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Development of Measurement System for Evaluating Forest Ecosystems: Measurement Method of Aboveground Biomass Growth by Using Airborne Laser Survey

By

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Summary

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In order to develop a monitoring system for evaluating forest ecosystems, a method of forest stand measurement using airborne laser survey was examined. The study area was a *Larix leptolepis* forest in the Tomakomai Flux Research Site. The laser survey data were taken in the year 1999, 2001 and 2003. A canopy DSM (Digital Surface Model) was constructed from first pulse of the laser survey data, and the DTM (Digital Terrain Model) was constructed from the last pulse of it. The DCHM (Digital Canopy Height Model) was made by the difference of the canopy DSM and DTM. The crowns of trees were extracted from the canopy DSM by the Watershed method. Tree height was measured by the DCHM within the crown. The stem volume of trees was calculated by using the relationship between tree height and the stem volume. Since the crowns of understorey tree could not be detected, the MNY method was used for the prediction of understorey trees.

The results that the growth of the forest stand height was 0.23~0.25$cm \cdot y^{-1}$,and that the the growth of the forest stand height was 11$m^3 \cdot y^{-1}$, both were near to the data obtained by complete enumeration, therefore, this method has a precision for the measurement of biomass growth.

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Introduction

Under Kyoto Protocol to the UNFCCC, Japan is committed to reduce carbon dioxide emission by 6% within the first commitment period compared to the base year, and 3.9% of which are expected to be achieved through "forest sink" activities. Although, afforestation is very difficult in Japan, the activities to increase CO_2 absorption is indispensable for the achievement of the obligation under the Kyoto Protocol in the "managed forest". Furthermore, it is required that the development of the technique of evaluating the increase effect in absorption through these forest management activities should be done. One of the techniques is a method of using airborne laser scanner which can survey the elevation of not only the top, but the ground, and it can survey tree height for wide area (YAMAGATA & al. 2001). Recently, many studies of the forest measurement using laser scanner have been made (e.g. LEFSKY & al. 1999, HYPPÄ J. & al. 2001), but the study for time change of a forest using laser scanner has not appeared yet, therefore, we undertake to develop the method that measures the time change of a forest.

Material and Methods

Site description

The study site is a Japanese larch (*Larix kaempferi*) plantation in Tomakomai National Forest managed by the Hokkaido Regional Office of the Forestry Agency. The larch forest was planted in 1958 and is located at 42°44'N, 141°31'E in Hokkaido, northern Japan. The site is on flat terrain and the elevation is about 140 m above sea level. In the larch forest, some deciduous broadleaf trees, such as birch (*Betula ermanii* and *Betula platyphylla*) and Japanese elm (*Ulmus japonica*), invade into the gaps, and individual trees of spruce (*Picea jezonensis*) grow sparsely (HIRANO & al. 2003).

Field measurement

The experiment plot (1ha, 100m × 100m) was set up in 1999, and the complete enumeration of DBH (stem diameter at breast height; 1.3m above ground) was done for the trees to which DBH size was more than 5cm in December 1999, November 2001 and April 2004. Since it was before the growth in 2004, the results of an investigation in 2004 was regarded as the data in 2003. The tree heights was measured for only trees representing a class of it in 1999 and the height-diameter curve formula are calculated as

$$H = -4.481 + 6.117 \log D, \quad R^2 = 0.7703 \qquad [1]$$

where H is tree height (m), D is DBH (cm) and R^2 is the coefficient of determination (YONE & al. 2002). The tree heights in this plot in 1999, 2001 and 2004 was calculated from their DBH using this equation. The stem volume of *Larix kaempferi*, *Picea jezonensis* and broadleaf trees are calculated, respectively, as

$$F1 = 0.435719 + 0.515867/H + 2.481278/H^2$$
$$F2 = 0.439004 + 0.916461/D - 0.073809/D^2$$
$$V = \pi(D/200)^2 \times H \times (F1 + F2) / 2 \qquad \text{(NAKAJIMA 1948)} \; [2]$$

$$V = 10^{(-4.0744 + 1.824080 \log D + 0.934568 \log H)} \times 1.0048 \qquad [3]$$

$$V = 10^{(-4.068644+1.756152\log D + 0.906210\log H)} \quad (D<12)$$
$$V = 10^{(-4.335395+1.903051\log D + 1.025410\log H)} \quad (12 \leqq D<22)$$
$$V = 10^{(-4.332596+1.853014\log D + 1.166956\log H)} \quad (22 \leqq D<30)$$

(FORESTRY AGENCY 1970) [4]

where V is stem volume (m^3), D is DBH (cm) and H is height (m).

Laser survey and data processing

The laser scanning acquisition was carried out in 1999, 2001 and 2003 using a airborne or heliborne laser survey (Table 1).

Table 1. Flight data.

Flight Name	**F1999**	**F2001**	**F2003**
Flight Data	9~10 Sep 1999	26 Sep 2001	9 Sep 2003
Carrier Aircraft	Airborne	Heliborne	Heliborne
Carrier Aircraft	Airborne	Heliborne	Heliborne

The laser survey provided a point cloud, in which the x, y and z coordinate of the points are known. The point cloud data are mixed with various part of a forest such as leaves, stems, ground and etc. So, to acquire the digital terrain model (DTM), the data are filtered out from the point which is not the ground from and the DTM is made from the filtered data. The digital surface model (DSM) was obtained by taking the highest elevation of laser hits within each 50cm pixel and by interpolating the value for missing points. The digital canopy height model (DCHM) was obtained by calculating the difference of DSM to DTM. The crowns of individual trees are detected by the watershed algorithm. The watershed algorithm is performed in the following process. 1) Markers are set as the local maximum of DSM. 2) The markers are expanded along with the inclination of DSM. 3) At the place where markers collide with, boundaries are generated (YONE & al. 2002). The heights of individual trees are obtained from the highest DCHM within the generated boundary. For the filtering, watershed algorithm processing and data integration, "TerraScan for Microstation v.004.006, Terrasolid Ltd, Finland", "HALCON v.6.1, MVTec software GmbH, Germany" and "ArcGIS 8.3, ESRI Inc., USA" are used, respectively.

The tree height measured by the laser survey tends to be underestimated. Height underestimation is caused by penetration in the foliage and missed tree tops. Therefore, tree heights is corrected as

$$H_c = A + B \times H \quad [5]$$

where H_c is the corrected tree height (m), H is the tree height (m), A and B are parameters. A and B are estimated from the data of F2001. Since the pulse density of F2001 was very high, it was assumed that the laser hit the top of tree and the height obtained by laser data was correct. Then the pulse density of F2001 was thinned out $1.20m^{-1}$, $6.56m^{-1}$ in the same density as F1999 and F2003. And the parameter was calculated based on the difference of the height obtained from the original data of F2001 and after thinning out that data. The stem volumes are estimated from the corrected height using the eq. 1 and eq. 2 by assuming that all are *larix kaempferi*.

Prediction of understorey trees

In the survey from an airplane, measurement of a understorey tree is difficult. So, the feature of understorey tree have to be predicted. For the solution, we use the method of OSAWA & ABAIMOV 2001a and OSAWA & al. 2001b which estimated total stem volume of a even-aged pure stand using the MNY method (HOZUMI & al. 1968) from data of only the largest trees in the stand. The MNYmethod was used to fit the beta-type distribution (HOZUMI 1971) to the stem volume data of all living individuals in a stand. The procedure of the MNY method is as follows. Let us denote w, w_{max}, and $\phi(w)$ as stem volume of a tree, maximum stem volume in a stand, and continuous distribution function of stem volume of a tree in a given stand, respectively. We then define (OSAWA & ABAIMOV 2001a) as below.

$$Y(w) = \int_{w}^{w_{max}} w\phi(w)\mathrm{d}w \quad [6]$$

$$N(w) = \int_{w}^{w_{max}} \phi(w)\mathrm{d}w \quad [7]$$

$$M(w) = \frac{Y(w)}{N(w)} \quad [8]$$

Examination of the quantitative relationships among $Y(w)$ and $M(w)$ could be used to determine the types and parameter values of certain distribution functions. For example, when w varies according to the beta-type distribution, we simultaneously have the following two relationships:

$$M(w) = Aw + B \quad [9]$$

$$N(w)^{(1-A)/A} = \frac{C}{A^{(1-A)/A}}(A-1)w + \left(\frac{C}{A}\right)^{(1-A)/A} B \quad [10]$$

where A, B, and C are parameters (HOZUMI 1971, OSAWA & ABAIMOV 2001a). The distribution density function becomes (HOZUMI 1971, OSAWA & ABAIMOV 2001a)

$$\phi(w) = C[(A-1)w + B]^{(2A-1)/(1-A)} \quad [11]$$

The total stem volume of the stand is calculated from eq. 6 and eq. 11 where the minimum volume is substituted for w. The minimum volume is that of minimum DBH for the complete enumeration, that is, the DBH is 5cm.

Results and Discussion

The result of the complete enumeration is shown in table 2. Although the total number of trees decreased during 2 years from 2001 to 2003, most total numbers and total stem volumes increased.

The height calibration equations for F1999 and F2003 are made from the data of F2001, respectively, as

$$H_c = 0.7755H + 3.6351,\ R^2 = 0.7419 \quad [14]$$

$$H_c = 0.9738H + 0.5851,\ R^2 = 0.9650 \quad [15]$$

Table 2. Total number and stem volume by complete enumeration.

Investigate Name	P1999	P2001	P2003
Investigate Date	Dec 1999	Sep 2001	Apr 2004
Total Number of Trees (ha^{-1})	1028	1036	1009
Total Stem Volume (m^3ha^{-1})	145.43	156.27	162.90

The average and histogram of calibrated tree heights obtained from the laser survey are shown in Fig. 1. This average of height means the height of upper storey tree. The difference of average height is significant ($P<0.01$) with the analysis of variance (ANOVA) and the annual growth of height is 0.23~0.25$cm \cdot y^{-1}$. The growth of the height investigated by the stem analysis in the next forest is about 0.25$cm \cdot y^{-1}$, therefore, the measurement result has validity.

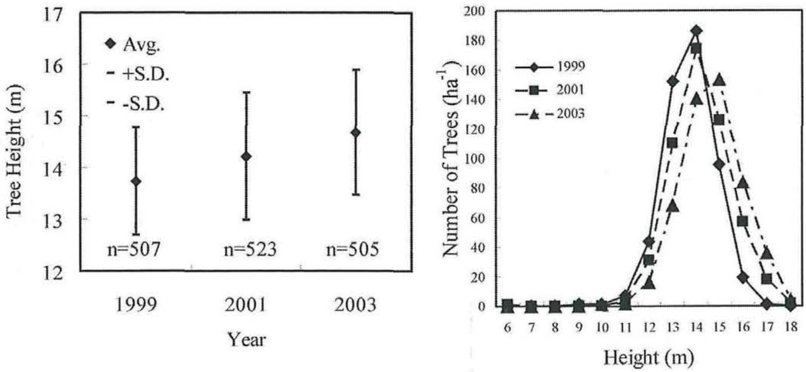

Fig. 1. Average (left) and Histogram (right) of tree height obtained by laser survey.

Histograms of tree height obtained from complete enumeration, laser survey and prediction from laser survey using the MNY method are shown in Fig. 2, and the estimated total stem volumes are shown in Fig. 3.

It shows that the tree height obtained from laser survey is only the upper storey trees and the total stem volumes are underestimated. But by using the MNY method, the shape of histograms of tree height and total stem volumes become in agreement with complete enumeration data.

We conclude that (1) only upper storey trees are surveyed by using laser scanner, but we can predict understorey trees combined with the MNY method and (2) time change of a forest can be detected by the method of this study.

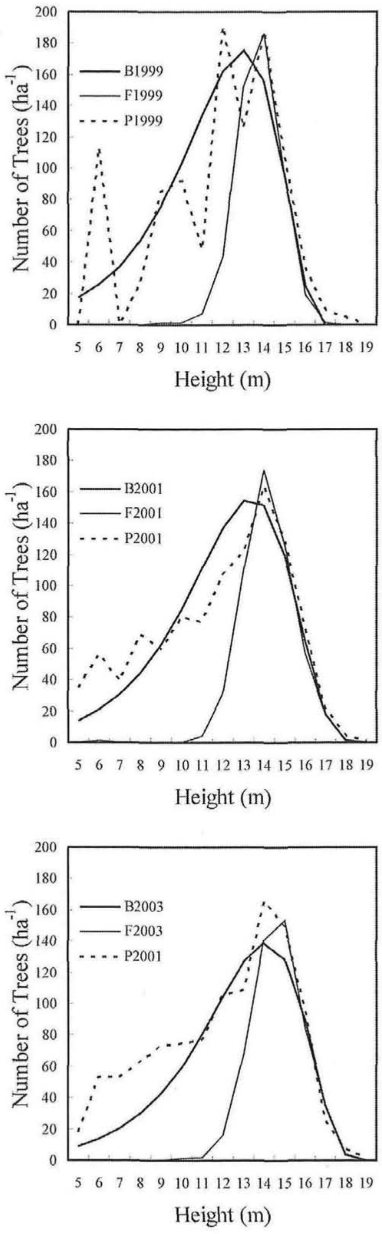

Fig. 2. Histogram of tree heights. Dotted lines (P), thin lines (F) and thick lines (B) are as a result of complete enumeration, laser survey and prediction from laser survey using the MNY method.

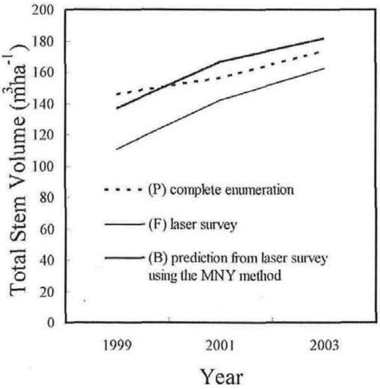

Fig. 3. Estimated total stem volumes. Dotted lines (P), thin lines (F) and thick lines (B) are same as in Fig. 2.

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