Short communication

Increase in Stem Volume per Unit Sunny Crown Dimension for Even-Aged Hinoki Cypress (Chamaecyparis obtusa) Stands

Yoshiaki Waguchi*1 and Masafumi Ueda*2

ABSTRACT

To investigate the quantitative relationships between increase in stem volume (SVI) and sunny crown dimensions for Hinoki cypress (Chamaecyparis obtusa ENDL.), we calculated the SVI per unit sunny crown dimension using three different sunny crown dimensions [i.e., volume (SCV), surface area (SCSA), and volume increase (SCVI)]. Samples were collected from six stands of even-aged Hinoki cypress in Nara Prefecture, Japan. For each SVI per sunny crown dimension, the mean among stands was compared. The SVI/SCV did not vary among the sampled stands, whereas the SVI/SCSA and SVI/SCVI varied with the stage of growth. Although our observed mean SVI/SCV was slightly larger than that in another region, the minimal difference observed between regions suggests that the SVI/SCV can be generally used to estimate the SVI of Hinoki cypress. Thus, SVI/SCV is an appropriate coefficient with which to estimate SVI.

Keywords: sunny crown volume, sunny crown surface area, sunny crown volume increase, stem volume increase, Hinoki cypress

INTRODUCTION

Crown dimensions are useful for predicting the responses of trees to silvicultural treatments (e.g., thinning or pruning) because crowns support foliage, the photosynthetic organ. Crown dimensions are often incorporated into growth and yield models as factors that are used to estimate tree growth (Mitchell, 1975; Shimizu et al., 1984; Takeda, 1985; Ottoni, 1991; Yoshida, 1991; Cole and Loimer, 1994; Rauner et al., 1996; Sagawa et al., 1996; Matsue, 2000; Valentine and Makela, 2005). Sunny crown dimensions are particularly effective predictors of stem volume growth. For example, Inose (1982) found that increases in the stem volume (SVI) of Toto fir (Abies sachalinensis Mast.) could be predicted by the increase in sunny crown volume. Similarly, Kajihara (1985) used the sunny crown surface area to predict the SVI of Japanese cedar (Cryptomeria japonica D. Don). Because sunny crown dimensions can clearly be used as predictors of SVI, it is valuable to thoroughly investigate the quantitative relationships between SVI and sunny crown dimensions.

The simplest expression of the relationship between sunny crown dimensions and SVI is the SVI per unit sunny crown dimension. When the SVI per unit sunny crown dimension of a tree is known, the SVI can be calculated by multiplying the sunny crown dimension by the SVI per unit sunny crown dimension. Therefore, the incorporation of the SVI per unit sunny crown dimension into a sunny crown dynamic model allows the prediction of SVI. However, because of the labor-intensive work required, very few detailed measurements of sunny crown dimensions and SVI have been collected. In particular, these data are lacking for one of the most widely distributed plantation trees in Japan, Hinoki cypress (Chamaecyparis obtusa ENDL.) (but see Kajihara, 1982; 1996). To generate additional data for the estimation of SVI from sunny crown dimensions, we calculated the SVI per unit sunny crown dimension using three different sunny crown dimensions (i.e., volume, surface area, and volume increase) in stands of even-aged Hinoki cypress.

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MATERIALS AND METHODS

Field Measurements

Samples were collected from six stands of even-aged Hinoki cypress in Nara Prefecture, Japan (Table 1). Stand age ranged from 10 to 72 years, and densities ranged from 1,000 to 5,250 trees/ha. The mean diameter at breast height ranged from 6.8 to 29.1 cm, and the mean total height varied from 5.5 to 16.8 m.

We randomly selected 112 sample trees in the stands. Prior to felling, the diameter at breast height (DBH) of each tree was measured using calipers. The DBH of the sample trees ranged from 3.6 to 32.5 cm. The height of the sunny crown base of each tree was measured on the percentage scale using a Spiegel relascope. A 5-m pole was placed upright against the tree trunk for these measurements. The sunny crown length (SCL) was calculated by subtracting the height of the sunny crown base from the total height (H) of the tree.

After each tree was felled, H was measured using surveyor’s tape; H ranged from 4.1 to 18.7m. To measure SVI, disks were removed from the stem at stump height (0.2m), at intervals of 0.5, 1, or 2m below the lowest live branch, and at intervals of 0.5 or 1m within the crown beginning at stump height. To measure the shape and size of the sunny crown, each crown segment was placed vertically on the ground, and the crown radius at the middle of each segment was measured in four directions at right angles using surveyor’s tape.

Laboratory Measurements

The removed stem disks were taken to the laboratory, and the annual rings were counted. For each disk, the current- and previous-year radii in four directions at right angles were measured. The current- and previous-year stem cross-sectional areas were calculated using average radius measurements of the stem cross-section, which was assumed to be circular in shape. The current- and previous-year log volumes for each segment were calculated using Smallian’s formula (OSUMI et al., 1987). Each log volume increase was calculated as the difference between the current- and previous-year log volumes. The SVI for each tree was computed as the sum of the log volume increases.

Calculation of Sunny Crown Dimensions

To obtain sunny crown volume (SCV), surface area (SCSA), and volume increase (SCVI), the sunny crown profile of each tree was represented using the following equation:

\[ r = ax^b \]  

(1)

where \( r \) is the crown radius at distance \( x \) from the apex and \( a \) and \( b \) are parameters. The parameters were estimated using the non-linear least squares method, minimizing the sum of squared residual (SSR):

\[ SSR = \sum \sum (r_{ij} - ax_i^b)^2 \]  

(2)

where \( r_{ij} \) is the \( j \)th crown radius \( (j = 1, 2, 3, 4) \) at the \( i \)th distance \( x_i \) \( (i = 1, 2, \cdots, n) \) from the apex. SCV and SCSA were calculated by rotating eq. (1) on the trunk axis. Because SCSA cannot be calculated directly, Romberg’s integration was used.

The mean leaf longevity of Hinoki cypress was estimated as 4.4 years (INAGAKI et al., 2003); thus, we calculated the SCVI over 4 years. The SCVI was calculated by subtracting the SCV from 4 years prior (above the current-year sunny crown base) from the current-year SCV. Because the shape and size of the sunny crown from 4 years prior were assumed to be the same as those of the current-year sunny crown, the SCVI was calculated as follows:

\[ \text{SCVI} = \pi \int_{H_i}^{\text{MAX}} r^2 dz - \pi \int_{H_i}^{\text{MIN}} r^2 dz \]  

(3)

where \( H_i \) is the total height increase over 4 years. The HI was calculated by subtracting the \( H \) from 4 years prior from the current-year \( H \). The \( H \) from 4 years prior was estimated using the ordinary stem analysis technique.

Statistical Analysis

The SVI per unit sunny crown dimension was calculated for each sampled tree. One-way analysis of variance was used to compare the means among stands.

Table 1 Stand descriptions.

<table>
<thead>
<tr>
<th>Stand</th>
<th>Age (year)</th>
<th>Density (trees/ha)</th>
<th>Mean diameter at breast height (cm)</th>
<th>Mean total height (m)</th>
<th>Number of sample trees</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>10</td>
<td>5,250</td>
<td>6.8</td>
<td>5.5</td>
<td>20</td>
</tr>
<tr>
<td>B</td>
<td>16</td>
<td>3,006</td>
<td>11.8</td>
<td>10.1</td>
<td>15</td>
</tr>
<tr>
<td>C</td>
<td>19</td>
<td>3,828</td>
<td>11.9</td>
<td>9.4</td>
<td>20</td>
</tr>
<tr>
<td>D</td>
<td>29</td>
<td>2,602</td>
<td>12.6</td>
<td>12.7</td>
<td>22</td>
</tr>
<tr>
<td>E</td>
<td>41</td>
<td>1,820</td>
<td>18.6</td>
<td>16.4</td>
<td>15</td>
</tr>
<tr>
<td>F</td>
<td>72</td>
<td>1,000</td>
<td>29.1</td>
<td>16.8</td>
<td>20</td>
</tr>
</tbody>
</table>
RESULTS AND DISCUSSION

Variations in SVI, SCV, SCSA, and SCVI were determined for the stage of growth (Fig. 1). Mean SVI, SCV, and SCSA increased with increasing mean H. Thus, trees with larger SCV or SCSA produce larger SVI. In contrast, mean SCVI decreased in stands > 12 m in mean H, whereas SCVI increased in stands < 12 m in mean H. This pattern emerged because trees in older stands have smaller H (i.e., thinner SCVI) than younger stands.

The SVI/SCV did not vary with increasing mean H, and there was no significant difference in SVI/SCV among stands ($F = 1.356, p > 0.05$; Table 2 and Fig. 2). KAJIHARA (1982) collected data from eight even-aged stands in Kyoto Prefecture, Japan, ranging from 9 to 76 years old and estimated the SVI/SCV for 26 Hinoki cypress trees ranging from 4 to 25m in H and from 5 to 34cm in DBH. Although our observed mean SVI/SCV of all sampled trees (Table 2) was slightly larger than that of KAJIHARA (1982) (mean ± standard deviation = 5.59 ± 3.00 × 10⁻⁴ m²/m³), this minimal difference observed between regions suggests that the SVI/SCV can be generally used to estimate the SVI of Hinoki cypress.

The SVI/SCSA increased with increasing mean H and differed among stands ($F = 6.257, p < 0.05$; Table 2 and Fig. 2). Although KAJIHARA (1996) presented measurements of changes in SVI/SCSA for an even-aged Hinoki cypress stand, ours are the first measurements of changes in SVI/SCSA among Hinoki cypress stands that vary in the stage of growth. KAJIHARA (1996) measured changes in SVI/SCSA for intervals ranging from 14 to 26 years old for an even-aged Hinoki cypress stand. However, no trends in SVI/SCSA were observed because these time intervals were likely too short (KAJIHARA, 1996). In contrast, KAJIHARA (1994) calculated SVI/SCSA for 30 even-aged Japanese cedar stands ranging from 6 to 60 years old, demonstrating that SVI/SCSA decreased with increasing stand age for stands > 30 years old, whereas SVI/SCSA increased in stands < 30 years old. Although the 41-year-old stand (Stand E) exhibited the largest SVI/SCSA among our sampled stands (Table 2), we did not have sufficient data from older stands to observe a trend in the

![Image](https://via.placeholder.com/150)

**Fig. 1** Means of the increase in stem volume (SVI) and three sunny crown dimensions [volume (SCV), surface area (SCSA), and volume increase (SCVI)] in six Hinoki cypress stands. Vertical bars indicate standard deviations.

Table 2  Means and standard deviations of the increase in stem volume (SVI) per unit sunny crown dimensions [volume (SCV), surface area (SCSA), and volume increase (SCVI)] for each stand sampled and for all stands combined.

<table>
<thead>
<tr>
<th>Stand</th>
<th>SVI/SCV ($\times 10^{-4}$ m³/m²)</th>
<th>SVI/SCSA ($\times 10^{-4}$ m³/m²)</th>
<th>SVI/SCVI ($\times 10^{-4}$ m³/m³/4-years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>6.66 ± 2.66</td>
<td>1.96 ± 0.82</td>
<td>6.94 ± 2.70</td>
</tr>
<tr>
<td>B</td>
<td>8.02 ± 2.21</td>
<td>3.34 ± 0.93</td>
<td>9.64 ± 2.79</td>
</tr>
<tr>
<td>C</td>
<td>7.44 ± 6.35</td>
<td>2.61 ± 1.20</td>
<td>10.31 ± 6.36</td>
</tr>
<tr>
<td>D</td>
<td>5.91 ± 2.65</td>
<td>2.81 ± 1.31</td>
<td>8.66 ± 3.31</td>
</tr>
<tr>
<td>E</td>
<td>8.48 ± 3.70</td>
<td>4.06 ± 1.65</td>
<td>16.32 ± 6.14</td>
</tr>
<tr>
<td>F</td>
<td>6.18 ± 2.95</td>
<td>3.11 ± 1.06</td>
<td>15.97 ± 4.70</td>
</tr>
<tr>
<td>all stands</td>
<td>6.99 ± 3.76</td>
<td>2.91 ± 1.31</td>
<td>11.11 ± 5.69</td>
</tr>
</tbody>
</table>

Fig. 2 Mean increase in stem volume (SVI) per unit sunny crown dimensions (volume (SCV), surface area (SCSA), and volume increase (SCVI)) in six Hinoki cypress stands. Vertical bars indicate standard deviations.

changes in SCV/SCSA with stand age.

The SVI/SCVI was very large in older stands (Table E and F) and differed significantly among stands ($F = 29.194, p < 0.05$; Table 2 and Fig. 2). This pattern was caused by the decrease in SCVI as the SVI increased in older stands. These opposing trends in SVI and SCVI suggest that changes in SVI/SCVI are more complex than those in SVI/SCV or SVI/SCSA.

CONCLUSION

We determined the SVI per unit sunny crown dimensions for six even-aged Hinoki cypress stands. The SVI/SCV did not vary among the sampled stands, whereas the SVI/SCSA and SVI/SCVI varied with the stage of growth. Thus, SVI/SCV is an appropriate coefficient with which to estimate SVI.

LITERATURE CITED


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