Short Communication

Variation in Form-factors for Stem Surface Area in Even-aged Pure Stands of Japanese Larch (Larix kaempferi)

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ABSTRACT

Variation in the form-factors for stem surface area was studied in two even-aged pure stands of Japanese larch (Larix kaempferi). In the stands, all living trees were felled for stem analysis, and then the form-factors for stem surface area and stem volume at breast height and 0.7 and 0.5 in relative height, i.e., \( k_{0.7}, k_{0.5}, \lambda_{0.7}, \lambda_{0.5} \) and \( \lambda_{b0.5} \) were calculated. The coefficients of variation (CV) of \( k_{0.7} \) and \( k_{0.5} \) ranged from 3.2 to 7.4% and from 3.9 to 8.8%, respectively. On the other hand, CV of \( k_i \) ranged from 9.1 to 15.4%, indicating that the variation in \( k_i \) was comparatively larger than those in \( k_{0.7} \) and \( k_{0.5} \). The ratios of CV of form-factor for stem surface area to that for stem volume ranged from 0.3 to 0.6, indicating that the variation in the form-factors for stem surface area was smaller than that for stem volume. In conclusion, \( k_{0.7} \) and \( k_{0.5} \) would be effective form-factors in estimating the total stem surface area of a stand with the angle count sampling precisely.

Keywords: angle count sampling, even-aged pure stand, form-factor for stem surface area, Japanese larch, stem form

INTRODUCTION

The stem surface area represents the base for potential volume growth (Lexen, 1943), stem respiration, and interception of radiation and rainfall (Schreuder et al., 1993). The stem surface area is also the habitat and food supply source for various insects, fungi, lichens and algae (Schreuder et al., 1993). Therefore, the stem surface area plays an important role in ecological and biological processes of trees or forests, and its efficient measurement or estimation is of inherent interest to ecologists and forest scientists. To measure the stem surface area, various methods have been proposed (Husch et al., 1972). However, it is difficult or often impossible to measure the stem surface area of standing trees directly, and hence alternative methods for estimating the surface area have been required.

Studies have shown that the normal form-factors for stem volume at 0.7 and 0.5 in relative height (tip: relative height = 0; base: relative height = 1) for coniferous trees are, respectively, almost steady at 0.7 and 1.0, independent of species, districts, growth stage and stand density control (e.g., Kajihara, 1969, 1985; Ueno, 1978, 1983; Wang and Uozumi, 2001). On the other hand, Inoue (2005) proposed a measure of the stem form in relation to the stem surface area and named the measure “form-factor for stem surface area”. The measure is given by the ratio of the stem surface area to the side area of a column, of which diameter and height are equal to the diameter at a given height and total tree height, respectively. As Inoue (2005) suggested, if there is a universal value of the form-factor for stem surface area, the total stem surface area of a stand can be estimated with the angle count sampling. To estimate the universal values of form-factors for stem surface area from those for stem volume, Inoue (2006) derived the following model that describes the relationship between form-factors for stem volume, \( \lambda_i \), and those for stem surface area, \( k_i \):

\[ k_i = k \lambda_i^{0.55} \]  

(1)

where \( k \) is a coefficient. The model expressed the relationship between these form-factors for Japanese cedar (Cryptomeria japonica D. Don) and Japanese cypress (Chamaecyparis obtusa Endl.) trees.

Variation in the form-factors within a stand will affect the precision of the angle count sampling with form-factors. To estimate the stand volume with the angle count sampling, the variation in the form-factors for stem volume in a stand has been studied by several forest scientists (e.g., Kajihara, 1969, 1985; Ueno, 1978, 1983; Wang and Uozumi, 2001). However, a careful review of the literature revealed that the variation in the form-factors for stem surface area has not been studied. To estimate the total stem surface area per hectare with the angle count sampling, it is important to understand the change and variation in the form-factors for stem surface area in a stand.

The objective of the present study is thus to analyze the

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variation in the form-factors for stem surface area in even-aged pure stands of Japanese larch (Larix kaempferi). First, all living trees were felled for stem analysis in two larch stands, and then the form-factors for stem surface area and stem volume were computed. Second, the change and variation of the form-factors for stem surface area were analyzed. The variation in the form-factors for stem surface area was also compared with that for stem volume.

MATERIALS AND METHODS

Study Site

This study was conducted in two Japanese larch even-aged pure stands in the Hiruzen Experimental Forest of Tottori University, Okayama Prefecture, western Japan (35°18’N and 133°35’E). The annual average temperature, annual average precipitation and maximum snowfall of the Experimental Forest were 11.3 °C, 2,140 mm and 2.1 m, respectively. The soils are mainly gray volcanic ash soils. The larch stands were located on gentle slopes with an average inclination of 5-10° at about 600-700 m asl. In these stands, larch seedlings were planted with a density of about 3,000 trees per hectare and no thinning regime was conducted after the planting. Attributes of each plot is summarized in Table 1.

Data

A square plot of 15 m×15 m was established for each larch stand, and then all living trees in the plot were felled for stem analysis. The number of sample trees was 28 for both plots. Stem disks were sampled from 0.2 m, 1.2 m and the upper portion at 2.0 m intervals, whereas only final disk at the highest position was taken at 1.0m interval. Each sample disk was measured along four different radii to determine ring width corresponding to growth intervals of three-years.

Analysis Methods

Using the stem analysis data of larch trees, the stem volume and surface area was computed with the sectional measurement method (HUSCH et al., 1972), and the diameters at each relative height, i.e., 0.1, 0.2,…, 1.0, were also estimated with the linear interpolation. Then, the form-factors for stem surface area and volume at breast height and each relative height were calculated.

Studies have shown that the form-factors for stem volume at breast height and 0.7 and 0.5 in relative height, \( \lambda_{b}, \lambda_{0.7} \) and \( \lambda_{0.5} \), are effective in estimating stand volume with the angle count sampling (e.g., KAJIHARA, 1969, 1985; UENO, 1978, 1983; WANG and UOZUMI, 2001). These studies suggest that the form-factors for stem surface area at breast height and 0.7 and 0.5 in relative height, \( K_{b}, K_{0.7} \) and \( K_{0.5} \) would also be effective in estimating total stem surface area with the angle count sampling (INOUE, 2006). The counting procedure of the angle count sampling will allow us to estimate the total stem surface area per hectare as well as the stand volume simultaneously. For these reasons, the variation in these six form-factors, i.e., \( \lambda_{b}, \lambda_{0.7}, \lambda_{0.5}, K_{b}, K_{0.7} \) and \( K_{0.5} \), were analyzed, and other form-factors were excluded from the analysis of the variation in the normal form-factors. The coefficient of variation of each form-factor, i.e., \( CV(\lambda) \) and \( CV(\mu) \), was then computed for each stand and age as a measure of variation in the form-factors. The ratio of the coefficient of variation of the form-factor for stem surface area to that for stem volume, \( CV(\lambda)/CV(\mu) \), was also calculated.

Since Eq. 1 holds independent of the height position (INOUE, 2006), Eq. 1 was fitted to the relationship between form-factors for stem surface area at breast height and all relative heights and those for stem volume.

RESULTS

Fig. 1 indicates the changes in average form-factors for stem surface area with stand age in two even-aged pure stands of Japanese larch. The average form-factor for stem surface area
area at breast height, $\kappa_b$, ranged from 0.618 to 0.687 for stand A and from 0.628 to 0.660 for stand B, and no remarkable change in the average $\kappa_b$ with stand age was found for both stands. In stand A, the average form-factor for stem surface area at 0.7 in relative height, $\kappa_{0.7}$, increased from 0.755 in 12-year-old to 0.801 in 15-year-old, and then average $\kappa_{0.7}$ was almost steady at 0.800. In stand B, $\kappa_{0.7}$ was increased slightly from 0.754 to 0.793. The average form-factor for stem surface area at 0.5 in relative height, $\kappa_{0.5}$, was tended to be gradually decreased from 1.059 to 0.992 for stand A and from 1.022 to 0.954 for stand B.

Changes in the coefficients of variation of the form-factors for stem surface area with stand age are shown in Fig. 2. The coefficients of variation of $\kappa_b$, $\kappa_{0.5}$ and $\kappa_{0.7}$, $\text{CV}(\kappa_b)$, $\text{CV}(\kappa_{0.5})$ and $\text{CV}(\kappa_{0.7})$, respectively, ranged from 8.933 to 15.436%, from 3.322 to 6.407% and from 3.899 to 8.093% for stand A and from 7.929 to 11.454%, from 3.322 to 6.407% and from 3.899 to 8.093% for stand B. For both stands and all stand ages, $\text{CV}(\kappa_{0.7})$ was slightly smaller than $\text{CV}(\kappa_{0.5})$, and $\text{CV}(\kappa_b)$ was comparatively larger than $\text{CV}(\kappa_{0.5})$ and $\text{CV}(\kappa_{0.7})$.

Fig. 3 depicts the changes in the ratio of the coefficient of variation of the form-factor for stem surface area to that for stem volume, $\text{CV}(\kappa)/\text{CV}(\lambda_b)$, with stand age. For both stands and all stand ages, $\text{CV}(\kappa)/\text{CV}(\lambda_b)$ was less than unity, indicating that $\text{CV}(\kappa)$ was smaller than $\text{CV}(\lambda_b)$.

As shown in Fig. 4, Eq. 1 was well fitted to the relationship between form-factors for stem surface area, $\kappa_b$, and those for stem volume, $\lambda_b$, and the relationship could be expressed by the following equation:

$$\kappa_b = 0.885 \lambda_b^{0.65} \quad (r^2 = 0.996, P < 0.001) \quad (2)$$
DISCUSSION

In a previous study, KAJIHARA (1969) analyzed the variations in $\lambda_b$ and $\lambda_{0.5}$ in even-aged pure stands of Japanese cedar, and reported that $\text{CV}(\lambda_b)$ and $\text{CV}(\lambda_{0.5})$ ranged from 4.8 to 10.7% and from 3.0 to 6.6%, respectively. UENO (1978) investigated the variations in form-factors for stem volume in even-aged pure stands of Japanese cedar, and showed that $\text{CV}(\lambda_b)$, $\text{CV}(\lambda_{0.7})$ and $\text{CV}(\lambda_{0.5})$ ranged from 7.9 to 10.7%, from 7.5 to 12.6% and from 6.2 to 6.3%, respectively. UENO (1983) also analyzed the changes in $\text{CV}(\lambda)$ with stand age in Japanese cedar stands and reported that $\text{CV}(\lambda_{0.5})$ was less than 10% independent of the stand age. By contrast, when the stand age was less than 20-years, $\text{CV}(\lambda_b)$ and $\text{CV}(\lambda_{0.5})$ decreased from 30-40% to 20% sharply with the increase in stand age. However, when the age was over than 20-years, $\text{CV}(\lambda_b)$ and $\text{CV}(\lambda_{0.5})$ gradually decreased with age, and became 10-20% and less than 10%, respectively. KAJIHARA (1985) reported that $\text{CV}(\lambda_{0.5})$ and $\text{CV}(\lambda_{0.7})$ in Japanese cedar, Japanese cypress, Japanese red pine (Pinus densiflora) and Japanese larch stands ranged from 4.2 to 7.7% and from 4.0 to 6.6%, respectively. WANG and UOZUMI (2001) studied the changes in $\text{CV}(\lambda_{0.5})$ and $\text{CV}(\lambda_{0.7})$ with stand age in Japanese larch stands, and reported that $\text{CV}(\lambda_{0.5})$ and $\text{CV}(\lambda_{0.7})$ gradually decreased with stand age and became steady at about 5%.

These studies showed that $\text{CV}(\lambda)$ was less than 10% except for the young stands, and suggested that the form-factors for stem volume enable us to estimate the stand volume with the angle count sampling precisely (KAJIHARA, 1969, 1985; UENO, 1978, 1983; WANG and UOZUMI, 2001). The result of this study indicated that $\text{CV}(\kappa)$ was less than 10%, except for the form-factor for stem surface area at breast. The ratio of the coefficient of variation of form-factors for stem surface area to that for stem volume, $\text{CV}(\kappa)/\text{CV}(\lambda)$, also ranged from 0.3 to 0.6 (see Fig. 2), indicating that the variation in form-factors for stem surface area was smaller than that for stem volume. These facts suggest that the form-factors for stem surface area allow us to estimate the total stem surface area in a stand with the angle count sampling precisely.

In this study, the data of stem analysis of all living trees within the un-thinned larch stands was used to examine the variations in the normal form-factors for stem surface area within the stands. Therefore, the dead trees due to the self-thinning process are excluded from our results. The average of the normal form-factors for stem surface area may vary with the inclusion of the dead trees. As show in Fig. 4, the normal form-factors for stem surface area are directly proportional to the root of those for stem volume. Generally, the exponent of the power equation is approximately equal to the ratio of the coefficient of variation of the two variables (e.g., INOUE, 2002), and thus Eq. 2 implies that ratio of the coefficient of variation of form-factors for stem surface area to that for stem volume, $\text{CV}(\kappa)/\text{CV}(\lambda)$, would be approximately 0.5. The fact that the variation in form-factors for stem surface area was smaller than that for stem volume will be true, even if including the dead trees into the analysis. For these reasons, the normal form-factors for stem surface area enables us to estimate the total stem surface area per hectare with the angle count sampling precisely. However, we should pay an attention into the effect of the inclusion of dead trees on the average form-factors, which may produced the biased and inaccurate estimator of the total stem surface area with the angle count sampling.

INOUE (2006) applied Eq. 1 to Japanese cedar and Japanese Cypress trees, and found that the coefficient $\kappa$ was 0.873 independent of species. Assuming that $\lambda_{0.7}$ and $\lambda_{0.5}$ were, respectively, steady at 0.7 and 1.0, INOUE (2006) also estimated the universal values of $\kappa_{0.7}$ and $\kappa_{0.5}$, i.e., $\kappa_{0.7} = 0.730$ and $\kappa_{0.5} = 0.873$. As shown in Fig. 4, the coefficient for the larch trees was 0.885, which results in the predicted normal form-factors, i.e., $\kappa_{0.7} = 0.740$ and $\kappa_{0.5} = 0.885$, with an assumption that $\lambda_{0.7} = 0.7$ and $\lambda_{0.5} = 1.0$. There are no clear differences in the predicted $\kappa_{0.7}$ and $\kappa_{0.5}$ among cedar, Cypress (INOUE, 2006) and larch trees. However, our result indicated that both $\kappa_{0.7}$ and $\kappa_{0.5}$ for the larch trees were larger than these predicted values (see Fig. 1). The true cause of such inconsistency is unknown to me at present. The inconsistency may produce the biased estimator of the total stem surface area per hectare with the angle count sampling. There is a need for further studies on the variation in the average form-factors as well as the variation in the form-factors within the stand examined in this study.

CONCLUSIONS

In this study, the variation in the form-factors for stem surface area within the even-aged pure stands of Japanese larch was studied. The result indicated that $\text{CV}(\kappa_{0.7})$ and $\text{CV}(\kappa_{0.5})$ ranged from 3.2 to 7.4% and from 3.9 to 8.8%, respectively, and the variations in $\kappa_{0.7}$ and $\kappa_{0.5}$ were comparatively smaller than that in $\kappa_{0.5}$. It was found that the variation in the form-factors for stem surface area was smaller than that for stem volume. In conclusion, $\kappa_{0.7}$ and $\kappa_{0.5}$ would be effective form-factors in estimating the total stem surface area of a stand with the angle count sampling precisely.

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LITERATURE CITED

INOUE, A., (2005): Proposing new measures for quantifying a stem


LEXEN, B., (1943): Bole area as an expression of growing stock. J. For. 41: 883-885


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