Note: bars indicate 95% confidence limits of the mean basic densities. CJ and NJ denote central Japan and northern Japan, respectively.

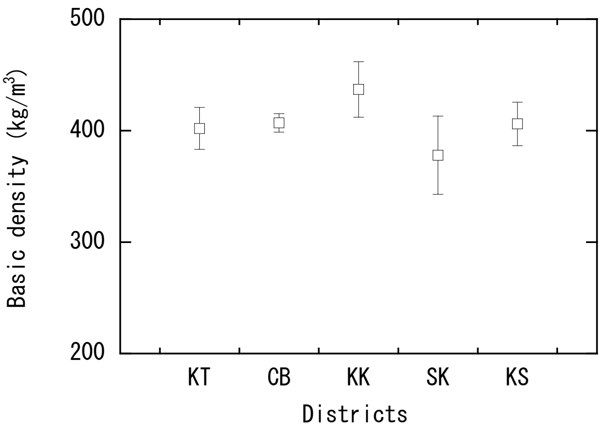

Fig. 10. Mean basic densities of *Chamaecyparis obtusa* in each district.
Note: bars indicate 95% confidence limits of the mean basic densities. KT, CB, KK, SK and KS denote the Kanto, Chubu, Kinki, Shikoku and Kyushu districts, respectively.

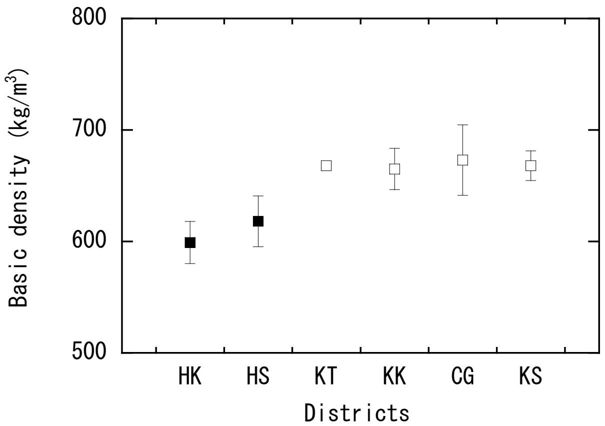

Fig. 12. Mean basic densities of *Quercus* crispula and *Q. acutissima* in each district.
Legend: ■, *Q. crispula*; □, *Q. acutissima*.
Note: bars indicate 95% confidence limits of the mean basic densities. HK, KT, KK, CG and KS denote the Hokkaido, Kanto, Kinki, Chugoku and Kyushu districts, respectively. HS denotes northern Honshu Island.

hondae is mainly in Aomori and Ishikawa prefectures in Japan. When the mean basic density of the species was compared between the two prefectures, the mean basic density in Aomori prefecture, 405±22 kg/m^3, did not differ significantly from that of Ishikawa prefecture, 402±22 kg/m^3. Thus, the differences among plots could not have been caused by geographic distance.

Basic densities of hardwood species and their variation

The averages of the basic density of the hardwood species are shown in Table 2. Among these species, *Quercus* spp. (subgenus *Quercus* and *Cyclobalanopsis*), *Castanopsis* spp. *Betula* spp. may be important because of their large stocks and wide distribution, while the other species may be less important because their stocks are lower and their species names may be recorded as “other hardwood” in Forest registers and National Forest Resources Database (Forestry Agency, 2006). Species belonging to the genus *Quercus* are widely distributed in Japan and one of the most important groups as forest resources. ANOVA for 4 *Quercus* species indicated significant differences between plots of *Q. crispula* and *Q. acutissima* (Table 4). For the other 2 species, the basic densities did not vary between plots. Although the mean basic densities of the plots for *Q. crispula* and *Q. acutissima* had diversity, the regional average of the basic density did not show a significant difference between districts (Fig. 12). Thus, the significant difference detected by ANOVA might have been due to an unspecified cause or causes. Because the mean basic densities of other species in the plots showed no significant difference among each other, it was concluded that the variation in their basic densities might be small.

Table 5. Basic density, standard deviation and 95% confidence limit in major hardwood groups.

Species	N[a)]	BD [b)] (kg/m^3)	SD [c)] (kg/m^3)	CL [d)] (kg/m^3)	UC [e)] (%)
Quercus spp. (*Q. crispula*, *Q. serrata*)	53	619	37	10	1.6
Quercus spp. (ever green)	31	644	38	13	2.1
Castanopsis spp.	21	473	48	20	4.3
Betula spp.	24	481	46	18	3.8

Note: a) Number of plots, b) basic density, c) standard deviation, d) 95% confidence limit, e) percentage uncertainty.

Basic densities of the hardwood group

When calculating the amount of carbon removed by forests, basic density should be used in conjunction with other parameters such as stand age and volume. When the biomass of individual trees was investigated, parameters like species, stand age and volume could be obtained from the Forest Registers. However, it would not be possible to measure the biomass of all trees in Japan individually. It would be much better to obtain specific data on a forest stand from a national database such as National Forest Resources Database (Forestry Agency, 2006) based on the Forest Register including information on species, stand age of each forest compartment, and so on (Greenhouse Gas Inventory Office of Japan *et al*., 2006; Matsumoto *et al*, 2007). When the database is used to obtain stand-specific parameters, types of records that the Forest Registers uses to keep on species in each compartment must be considered. In many cases of hardwood species, the trees grow up in mixed forests of several species and species names are classified into groups by genus or subgenus like Nara (*Quercus crispula* and *Quercus serrata*), Kashi (*Quercus* spp., subgenus *Cyclobalanopsis*), and Shii (*Castanopsis* spp.). Thus, the mean basic densities of such groups will be required. Table 5 shows the mean basic densities and other statistics. Standard deviations and 95% confidence limits calculated for the groups did not change very much from the calculations for each individual species (Tables 2, 5). Therefore, group calculations of the mean basic densities and 95% confidence limits could be applicable as the parameters for estimating the amount of carbon removal by forests.

Conclusions

As one of the parameters for calculating the total amount of carbon removed by forests under guidelines defined in the Kyoto Protocol and the Marrakesh Accords, basic density was measured for 10 species of softwoods and 50 species of hardwoods and the average basic density and its 95 % confidence limit were calculated for each species. Variations in the basic densities within species and among plots were also analyzed to evaluate the necessity of establishing regional parameters.

The average and 95% confidence limits of the basic densities in most species that were collected for a certain number of sample trees converged. Most species showed low uncertainty up to 5 %. No regional difference was statistically detected among districts, while significant differences of the mean basic densities between plots were observed in several species. Neither tree age nor stand age showed a significant correlation with basic density and the basic densities of younger stands (younger than 20 years old) did not differ from those of the older stands in the major tree species registered in the National Forest Resources Database excepting *Thujopsis dolabrata* var. *hondae*. The younger stands of *T. dolabrata* var. *hondae* showed significantly high basic density than the older stands. The mean basic densities of *T. dolabrata* var. *hondae* in the younger stands, the older stands and all stands were 443±31, 386±28 and 412±16 kg/m^3, respectively. These results suggest that using basic densities as a parameter for estimating carbon removal by forests would not require preparing values for districts or age classes in most species and *T. dolabrata* var. *hondae* might be considered the effect of the stand age on the basic density.

The basic density as the parameter for estimating the amount of carbon removal by forest would be fixed value for each species and species group. However, it might be desirable to establish parameters for individual groups within species to improve the accuracy of the basic density calculation, even though it is not required under present regulations defined in Good Practice Guidance (IPCC, 2003a). Increasing the number of species and trees would also be important for improving the accuracy of the parameters.

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森林による炭素吸収量算定のためのパラメータとしての容積密度数とその変動

藤原　健 [1)*]、山下香菜 [1)]、黒田克史 [1)]

要 旨

京都議定書及びマラケシュ合意に基づく森林による二酸化炭素吸収量算定のためのパラメータの一つとして、針葉樹 10 種 572 個体、広葉樹 50 種 440 個体について、容積密度数の測定を行い、樹種別に平均値及びその 95％信頼区間を求めた。それらの樹種のうち、プロット数及び測定個体数が多い 14 樹種を選択し、分散分析により平均容積密度数のプロット間差を検討した。また、針葉樹材について林齢と容積密度数の関係、地域による容積密度数の差の有無を検討した。スギ、カラマツ、エゾマツなどの数樹種では、容積密度数のプロットごとの平均値間で有意な差が認められた。しかしながら、地域別に平均値を比較したところ、容積密度数に有意差はなく、プロット間の有意差は地域差によるものではないと考えられた。針葉樹にみとめられたプロット間差はミズナラやクヌギなどにもみられたが、同様に地域別の平均値には有意な差は認められなかった。また、林齢と容積密度数との間には有意な相関関係は認められず、20 年生未満及び以上に区分して求めた平均容積密度数にも有意差が認められなかったことから、林齢の影響は小さいと考えられた。これらの結果から、容積密度数は樹種別に求めれば十分であり、地域ごとあるいは林齢ごとに求める必要はないと考えられた。

キーワード：容積密度数、京都議定書、針葉樹、広葉樹、不確実性

＊森林総合研究所木材特性研究領域　〒 305-8687　茨城県つくば市松の里 1　e-mail: fujiwara@ffpri.affrc.go.jp
1) 森林総合研究所木材特性研究領域