Conversion Parameters for Stand Biomass Estimation of Four Subtropical Forests in Southern China

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Abstract. Even though the National Forest Resource Inventory (NFRI) does not provide detailed forest biomass information directly, the NFRI data are useful for estimating forest biomass and carbon stocks by using conversion parameters. However, the accuracy and errors of this approach for estimating the stand biomass of subtropical forests remain unclear. In this study, we selected four typical subtropical forests (Cunninghamia lanceolata plantation, Pinus massoniana evergreen coniferous forest, Choerospondias axillaris deciduous broadleaved forest, and Lithocarpus glaber–Cyclobalanopsis glauca evergreen broadleaved forest) in Dashanchong Forest Park to calculate the biomass expansion factor (BEF) and the root:shoot ratio (R). Our results showed that the average BEF values for the four forests were 1.144, 1.301, 1.592 and 1.396, respectively, while the average R values were 0.197, 0.192, 0.226 and 0.221, respectively. These results may be important for estimating forest biomass in the subtropical zone of southern China.

Introduction

It is generally known that the global carbon balance has been negatively affected over the course of time, which has had a serious impact on global climate change. Forest plays a critical role in the global carbon cycle because the global forest contains a large proportion of the global carbon. Over the past few decades, the change in forest biomass carbon stocks has attracted considerable attention. Thus, the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol have been successively developed, requiring countries to estimate and report each country’s CO₂ emissions and forest carbon stocks. Accurate carbon sink data have an important impact on controlling and reducing the release of CO₂.

The land use, land-use change and forestry (LULUCF) sector has highlighted that the amount of CO₂ emissions and eliminations can only be calculated by estimating the change in forest carbon stocks (forest biomass) [1]. The Intergovernmental Panel on Climate Change (IPCC) has reported that the conversion parameters for estimating stand biomass is a method that is widely and commonly used at both a provincial and national level. Main conversion parameters include biomass conversion and expansion factor (BCEF), biomass expansion factor (BEF), root:shoot ratio (R) and basic wood density (WD) [2].

In China, research into the conversion parameters for stand biomass estimation is extremely scarce. In spite of the fact that we checked the National Forest Resource Inventory (NFRI) eight times in succession, this inventory was found to contain abundant forest volume data, yet no detailed forest biomass data [3]. Moreover, few large-scale studies of forest biomass have been conducted. Thus, in our own study we combined the NFRI data with the IPCC conversion parameters, and used the Dashanchong Forest Park mensuration data to determine the average values of BEF and R in four subtropical forests: Cunninghamia lanceolata plantation, Pinus
massoniana evergreen coniferous forest, Choerospondias axillaris deciduous broadleaved forest, and Lithocarpus glaber–Cyclobalanopsis glauca evergreen broadleaved forest.

Materials and Methods

Study Site Description

This study was carried out in Dashanchong Forest Park (28°23'58"–28°24'58" N, 113°17'46"–113°19'08" E), situated in eastern Changsha County, Hunan Province, China. The area is a typical example of the low hilly landscape endemic to the region, with an altitude ranging from 55 m to 217.4 m above sea level. Soil type is well-drained clay loam red soil developed from slate and shale parent rock. The region experiences a monsoonal climate of mid-subtropical regions. Based on climate data obtained from 1954 to 2010, the annual mean air temperature in the area is 17.3 °C, and maximum and minimum temperatures are 39.8 °C and −10.3 °C, respectively. Annual precipitation ranges from 936.4 mm to 1954.2 mm, and annual average precipitation is 1416.4 mm.

Determination of Forest Biomass

Four forest types [C. lanceolata plantation, P. massoniana evergreen coniferous forest, C. axillaris deciduous broadleaved forest, and L. glaber–C. glauca evergreen broadleaved forest] were selected for this study along a gradient of successional stages and differing in tree species diversity that spanned from single tree species plantations to highly diverse tree species forest stands. In 2013, a study plot was established within each forest type with an area of 50×50 m for the C. lanceolata plantation, 100×100 m for the P. massoniana evergreen coniferous forest, 100×100 m for the C. axillaris deciduous broadleaved forest, and 100×100 m for the L. glaber–C. glauca evergreen broadleaved forest. Each plot was subdivided into subplots (10×10 m) for investigating floristic components and tree spatial patterns of the forests. All tree stems were measured for total height (H), diameter at breast height (DBH, if the DBH ≥4 cm at the H=1.3 m) and species name. The numbers of subplots of each forest type that met the criteria were: 62 for the C. lanceolata plantation, 99 for the P. massoniana coniferous forest, 98 for the C. axillaris deciduous broadleaved forest, and 91 for the L. glaber–C. glauca evergreen broadleaved forest. The biomass of each forest type and each tree component was estimated by allometric equations [4] using DBH as the predictor variable.

Analysis of Conversion Parameters for Forest Biomass Estimation

According to the IPCC [1,2], the formula for estimating the forest biomass ($B_{Total}$) using conversion parameters is as follows:

$$B_{Total} = V_{Total} \times WD \times BEF \times (1 + R)$$  \hspace{1cm} (1)

In this formula, $V_{Total}$ is the stand volume ($m^3$), which is defined as the total volume of stand stem in a certain forest area; $WD$ is the wood basic density ($Mg/m^3$), which can be used to convert the stand volume to the stand stem biomass; $BEF$ is the ratio of stand aboveground biomass to stem biomass (dimensionless), which can be used to expand stand stem biomass to aboveground biomass; and $R$ is the root:shoot ratio (dimensionless), which can be used to expand the stand aboveground biomass to underground biomass.

Data Analysis

All statistical analyses were performed using Excel software, and all figures were constructed using Origin 8.0 software.
Results

Biomass Expansion Factor

Based on biomass allometric equations, we obtained the forest biomass data of the four forest types. Using these biomass data, we then calculated the average biomass expansion factor (BEF) values for the four forest types, as follows: *C. lanceolata* plantation, BEF=1.144 (n=62, SD=0.0429); *P. massoniana* coniferous forest, BEF=1.301 (n=99, SD=0.0117); *C. axillaris* deciduous broadleaved forest, BEF=1.592 (n=98, SD=0.0185); *L. glaber*–*C. glauca* evergreen broadleaved forest, BEF=1.396 (n=91, SD= 0.0108). The order of BEF values for the four forest types was: *C. axillaris* deciduous broadleaved forest > *L. glaber*–*C. glauca* evergreen broadleaved forest > *P. massoniana* coniferous forest > *C. lanceolata* plantation.

We analyzed the distribution of BEF values for these four forest types. The BEF for the *C. lanceolata* plantation was mainly distributed in the range 1.08–1.16, for the *P. massoniana* coniferous forest 1.15–1.35, for the *C. axillaris* deciduous broadleaved forest 1.32–1.80, and for the *L. glaber*–*C. glauca* evergreen broadleaved forest 1.28–1.44. The results are shown in Figure 1.

![Relative frequency distribution of BEF values for four forests of Dashanchong Forest Park.](image)

Root: Shoot Ratio

We also calculated the average root:shoot ratio (R) values for the same four forest types, thus: for the *C. lanceolata* plantation, R=0.197 (n=62, SD=0.0164), for the *P. massoniana* coniferous forest, R=0.192 (n=99, SD=0.0030), for the *C. axillaris* deciduous broadleaved forest, R=0.226 (n=98, SD=0.0038), and for the *L. glaber*–*C. glauca* evergreen broadleaved forest, R=0.221 (n=91, SD= 0.0021)). The order of R values for the four forest types was: *C. axillaris* deciduous broadleaved forest > *L. glaber*–*C. glauca* evergreen broadleaved forest > *C. lanceolata* plantation > *P. massoniana* coniferous forest.
We also analyzed the distribution of $R$ values for these four forest types. The $R$ value for the *C. lanceonata* plantation was mainly distributed in the range 0.18–0.20, for the *P. massoniana* coniferous forest 0.16–0.24, for the *C. axillaris* deciduous broadleaved forest 0.15–0.27, and for the *L. glaber–C. glauca* evergreen broadleaved forest 0.19–0.25. The results are shown in Figure 2.

**Figure 2.** The relative frequency distribution of the root:shoot ratio ($R$) value of four forests of Dashanchong Forest Park.

**Discussion**

In the estimation of forest biomass over large areas by appropriate biomass equations or conversion parameters, methodological options should be carefully evaluated and understood in order to avoid obtaining biased estimates [5]. In our previous study [6], we calculated the average $BEF$ and $R$ values of four typical subtropical forests (*C. lanceonata* plantation, *P. massoniana* forest, deciduous broadleaved forest and evergreen broadleaved forest) based on the National Forest Inventory System and published literatures relating to the subtropical zone of southern China. To test the accuracy of the conversion parameters for stand biomass estimation of subtropical forest types, we calculated the average $BEF$ and $R$ values of corresponding forest types (*C. lanceolata* plantation, *P. massoniana* coniferous forest, *C. axillaris* deciduous broadleaved forest, and *L. glaber–C. glauca* evergreen broadleaved forest).

The Intergovernmental Panel on Climate Change (IPCC) provided the $BEF$ and $R$ default values of different forest types in different climatic zones [2]. In terms of the $BEF$, the average default value was found to be 1.300 for coniferous forest and 1.400 for broadleaved forest. In this study, the average $BEF$ value was found to be 1.144 for *C. lanceolata* plantation, 1.301 for *P. massoniana* coniferous forest, 1.592 for *C. axillaris* deciduous broadleaved forest, and 1.396 for *L. glaber–C. glauca* evergreen broadleaved forest. These values differ from the IPCC default values in that we found a relatively large difference between the *C. lanceolata* plantation and the *C. axillaris* deciduous broadleaved forest. However, the average $BEF$ values of the four forest types in this study were found to be larger than those found in the study by Hou *et al.* [6], except for the value
for the *C. lanceolata* plantation. This may have been because the *C. lanceolata* plantation had been affected by human activities, such as proper thinning and pruning to reduce the stand density and increase the photosynthesis rate, and accordingly there was an increase in the proportion of stem component biomass in the aboveground component biomass.

In terms of *R*, the average default value was found to be 0.270 for subtropical dry forest, which related to the corresponding values reported by the IPCC for aboveground biomass of different forest types. In our study, the average *R* value was 0.197 for the *C. lanceolata* plantation, 0.192 for the *P. massoniana* coniferous forest, 0.226 for the *C. axillaris* deciduous broadleaved forest, and 0.221 for the *L. glaber*–*C. glauca* evergreen broadleaved forest. These values are smaller than those found in the study by Hou et al. [6] and by the IPCC. In addition, the IPCC default value was larger than all *R* average values relating to Dashanchong Forest Park and the study by Hou et al. [6]. Thus it can be seen that the more extensive the data sources, the larger the *R* values. This means that large-scale forest biomass estimation should take into account different forest types and the dominant tree species; only in this way can estimation errors be minimized.

In this study, it is clear that there are obvious differences in the conversion parameters used to estimate stand biomass between different forest types. There may be various reasons for such differences. 1) Different forest types comprising different tree species lead to significant differences in stand volume and forest biomass. The annual increase in coniferous forest stand volume is 2.7-fold that in broadleaved forest, and the live biomass for coniferous forest is 3.19-fold that of broadleaved forest in Longquan city, Zhejiang province [7]. 2) Different forest types have different site conditions, such as variations in soil, moisture, sunshine, et al. [8]. *C. lanceolata* plantation is man-made forest, it is mostly planted in fertile soil and its roots are shallow because there are sufficient nutrients for growth. However, most broadleaved forests are natural secondary forests, where the soil is barren and the trees must develop deep roots to absorb nutrients for growth. Thus, the root biomass of *C. lanceolata* plantation is relatively small, while the aboveground biomass is relatively high, and this in turn leads to its lower *BEF* and *R* average values than those of broadleaved forest. 3) Different forest types are inordinately influenced by various stand factors, for example stand age, stand density, diameter at breast height, and stand height. Studies have revealed that *BEF* and *R* values decrease with stand age, diameter at breast height and increasing stand height, yet increase with increasing stand density [6,9,10].

In conclusion, conversion parameters for stand biomass estimation play a vital role in large-scale forest biomass estimation. More attention should be paid to researching the conversion parameters for subtropical zone forest biomass estimation because these forests represent an important form of carbon stock.

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**Author Contributions**

Yannan Hou and Wenhua Xiang conceived and designed the experiments; Yannan Hou and Weixian Zeng performed the experiments; Wenhua Xiang, Huili Wu and Weixian Zeng analyzed the data; Wenhua Xiang and Huili Wu contributed reagents/materials/analysis tools; Yannan Hou and Huili Wu wrote the paper.

**Conflicts of Interest**

The authors declare no conflict of interest.
References


