「森林総合研究所研究報告」(Bulletin of FFPRI) Vol.12 No.3 (No.428) 125 - 141 September 2013

論　文（Original article）

Estimating forest biomass using allometric model in a cool-temperate *Fagus crenata* forest in the Appi Highlands, Iwate, Japan

Kenji ONO [1)*], Yukio YASUDA [1)], Toru MATSUO [2)],
Daisuke Hoshino [3)], Yukihiro CHIBA [4)] and Shigeta MORI [4)]

Abstract

To estimate forest biomass and productivity in a cool-temperate deciduous hardwood forest of the Appi Highlands in northern Japan, we developed allometric equations for estimating relationships between size-related variable (stem diameter at breast height (dbh)) and biomass of leaves, branches, stems, and roots for Japanese beech (*Fagus crenata*) trees. This is one of the most typical species growing in the cool-temperate zones of Japan. At the present study site, Japanese beech trees comprised 75% of all forest trees (1,666 trees ha^{-1} in 2012) and 80% of the sum of basal areas for all species. Twelve trees of various sizes were comprehensively harvested to measure tree biomass at the study site. Allometric equations developed for all parts of biomass as a function of dbh showed high correlations (*Adjusted* R^2 = 0.92-0.99). Using two independent external datasets, validation results for stem biomass estimates were quite good although those for branch, leaf, and root biomass were not as accurate because of relatively large *SEP* (standard error of prediction) of branch and leaf biomass estimates for the validation dataset and underestimation of leaf and root biomass for small-sized trees. Insufficient accuracy of those biomass estimates may not have hindered the accurate estimation of forest biomass in the Appi Highlands because stem biomass was a main component of forest biomass and the low accuracy estimates only involved inaccuracies in the estimates for some of small-sized trees (dbh < 10 cm). Forest biomass in the Appi Highlands was estimated to be 343 t ha^{-1} using the equations developed here. This value was slightly higher than average values of Japanese beech forest in previously published biomass data. Results of the present study will be helpful for advancing further studies on the determination of annual changes in forest productivity and carbon dynamics in Japanese beech forests in the Appi Highlands.

Key words : dbh-based allometric equations, *Fagus crenata*, forest biomass, root excavation, temperate secondary forest

1. Introduction

Measuring carbon dioxide (CO_2) flux using micrometeorological techniques is a means of determining carbon (C) dynamics in forested ecosystems (Mizoguchi et al. 2012). Determining net ecosystem production (NEP), gross primary production (GPP), and ecosystem respiration (R_E) via CO_2 flux in forest ecosystems is an important part of understanding C dynamics in forested ecosystems. The Forestry and Forest Product Research Institute has formed a research group (Forestry and Forest Product Research Institute Flux Observation Network (FFPRI FluxNet)) which has observed CO_2 flux in several forest types in Japan since 1995 (FFPRI FluxNet 2013). Since then, FFPRI FluxNet has continuously measured CO_2 exchange between vegetated surfaces and the atmosphere at six research sites in Japan (five currently active) (FFPRI FluxNet 2013).

One of these FFPRI sites is the Appi forest meteorology research site (API site; FFPRI FluxNet 2013), located in northern Japan. The API site is a secondary cool-temperate deciduous hardwood forest mainly dominated by Japanese beech (*Fagus crenata*), very typical species in the cool-temperate region which occurs over large areas of northeastern Japan (Kira 1977, Maruyama 1977). The results of various studies and observations at the API site, e.g., litter production (Hoshino, JIRCAS, personal communication), soil respiration (Hashimoto et al. 2009, Ishizuka et al. 2006), soil carbon dynamics (Koarashi et al. 2009), CO_2 flux observation (Yasuda et al. 2012) have already been published allowing the comparison and validation of the results of various scientific techniques typically used in Japanese beech forest. Forest biomass and productivity in the API site have not yet been estimated and should be determined using an ecological summation method to validate and predict the future changes of C

原稿受付：平成 25 年 2 月 12 日 Received 12 February 2013　　原稿受理：平成 25 年 7 月 9 日 Accepted 9 July 2013
1) Tohoku Research Center, Forestry and Forest Products Research Institute (FFPRI)
2) Iwatehokubu District Forest Office, Touhoku Regional Forest Office, Forest Agency
3) Japan International Research Center for Agricultural Science
4) Forestry and Forest Products Research Institute (FFPRI)
* Tohoku Research Center, 92-25, Nabeyashiki, Shimo-Kuriyagawa, Morioka, Iwate 020-0123, JAPAN

balances in forested ecosystems in Japan.

Therefore, we conducted destructive sampling of several variously-sized Japanese beech trees including roots in the Appi Highlands and estimated stem, branch, leaf, and root biomass of each tree individually. Next, we used these data to develop and calibrate allometric equations between tree diameter at breast height (= 1.3 m; dbh) and individual plant-part biomass data to accurately determine forest biomass at the API site. Using two previously reported forest biomass datasets (Karizumi 1990, Mori et al. 1979) as the independent external datasets, we also validated the allometric relationships developed here. Finally, we estimated forest biomass at the API site and compared the results obtained in the present study with estimates of Japanese beech biomass previously reported (e.g., Japanese Committee for the International Biological Program (JIBP) project (Shidei and Kira 1977)).

2. Methods

2.1 Site description

The study was conducted to determine Japanese beech forest biomass at the API site located in the Appi Highlands, Iwate Prefecture (Fig. 1; 40°00’N, 140°56’E, 800-900 m asl), which is on the eastern side of the Ohu Mountains in northern Honshu, Japan in a very gently sloping area (ca. 5°). A four-hectare permanent research plot (200 m × 200 m) was established to continuously measure changes of forest biomass and productivity. The API site matches “cool-temperate deciduous hardwood forest” as described by Kira (1977). The forest is mainly dominated by 70- to 80-year-old Japanese beech (*Fagus crenata*) with a few stems of deciduous hardwood species (e.g., *Betula maximowicziana*, *Aesculus turbinata*, *Magnolia obovata*, *Tilia japonica*, and *Kalopanax pictus*). This secondary forest probably regenerated from an abandoned pasture. Evergreen dwarf bamboo (*Sasa kurilensis*) and a thin layer of understory vegetation sparsely covered the forest floor. Yasuda et al. (2012) provided a mean annual temperature of 5.9 °C and an annual precipitation of ca. 2,000 mm. The Andosol soil (World Reference Base for Soil Resources; IUSS Working Group 2006) is classified as a moderately moist brown forest soil, B_D(d) (Forest Soil Division 1976).

2.2 Field measurement and sampling

Stem dbh (= 1.3 m) of all living trees were measured in May, 2012 in the single four-hectare permanent plot. Frequencies of the dbh of beech trees peaked at between 10-15 cm (mean = 16.1 cm with a maximum of ca. 109.4 cm for one of the reserved trees in the Appi Highlands) (Fig. 2). Japanese beech trees comprised 75% of all trees (1,666 trees ha^{-1} in May, 2012) and 80% of the sum of the basal area the sum of the basal area of all trees in the plot. We measured individual tree biomass of only Japanese beech.

Twelve Japanese beech trees ranging from 4.5 to

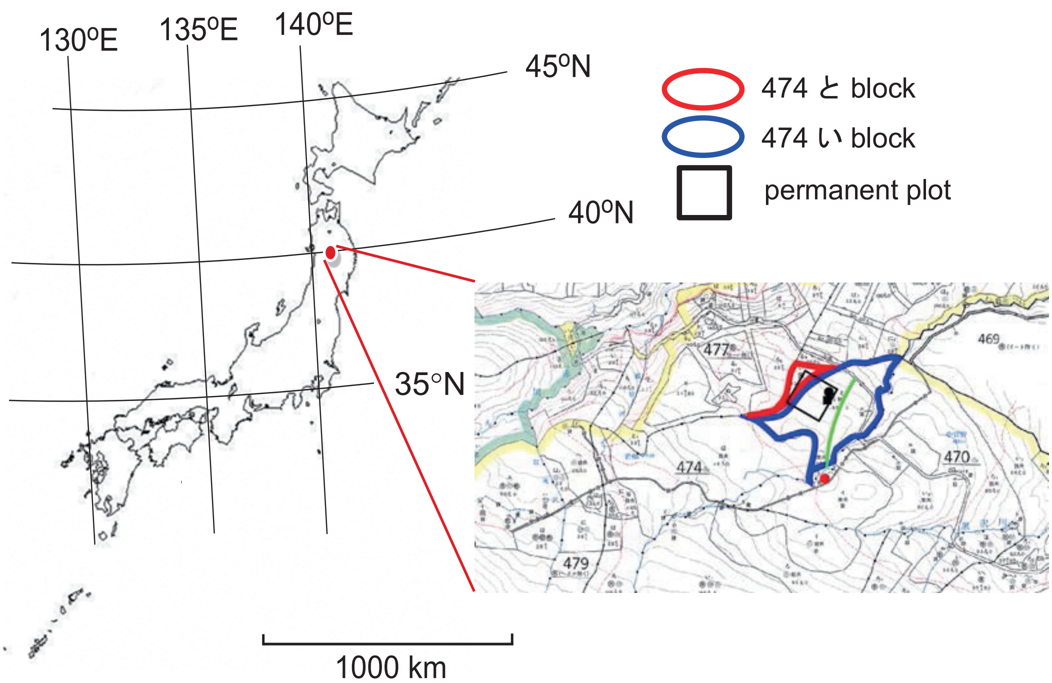

Fig. 1. Location of the study site in the present study.

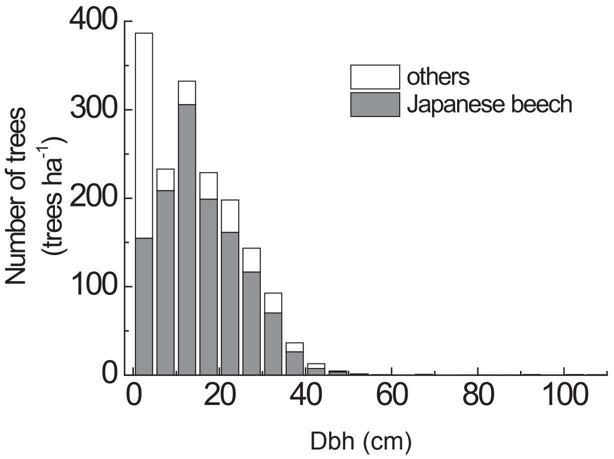

Fig. 2. Frequency distribution of trees at the Appi forest meteorology research site. Dbh class intervals were 5 cm.

75.4 cm dbh were selected for determining individual tree biomass near the plot (Appendix). Ten small trees (< 30 cm dbh) were harvested in September, 2000 and two large trees (> 30 cm dbh) were also harvested in June, 2012. Of these 12 trees, both above- and below-ground plant-parts of eight individuals were harvested and weighed in the field, but only above-ground parts of four other mid-sized individuals were measured. After felling, trees were individually divided into leaves, branches and main stems in the field (Photo 1). Roots were excavated manually or using a power shovel (Photo 2) and smaller roots which had been cut in the field were carefully picked up from the soil by hand. All roots were separated from adhering mineral soils using brushes and crowbars as carefully as possible, and then weighed using digital scales (DS10 (range 0.2-50 kg; Ohaus Corporation, Parsippany, NJ, USA), and FW-100K (range 0.5-100 kg; A&D Co. Ltd, Tokyo, Japan) and lord cells (LTZ-500KA and LTZ-2TA (ranges 5-500 and 20-2,000 kg, respectively; Kyowa Electronic Instruments Co., Ltd., Tokyo, Japan) (Photo 3). Representative subsamples (2-50 kg) were taken from each type of plant-parts for each individual and dry/fresh mass ratios were determined after oven-drying for 72 h or more at 70 °C to constant weight; longer drying times (maximum = 14 d) were required for relatively large subsamples of mostly stems and roots from large trees. To estimate the leaf area index (LAI) at the API site, the average weight of individual beech leaves was estimated from the relationships between the weight and the number of leaves using representative leaf subsamples. Soils were removed from root samples with high-pressure water as carefully as possible to avoid soil contamination when estimating root biomass.

2.3 Development and validation of allometric equations of Japanese beech tree biomass

Size-mass allometry is generally expressed as a power-form equation: $Y = aX^b$, where X is an appropriate size-related variable, Y is a dependent mass variable, a is a normalization constant, and b is a scaling exponent (Ogawa and Kira 1977). In the present study, all allometric relationships between dbh, i.e. one of the size-related variables and dry mass obtained were approximated by ordinary least-squares regression to create the simplest allometric model possible to estimate forest biomass in the four-hectare permanent plot after the logarithmic transformation of the parameters (X, Y). Coefficients (a, b) were calculated by the regression for each biomass data unit (e.g., leaves, roots, etc.). Log-transformation of tree mass satisfied the normality assumption (Poorter et al. 2008, Utsugi et al. 2012).

To evaluate the calibration results of allometric relationships between dbh and each part of biomass, regression coefficients (r) and standard errors of calibration of data (*SEC*) between calibrated and measured values were calculated for each part of biomass using allometric equations.

To verify the adequacy of calibration results, the allometric equations developed here were validated using a previously published independent dataset (Karizumi 1990). Karizumi (1990) reported individual tree biomass data for 42 species investigated in 126 forest stands across the major ecoclimatic regions of Japan since 1951. In the present study, the main target for biomass estimation was Japanese beech. Here, biomass data from 60 Japanese beech trees measured at Yamagata (1 stand), Niigata (3 stands), and Gunma (2 stands) pref. (Table 3) were extracted from Karizumi (1990). In addition, biomass data were adopted from Mori et al. (1979) in the present study, although root biomass data from 31 beech trees in their study located in the northeastern district in Japan were excluded. To evaluate the allometric relationships developed in the present study, the biomass of each part of the biomass data collected from different sections of trees were predicted using two independent dataset of Karizumi (1990) and Mori et al. (1979) and r, standard errors of calibration (*SEC*), standard errors of prediction (*SEP*), and the ratio of standard deviation of the prediction reference dataset to the *SEP* (*RPD*: an indicator of the usefulness of the calibration results (Williams 1996)) was calculated for each part of biomass.

SEC was expressed using equation (1):

$$SEC = \sqrt{\frac{1}{I} \sum_{i=1}^{I} (y_i - \hat{y}_i)^2}, \quad (1)$$

Photo 1. Process of dividing leaves, branches and main stems in the field after felling.

Root excavation using a power shovel.

Carefully picking up of small roots from the soil.

Removing the soil from the stump.

Dividing small roots into several boxes after collection.

Photo 2. Root excavation using a power shovel and carefully picking up of small roots by hand which were left behind in the field.

Weighing leaves and branches.

Weighing main stems.

Weighing root stumps.

Photo 3. Weight of all parts of a felled tree using a lord cell in the field. After weighing, representative subsamples were taken back to the laboratory and dry/fresh mass ratios were determined after over-drying at 70 °C.

where y is the measured value and $\hat{y}$ is the calibrated value of sample i, and I is the total number of samples. For external predictions, the *bias* was determined as follows:

$$bias = \sqrt{\frac{1}{I}\sum_{i=1}^{I}(y_i - \hat{y}_i)} \quad , \qquad (2)$$

SEP was corrected for *bias* using equation (3):

$$SEP = \sqrt{\frac{1}{I}\sum_{i=1}^{I}(y_i - \hat{y}_i - bias)^2} \quad , \qquad (3)$$

and *RPD* was also described as:

$$RPD = (standard\ deviation\ of\ independent\ external\ dataset)\ /\ SEP. \quad (4)$$

2.4 Comparison of Japanese beech tree biomass estimation at the API site with previous studies

Allometric equations were developed to estimate the biomass of Japanese beech trees at the API site. Then these forest biomass estimates were compared with previously reported biomass data such as data from the research project established by the Japanese Committee for the International Biological Program (JIBP) (Shidei and Kira 1977).

.3. Results

3.1 Allometric equation development

The allometric equations developed for estimation of biomass of stems, branches, leaves, and roots of beech trees at the API site were strongly positively correlated with dbh (*Adjusted* R^2 = 0.92 to 0.99; Table 1, Fig. 3). Calibration results using the allometric equations developed for each part of biomass of Japanese beech trees agreed very closely with measured biomass values (Fig. 4). Regression coefficients (r) showed high values ranging from 0.97 to 1.00 and *SEC* was less than 10% of data ranges for all parts of biomass except for leaf biomass (Fig. 4, Appendix). Thus, the allometric equations developed in the present study showed a close fit as well (Fig. 4).

Figure 5 shows the validation results using the external independent datasets of Karizumi (1990) and Mori et al. (1979). The values determined by destructive measurement showed a close correlation with those predicted by the allometric equation developed in the present study for stem (n = 91, r = 0.97), branch (n = 91, r = 0.94), and root (n = 60, r = 0.94) biomass, respectively. However, the regression coefficient for leaf biomass, which is a very small proportion of an entire tree, was not as high, r = 0.73, because the *SEP* for leaf biomass was relatively large when compared to other parts of biomass. Also, for prediction results of leaf and root biomass, their biomass for some of small-sized trees (dbh < 10 cm) were underestimated although those for middle- and large-sized trees were estimated quite well (Fig. 5). Moreover, *RPD* values for branch and leaf biomass were low, below 2.0 (Fig. 5). Inversely, those for stem and root biomass were high, 3.4 and 2.6, respectively (Fig. 5).

Meanwhile, the prediction data for individual parts of Japanese beech tree were close to the 1:1 line except for leaf and root biomass for some of small-sized trees (dbh < 10). Thus, the allometric equations developed in the present study showed relatively good prediction results (Fig. 5).

3.2 Biomass and biomass allocation in Japanese beech forests at the Appi Highlands

Table 2 summarizes estimates of above- and below-ground biomass in a Japanese beech forest at the API site in May, 2012. The estimates of respective parts of beech tree biomass were 184, 31, 3, and 52 t ha^{-1} for stems, branches, leaves, and roots, respectively. Total above-ground biomass (TAGB) was estimated to be 217 t ha^{-1} and the ratio of TAGB to root biomass (T/R) was 4.2. At the API site, 25% of the trees and 20% of the sum of the stand basal areas were not Japanese beech trees. By assuming that all trees in the stand except for Japanese beech have the same allometric relationships as those of the same-sized Japanese beech trees, the biomass of the API site was estimated to be 343 t ha^{-1} (Table 2). Therefore, 27% of forest biomass at the API site was attributed to tree biomass of species other than Japanese beech. Since the average dry weight of a single leaf was estimated to be 0.174 ± 0.009 g in 2012, gravimetry could be used to calculate that there were

Table 2. Estimates of respective parts of tree biomass, total above-ground biomass (TAGB), total biomass (TB), and T/R at the Appi forest meteorology research site.

		Beech tree	All tree*
Stem	(t ha^{-1})	183.9	233.8
Branch	(t ha^{-1})	30.5	39.2
Leaf	(t ha^{-1})	2.8	3.5
Root	(t ha^{-1})	52.3	66.9
TAGB	(t ha^{-1})	217.1	276.5
TB	(t ha^{-1})	269.4	343.4
T/R		4.2	4.1

*taking tree biomass of other tree species aside from Japanese beech into consideration.

Table 1. Coefficients and other allometric statistics (Y = a × Xb) used for estimating respective parts of biomass. X, an appropriate size-related variable; Dbh, means stem diameter at breast height (= 1.3 m).

Variables		*Coefficients*		*n*	*Adjusted* R^2
Y (kg per tree)	*X* (cm)	*a*	*b*		
Stem	Dbh	0.0946	2.44	12	0.99
Branch	Dbh	0.0049	2.78	12	0.96
Leaf	Dbh	0.0010	2.56	12	0.92
Root	Dbh	0.0147	2.62	8	0.99

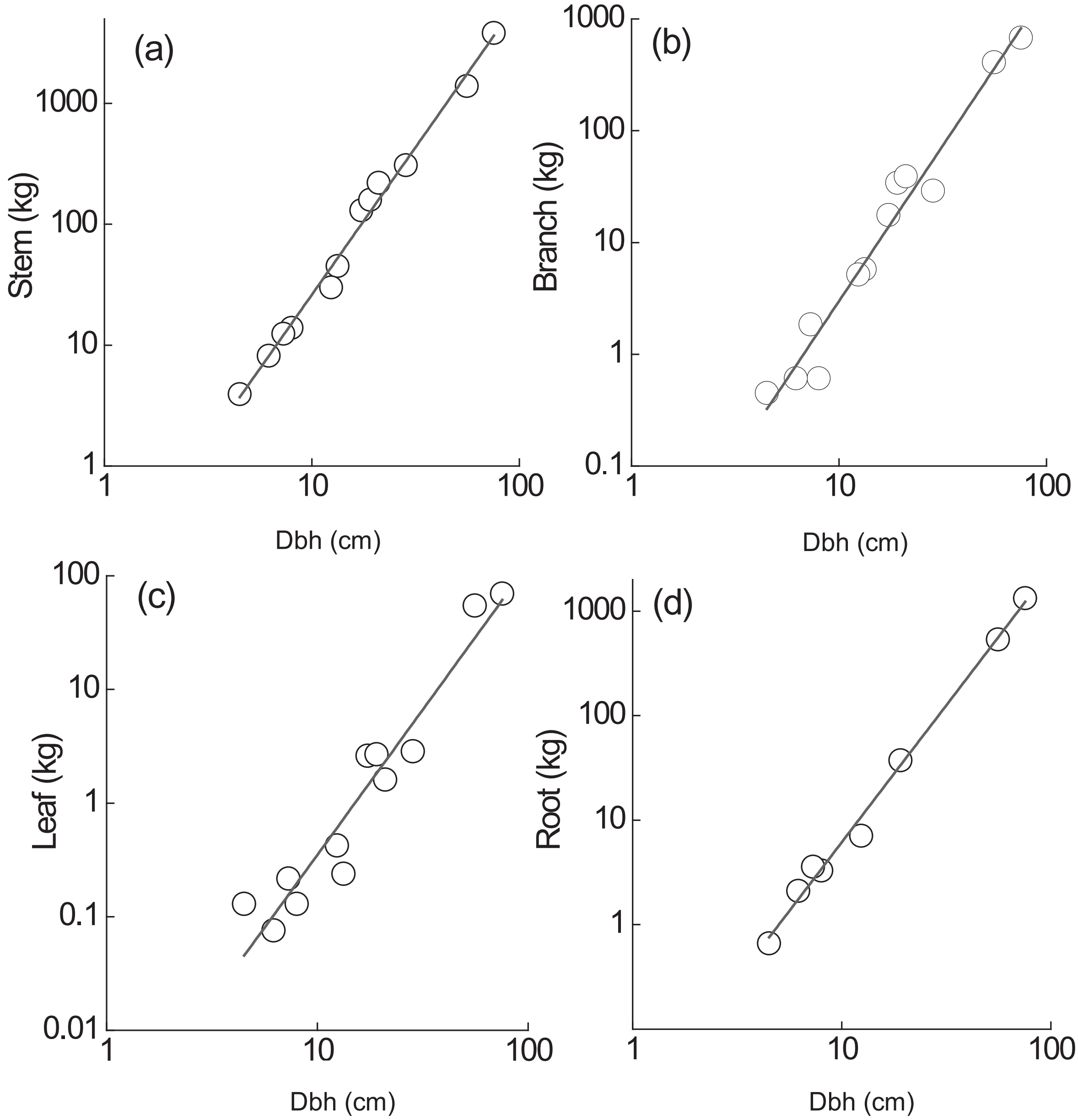

Fig. 3. Allometric relationships between dbh and dry mass of above- and below-ground biomass of Japanese beech trees at the Appi forest meteorology research site. Solid lines were drawn by least-square regression.

ca. 0.4 million of leaves in a measured tree with large dbh (= 75.4 cm), which is a reserved size tree, and that there were approximately 20 million of leaves in one-hectare of Japanese beech forest at the API site. In our previous study, Yasuda et al. (2012) reported that the specific leaf area (SLA) in the API site was 0.0154 m^2 g^{-1}. Based on this value, the mean area of a single leaf and LAI at the API site were estimated at 0.00268 m^2 per leaf and 5.45 m^2 m^{-2}, respectively.

4. Discussion

4.1 Accuracy of allometric relationships

Currently, the characterization of allometric relationships between individual parts of biomass including roots and size-related variables (dbh and height) has been widely accepted and applied by numerous previous studies for estimating forest biomass (i.e., Karizumi 1974, Shidei and Kira 1977). The accuracy of forest biomass estimates depends on the variation and quality of data used for developing allometric equations because

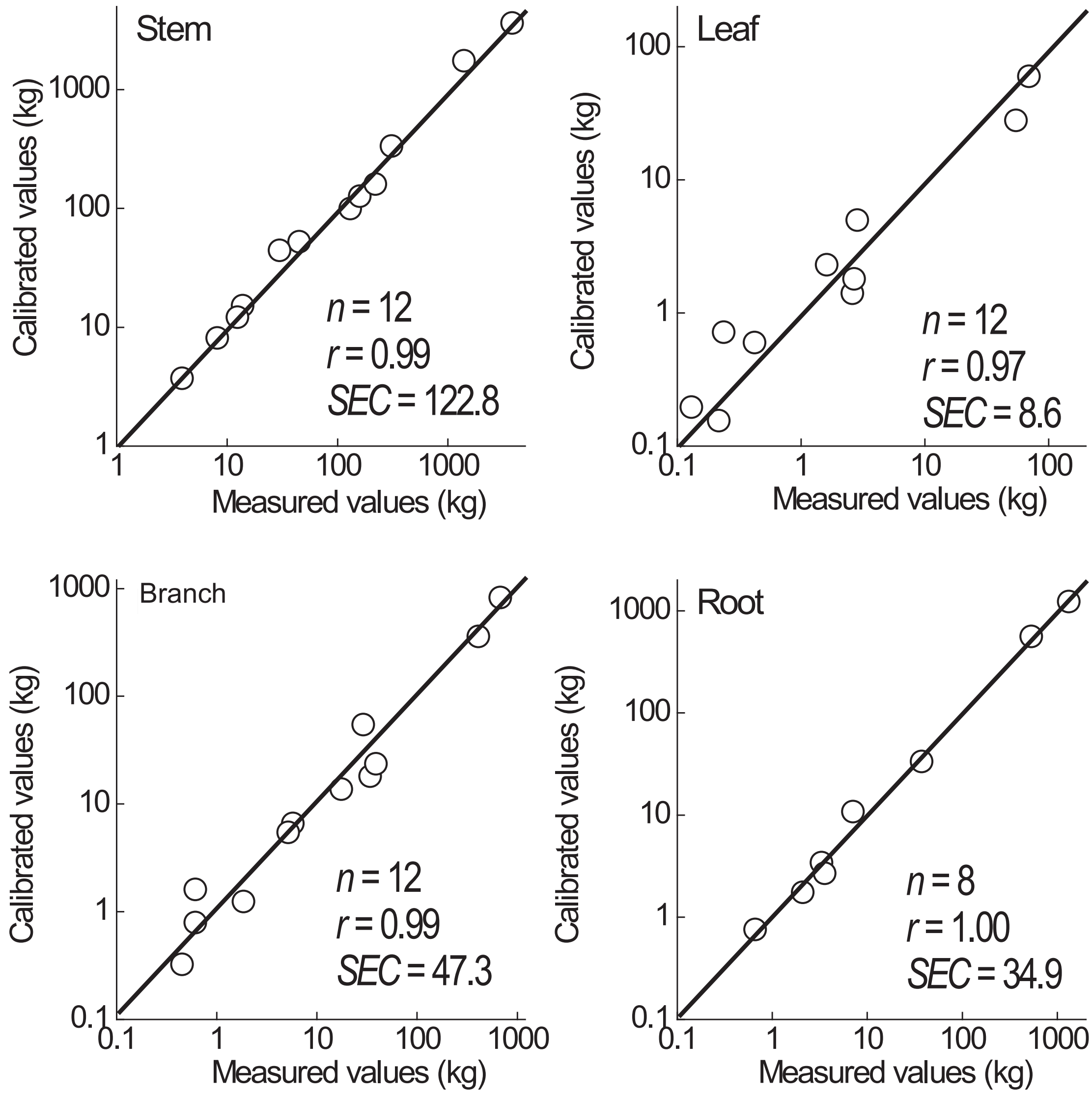

Fig. 4. Calibrated values versus measured values for each part of biomass of Japanese beech trees. Solid lines are the 1:1 line, having a slope of 1. r: regression coefficients; SEC: standard errors of calibration.

allometric relationships between tree biomass and size-related variables shows specific tendencies under different environmental conditions (i.e., tree species, climate zone) (Kira and Shidei 1967, Research Group on Forest Productivity of the Four Universities 1960). In the present study, sample trees used for making allometric equation for estimating each part of biomass of Japanese beech ranged from small- to large-sized trees typical of the forest at the API site (Fig. 2 and Appendix). In addition, dbh was adopted as an appreciable size-related variable to make the simplest allometric equation used to estimate forest biomass in a four-hectare plot (Fig. 3). As a result of allometric equation development for estimating tree biomass, linear relationships and high regression coefficients (r) were obtained between calibrated and measured values (Fig. 4). Moreover, *RPD* values, an indicator of the usefulness of the calibration results, were calculated for validating the accuracy of these allometric equations. According to Williams (1996), an *RPD* value of 2.5-3.0 is regarded as adequate for rough prediction. Validation results for stem and root biomass estimates using independent external datasets (n = 91 and 60, respectively) reported by Karizumi (1990) and Mori et al. (1979) were also good: r = 0.97 and 0.94, and *RPD* = 3.4 and 2.6, respectively (Fig. 5). However, validation results for branch and leaf biomass estimates showed that these estimates were not as accurate (*RPD* = 2.0 and 1.4, respectively) because of relatively larger *SEP* of branch and leaf estimates for the validation

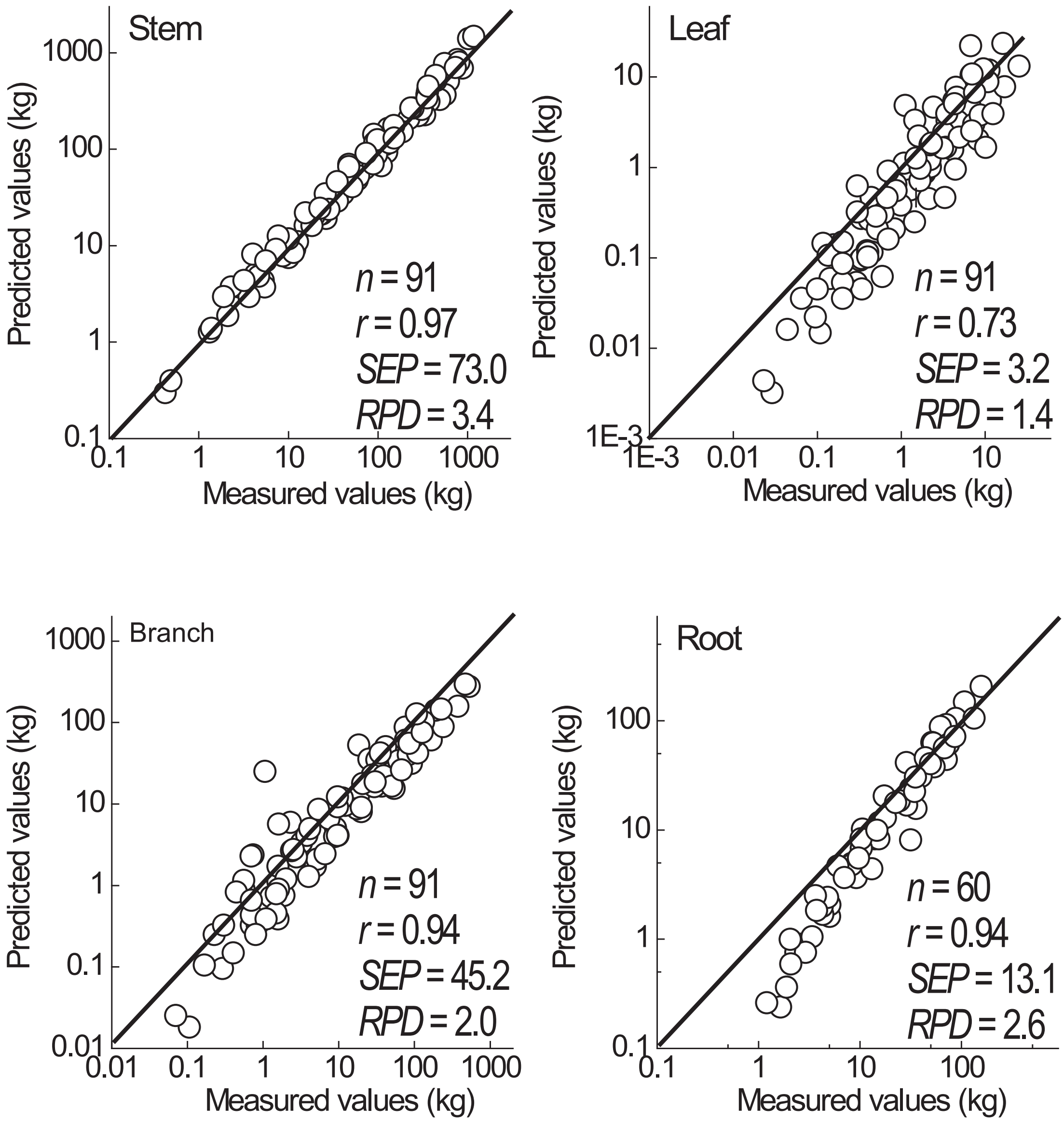

Fig. 5. Predicted values versus measured values of external independent data for each part of biomass of Japanese beech trees. Solid lines are the 1:1 line, having a slope of 1. r: regression coefficients; SEP: standard errors of prediction; RPD: ratio of standard deviation of prediction dataset to SEP.

dataset when compared with stem and root biomass estimates (Fig. 5). In addition, site-specific characteristics (i.e., soil condition, forest structure, tree density, age, climate, etc.) may influence the allometric relationships between size-related variables (e.g., dbh) and each part of biomass except for stem (Research Group on Forest Productivity of Four Universities and Shinshu University 1966, Saito et al. 1968). Therefore, leaf and root biomass for some of small-sized trees were underestimated although those for middle- and large-sized trees were reasonable estimates (Fig. 5). However, insufficient accuracy of biomass estimates might be insignificant and relatively unaffected when estimating the total forest biomass at the API site because stem biomass was a main component of forest biomass and biomass underestimation occurred only for other plant-parts and only for some of small-sized trees (dbh < 10 cm).

4.2 Forest biomass of Japanese beech

In the present study, nine reports covering a total of 39 forest stands were selected regarding the study of forest biomass of Japanese beech (Table 3). They were based on destructive measurements of each part of biomass of individual trees. Some reports did not provide (or did not determine) some parts of biomass data (e.g., root biomass). Most of these studies were conducted as part of a research project established by the Japanese Committee for the International Biological Program (JIBP) in 1960s-1970s, which focused on biological productivity and ecological processes in the forest ecosystems in Japan (e.g., Shidei and Kira 1977). All these studies applied allometric equations for estimating forest biomass using the relationships between tree biomass and tree size-related variables (dbh, diameter at the stem base (d_0), and tree height) (Kira and Shidei 1967).

Forest biomass of Japanese beech forests greatly varied among the forest stands, ranging from 35 to 441 t ha^{-1} because the study sites have a variety of microsite conditions (elevation, slope direction, age, density, growth stage, forest type, tree size, etc.) (Table 3). The relationships between tree age, tree size (tree height, BA) and forest biomass were not clear. However, stands with small amount of biomass (e.g., Gunma F2, Mie P1) tended to be relatively young forest with small tree sizes, while most of the stands with a large biomass exceeding 300 t ha^{-1} were mature and older-aged forests, which probably negated the effects of tree size or tree density because they reflected the influences of past and more extensive forest management. The forest biomass at the API site was estimated to be 343 t ha^{-1}, which is slightly higher than average values from other studies (Tables 2 and 3). Furthermore, the amount of biomass allocated to each part of the tree varied among the stands (Table 3). As a result, the ratio of TAGB to root biomass (T/R) ranged widely from 2.4 to 6.7 (Table 3), and was probably affected by each stand' s growth stages and site conditions.

5. Conclusion

We developed accurate allometric relationships for estimating whole tree biomass of Japanese beech in the Appi Highlands. Using two independent external datasets, validation results for stem, branch, and root biomass estimates were quite good although those for leaf biomass were not very accurate estimates because of the relatively large *SEP* of branch and leaf biomass for the validation dataset and underestimation of leaf and root biomass for small-sized trees. Low accuracy of their biomass estimates may have not hindered the estimation of forest biomass at the API site. This occurred because stem biomass was the main component of forest biomass and insufficient accuracy for estimates of other parts of biomass were caused only by data from some small-sized trees (dbh < 10 cm). The forest biomass in the API site was estimated to be 343 t ha^{-1} using the developed allometric equations. This value was slightly higher than average values of Japanese beech forest that had already been estimated in previous studies. The results of the present study will be helpful for advancing further studies on the determination and clarification of NEP and the cross-validation of the results of GPP estimation and carbon flux observation in Japanese beech forests, which is one of the most typical species in the cool-temperate regions of northeastern Japan.

Acknowledgments

We are grateful to Drs. Kaoru Niiyama, Tomomasa Amano, and Gaku Hitsuma for their valuable advice and comments, and we thank Drs. Masaki Jinkawa, Tatsuya Sasaki, Shoji Noguchi, Tsutomu Yagihashi, Takashi Okamoto, Yu Ichihara, Tsuyoshi Yamada, Takuya Aikawa, Koji Shichi, Mohoko Noguchi, Mayuko Jomura, Mr. Toshihiko Takahashi, and Ms. Keiko Sawai for their help with field work and laboratory analysis. We wish to express our appreciation to the staff of Abe Ringyo Co. Ltd. and the Iwate-hokubu District Forest Office since their advice and assistance were extremely helpful during our study. This study was supported in part by the Japanese Ministry of the Environment program, titled "Evaluation, Adaptation and Mitigation of Global Warming in Agriculture, Forestry, and Fisheries: Research and Development (A1120)" and by Grants-in-Aid for scientific research from the Japanese Ministry of Education, Culture, Sports, Science, and Technology, titled "Evaluation of the GHGs emission processes from forest soil surface to atmosphere in snow cold areas (No. 24380086)" .

References

FFPRI FluxNet (2013) FFPRI FluxNet website, http://www2.ffpri.affrc.go.jp/labs/flux/index. html, Accessed 29 Jan 2013.

Forest Soil Division (1976) Classification of forest soil in Japan (1975). Bull. Gov. For. Exp. Stat., 280, 1-28.

Hashimoto, T., Miura, S. and Ishizuka, S. (2009) Temperature controls temporal variation in soil CO_2 efflux in a secondary beech forest in Appi Highlands, Japan. J. For. Res., 14, 44-50.

Ishizuka, S., Sakata, T., Sawata, S., Ikeda, S., Takenaka, C., Tamai, N., Sakai, H., Shimizu, T., Kan-na, K., Onodera, S., Tanaka, N. and Takahashi, M. (2006) High potential for increase in CO_2 fluz from forest soil surface dur to global warming in cooler areas of Japan. Ann. For. Sci., 63, 537-546.

IUSS Working Group (2006) World Reference Base for Soil Resource 2006: A Framework for International Classification, Correlation and Communication: World

Soil Resource Reports, vol. 103, 128 pp.

Kakubari, Y. (1977) Chapter 7. Studies at IBP Research Sites (JIBP/PT Supporting Projects). 7.3 Beech forests in Naeba Mountains. [Part II] Distribution of primary productivity along the altitudinal gradient. In Shidei, T. and Kira, T. (eds.) *"JIBP synthesis. Vol.* 16. *Primary productivity of Japanese forests. - Productivity of terrestrial communities -"*. Japanese Committee for the International Biological Program, University of Tokyo press, 201-212.

Karizumi, N. (1974) The mechanism and Function of tree root in the process of forest production. I. Methods of investigation and estimation of the root biomass. Bull. Gov. For. Exp. Sta., 259, 1-99.

Karizumi, N. (1990) The mechanism and Function of tree root in the process of forest production. V. Reduction of inorganic matters to soil and formation of porosity resulting from root system. Bull. FFPRI., 357, 1-49.

Karizumi, N. (2010) The latest illustrations of tree roots. General remarks. Seibundo Shinkosha Publishing Co. Ltd, 937 pp.

Katagiri, S. and Tsutsumi, T. (1975) The relationship between site condition and circulation of nutrients in forest ecosystem (III). Above ground biomass and nutrient contents of stands. J. Jap. For. Soc., 57, 412-419.

Kawahara, T., Tadaki, Y., Takeuchi, I., Sato, A., Higuchi, K. and Kamo, K. (1979) Productivity and cycling of organic matter in natural *Fagus crenata* and two olanted *Chamaecyparis obtuse* forests. Jap. J. Ecol., 29, 387-395.

Kawaguchi, H. and Yoda, K. (1986) Carbon-cycling changes during regeneration of a deciduous broadleaf forest after clear-cutting. I. Changes in organic matter and carbon storage. Jap. J. Ecol., 35, 551-563

Kawaguchi, H. and Yoda, K. (1989) Carbon-cycling changes during regeneration of a deciduous broadleaf forest after clear-cutting. II. Aboveground net production. Ecol. Res., 4, 271-286.

Kira, T. (1977) Chapter 1. Forest vegetation of Japan. 1.1 Introduction. In Shidei, T. and Kira, T. (eds.) *"JIBP synthesis. Vol.* 16. *Primary productivity of Japanese forests. - Productivity of terrestrial communities -"*. Japanese Committee for the International Biological Program, University of Tokyo press, 1-9.

Kira, T. and Shidei, T. (1967) Primary production and turnover of organic matter in different forest ecosystems of the western Pacific. Jap. J. Ecol., 17, 70-87.

Koarashi, J., Atarashi-Andoh, M., Ishizuka, S., Miura, S., Saito, T. and Hirai, K. (2009) Quantitative aspects of heterogeneity in soil organic matter dynamics in a cool-temperate Japanese beech forest: a radiocarbon-based approach. Global Change Biology, 15, 631-642.

Maruyama K (1977) Chapter 7. Studies at IBP Research Sites (JIBP/PT Supporting Projects). 7.3 Beech forests in Naeba Mountains. [Part I] Comparison of forest structure, biomass and net productivity between the upper and lower parts of beech forest zone. In Shidei, T. and Kira, T. (eds.) *"JIBP synthesis. Vol. 16. Primary productivity of Japanese forests. - Productivity of terrestrial communities -"*. Japanese Committee for the International Biological Program, University of Tokyo press, 185-200.

Mizoguchi, Y., Ohtani, Y., Takanashi, S., Iwata, H., Yasuda, Y. and Nakai, Y. (2012) Seasonal and interannual variation in net ecosystem production of an evergreen needleleaf forest in Japan. J. For. Res., 17, 283-295.

Mori M., Inuma M., Sato A. and Saito K. (1979) Land-use and management of Japanese beech natural forests in east- northern district of Japan (Investigation of forest biomass and forest production). In Agriculture, Forestry and Fisheries Research Council (ed.) *"Report of Comprehensive studies on conservation technology in agriculture, forestry, and Fishery environments."* Agriculture, Forestry and Fisheries Research Council, 5:83-93.

Ogawa, H. and Kira, T. (1977) Chapter 2. Methodology. 2.1 Methods of estimating forest biomass. In Shidei, T., and Kira, T. (eds.) *"JIBP synthesis. Vol. 16. Primary productivity of Japanese forests. - Productivity of terrestrial communities -"*. Japanese Committee for the International Biological Program, University of Tokyo press, 15-25.

Ogino, K. (1977) Chapter 7. Studies at IBP Research Sites (JIBP/PT Supporting Projects). 7.2 A beech forest at Ashiu. - biomass, its increment and net production. In Shidei, T. and Kira, T. (eds.) *"JIBP synthesis. Vol. 16. Primary productivity of Japanese forests. - Productivity of terrestrial communities -"*. Japanese Committee for the International Biological Program, University of Tokyo press, 172-185.

Poorter, L., Wright, S. J., Paz, H., Ackerly, D. D., Condit, R., Ibarra-Manriquez, G., Harms, K. E., Licona, J. C., Martinez-Ramos, M., Mazer, S. J., Muller-Landau, H. C., Pena-Claros, M., Webb, C. O. and Wright, J. J. (2008) Are functional traits good predictors of demographic rates? Evidence from five neotropical forests. Ecology, 89, 1908-1920.

Research Group on Forest Productivity of the Four Universities (1960) Studies on the productivity of the forest. Part I. Essential needle-leaved forests of Hokkaido. Kokusaku Pulp Industry Ltd. 99 pp.

Research Group on Forest Productivity of Four Universities and Shinshu University (1966) Studies on the productivity of forest. Part III. Productivity of Sugi forests. Jap. For. Tech. Assoc. 63 pp.

Saito, H., Tamai, S., Ogino, K. and Shidei, T. (1968) Studies on the effects of thinning from small diameter trees (III). Changes in stand condition after the second growing season. Bull. Kyoto Uni. For., 40, 81-92.

Shidei, T. and Kira, T. (1977) JIBP synthesis. Vol. 16. Primary productivity of Japanese forests. - Productivity of terrestrial communities -”. Japanese Committee for the International Biological Program, University of Tokyo press, 289 pp.

Tadaki, Y., Hachiya, K. and Tochiaki, K. (1969) Studies on the production structure of forest (XV). Primary productivity of *Fagus crenata* in plantation. J. Jap. For. Soc., 51, 331-339.

Tateno, R., Hishi, T. and Takeda, H. (2004) Above- and Belowground biomass and net primary production in a cool-temperate deciduous forest in relation to topographical changes in soil nitrogen. For. Ecol. Manag., 193, 297-306.

Ustugi, H., Suganuma, H., Aikawa, S., Kojima, T., Tanouchi, H. and Tabuchi, R. (2012) General allometric equations for *Eucalyptus camaldulensis* and other tree species. J. For. Manage., 6, 241-250.

Yasuda, Y., Saito, T., Hoshino, D., Ono, K., Ohtani, Y., Mizoguchi, Y. and Morisawa, T. (2012) Carbon balance in a cool-temperate deciduous forest in northern Japan: seasonal and interannual variations, and environmental controls of its annual balance. J. For. Res., 17, 253-267.

Williams, P. (1996) Recent advances in near-infrared applications for the agriculture and food industries. Dai 12kai Nihon syokuhin kagaku kougaku-kai Hihakai keisoku Symposium Kouen Yousisyuu, 1-11.

Table 3. Biomass of Japanese beech forests.

Prefecture	Lat.	Long.	Elev. (m)	Subsites	Forest Type	Age (yr)	Density (trees ha^{-1})	Ave. Tree Height (m)	Basal Area (m^2 ha^{-1})
Iwate	40°00'N	140°56'E	825	API	Natural	80	1,666	13.9	44.4
Yamagata	38°36'N	140°11'E	--	F3	Natural	40	1,246	16.1	25.1
Niigata	37°30'N	139°00'E	400	P3	Planted	35	5,233	10.0	40.6
			470	P4	Planted	41	2,186	13.6	38.8
			580	P6	Planted	>50	2,829	13.9	39.9
Niigata	37°01'N	138°37'E	--	F4	Planted	35	1,154	11.5	45.6
			--	F5	Planted	37	2,184	12.6	34.8
			--	F6	Planted	37	2,829	16.1	46.3
Niigata	36°51'N	138°41'E	550	P1	Natural	to 100	375	18.8	24.9
			700	P2	Natural	to 100	327	15.6	24.5
			700	P3	Natural	to 100	235	24.6	32.7
			900	P4	Natural	to 100	680	11.2	22.7
			1100	P5	Natural	to 100	1,050	7.3	21.9
			1300	P6	Natural	to 100	875	8.3	14.4
			1500	P7	Natural	to 100	590	9.6	17.7
			1500	P8	Natural	to 100	357	12.6	21.4
Niigata	36°51'N	138°41'E	650	650-1	Natural	to 100	367	24.6	43.3
			650	650-2	Natural	to 100	289	23.6	41.3
			700	700-1	Natural	to 100	321	25.3	44.0
			700	700-2	Natural	to 100	470	18.7	39.2
			700	700-3	Natural	to 100	356	22.3	46.9
			700	700-4	Natural	to 100	400	23.0	39.1
			900	900-1	Natural	to 100	1,016	8.7	40.4
			1300	1300-1	Natural	to 100	959	11.3	38.5
			1500	1500-1	Natural	to 100	639	11.5	37.5
			1500	1500-2	Natural	to 100	422	13.2	33.5
			1500	1500-3	Natural	to 100	820	10.6	34.7
Gunma	36°46'N	138°58'E	--	F2	Natural	40	975	7.6	4.5
	36°52'N	139°05'E	--	F1	Natural	125	611	21.0	31.0
Tochigi	36°47'N	139°56'E	940	--	Natural	mature	868	11.2	29.7
			940	--	Natural	mature	844	11.5	30.9
Kyoto	35°20'N	135°45'E	680	--	Natural	ca. 150	785	14.3	30.7
Kyoto	35°18'N	135°43'E	725	N-1	Natural	--	2,737	7.9	19.9
	35°18'N	135°43'E	725	N-7	Natural	--	3,808	6.0	25.6
Kyoto	35°18'N	135°43'E	680-720		Natural	ca. 100	1,572	--	31.7
Mie	34°41'N	136°16'E	670	P1	Natural	12	63,258	3.4	25.1
	34°41'N	136°16'E	670	P2	Natural	45	19,893	6.5	34.1
	34°41'N	136°16'E	675	P3	Natural	75	19,279	8.8	43.5
	34°41'N	136°16'E	675	P4	Natural	100	3,540	11.4	44.1
	34°41'N	136°16'E	650	P5	Natural	mature	11,063	15.0	54.8
Ave.	--	--	--	--	--	--	--	13.7	33.5
SD	--	--	--	--	--	--	--	5.7	10.4
Min.	--	--	--	--	--	--	--	3.4	4.5
Max.	--	--	--	--	--	--	--	24.6	54.8
Range	--	--	--	--	--	--	--	21.3	50.3

Forest biomass	Biomass of respective tree parts							
	Stem	Branch	Leaf	TAGB	Root	T/R	Biomass estimation method	Reference
($t\ ha^{-1}$)	($t\ ha^{-1}$)	($t\ ha^{-1}$)	($t\ ha^{-1}$)	($t\ ha^{-1}$)	($t\ ha^{-1}$)			
343.4	233.8	39.2	3.5	276.5	66.9	4.1	allometry	the present study
252.0	162.7	37.4	3.6	203.7	48.3	4.2	allometry	Karizumi (1990, 2010)
258.4	168.0	31.4	4.8	204.2	54.2	3.8	allometry	Tadaki et al. (1969)
272.9	166.5	43.5	4.7	214.7	58.2	3.7		
296.5	202.2	39.5	4.9	246.6	49.9	4.9		
372.6	233.3	58.2	7.1	298.6	74.0	4.0	allometry	Karizumi (1990, 2010)
289.3	171.9	53.2	5.1	230.2	59.1	3.9		
441.0	292.6	60.2	7.3	360.1	80.9	4.5		
332.3	227.2	45.9	2.4	275.5	56.8	4.9	allometry	Kakubari (1977)
370.5	250.6	54.0	2.4	307.0	63.5	4.8		
415.4	281.6	60.0	2.7	344.3	71.1	4.8		
417.7	243.9	99.8	3.8	347.5	70.2	5.0		
364.8	213.9	86.1	3.6	303.6	61.2	5.0		
241.6	161.0	42.2	2.4	205.6	36.0	5.7		
183.3	118.3	31.0	1.8	151.1	32.2	4.7		
208.1	133.9	35.6	1.9	171.4	36.7	4.7		
334.2	275.1	56.1	3.0	334.2	--	--	allometry	Maruyama (1977)
349.2	287.7	58.6	2.9	349.2	--	--		
361.6	299.7	58.9	3.0	361.6	--	--		
313.8	256.9	54.4	2.5	313.8	--	--		
365.2	301.1	60.9	3.2	365.2	--	--		
311.6	258.0	50.9	2.7	311.6	--	--		
256.4	181.0	72.2	3.2	256.4	--	--		
245.8	192.3	50.4	3.1	245.8	--	--		
207.1	161.6	43.0	2.5	207.1	--	--		
152.9	119.4	31.6	1.9	152.9	--	--		
214.0	167.0	44.3	2.7	214.0	--	--		
35.3	18.1	5.9	1.0	25.0	10.3	2.4	allometry	Karizumi (1990, 2010)
304.3	237.2	26.0	1.7	264.9	39.4	6.7		
233.1	156.1	77.0	--	233.1	--	--	allometry	Kawahara et al. (1979)
247.2	163.0	81.2	3	247.2	--	--		
357.0	194.3	95.1	3	292.4	64.6	4.5	allometry	Ogino (1977)
79.1	56.0	19.9	3.2	79.1	--	--	allometry	Katagiri and Tsutsumi
78.5	56.5	18.7	3.3	78.5	--	--		(1975)
195.8	--	--	--	156.2	39.6	3.9	allometry	Tateno & Takeda (2004)
39.6	23.5	6.2	2.3	32.0	7.6	4.2	allometry	Kawaguchi and Yoda
90.1	55.5	14.7	1.9	72.2	17.9	4.0		(1986, 1989)
156.2	96.8	25.7	2.4	124.9	31.3	4.0		
226.6	141.2	37.5	2.4	181.0	45.6	4.0		
321.8	201.0	53.3	2.6	256.9	64.9	4.0		
263.4	183.6	47.7	3.1	232.4	49.6	4.4		
104.2	76.8	22.1	1.3	92.7	19.7	0.8		
35.3	18.1	5.9	1.0	25.0	7.6	2.4		
441.0	301.1	99.8	7.1	365.2	80.9	6.7		
405.7	283.0	93.9	6.1	340.2	73.3	4.3		

Appendix. All data sets for dry weight (kg) of plant parts biomass, total above-ground biomass (TAGB), total biomass (TB), diameter at breast height (dbh), tree height (H), and bole height (HB).

ID No.	Dbh (cm)	H (m)	HB (m)	Stem (kg)	Branch (kg)	Leaf (kg)	TAGB (kg)	Root (kg)	TB (kg)
F1	17.3	17.4	9.7	130.5	17.6	2.6	150.7	--	--
F2	8.0	11.1	7.2	13.9	0.6	0.1	14.6	3.3	17.9
F3	19.1	18.7	13.4	159.0	34.1	2.7	195.8	37.3	233.0
F4	7.3	10.0	7.0	12.4	1.9	0.2	14.5	3.6	18.0
F5	6.2	7.8	4.2	8.2	0.6	0.1	8.8	2.1	10.9
F6	4.5	5.3	2.0	3.9	0.5	0.1	4.5	0.7	5.2
F7	28.4	18.3	10.7	307.9	29.0	2.9	339.7	--	--
F8	21.0	18.6	8.6	220.3	39.0	1.6	260.8	--	--
F9	13.3	12.2	6.4	45.1	5.8	0.2	51.1	--	--
F10	12.4	12.3	7.6	30.0	5.2	0.4	35.6	7.1	42.7
F11	55.9	18.2	5.1	1394.6	409.0	54.6	1858.2	533.7	2391.9
F12	75.4	23.8	5.4	3816.9	680.0	69.5	4566.3	1328.4	5894.7
Ave.	22.4	14.5	7.3	511.9	101.9	11.3	625.1	239.5	1076.8
SD	21.8	5.5	3.1	1110.2	215.1	24.0	1343.8	476.9	2112.9
Range	70.9	18.5	11.4	3813.0	679.5	69.4	4561.8	1327.7	5889.6

安比高原ブナ二次林における地上部・地下部バイオマス現存量の推定

小野 賢二[1)*]、安田 幸生[1)]、松尾 亨[2)]、星野 大介[3)]、千葉 幸弘[4)]、森 茂太[4)]

要 旨

岩手県八幡平市安比高原の緩斜面に成林したブナ林における森林動態を評価するため、ブナ生立木の伐倒および掘取調査を行い、そのバイオマス推定式を作成した。安比高原の調査対象地では立木密度が 1,666 本 ha^{-1} であったが、そのうちブナが本数で 75%、胸高断面積合計で 80% を占めた。調査地周辺から大小さまざまなサイズのブナ 12 本を選定し、個別に葉、枝、幹、根の各重量を測定した。データを解析し、各部位のバイオマス推定式の作成を試みたところ、各部位のバイオマス量は胸高直径を独立関数としたアロメトリー式に高度に有意であった（*Adjusted* R^2 = 0.92-0.99）。精度検証用の外部データを用い、部位別にアロメトリー式の精度評価を行ったところ、幹の推定精度が高いことを確認したが、葉や枝、根は、樹木サイズが小さな立木において林分分離が認められ、幾分精度が低かった。これは、従来、幹に比べその他の器官は林分や成長ステージによって林分分離や林分内分離を起こしやすいとの報告があり、精度検証用の外部データに対する枝や葉の推定値の標準誤差（*SEP*）が相対的に大きくなったためである。しかし、葉や枝、根のバイオマス量が過小評価となった個体は dbh < 10 cm のものが主であり、森林バイオマスの主体は幹であったことから、安比高原ブナ林全体のバイオマス量を推定する上では概ね問題とならない。作成したアロメトリー式を用いて安比高原ブナ林のバイオマス量を計算した結果 343 t ha^{-1} と試算された。この値は日本のブナ林を対象とした既往のバイオマス調査データの平均値に比べ、やや高めであった。本研究で作成したブナ生立木のアロメトリー式を用いることで、安比高原ブナ林における炭素動態の年変動を高精度で定量的に評価可能となり、今後森林動態に関わる研究を進めていく上で大変有用である。

キーワード：バイオマス量、胸高直径、相対成長式、ブナ林、根掘取法

1) 森林総合研究所東北支所
2) 林野庁東北森林管理局岩手北部森林管理署
3) 独立行政法人国際農林水産業研究センター
4) 森林総合研究所
＊森林総合研究所東北支所　〒 020-0123　岩手県盛岡市下厨川字鍋屋敷 92-25