UDC 630*5/524.2/533/562.1/564

# CORRECTION OF STAND VARIABLE ESTIMATES OBTAINED BY THE STAND RECONSTRUCTION TECHNIQUE: CAN STUMP INFORMATION IMPROVE THE PREDICTIONS?

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*Received 20.04.2018*

Information on thinned tree stumps was included in a stand reconstruction technique to test possible improvements in the estimates of stand variables (aboveground biomass, total stem volume, stem volume growth and stand density). Thirty sample trees and one hundred and sixty-eight stumps of the Sakhalin fir *Abies sachalinensis* (F. Schmidt) Mast., the Ezo spruce *Picea jezoensis* (Siebold & Zucc.) Carrière, and Glehn's spruce *Picea glehnii* (F. Schmidt) Mast., were collected in six stands of pure tree species within the Hitsujigaoka Experimental Forest in Hokkaido, Japan. Stem analysis data and census data both gathered in 2013 from six stands were used to estimate stand variables in the past. Then, the stand variables were estimated by the stand reconstruction technique, with and without the stump information and subsequently compared in terms of prediction accuracy. In other words, the reconstructed values were statistically compared with the observed values obtained from censuses between 1988 and 2013. The results showed that the accuracy of the estimated variables can be improved by alleviating underestimation after adding old stumps. Without adding data on the stumps, the percentage error of the estimates of the stand variables varied within ± 20 % of the observed values. By including the stumps, the percentage error of the estimates of the same stand variables generally fell within ± 15 % for the years after 1997. The 95 % confidence intervals of the estimated means by the bootstrap method suggested that adding stumps does not always improve the prediction in stand density; but generally, improves the predictions on aboveground biomass, stem volume and stem volume growth. Overall, dramatic changes in the aboveground biomass and stand density through thinning operations were reproduced better, although the amount of improvement is sometimes minimal, by incorporating information on the stumps for all 3 species examined.

**Keywords:** *stand reconstruction technique, decay stumps, aboveground biomass, total stem volume, stem volume growth, stand density, Hitsujigaoka experimental forest, Hokkaido, Japan.*

**How to cite:** *Sovanchandara H., Murakami D., Fujii S., Aizawa S., Osawa A.* Correction of stand variable estimates obtained by the stand reconstruction technique: can stump information improve the predictions? // *Sibirskij Lesnoj Zurnal* (Sib. J. For. Sci.). 2018. N. 6: 25–45 (in English with Russian abstract). DOI: 10.15372/SJFS20180603

## INTRODUCTION

Changes in the composition, structure and functions of forest ecosystem usually develop over long periods of time. Quantifying the changes in these components and processes would increase scientific and ecological understanding of forest development and their role in regulating climate system. Several methods have been employed to document and understand these changes: tree-ring analysis (Esper et al., 2012; Villalba et al., 2012; Zang et al., 2012), forest inventory data (Pretzsch, 1996; Lines et al., 2010; Corona et al., 2011), chronosequences (Marks, 1974; Johnson, Miyanishi, 2008; Permafrost ecosystems…, 2010), stand reconstruction (Henry, Swan, 1974; Peter, Harrington, 2010), and simulation model (Shugart, 2003; Kurz et al., 2008, 2009).

Another method to deal with the question of quantitatively reconstructing long-term changes in stand development was developed by A. Osawa et al. (2000). It is referred to as a stand reconstruction technique, which uses information of present stand structure and tree-ring data of selected trees to reconstruct forest structure that existed long ago. Information on the historical stand structure is derived from tree-ring patterns. A. Osawa et al. (2005) applied the method to reconstruct the aboveground biomass, total stem volume, stem volume growth, and stand density of even-aged monospecific stands and compared the estimates to the observed values on the previous stand measurements. The results suggested that the effect of thinning causes underestimation in the stand reconstruction technique for years before thinning operations. Therefore, it has become apparent that thinning or other disturbances cause loss of information on individual trees in the stand and make it difficult to accurately reconstruct tree size distribution that existed in the past. Yet, the effect of disturbances (e. g., artificial thinning) on the accuracy of the stand reconstruction method has not been examined in sufficient detail. At the same time, the accuracy of this method could be potentially improved by explicitly taking the effect of thinning into account by including information obtained from the old stumps in the analysis from which the quantitative effect of thinning can be calculated. Usefulness of using information on the dead stems in reconstructing stand structure in the past is also evident from the study by J. M. Metsaranta et al. (2008), in which stand structure in the past was estimated from tree-ring and stem size data of both living and dead stems in the stands.

The objective of this study was to test the feasibility of correction of the stand variables by the stand reconstruction technique (Osawa et al., 2000, 2005) by including information on thinned tree stumps found in the stands examined. The reconstructed values of the aboveground biomass, total stem volume, stem volume growth and stand density were compared to those observed during previous stand measurements. In other words, the reconstructed values before and after adding information on the stumps will be compared to that on the census data. This kind of assessment has not been made previously and hence the results may lead to possible improvement in the estimates of stand variables in the stand reconstruction technique.

## MATERIALS AND METHODS

*Plot establishment and treatment.* The study was conducted at Hitsujigaoka Experimental Forest (43°00′ N, 141°23′ E) at the island of Hokkaido, northern Japan at an altitude of approximately 150 m above sea level, on a flat terrain. Mean annual temperature and annual precipitation are 7.5 °C, and 952 mm, respectively (29-year means) (Mizoguchi, Yamanoi, 2015). General vegetation of the area is secondary deciduous broadleaf forest regenerated after wildfires in the late 19th century.

A few of even-aged monospecific plantations were established in 1973 (Sanada et al., 1995). Those included pairs of stands of the Sakhalin fir *Abies sachalinensis* (F. chmidt) Mast. (Plots 8 and 9), the Ezo spruce *Picea jezoensis* (Siebold & Zucc.) Carrière (Plots 14 and 15), and Glehn's spruce *Picea glehnii* (F. Schmidt) Mast. (Plots 18 and 19), each of which had a varying stand area between 153.6 and 306.7 $m^2$ (Osawa et al., 2005). The three species occur in northern Japan and in the surrounding maritime regions of northeast Asia. The secondary forest of the area was cleared, and slash burned before the establishment of the plot. The initial planting density was 3900 stems per hectare. The plantations were intended for a a fertilization experiment. One block of the original plantation consisted of 12 rows of 15 trees in each row for the Sakhalin fir, 10 rows of 10 trees for both the Ezo spruce, and Glehn's spruce. Plots 9, 14, and 18 received NPK fertilizers annually starting in 1978, while plots 8, 15, and 19 did not receive any and were treated as control. The amount and timing of N, P, and K supplied to each fertilized plot were described in detail in M. Sanada et al. (1995). For the Sakhalin fir (Plots 8 and 9), 15–22 % of the trees in the plots were selected systematically without regard to tree size and quality and were thinned between 1998 and 2001 (Aizawa et al., 2012). As for the Ezo spruce and Glehn's spruce (Plots 14 and 15, Plot 18 and 19), 15–25 % of the trees, most of which were suppressed individuals, were thinned in 2003 (Tanaka et al., 2004; Aizawa et al., 2012). It should be noted that examining the effects of fertilization or thinning on stand development was not the purpose of the present study. Rather, these stands were used so that effectiveness of the stand reconstruction technique could be tested quantitatively when the stands developed with or without the thinning treatments.

*Stand measurement and stem disk collection.* Tree height and *DBH* of all living stems were measured in 1978 when the stands were 5-year-old. Similar stand measurements were repeated at irregular intervals: years of censuses after 1978 varied depending on the study plot. Tree height was measured for only the selected trees in 1995. *DBH* of the living trees in all the plots has been measured annually since the year 2000, but measurement were made for only selected years from the 1970s to the 1990s. Annual increment of tree height was also estimated from positions of branch whorls along a stem for the following years: 1974, 1975, 1976, and 1977 in 1978 census; 1979 in 1980 census; 1983 and 1984 in 1985 census; and 1989 and 1990 in 1991 census (Osawa et al., 2005). All the living trees in the selected six plots were censused in November, 2013, and 30 sample trees (5 trees of various sizes per plot) were selected and felled for collecting stem disks at 0, 1.3, 3.3 m, then at two-meter intervals throughout the length of the stem. Stem disks were first sanded with a mechanical belt sander, then manually with sand paper, with progressively finer grades sand paper (80–1200 grits) (Stokes, Smiley, 1996) to reveal their growth ring boundaries.

*Stump sampling protocol.* We attempted to collect old stumps from the six plots in November 2015 from all trees that were cut by thinning operations in the previous years. Trees were originally planted at grid points of approximately 1.6 m intervals. All trees were numbered systematically, and the history of stand treatment was registered with specific cutting date for each thinned tree. Therefore, it was possible to determine for a given stump, the cutting date and tree size when harvested. When a stump wasselected, its diameter was measured with a diameter tape. If bark was absent or the perimeter of the stump was lost due to decay, notes were taken. Then, the stump was cut carefully with a handsaw at the height of about 0.3 m to yield a sample disk of 5–8 cm thickness. The stump samples were protected by covering them tightly with thin plastic film and then transported to the laboratory for analysis.

*Decay classification.* The rate and speed of the decomposition of stumps depend on a number of factors such as wood characteristics (tree species, dimensions), and site environmental factors (Radtke et al., 2004). The characterization of decay classes is usually based on the morphological features (e. g. presence or absence of bark) or hardness of the wood. Analysis of the level of decay of the stumps allows a rough estimate of the cutting date., Based on decay level stumps were classified into five-class system with a five-point scale, according to M. L. Hunter and F. K. A. Schmiegelow (2011). This system is based on morphological wood features and other characteristics, such as colour of wood and wood integrity. Since a large number of the stumps have already disappeared and are gone, our study only covered classes 1 to 3. In the M. L. Hunter and F. K. A. Schmiegelow (2011) classification system, class 1 refers to the stumps that have entire bark and the wood is hard with an intact structure and original colour. Class 2 includes the stumps with the bark partly gone. However, the wood is still firm and shows its original colour. Class 3 is categorized as stumps with the bark absent and the wood getting softer, while the core is still firm and the colour starts fading away. Figure 1 shows some photographs of stump samples after sanding.

*Treatment of stumps.* The stump samples were dried at room temperature for about one week, then the decaying portions were fixed to prevent disintegration with ROTFIX®, epoxy resin developed specially for decaying wood material. The epoxy resin was generously applied to the stump surface so that a sufficient amount of resin should penetrate into the wood. When the decay was extensive, the stump sample was soaked in the epoxy resin. The samples were left to dry and harden for five to six hours. To reveal their growth rings, the stump samples were first sanded with a mechanical belt sander, then manually with sand paper, with progressively finer sand paper beginning with 240, 320, 400 grits, and ending with 800 grits (Stokes, Smiley, 1996). It should be noted that only the decay classes 1 and 2 of the stumps were sanded with the mechanical belt sander. The stumps of class 3 were sanded manually only with sand paper.

*Tree-ring measurements, cross-dating and stem analysis.* For stem analysis, tree-ring widths of stem samples of living trees and the stump samples were measured with 0.01 mm accuracy with the «Velmex TA system» linear measurement de-

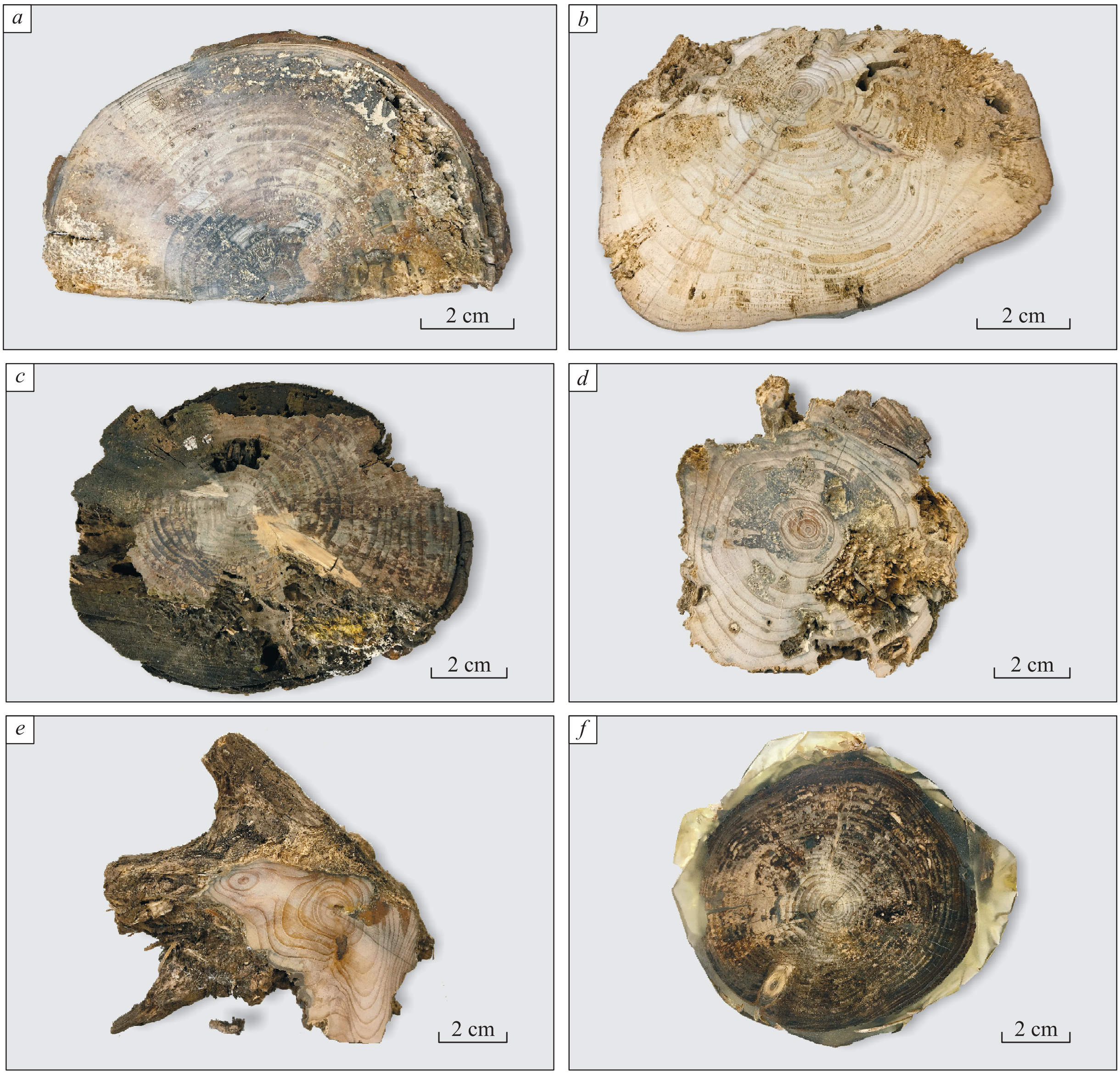


**Fig. 1.** Examples of stump samples for: *a* – undecayed stump with intact bark of the Sakhalin fir, N. 72; *b* – undecayed stump without bark of Glehn's spruce, N. 12; *c* – decaying stump with intact bark (at least a small portion) of Glehn's spruce, N. 92; *d* – decaying stump without bark of the Sakhalin fir, N. 42; *e* – stump with poor circuit uniformity of the Ezo spruce, N. 33; *f* – sanded stump of Glehn's spruce, N. 52 after applying epoxy resin. A scale bar in each photograph represents a length of 2 cm.

vice (Velmex…, 2009) using tree-ring measuring program «MeasureJ2X» (Voor Tech…, 2008). Tree rings of the stem disks from living trees were measured and counted starting from the outermost ring beginning with the year 2013 to the innermost ring. Every 10$^{th}$ ring was marked with a single dot (Speer, 2012). However, the stump samples were measured differently from the living stem disks. Specifically, the starting point of measurement was from the pith, and the rings were read beginning with the relative year of 1 and continued to the outermost part of the rings. All tree-rings were visually cross-dated to match the corresponding years of tree-ring production. However, more systematic cross-dating (such as the use of CDendro and COFECHA programs) was not practical due to relatively young tree age (ca. 40 years) in the present analysis. This may have caused some errors in the estimated cutting dates of the stumps

On the other hand, we assume that its effect on the estimated tree size in the past would be minimal, if the decay of the stump was not extensive. The stem analysis program «stem4r.xls» was applied to the visually cross-dated tree ring data from a series of stem disks collected at various heights of a tree, and stem volume, stem diameter at breast height, total tree height, and annual stem volume increment were calculated (Miyaura, 2015).

*Stand reconstruction technique.* A detailed description of the concept and idea of stand reconstruction technique is presented by A. Osawa et al. (2000). A. Osawa et al. (2005) also gave a description of the technique and applied it to estimate the aboveground biomass, total stem volume, stem volume growth and stand density of even-aged the Sakhalin fir stands. A. Osawa et al. (2005) should be addressed for the details of the technique. However, in order to provide basic understanding of the method in the following discussion, a short description of the stand reconstruction technique is presented.

We denote $v$ as stem volume without bark and $w$ as aboveground tree mass (or stem volume) with bark. $DBH$, tree height ($H$), $v$ and $w$, in the year of last tree census in 2013 are denoted as $DBH^*$, $H^*$, $v^*$, and $w^*$, respectively. Stem analysis data obtained from the sample trees supply information on fresh stem volume without bark, given that an appropriate correction between air-dried and fresh samples is made. Then we can express the relationship between $v$ and $DBH^*$ and $H^*$ as

$$v(t) = \alpha_2 \cdot (DBH^{*2} \cdot H^*)^{\beta_2}. \quad (1)$$

Eq. (1) states that stem volume without bark in a given year in the past can be estimated from $DBH$ and tree height in 2013, the most recent year of tree census. The parameter values of $\alpha_2$ and $\beta_2$ change over time $t$. Stem analysis data was used to calculate these two parameter values at a given time in the past. Furthermore, the allometric relationship between $w^*$ and $v^*$ can be derived as

$$w^* = \alpha_3 \cdot v^{*\beta_3}. \quad (2)$$

The parameters $\alpha_3$ and $\beta_3$ can be considered time independent in a given stand. Then, at a given year $t$, the above relationship can also be rewritten as,

$$w(t) = \alpha_3 \cdot v(t)^{\beta_3}. \quad (3)$$

By inserting Eq. (1) into Eq. (3), we have

$$w(t) = \alpha_3 \alpha_2^{\beta_3} (DBH^{*2} \cdot H^*) \beta_2 \beta_3. \quad (4)$$

The above equation allows us to estimate the stem volume or aboveground tree mass with bark of all trees in a stand at any year in the past from the most recent tree census data of 2013.

The following cumulative functions are also determined to characterize stand statistics. We define $\varphi(w)$ as a frequency distribution function of $w$ for a given stand at a given year (Hozumi, 1971). Then, $Y(w)$, $N(w)$ and $M(w)$ are obtained with the maximum value of stem size for this stand and year as (Hozumi, 1971)

$$Y(w) = \int_w^{w_{\max}} w \cdot \varphi(w) dw, \quad (5)$$

$$N(w) = \int_w^{w_{\max}} w \cdot \varphi(w) dw, \quad (6)$$

$$M(w) = Y(w) / N(w). \quad (7)$$

$Y(w)$ and $N(w)$ are cumulative aboveground biomass (or stem volume) of trees and the number of trees for those larger than or equal to $w$ in a stand, respectively. $M(w)$ represents mean stem size for trees greater than or equal to the size $w$. Given that there is linearity between $M(w)$ and $w$ with constants $A$ and $B$ (Hozumi, 1971)

$$M(w) = A \cdot w + B, \quad (8)$$

the distribution function of stem size $\varphi(w)$ can be described as the beta-type distribution (Eq. (9)) with a constant $C$ in Eq. (10) (Hozumi, 1971)

$$\varphi(w) = C \{(A-1)w + B\}^{(2A-1)/(1-A)}, \quad (9)$$

$$C = \frac{A}{Q} \cdot \left(\frac{\beta_1}{B}\right)^{A/(1-A)}, \quad (10)$$

where $Q$ is plot area, and $\beta_1$ is a parameter satisfying the following relationship,

$$(Q \cdot N(w))^{(1-A)/A} = \alpha_1 \cdot w + \beta_1, \quad (11)$$

where $\alpha_1$ is an additional constant (Hozumi, 1971).

Using the beta-type distribution function, total aboveground biomass ($Y(w_{\min})$) and stand density ($N(w_{\min})$) are expressed, respectively as (Hozumi, 1971),

$$Y(w_{\min}(t)) = \{A \cdot w_{\min}(t) + B\} \times \times \frac{C}{A} \{(A-1) \cdot w_{\min}(t) + B\}^{A/(1-A)}, \quad (12)$$

$$N(w_{\min}(t)) = = \frac{C}{A} \{(A-1) \cdot w_{\min}(t) + B\}^{A/(1-A)}, \quad (13)$$

where $w_{\min}$ is the size of the smallest living tree in the stand.

Finally, the stem volume growth of a tree in year $t$, $\Delta v(t)$, was obtained from stem analysis data. The stem volume growth in year $t$ was calculated using Eq. (14),

$$\Delta v(t) = v(t_2) - v(t_1), \quad (14)$$

where $v(t_2)$ and $v(t_1)$ represent stem volume without bark in years $t_2$ and $t_1$, respectively. Plus, additional information on stem volume without bark in the same year and Eq. (3) generate the following relationship:

$$\Delta v(t) = \alpha_4 \cdot w(t)^{\beta_4}. \quad (15)$$

Parameters $\alpha_4$ and $\beta_4$ are time-dependent and could be derived from fitting the Eq. (15) to the data logarithmically. Stem volume growth at a stand level was estimated by summing the growth estimate of all trees in a given stand. Therefore, Eq. (15) can be applied to estimate stem volume growth at a stand level.

Eqs. (1), (12), (13) and (15) allow us to calculate total stem volume, total aboveground biomass, stand density and stem volume growth, respectively, using the stand reconstruction technique.

*Incorporating stump information into the stand reconstruction technique.* Stump diameter and tree-ring data provide sufficient information for adding to the stand reconstruction technique. Stumps of the Sakhalin fir, the Ezo spruce, and Glehn's spruce from the six plots were incorporated into the analysis of the original stand reconstruction method. Four main variables including stem mass with bark, stem volume with bark, stem volume growth and stand density were estimated with the added information on the stumps in the stand reconstruction technique. To estimate these variables, we first estimated *DBH*, stem volume without bark, stem volume with bark, and aboveground biomass of a tree from the stump sample. Then, stem volume, stem volume growth, stem mass with bark and stand density at the stand level and before the thinning were reconstructed by adding quantities of the trees estimated from the stumps. Methods for estimating several tree variables (*DBH*, total tree height, stem volume with bark and stem mass with bark) from the thinned tree stumps were described as follows.

*Diameter at breast height* (*DBH*): *DBH* of a thinned tree at the time of thinning was estimated from the measurement of stump diameter, $D_{0.3}$ and a quantitative relationship between *DBH* and $D_{0.3}$,

$$DBH = \alpha_5 + \beta_5 \cdot D_{0.3}, \quad (16)$$

where $\alpha_5$ and $\beta_5$ are time independent parameters determined for the trees used in stem analysis. The $R^2$ values for the Sakhalin fir, the Ezo spruce, and Glehn's spruce are 0.97, 098, and 0.98, respectively.

*Stem volume with bark:* Stem volume for fresh bark, $W$(m$^3$), was estimated from *DBH* with bark for fresh samples with the allometric function as follows:

$$W = \alpha_6 \cdot DBH^{\beta_6}, \quad (17)$$

where the values for time-dependent parameters $\alpha_6$ and $\beta_6$ were determined by fitting a linear relationship to the log-transformed (base 10) form of Eq. (17). Stem analysis supplied data on stem volume and *DBH* without bark (air-dried) for different years. *DBH* with bark (fresh) was calculated as the without-bark *DBH* multiplied by 1.0331, 1.0387, and 1.0278 ($R^2$ = 0.99 for all species, $n$ = 10) for the Sakhalin fir, the Ezo spruce, and Glehn's spruce, respectively. Stem volume with fresh bark was calculated similarly as without that bark (air-dried) multiplied by 1.043, 1.070, and 1.091 ($R^2$ = 0.99 for all species, $n$ = 10) for the Sakhalin fir, the Ezo spruce, and Glehn's spruce, respectively.

*Stem volume growth:* Eq. (15) also allows us to estimate stem volume growth of a tree from the data on the stumps and information on the estimated stem volume without bark ($v$) using Eq. (3). Parameters $\alpha_4$ and $\beta_4$ vary over time.

*Aboveground mass with bark:* Eqs. (2), and (3) provide data to estimate the aboveground mass at any time in the past, in which the aboveground mass was calculated from the stem volume. Stem volume of a tree when harvested was derived from the size of the stump at any time in the past.

*Stand density:* stand density including the thinned trees was estimated by adding the number of stumps on the assumption that those trees were living just before they were cut at a given year in the past.

*Testing predictions.* Reconstructed values of aboveground biomass, total stem volume, total stem volume growth and stand density were compared with those of the obtained values or those calculated with the census data in the previous years. Comparisons were made by plotting the reconstructed vs. obtained values on linear coordinates of the variables concerned. We assume that the reconstructed and obtained values to be equal. Therefore, the plotted points on the X–Y plane are expected to lie along a straight line, $y = \alpha + \beta \cdot x$, with its regression slope being equal to unity and intercept equal to zero simultaneously (Dent, 1979; Osawa et al., 1991). This hypothesis was tested simultaneously with F-test (Dent, 1979; Osawa et al., 1991) with the significance level equal to 5 %. Bootstrap method was used to calculate the 95 % confidence limits of the estimated means by sampling tree data $n$ times ($n$ being the number of living stems) with replacement from the population of trees in the stand in 2013, then repeating the process 1000 times to estimate the 95 % confidence interval (CI) (Efron, 1979; Efron, Gong, 1983).

## RESULTS AND DISCUSSION

Without adding the stumps (the original stand reconstruction technique), the null hypothesis of zero intercept (α = 0) and unity slope (β = 1) for the relationships between reconstructed and observed values of aboveground biomass could not be rejected at the 5 % level for most plots, except for plot 9, indicating that the differences were not significant. The critical value of $F_{0.05}$ with 2 and 5 degrees of freedom were 5.79. The representing *F* statistical values were $3.66^{NS}$, $8.18^{*}$, $1.57^{NS}$, $2.17^{NS}$, $1.63^{NS}$, and $3.45^{NS}$ for plots 8, 9, 14, 15, 18, and 19, respectively. By adding the stump information to the original stand reconstruction technique, the relationships between the reconstructed and obtained values registered for the aboveground biomass showed slight improvements in plots 8, 14 and 19. The null hypothesis could not be rejected at the 5 % level for most plots, except for plot 9. The corresponding *F* values were $3.14^{NS}$, $5.91^{*}$, $0.28^{NS}$, $4.48^{NS}$, $3.36^{NS}$, and $0.94^{NS}$ for plots 8, 9, 14, 15, 18, and 19, respectively.

When the stump data were not added to the reconstructed values, patterns of the relationships between the reconstructed and obtained values for total stem volume were similar to those of the aboveground biomass. The representing *F* values were $3.70^{NS}$, $8.33^{*}$, $2.83^{NS}$, $1.19^{NS}$, $2.14^{NS}$, and $3.88^{NS}$ for plots 8, 9, 14, 15, 18, and 19, respectively. The null hypothesis ($H_0$: α = 0, β = 1) could not be rejected at the 5 % level for most plots (except for plot 9), since $F_{0.05}$ (2.5) = 5.79. Even though the data on the stumps were integrated into the reconstructed values, general patterns of the relationships between the reconstructed and obtained values for total stem volume only revealed minimal improvements in plots 8, 14 and 19. Statistical data for *F* were $3.45^{NS}$, $6.65^{*}$, $1.07^{NS}$, $3.59^{NS}$, $4.59^{NS}$, and $2.00^{NS}$ for plots 8, 9, 14, 15, 18, and 19, respectively.

Without adding the data on the stumps, the relationships between the reconstructed and obtained values for stem volume growth indicated no significant differences at the 5 % level in all comparisons, except for plot 9. The corresponding *F* values were $1.95^{NS}$, $11.41^{*}$, $1.86^{NS}$, $1.96^{NS}$, $1.63^{NS}$, and $2.22^{NS}$ for plots 8, 9, 14, 15, 18, and 19, respectively. The null hypothesis of zero intercept and unity slope could not be rejected at the 5 % level for most plots, given that $F_{0.05}$ (2.5) = 5.79. When data on the stumps were included into the analysis of reconstructed values, general trend of the relationships was improved in most plots. The representing *F* values were $0.58^{NS}$, $4.85^{NS}$, $1.86^{NS}$, $1.22^{NS}$, $0.35^{NS}$, and $3.23^{NS}$ for plots 8, 9, 14, 15, 18, and 19, respectively. Since the critical value of $F_{0.05}$ with degrees of freedom 2 and 5 is 5.79, the null hypothesis of zero intercept (α = 0) and unity slope (β = 1) could not have been rejected in all cases.

Without the data on the stumps being added to the reconstructed values, the patterns of the relationships between the reconstructed and registered values for stand density were deleted for some plots. The corresponding *F* values were $5.87^{NS}$, $74.66^{*}$, $2.58^{NS}$, $1.70^{NS}$, $7.31^{*}$, and $3.38^{NS}$ for plots 8, 9, 14, 15, 18, and 19, respectively. The null hypothesis was rejected at the 5 % level for plots 8, 9 and 18. When the stump information was added to the analysis, however, the patterns of the relationships between the reconstructed and observed values for stand density did not highlight any significant improvement, except for plots 14, 15, and 19. Values of the *F* statistic were $16.94^{*}$, $7.63^{*}$, $1.86^{NS}$, $0.26^{NS}$, $9.28^{*}$, and $1.76^{NS}$ for plots 8, 9, 14, 15, 18, and 19, respectively. Nevertheless, the null hypothesis of zero intercept and unity slope was rejected at the 5 % level for plots 8, 9, and 18, as the critical value of $F_{0.05}$ with the degrees of freedom of 2 and 5 was 5.79.

The present study attempted to answer the question whether adding the information on stumps into the original stand reconstruction technique could yield better predictions of long-term stand development for even-aged plantations. In general, our results from the statistical *F* tests have shown that adding the stump information improves the overall estimates of aboveground biomass, total stem volume, and stem volume growth only slightly. The estimates of stand density have indicated general improvement in the Ezo spruce (Plots 14 and 15) and Glehn's spruce (Plot 19 only), but not in the Sakhalin fir (Plots 8 and 9). However, most *F* tests were not statistically significant, suggesting that the estimated stand variables with or without the stump information were not different from those observed in the plots in the past. This observation implies that the improvement gained by adding the stump data is minimal, when the level of thinning is relatively small as was the case in the present study (15–25 % of the total tree number). However, the improvement due to adding stump data tends to be seen clearly in the estimates of stand density.

Significant differences between the reconstructed and registered values were revealed in the Sakhalin fir (especially plot 9) even after adding the stump information. In these two plots, information for the stumps only made a small contribution to the improvement in predictions. The differences probably resulted from the fact that fir stands experienced heavier thinning in comparison to other stands revealed by the number of thinned trees. The number of thinned trees was 48, 50, 14, 13, 22, and 20 for plots 8, 9, 14, 15, 18, and 19 respectively.

An alternative approach in testing the improvement of the predictions is a comparison of the reconstructed vs. registered values by calculating percentage error, defined as $(R - O)/O$, in which $R$ and $O$ stand for reconstructed and observed values, respectively. In the following, we discussed the stand reconstruction technique without adding the stumps, followed by that incorporating the stump information.

Without adding the stump information, values of the percentage error of the estimates generally varied within ±10 % of the observed values of aboveground biomass, stem volume, stem volume growth, and stand density after the year 2003, except for some years that the error ascended to ±20 %. However, the percentage error grew larger sometimes to ±40 % before 1997 (for fir) or before 2003 (for spruce). This suggested that the predictions of these variables can be trusted within ±10 to 20 % only for the years after the major thinning operations in 1998 and 2001 (for fir) or in 2003 (for spruce). If we focus on the estimates of stand density, it is generally reconstructed with reasonable accuracy (< ±15 %) after the thinning operations of 1998 and 2001 for fir plots 8 and 9, and of 2003 for spruce plots 14, 15, 18, and 19. Our results disagreed with those of A. Osawa et al. (2005) that the percentage error of the estimates can be generally trusted within ±17 % of the obtained values of three variables from 1985 to 1998, except for stand density. In other words, our predictions from 1985 to 1997 revealed larger errors (±40 %) than those from 1985 to 1998 (±17 %) by A. Osawa et al. (2005). This difference can be attributed to the fact that the stands used for the analysis (Plots 8 and 9) by A. Osawa et al. (2005) never experienced thinning.

When the stump information was integrated into the analysis, our result indicated that values of the percentage error of aboveground biomass, total stem volume, stem volume growth and stand density generally decreased to less than ±15 % (as opposed to ±20 % without adding the stumps) of the observed values in any year after the thinning operations (i. e. 1998 and 2001 in fir stands and 2003 in spruce stands), indicating that including the stumps slightly improved the predictions. For the years before 1997, the values of the percentage error generally descended to ±30 % (as opposed to ±40 % without the stumps) (Table 1).

In general, our results of percentage error suggested that adding the stump information showed small improvement of predictions in most plots, particularly for years before the thinning.

To reaffirm our predictions, bootstrap method was used to estimate the 95 % confidence intervals (C. I.) of the estimated means of reconstructed values with and without the stump information. For aboveground biomass and stem volume without adding stumps, general lack of overlap between the estimated 95 % C. I. of the mean of the reconstructed value (vertical bar in broken line) and the observed value before thinning operations was shown in plots 8, 9, 18 and 19. In contrast, general overlap between them was indicated in plots 14, and 15. The general overlap of the estimated 95 % C. I. and the observed value in plots 14 and 15 in the year before the thinning suggested that these two means, without adding stumps, were not different statistically (Fig. 2 and 3).

After including the stump information, the overlap between the 95 % C. I. of the reconstructed values (vertical bar in solid line) and the observed values for aboveground biomass and stem volume was reported in plots 8, 18, and 19. This suggested that adding stump data can improve the predictions in these three plots in contrast to those without adding stump data.

Overall, after adding stump data, significant improvements of the prediction could be seen clearly in Glehn's spruce (especially plot 19), in comparison to the Sakhalin fir and the Ezo spruce. This is probably due to the slow decay rate of the Glehn's spruce stumps which depends on a number of factors such as tree species, dimensions (tree size), and site environmental factors (Radtke et al., 2004).

According to Y. Sakai et al. (2008), stumps of the Sakhalin fir and Glehn's spruce, which are planted in a relatively cool region, tend to decay slower than other coniferous tree species. In our study we confirmed that Glehn's spruce decayed slower than the other two species since the number of missing stumps was greater in the Sakhalin fir and the Ezo spruce (20 missing stumps in each species), but smaller in Glehn's spruce (13 missing stumps).

**Table 1.** Percentage error of the reconstructed values of aboveground biomass (AGB), total stem volume (SV), stem volume growth (SVG) and stand density (SD) for different years. Percentage error is defined as (*R*–*O*)/*O*, with *R* and *O* denoting reconstructed and obtained values, respectively

| Species | Plot | Year | With stumps (*R*–*O*)/*O* | | | | Without stumps (*R*–*O*)/*O* | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | AGB | SV | SVG | SD | AGB | SV | SVG | SD |
| Sakhalin fir | 8 | 2013 | –2.0 | –3.0 | 0.0 | 4.2 | –2.0 | –3.0 | 0.0 | 4.2 |
| | | 2010 | –3.9 | –4.2 | 1.1 | –1.0 | –3.9 | –4.2 | 1.1 | –1.0 |
| | | 2006 | –7.1 | –7.2 | –9.7 | –8.1 | –7.1 | –7.2 | –9.7 | –8.1 |
| | | 2003 | –8.8 | –8.5 | –13.6 | –11.8 | –8.8 | –8.5 | –13.6 | –11.8 |
| | | 1997 | –26.0 | –25.7 | –16.4 | –33.7 | –35.9 | –37.3 | –28.4 | –43.6 |
| | | 1993 | –16.5 | –18.9 | –9.1 | –29.2 | –33.6 | –36.9 | –27.9 | –46.9 |
| | | 1988 | –1.4 | 9.8 | 0.6 | –26.6 | –30.2 | –26.8 | –24.5 | –51.6 |
| | 9 | 2013 | –1.5 | –2.0 | 2.3 | –0.5 | –1.5 | –2.0 | 2.3 | –0.5 |
| | | 2010 | –3.7 | –3.9 | 4.9 | –8.7 | –3.7 | –3.9 | 4.9 | –8.7 |
| | | 2006 | –8.3 | –8.4 | –11.4 | –18.1 | –8.3 | –8.4 | –11.4 | –18.1 |
| | | 2003 | –7.8 | –7.9 | –12.6 | –17.0 | –7.8 | –7.9 | –12.6 | –17.0 |
| | | 1997 | –27.0 | –27.1 | –24.6 | –37.5 | –32.9 | –32.9 | –29.4 | –44.8 |
| | | 1993 | –26.7 | –27.8 | –25.8 | –28.4 | –37.6 | –38.4 | –37.2 | –43.8 |
| | | 1988 | –26.0 | –26.6 | –23.8 | –21.8 | –44.6 | –45.1 | –42.6 | –44.2 |
| Ezo spruce | 14 | 2013 | 0.7 | 0.0 | 0.0 | 5.4 | 0.7 | 0.0 | 0.0 | 5.4 |
| | | 2010 | 0.9 | –0.6 | –1.0 | 6.6 | 0.9 | –0.6 | –1.0 | 6.6 |
| | | 2006 | –4.2 | –6.5 | –8.4 | 5.8 | –4.2 | –7.0 | –8.4 | 5.8 |
| | | 2003 | –13.2 | –16.2 | –17.4 | –14.6 | –13.2 | –19.3 | –17.4 | –14.6 |
| | | 1997 | –5.3 | –10.9 | –15.5 | –7.9 | –17.3 | –25.9 | –22.7 | –15.3 |
| | | 1993 | 1.8 | –5.7 | –12.3 | –6.3 | –13.7 | –22.7 | –21.1 | –15.0 |
| | | 1988 | 42.4 | 30.3 | 10.0 | 6.8 | 6.0 | –5.2 | –6.6 | –9.2 |
| | 15 | 2013 | –1.6 | 0.0 | 0.0 | 1.1 | –1.6 | 0.0 | 0.0 | 1.1 |
| | | 2010 | 1.0 | 2.2 | 2.5 | 2.3 | 1.0 | 2.2 | 2.5 | 2.3 |
| | | 2006 | –5.5 | –5.1 | –6.7 | 3.3 | –5.5 | –5.1 | –6.7 | 3.3 |
| | | 2003 | 7.7 | 8.0 | 6.5 | –4.2 | –7.4 | –7.6 | –6.9 | –10.7 |
| | | 1997 | 48.0 | 54.7 | 26.0 | –9.1 | –9.4 | –10.1 | –12.4 | –28.1 |
| | | 1993 | 81.2 | 86.8 | 65.3 | –4.9 | –8.5 | –8.1 | –6.3 | –31.5 |
| | | 1988 | 174.7 | 190.3 | 77.9 | 3.7 | –4.6 | –1.9 | –7.1 | –34.6 |
| Glehn's spruce | 18 | 2013 | –1.8 | 0.0 | 0.0 | –0.9 | –1.8 | 0.0 | 0.0 | –0.9 |
| | | 2010 | 6.0 | 6.9 | 10.3 | –0.2 | 6.0 | 6.9 | 10.3 | –0.2 |
| | | 2006 | 2.8 | 3.0 | 3.3 | 1.9 | 2.8 | 3.0 | 3.3 | 1.9 |
| | | 2003 | 10.3 | 8.9 | 3.8 | –28.1 | –1.0 | –1.0 | –2.8 | –31.0 |
| | | 1997 | 7.8 | 9.4 | –11.9 | –28.3 | –16.2 | –12.6 | –23.7 | –37.8 |
| | | 1993 | 7.7 | 10.9 | –6.4 | –25.6 | –28.6 | –22.4 | –25.6 | –40.0 |
| | | 1988 | 23.6 | 30.2 | –1.9 | –29.6 | –39.2 | –28.0 | –31.9 | –50.6 |
| | 19 | 2013 | 0.0 | 0.0 | 0.0 | –2.8 | 0.0 | 0.0 | 0.0 | –2.8 |
| | | 2010 | –0.3 | –3.6 | –3.8 | –3.8 | –0.3 | –3.6 | –3.8 | –3.8 |
| | | 2006 | –10.0 | –12.0 | –12.8 | –5.2 | –10.0 | –12.0 | –12.8 | –5.2 |
| | | 2003 | –1.9 | –6.3 | –10.7 | –21.7 | –23.4 | –25.1 | –25.1 | –27.7 |
| | | 1997 | –7.1 | –8.6 | –15.0 | –15.6 | –45.8 | –44.9 | –43.7 | –38.0 |
| | | 1993 | –17.1 | –15.7 | –21.1 | –12.5 | –55.5 | –52.9 | –52.4 | –40.1 |
| | | 1988 | 34.6 | 36.0 | 25.6 | 2.5 | –56.0 | –51.3 | –51.3 | –40.6 |

In other words, our study showed that the stumps of tree species with slower decay rate can improve estimates of the stand variables of the stand reconstruction technique better than those with faster decay rate. However, our study showed negative correlation between tree size and decay rate, which is contrary to the general notion that trees with a larger diameter decompose more slowly than smaller ones (Harmon et al., 1986; Frangi et al., 1997). The mean stump diameters of the Sakhalin fir, the Ezo spruce, and Glehn's spruce are 12.26 cm, 14.16 cm, and 11.18 cm, respectively.

For stem volume growth excluding stumps, generally non-overlap patterns between 95 % C. I. of the mean (vertical bar in broken line) and the obtained mean before the thinning were shown in almost all the plots. This implied that the two means were statistically different. After adding the stump

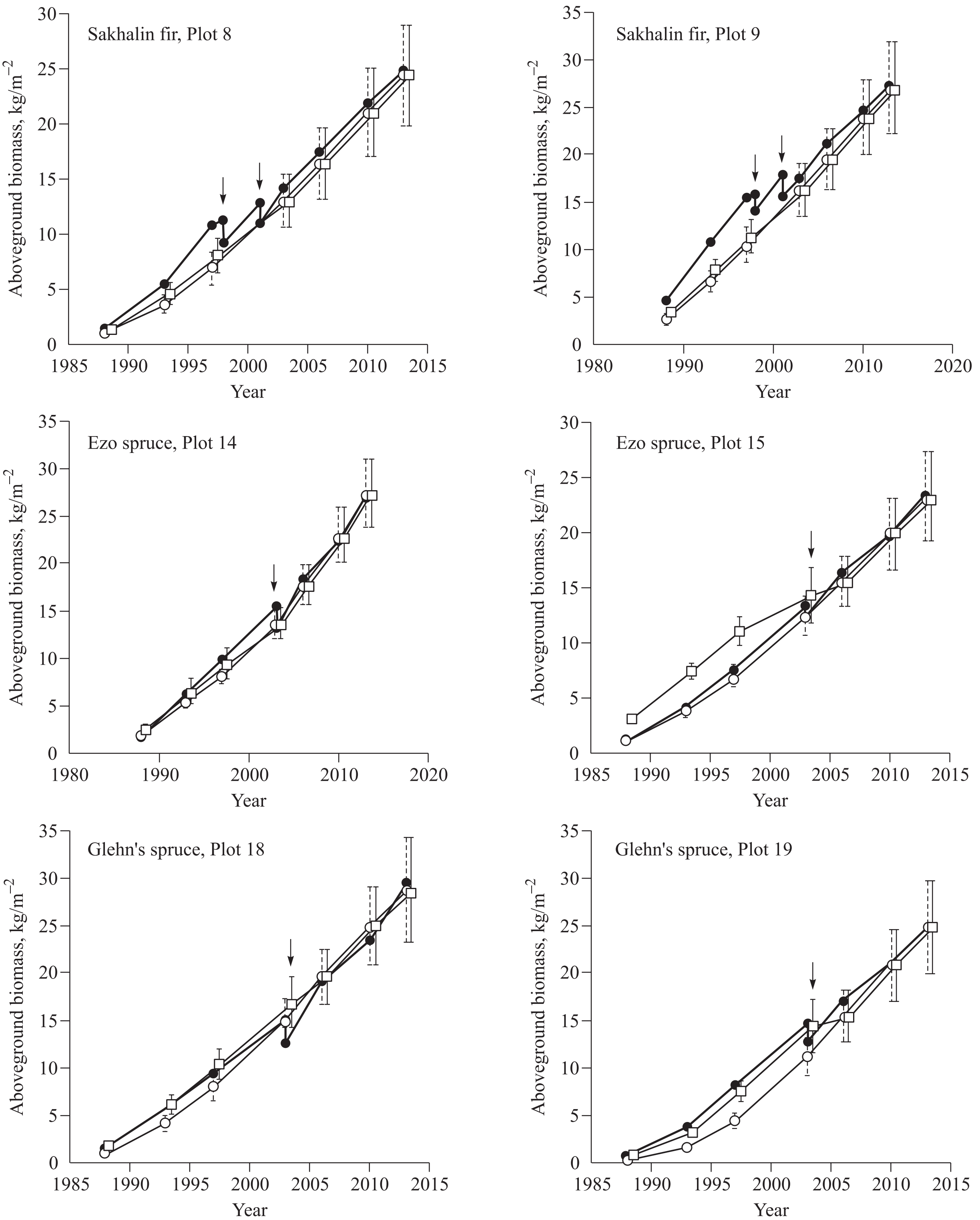


**Fig. 2.** Relationship between reconstructed and obtained values of aboveground biomass.Conventional symbols, represent reconstructed values using original stand reconstruction, reconstructed values after adding the stumps and observed values, respectively. Arrows indicate main years of thinning operations. Solid and broken vertical bars indicate the upper and lower 95 % confidence limits of the reconstructed values with and without stumps, respectively, based on the bootstrap method. The 95 % confidence limits cannot be estimated for plot 18 in 1988.

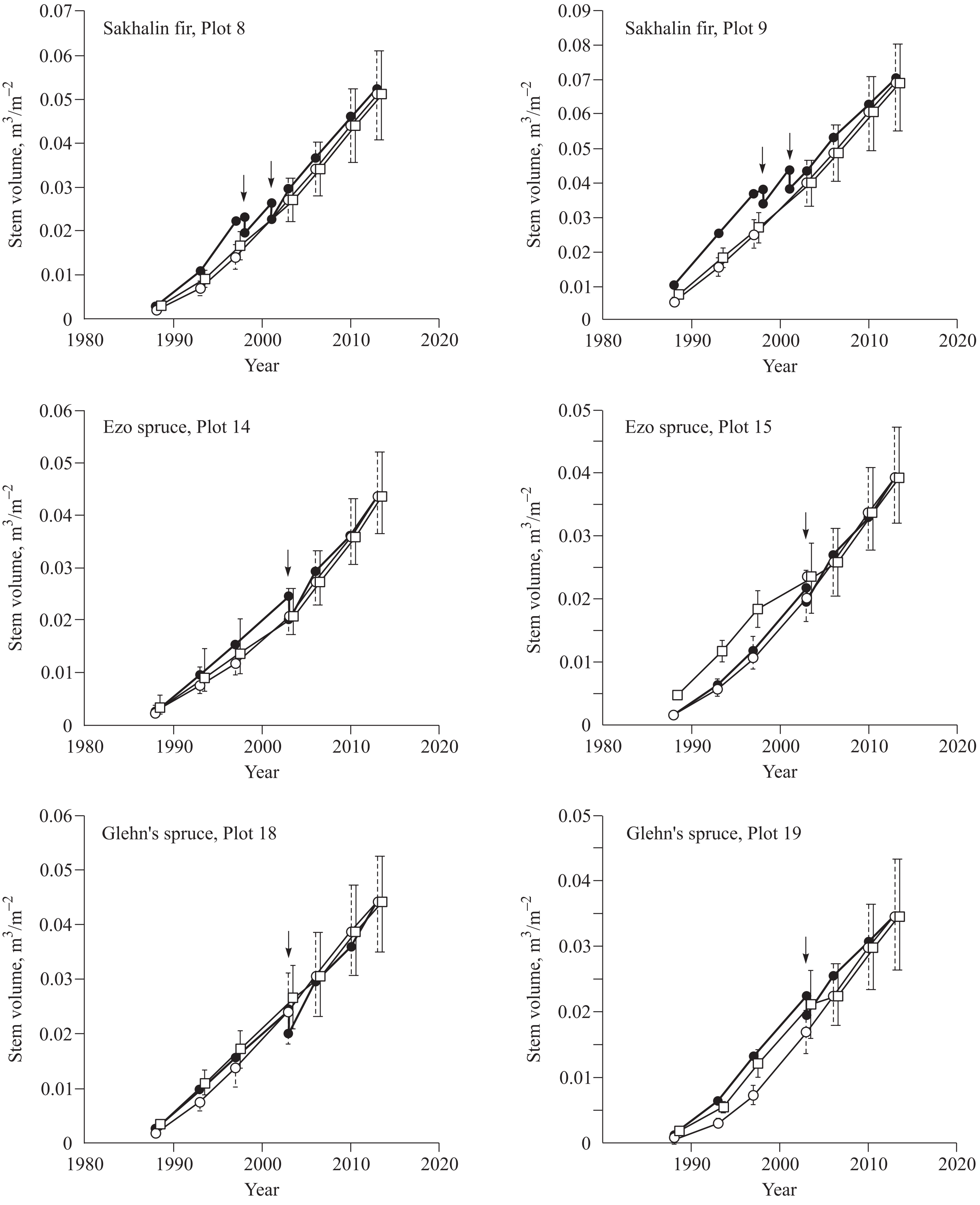


**Fig. 3.** Relationship between reconstructed and observed values of total stem volume. Conventional symbols, represent reconstructed values using original stand reconstruction, reconstructed values after adding the stumps and observed values, respectively. Arrows indicate main years of thinning operations. Solid and broken vertical bars indicate the upper and lower 95 % confidence limits of the reconstructed values with and without stumps, respectively, based on the bootstrap method. The 95 % confidence limits cannot be estimated for plot 18 in 1988.

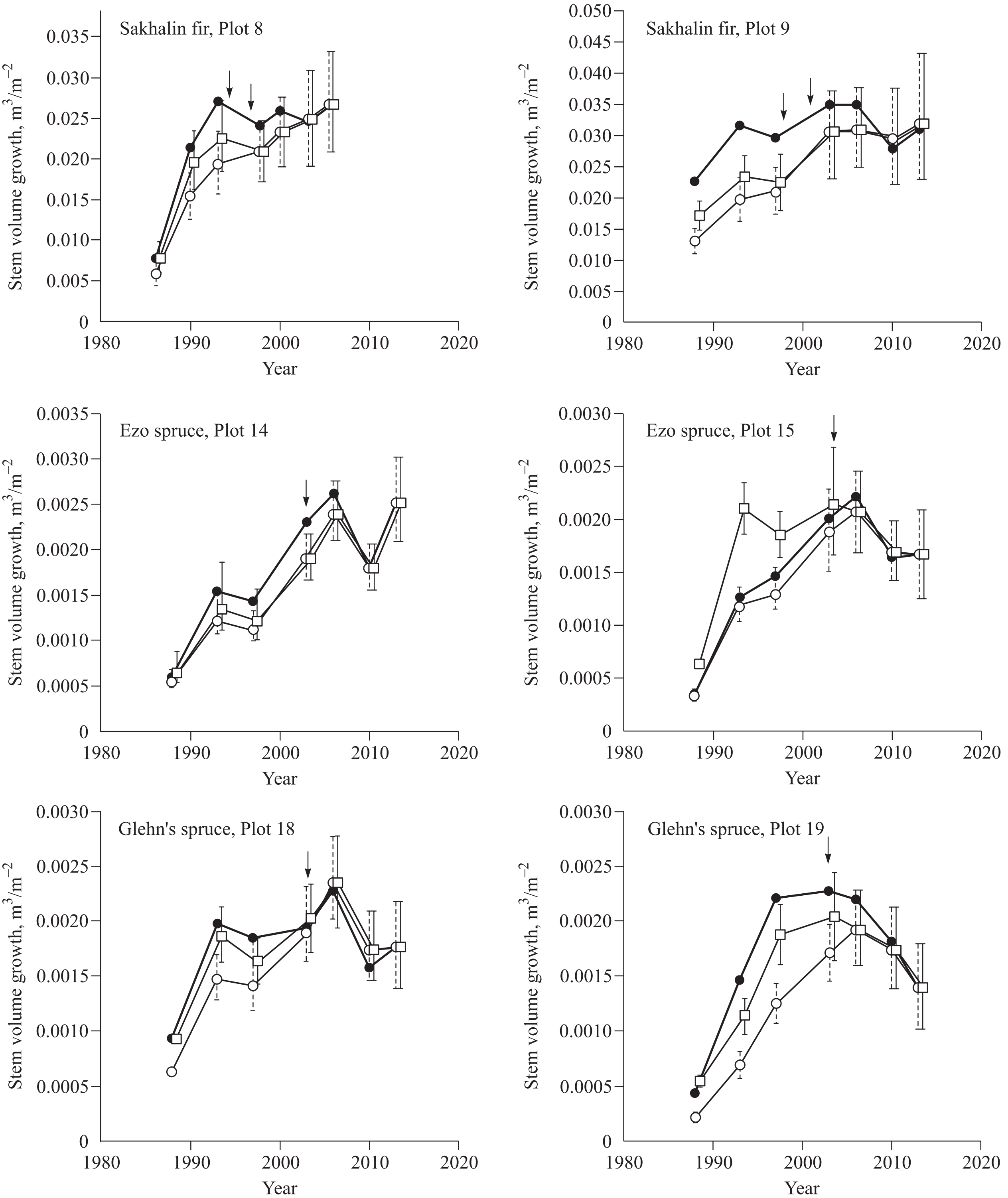


**Fig. 4.** Relationship between reconstructed and obtained values of stem volume growth. Conventional symbols, represent reconstructed values using original stand reconstruction, reconstructed values after adding the stumps and observed values, respectively. Arrows indicate main years of thinning operations. Solid and broken vertical bars indicate the upper and lower 95 % confidence limits of the reconstructed values with and without stumps, respectively, based on the bootstrap method. The 95 % confidence limits could not be estimated for plot 18 in 1988.

information, however, the improvement in predictions, indicated by generally overlapping patterns, could be seen in plots 8, 14, and 18. This suggested that including stumps could improve the predictions in these three plots, but not those in plots 9, 15, and 19 (Fig. 4).

For the estimates of stand density without stumps, nonoverlapping patterns of the estimated 95 % C. I. of the means in the reconstructed and obtained values before the thinning operations (1998 and 2001 in fir and 2003 in spruce stands) were displayed in plots 8, 9, 18, and 19, while their overlap in plots was demonstrated in plots 14 and 15. The nonoverlapping patterns for the Sakhalin fir and Glehn's spruce suggested that the differences were significant. Even though the data for stumps were included, the improvement was only minimal in the Sakhalin fir and Glehn's spruce plots and this was shown by the lack of overlap patterns within the confidence limits (Fig. 5).

In addition, the errors were commonly loomed large for years before the thinning operations. A relatively young stand age is partly the cause of this error. Since the plantation is still young, changes in tree number in the early years of stand development should be small. In addition, trees were relatively small during the 1980s, making the predictions of stand density more difficult. In contrast to the aboveground biomass, stem volume and stem volume growth, stand density is more difficult to reconstruct (Osawa et al., 2005) and even after adding stump information, the reconstructed and observed values still do not agree well. For this reason, stand density estimation of our study did not reproduce the observed values well in most plots.

The Rresults from the statistical *F* test, percentage error and the estimates of the 95 % C. I. by the bootstrap method suggested moderate to large errors in estimating the aboveground biomass, total stem volume, stem volume growth, and stand density in some plots.

Additional error could be due to the error associated with the cutting dates of the stumps, inferred from the tree-ring analysis. In our study, some stumps did not show sufficiently clear rings. More importantly, the majority of the stump samples did not have many rings due to their young age which prevented a detailed cross-dating. Furthermore, the growth of some stumps showed poor circuit uniformity, which can be ascribed to the tree rings concentrating around the middle of the cross-section of a stem, while circuit uniformity is required for successful cross-dating (Speer, 2012). In our study, a large number of the stump samples falls into class 3 of decay classification system, indicating extensive decay and barkless condition. Therefore, error in the estimates of cutting dates of the stumps may have occurred. We discovered that the estimated cutting dates are close to the actual cutting dates for the stumps categorized as class 1, and the error in cutting dates was as much as 4 years. However, for the class 2 and 3 stumps, the estimated and actual years of cutting differed greatly (up to 20 years) (Table 2).

Errors in estimating cutting dates also led to errors in estimating *DBH* from the stumps, which was the main variable in estimating stem volume with bark and stem mass with bark. This may have resulted in underestimation or overestimation of the stand variables when the stumps were added to the original stand reconstruction technique. It is noted that estimating *DBH*, stem volume with bark and stem mass with bark from the stump samples is intractable when most of the stump samples fall onto the class 3 decay classification system.

## CONCLUSION

The present analysis of taking into account stump information in the structural stand reconstruction in thinned plantations showed that the method could be applied to improve estimates of the aboveground biomass, total stem volume and stem volume growth; the estimates of stand density do not always improve for the periods before the thinning operations even after adding the stump information for estimation. The improvement can be small or unclear when the level of the thinning is minor. However, the inclusion of stump information in the stand reconstruction technique generally improves the levels of the relative error of the estimates and so is recommended. Successful collection of suitable stumps and/or dead stems, which is related to the quality of wood material (whether it is undecayed or decaying), would further improve the predictions. Caution should be applied when reading and cross-dating tree rings from the stumps sampled from a younger plantation. The improvement by adding the data on stumps to the stand reconstruction technique could probably be seen clearly, given that the level of thinning is larger and the decay rate of stumps is slower. Taking into account the data on stumps would widen applicability of the original stand reconstruction technique and provide further insights into analysis of long-term structural changes in forest stands.

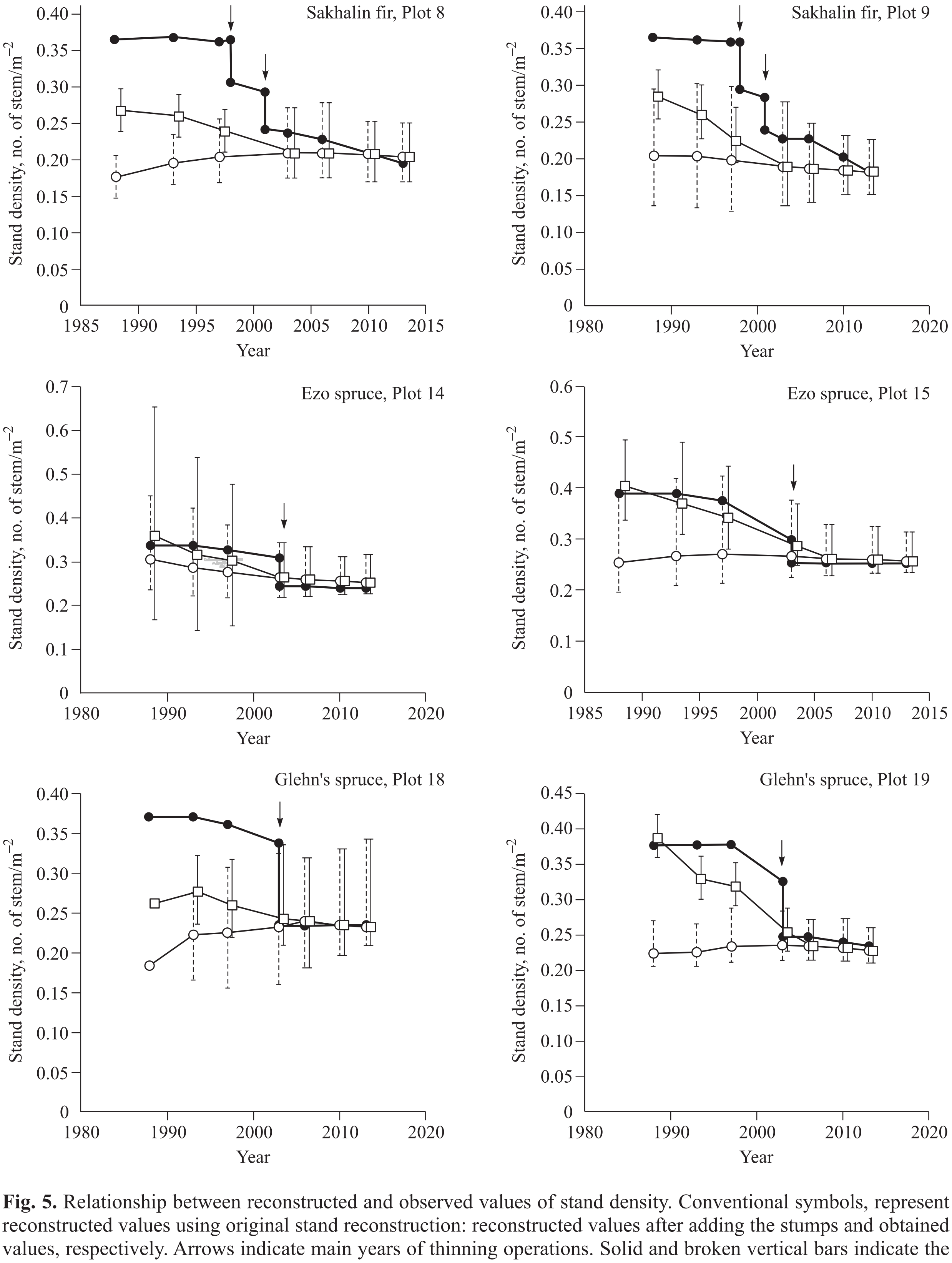


**Fig. 5.** Relationship between reconstructed and observed values of stand density. Conventional symbols, represent reconstructed values using original stand reconstruction: reconstructed values after adding the stumps and obtained values, respectively. Arrows indicate main years of thinning operations. Solid and broken vertical bars indicate the upper and lower 95 % confidence limits of the reconstructed values with and without stumps, respectively, based on the bootstrap method. The 95 % confidence limits could not be estimated for plot 18 in 1988.

**Table 2.** Decay classification of the stumps in the study plots with estimated and actual cutting dates. Absent stumps (i. e. stumps that could not be found at the time of field sampling) were also included. *G* denotes the stump which is gone and could not have been sampled

| Plot No. | Stump No. | Decay class | Number of rings | Estimated cutting date | Actual cutting date |
|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 |
| 8 | 27 | 1 | 27 | 2000 | 2001 |
| 8 | 29 | 1 | 28 | 2001 | 2001 |
| 8 | 31 | 1 | 15 | 1988 | 1997 |
| 8 | 33 | 1 | 26 | 1999 | 2001 |
| 8 | 35 | 1 | 28 | 2001 | 2001 |
| 8 | 54 | 1 | 28 | 2001 | 2001 |
| 8 | 73 | 1 | 24 | 1997 | 2001 |
| 8 | 101 | 1 | 27 | 2000 | 1997 |
| 8 | 105 | 1 | 20 | 1993 | 2002 |
| 8 | 113 | 1 | 21 | 1994 | 2000 |
| 8 | 155 | 1 | 34 | 2007 | 2007 |
| 8 | 51 | 2 | 25 | 1998 | 2001 |
| 8 | 1 | 2 | 26 | 1999 | 2002 |
| 8 | 19 | 2 | 28 | 2001 | 2002 |
| 8 | 22 | 2 | 28 | 2001 | 2001 |
| 8 | 62 | 2 | 26 | 1999 | 2001 |
| 8 | 64 | 2 | 23 | 1996 | 2001 |
| 8 | 65 | 2 | 22 | 1995 | 1997 |
| 8 | 88 | 2 | 26 | 1999 | 2000 |
| 8 | 94 | 2 | 25 | 1998 | 1997 |
| 8 | 122 | 2 | 21 | 1994 | 1997 |
| 8 | 60 | 3 | 27 | 2000 | 2001 |
| 8 | 17 | 3 | 17 | 1990 | 2001 |
| 8 | 25 | 3 | 23 | 1996 | 2001 |
| 8 | 36 | 3 | 16 | 1989 | 1997 |
| 8 | 39 | 3 | 16 | 1989 | 2001 |
| 8 | 41 | 3 | 19 | 1992 | 2001 |
| 8 | 45 | 3 | 24 | 1997 | 2001 |
| 8 | 48 | 3 | 18 | 1991 | 2001 |
| 8 | 52 | 3 | 26 | 1999 | 2001 |
| 8 | 57 | 3 | 21 | 1994 | 1997 |
| 8 | 75 | 3 | 23 | 1996 | 2001 |
| 8 | 82 | 3 | 17 | 1990 | 1997 |
| 8 | 83 | 3 | 19 | 1992 | 1997 |
| 8 | 87 | 3 | 25 | 1998 | 2004 |
| 8 | 90 | 3 | 18 | 1991 | 2002 |
| 8 | 93 | 3 | 22 | 1995 | 1997 |
| 8 | 130 | 3 | 13 | 1986 | 1988 |
| 8 | 111 | G | – | – | 1988 |
| 8 | 68 | G | – | – | 2001 |
| 8 | 84 | G | – | – | 1997 |
| 8 | 104 | G | – | – | 1997 |
| 8 | 133 | G | – | – | 1997 |
| 8 | 167 | G | – | – | 2000 |
| 8 | 69 | G | – | – | 1997 |
| 8 | 71 | G | – | – | 2001 |
| 8 | 110 | G | – | – | 1998 |
| 8 | 123 | G | – | – | 1997 |

**Continuation of the Table 2**

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| 9 | 68 | 1 | 17 | 1990 | 1997 |
| 9 | 70 | 1 | 27 | 2000 | 2001 |
| 9 | 72 | 1 | 26 | 1999 | 2001 |
| 9 | 20 | 2 | 24 | 1997 | 2001 |
| 9 | 17 | 2 | 20 | 1993 | 2000 |
| 9 | 29 | 2 | 24 | 1997 | 2001 |
| 9 | 31 | 2 | 24 | 1997 | 2001 |
| 9 | 36 | 2 | 27 | 2000 | 2001 |
| 9 | 41 | 2 | 17 | 1990 | 1997 |
| 9 | 45 | 2 | 22 | 1995 | 1997 |
| 9 | 54 | 2 | 23 | 1996 | 1997 |
| 9 | 57 | 2 | 14 | 1987 | 1997 |
| 9 | 61 | 2 | 24 | 1997 | 2001 |
| 9 | 67 | 2 | 23 | 1996 | 1997 |
| 9 | 74 | 2 | 28 | 2001 | 2001 |
| 9 | 79 | 2 | 16 | 1989 | 2000 |
| 9 | 171 | 2 | 21 | 1994 | 1997 |
| 9 | 103 | 2 | 7 | 1980 | 1997 |
| 9 | 111 | 2 | 24 | 1997 | 1997 |
| 9 | 33 | 3 | 19 | 1992 | 2001 |
| 9 | 42 | 3 | 26 | 1999 | 2001 |
| 9 | 51 | 3 | 14 | 1987 | 2001 |
| 9 | 63 | 3 | 22 | 1995 | 2001 |
| 9 | 76 | 3 | 23 | 1996 | 1997 |
| 9 | 1 | 3 | 14 | 1987 | 2000 |
| 9 | 22 | 3 | 26 | 1999 | 2001 |
| 9 | 26 | 3 | 26 | 1999 | 2001 |
| 9 | 39 | 3 | 14 | 1987 | 1997 |
| 9 | 44 | 3 | 18 | 1991 | 2001 |
| 9 | 46 | 3 | 28 | 2001 | 2001 |
| 9 | 48 | 3 | 9 | 1982 | 2001 |
| 9 | 56 | 3 | 10 | 1983 | 1997 |
| 9 | 59 | 3 | 14 | 1987 | 1997 |
| 9 | 95 | 3 | 13 | 1986 | 2000 |
| 9 | 131 | 3 | 17 | 1990 | 2002 |
| 9 | 134 | 3 | 17 | 1990 | 2008 |
| 9 | 139 | 3 | 16 | 1989 | 1997 |
| 9 | 149 | 3 | 19 | 1992 | 1997 |
| 9 | 150 | 3 | 21 | 1994 | 2000 |
| 9 | 152 | 3 | 30 | 2003 | 2008 |
| 9 | 155 | 3 | 14 | 1987 | 2000 |
| 9 | 24 | G | – | – | 1997 |
| 9 | 27 | G | – | – | 2001 |
| 9 | 53 | G | – | – | 1993 |
| 9 | 65 | G | – | – | 1997 |
| 9 | 89 | G | – | – | 1997 |
| 9 | 91 | G | – | – | 1997 |
| 9 | 113 | G | – | – | 1997 |
| 9 | 124 | G | – | – | 1997 |
| 9 | 147 | G | – | – | 1997 |
| 9 | 179 | G | – | – | 1997 |

**Continuation of the Table 2**

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| 14 | 37 | 1 | 29 | 2002 | 2004 |
| 14 | 39 | 1 | 25 | 1998 | 2004 |
| 14 | 83 | 2 | 23 | 1996 | 2004 |
| 14 | 89 | 2 | 26 | 1999 | 2004 |
| 14 | 25 | 3 | 19 | 1992 | 2004 |
| 14 | 94 | 3 | 16 | 1989 | 2003 |
| 14 | 30 | 3 | 13 | 1986 | 2003 |
| 14 | 32 | 3 | 28 | 2001 | 2004 |
| 14 | 97 | 3 | 15 | 1988 | 2003 |
| 14 | 24 | 3 | 19 | 1992 | 2004 |
| 14 | 54 | 3 | 27 | 2000 | 2004 |
| 14 | 3 | 3 | 16 | 1989 | 2001 |
| 14 | 50 | 3 | 14 | 1987 | 2003 |
| 14 | 1 | G | – | – | 2001 |
| 14 | 2 | G | – | – | 2001 |
| 14 | 18 | G | – | – | 2001 |
| 14 | 22 | G | – | – | 2004 |
| 14 | 34 | G | – | – | 2004 |
| 14 | 58 | G | – | – | 2004 |
| 14 | 60 | G | – | – | 2004 |
| 14 | 65 | G | – | – | 2004 |
| 14 | 74 | G | – | – | 1994 |
| 14 | 78 | G | – | – | 1995 |
| 14 | 86 | G | – | – | 2003 |
| 14 | 91 | G | – | – | 2001 |
| 15 | 13 | 1 | 31 | 2004 | 2004 |
| 15 | 97 | 1 | 24 | 1997 | 2004 |
| 15 | 38 | 1 | 25 | 1998 | 2004 |
| 15 | 82 | 2 | 30 | 2003 | 2004 |
| 15 | 32 | 2 | 30 | 2003 | 2004 |
| 15 | 39 | 2 | 26 | 1999 | 2004 |
| 15 | 24 | 2 | 22 | 1995 | 2004 |
| 15 | 54 | 2 | 24 | 1997 | 2004 |
| 15 | 77 | 2 | 20 | 1993 | 2000 |
| 15 | 12 | 2 | 28 | 2001 | 2001 |
| 15 | 66 | 2 | 26 | 1999 | 2004 |
| 15 | 94 | 3 | 25 | 1998 | 2003 |
| 15 | 33 | 3 | 18 | 1991 | 2000 |
| 15 | 35 | 3 | 22 | 1995 | 2004 |
| 15 | 21 | 3 | 17 | 1990 | 2001 |
| 15 | 7 | 3 | 24 | 1997 | 2004 |
| 15 | 59 | 3 | 19 | 1992 | 2000 |
| 15 | 37 | 3 | 16 | 1989 | 2000 |
| 15 | 26 | 3 | 15 | 1988 | 2001 |
| 15 | 72 | 3 | 15 | 1988 | 2003 |
| 15 | 45 | 3 | 13 | 1986 | 2000 |
| 15 | 67 | 3 | 22 | 1995 | 2003 |
| 15 | 88 | 3 | 18 | 1991 | 2004 |
| 15 | 85 | 3 | 20 | 1993 | 2000 |
| 15 | 3 | G | – | – | 1997 |
| 15 | 4 | G | – | – | 2000 |
| 15 | 19 | G | – | – | 2004 |

**Continuation of the Table 2**

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| 15 | 42 | G | – | – | 1997 |
| 15 | 52 | G | – | – | 2000 |
| 15 | 53 | G | – | – | 2000 |
| 15 | 57 | G | – | – | 1997 |
| 15 | 83 | G | – | – | 1994 |
| 18 | 77 | 1 | 29 | 2002 | 2004 |
| 18 | 92 | 1 | 30 | 2003 | 2004 |
| 18 | 12 | 2 | 30 | 2003 | 2004 |
| 18 | 16 | 2 | 29 | 2002 | 2004 |
| 18 | 89 | 2 | 21 | 1994 | 1995 |
| 18 | 22 | 2 | 28 | 2001 | 2004 |
| 18 | 46 | 2 | 26 | 1999 | 2004 |
| 18 | 85 | 2 | 25 | 1998 | 2004 |
| 18 | 38 | 3 | 20 | 1993 | 2004 |
| 18 | 18 | 3 | 18 | 1991 | 2004 |
| 18 | 11 | 3 | 20 | 1993 | 2004 |
| 18 | 54 | 3 | 17 | 1990 | 2004 |
| 18 | 57 | 3 | 15 | 1988 | 2004 |
| 18 | 3 | 3 | 11 | 1984 | 2005 |
| 18 | 13 | 3 | 16 | 1989 | 2004 |
| 18 | 74 | 3 | 13 | 1986 | 2004 |
| 18 | 51 | 3 | 11 | 1984 | 2003 |
| 18 | 88 | 3 | 16 | 1989 | 2004 |
| 18 | 52 | 3 | 11 | 1984 | 2004 |
| 18 | 62 | 3 | 11 | 1984 | 2003 |
| 18 | 40 | 3 | 9 | 1982 | 2004 |
| 18 | 26 | 3 | 21 | 1994 | 2004 |
| 18 | 68 | 3 | 10 | 1983 | 2004 |
| 18 | 15 | G | – | – | 2000 |
| 18 | 24 | G | – | – | 2004 |
| 18 | 29 | G | – | – | 2004 |
| 18 | 33 | G | – | – | 2000 |
| 18 | 36 | G | – | – | 1995 |
| 18 | 48 | G | – | – | 1991 |
| 18 | 59 | G | – | – | 2000 |
| 18 | 81 | G | – | – | 2004 |
| 18 | 94 | G | – | – | 2003 |
| 19 | 33 | 1 | 30 | 2003 | 2004 |
| 19 | 52 | 1 | 27 | 2000 | 2004 |
| 19 | 23 | 2 | 19 | 1992 | 2003 |
| 19 | 31 | 2 | 22 | 1995 | 2004 |
| 19 | 71 | 2 | 29 | 2002 | 2004 |
| 19 | 92 | 2 | 30 | 2003 | 2004 |
| 19 | 25 | 3 | 24 | 1997 | 2004 |
| 19 | 6 | 3 | 30 | 2003 | 2004 |
| 19 | 78 | 3 | 28 | 2001 | 2004 |
| 19 | 55 | 3 | 28 | 2001 | 2004 |
| 19 | 29 | 3 | 27 | 2000 | 2004 |
| 19 | 86 | 3 | 28 | 2001 | 2004 |
| 19 | 43 | 3 | 25 | 1998 | 2004 |
| 19 | 93 | 3 | 24 | 1997 | 2004 |
| 19 | 98 | 3 | 25 | 1998 | 2004 |

**End of the Table 2**

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| 19 | 34 | 3 | 19 | 1992 | 2004 |
| 19 | 89 | 3 | 18 | 1991 | 2001 |
| 19 | 58 | 3 | 18 | 1991 | 2003 |
| 19 | 35 | 3 | 21 | 1994 | 2003 |
| 19 | 38 | 3 | 19 | 1992 | 2004 |
| 19 | 18 | 3 | 15 | 1988 | 2004 |
| 19 | 99 | 3 | 15 | 1988 | 2003 |
| 19 | 62 | 3 | 14 | 1987 | 2004 |
| 19 | 76 | 3 | 15 | 1988 | 2002 |
| 19 | 17 | 3 | 15 | 1988 | 2001 |
| 19 | 13 | 3 | 13 | 1986 | 2003 |
| 19 | 73 | 3 | 20 | 1993 | 2001 |
| 19 | 37 | 3 | 11 | 1984 | 2003 |
| 19 | 69 | 3 | 6 | 1979 | 2001 |
| 19 | 1 | G | – | – | 2004 |
| 19 | 3 | G | – | – | 2004 |
| 19 | 11 | G | – | – | 2004 |
| 19 | 54 | G | – | – | 2000 |

*The authors thank the scientists of the Forest Soils Laboratory, Forestry and Forest Products Research Institute at Sapporo, Hokkaid, who have established and maintained the experimental plots and provided census data since 1973. Colleagues from the study group for soil-plant interaction are acknowledged for the census and stem and stump sample collections of 2013 and 2015. We thank anonymous reviewers for improving the earlier versions of the manuscript.*

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# КОРРЕКЦИЯ ТАКСАЦИОННЫХ ПОКАЗАТЕЛЕЙ МЕТОДОМ РЕКОНСТРУКЦИИ СТРУКТУРЫ И РОСТА НАСАЖДЕНИЙ: МОЖЕТ ЛИ ИНФОРМАЦИЯ О ПНЯХ УЛУЧШИТЬ ОЦЕНКИ?

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*Поступила в редакцию 20.04.2018 г.*

Данные о размерах пней деревьев, срубленных при прореживании, использовались в процессе реконструкции (моделировании) параметров структуры и роста насаждений для проверки возможности улучшения определения таких таксационных показателей, как надземная фитомасса, объем ствола, рост ствола по объему и густота насаждения. Выполнены измерения 30 растущих модельных деревьев и 160 пней срубленных ранее деревьев пихты сахалинской *Abies sachalinensis* (F. Schmidt) Mast., ели аянской *Picea jezoensis* (Siebold & Zucc.) Carrière и ели Глена *Picea glehnii* (F. Schmidt) Mast. в шести чистых по породному составу насаждениях в экспериментальном лесу Хицусигаока на о-ве Хоккайдо, Япония. Данные анализа стволов и таксационных измерений, полученные в 2013 г., использовались для реконструкции и оценки таксационных параметров насаждений в прошлом. Таксационные показатели оценивали посредством реконструкции характеристик насаждений с учетом данных измерений пней срубленных деревьев и без них, а затем сравнивали с целью оценки точности моделирования. Восстановленные (реконструированные) таксационные показатели статистически сопоставили с фактическими значениями, полученными в результате таксационных измерений в период 1988–2013 гг. Результаты сопоставлений показали, что точность оценки переменных может быть улучшена путем уменьшения погрешностей вычислений за счет включения в расчеты данных измерений старых пней. Без включения в расчеты данных измерений пней погрешность оценки таксационных показателей насаждений варьировала в пределах ±20 % от фактических значений. При учете данных измерений пней погрешность определения одних и тех же показателей обычно снижалась до уровня ±15 % в период после 1997 г. На уровне 95 % доверительного интервала установлено, что определение таксационных показателей методом самонастройки путем включения в расчеты данных измерений пней не всегда повышает точность определения полноты насаждения, но, как правило, повышает точность определения надземной фитомассы, объема стволов и его прироста. В целом при включении в расчеты данных измерений пней резкие изменения параметров надземной фитомассы и густоты насаждений после рубок прореживания были реконструированы в лучшей степени для всех трех исследованных древесных видов, хотя в количественном отношении повышение точности определений в некоторых случаях было минимальным.

**Ключевые слова:** *структура и рост насаждений, реконструкция, разложившиеся пни, надземная фитомасса, объем ствола, рост объема ствола, густота насаждения, экспериментальный лес Хицусигаока, Хоккайдо, Япония.*