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ESTIMATION OF TREE SPECIES PROPORTIONS USING RANGING SCATTEROMETER

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ABSTRACT

Tree species proportions of forest stands were estimated using ranging scatterometer called HUTSCAT. Employed estimation method was multilayer perceptron neural network with error backpropagation training algorithm. Two methods for feature extraction were tested; other based on intensity and shape of measured profiles, other only shape. Different neural network configurations were tried and it was found that differences between them were rather small. Shape-features performed little better because the differences between different networks were smaller. The best classification accyracy of the main tree species was about 86% and the mean error of estimation for tree species proportions was 0.30. Largest errors are due to low stem volume, because stand is in the beginning of its production cycle (clearing or sapling) or soil is poor.

1. INTRODUCTION

Forest assessment deals with the methods of obtaining information on forest resources: estimation of growing stock, growth and health of the forest. That information is a basis for decisions of the forest industry, the official forest policy and the forest owners. For countries such as Finland, where about 30 % of exports is based on forestry products and the percentage of the forest area (76%) is the highest in the world, development of inventory methods are a necessity.

Typically, forests are operationally assessed with two scales: economic planning of forests at stand level (small-area inventory) and monitoring of forest resources at the national level (large-area inventory). The forest stand is a homogeneous forest area with respect to forest resources and treatments needed. Typical stand size in Finland is between 0.5 and 5 hectares. Conventionally, forest inventory data has been collected primarily by means of field surveys, which is both expensive and time-consuming. Important forest attributes, including stem volume per hectare and tree species proportions, are then assessed to these stands by measuring sample plots and individual trees, and by using personal experience.

The national forest inventory of Finland was the first national inventory in the world to use satellite images (Tomppo 1991). Even though, remote sensing techniques have been regarded as a good alternative and/or a supporting method for traditional forest inventory for a long time, at stand level no remote sensing technique or data source has succeeded in providing accurate enough information cost–effectively. This has stimulated remote sensing research into entirely new approaches.

According to Hyyppä et al. (1998), radar–derived stand profiles obtained with airborne ranging scatterometer was more feasible data source for forest inventory than aerial photographs and images provided by imaging spectrometer AISA. Stand profiles were also of equivalent accuracy with conventional forest inventory for mean height and stem volume estimation. There is also a potential in radar profiles to estimate tree species information; that kind of study has not been qualitatively carried out previously, even though Dechambre et al. (1992) has already concluded that the ranging radar can discriminate between trees with crowns of different shapes and Salo's (1992) results indicate that the shape of profile can be used to discriminate tree species.

The objective of this study was to verify qualitatively the capability to discriminate main tree species and tree species proportions of forest stands using a helicopter–borne ranging scatterometer at a stand level.

2. HUTSCAT

A helicopter–borne ranging scatterometer (named as HUTSCAT) was constructed at the Helsinki University of Technology during 1986–89. The radar is a frequency–modulated continuous–wave (FM–CW) radar that operates at 5.4 (C–band) and 9.8 GHz (X–band) and it employs four linear polarization modes (VV, HH, VH and HV) at both frequencies. The range resolution cell is 65 cm.

Figure 1 shows the measurement principle of the radar–derived stand profiles. The radar transmits microwave energy into the studied area. Some of the signal is then backscattered or reflected to the radar, some is absorbed by the material. The coming signal is then interpreted in the radar. Due to the frequency–modulation, targets with different ranges are separated by the intermediate frequency and the signal strength of backscatter contributes to the physical characteristics of the target (e.g. geometry, roughness and dielectric properties). Simultaneous recording of four linear polarization modes helps in characterizing the target. The basic output product of the HUTSCAT is a radar return spectrum of a target (backscattered power versus distance from radar). When a forest stand is used as a target, the term stand profile is more appropriate for representing the consecutive radar return spectra.

2.1 Quality of stand profile

The factors of airborne ranging radars and of measurement geometry that determine the quality of the stand profile are the following: 1) flight altitude and antenna characteristics, 2) range resolution, 3) system sensitivity, 4) flight speed and sampling rate and 5) incidence angle (Hyyppä 1993):

1. The flight altitude and antenna beamwidth together determine the illumination geometry of a target. The volume of the illumination is a truncated cone. This suggests that it is difficult to discriminate between trees within this volume using radar–derived stand signature. Therefore, only the height of the tallest tree within the footprint may be determined with good accuracy. Also, the antenna sidelobes

falling on nearby trees may give false tree height. When the diameter of the truncated cone at the crown level is small compared with the crown width, the signature of individual trees may be separated and the height of each tree can be calculated from the stand profile. However, it is not guaranteed that the tip of the tree is illuminated, implying an underestimate in tree height evaluation. The antenna sidelobes can produce peculiar effects on stand profiles; e.g. the backscatter measured by antenna sidelobes may also be located above tree tops and below ground level depending on the incidence angle.

2. The accuracy of the radar–derived tree height estimate is limited by the range resolution.
3. Reflection clutter due to the range sidelobes may worsen tree height determination. In order to measure the tree height accurately, very high sensitivity is needed.
4. The profiling radar selects trees with a probability proportional to tree height and crown diameter. Therefore, trees with a wider crown have a higher probability of being sampled.
5. The ability to determine tree height is assumed to decrease with increasing incidence angle due to the spreading of the ground echo. With near vertical measurements, the ground backscatter is sensitive to variations in the incidence angle.

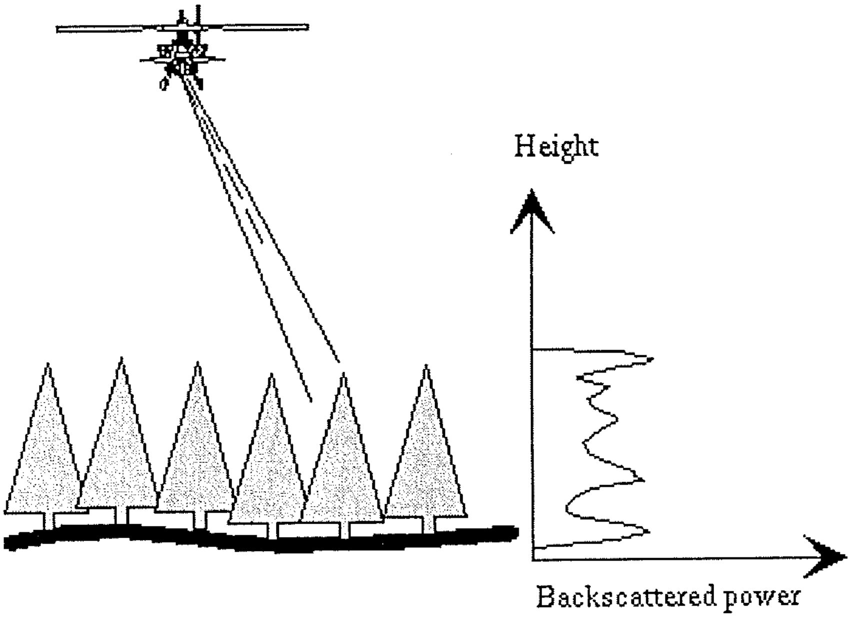

Figure 1. *The measurement principle of HUTSCAT. On the left HUTSCAT measures the backscattering behaviour of a target as a function of the range. The measured profile is on the right.*

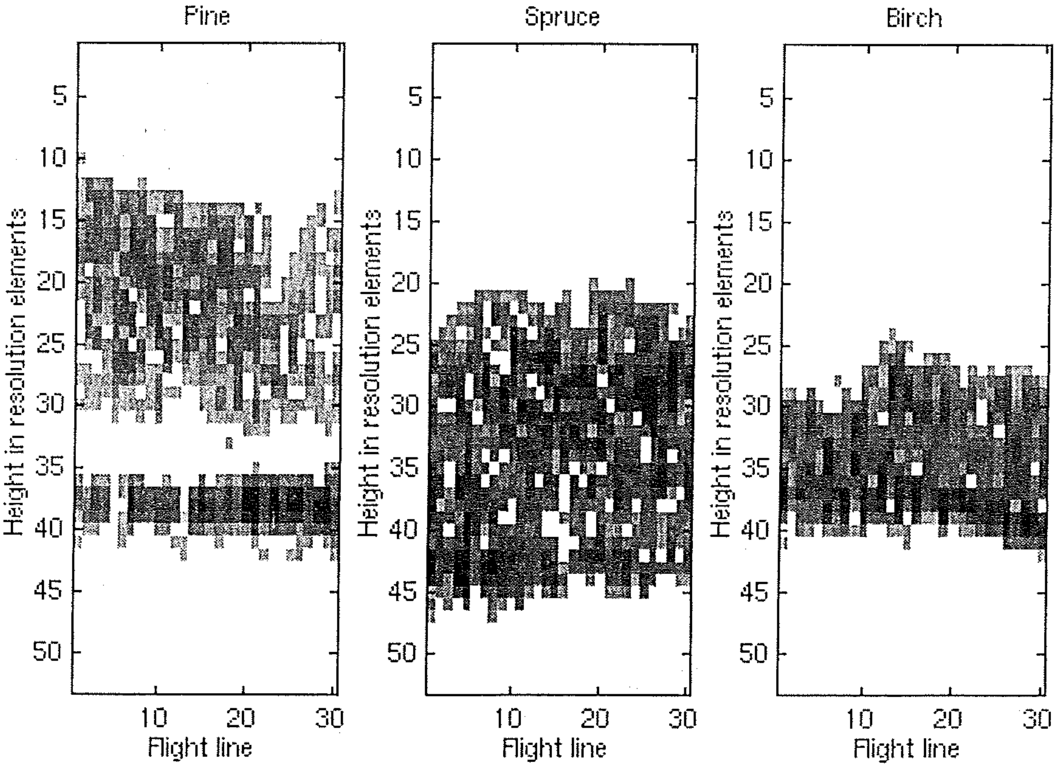

Figure 2. Examples of measured profiles, on the left and center are examples of pine and spruce dominated forest stands and on the right birch dominated sapling.

2.2 Example of stand profile

Figure 1 indicate that the stand profile includes information from the tree top to the ground. The backscatter power peaks at the minimum and maximum distances from the radar correspond to backscatter contributions from tree tops and the ground, respectively. The range difference between these values can be used for tree height determination. Pine and spruce canopies have a different kind of radar response due to the distribution of wooded material within the forest canopy. The sapling stands can be discriminated by the height of the profile. Figure 2 represents examples of measured profiles, on the left and center are examples of old pine and spruce dominated forest stands and on the right birch dominated sapling.

3. TEST SITE AND APPLIED MATERIAL

The 1300–ha test area (named Teijo) locating 130 km west of Helsinki was selected originally in cooperation with the Finnish Forest and Park Service (FFPS). The reference information of forests (field inventory) was carried out by FFPS in 1991 with the typical inventory process. Inventory started with colour–infrared aerial photographs on a scale of 1:10000. Preliminary boundaries of the stands were obtained and a walking route in the stand was planned using aerial photographs. Typically, two to ten sample plots of each stand were measured depending on the size and homogeneity of the stand. The plots were located evenly and systematically over the stand. Stand characteristics were then derived from these plot measurements. The subsequent tree parameters were measured on each plot. The basal area was measured with a relascope sweep (with factor 1). The median tree was selected to represent the whole plot. Height, diameter and age were measured from this tree. The height was measured with a SUUNTO clinometer. The number of tree stems was counted in plantations and young stands using a 50 m^2 plot. The stem volume corresponding to each tree species within the stand was obtained from height, basal area, number of stems and diameter information. Therefore, the tree species proportions represents the percentage of each tree species of the whole stem volume in the stand.

The test area includes various topographical and vegetational features: hilltop sites, flatlands, Scots pine forests, Norway spruce forests, poorly productive land (scrub land), bogs and lakes. The maximum height difference was 70 m. The number of forest stands in this study was 197 with mean size of 3.2 hectares, varying from 0.3 to 17.5 ha. The mean of stem volume was 135.5 m^3/ha, varying from 5.9 m^3/ha to 367.9 m^3/ha. 168 stands were well productive and 29 stands poorly productive forest lands. The dominant soil type was moraine (134 stands), then there were some peatlands (22 stands), mineral soil (12 stands) and 29 stands were unclassified. The developments classes were logging clearing (29 stands), sapling stand (13), young forest (54), old forest (60) and forest for regeneration felling (41).

The number of pine dominated forest stands was 146 (89 stands where the dominant tree species was pine) with mean size of 3.3 hectares, varying from 0.3 to 17.5 ha. The mean of stem volume was 114.4 m^3/ha, varying from 8.0 m^3/ha to 321.0 m^3/ha. 117 stands were well productive and 29 stands poorly productive forest lands. The dominant soil type was moraine (90 stands), then there were some peatlands (16 stands), mineral soil (11 stands) and 29 stands were unclassified. The developments classes were logging clearing (29 stands), sapling stand (10), young forest (45), old forest (32) and forest for regeneration felling (30).

The number of spruce dominated forest stands was 48 (6 stands where the only tree species was spruce) with mean size of 2.7 hectares, varying from 0.4 to 10.5 ha. The mean of stem volume was 204.7 m^3/ha, varying from 5.9 m^3/ha to 367.9 m^3/ha. All stands were well productive forest lands. The dominant soil type was moraine (43 stands), then there were some peatlands (4 stands) and one stand of mineral soil. The developments classes were sapling stand (1), young forest (9), old forest (27) and forest for regeneration felling (11).

The number of birch dominated forest stands was only 3 with mean size of 3.7 hectares, varying from 0.6 to 7.8 ha. The mean of stem volume was 59.3 m^3/ha, varying from 9.2 m^3/ha to 143.5 m^3/ha. The dominant soil type was peatland (2 stands). The developments classes were sapling stand (2) and old forest (1).

Because HUTSCAT measures target properties along the flight line, the Teijo forest area was divided into strips of equal widths. Eighteen parallel flight lines with 150 metres spacing were designed to be at right angles to the maximal stand diameter in order to increase the number of strip transects covering all stand conditions. The strip width was designed to be from 8 to 12 metres depending on the range from the radar corresponding to 6.7% relative illumination of the total area. Data from these flight lines were divided to two groups, even numbered flight lines were used to obtain training data and odd numbered flight lines were used as independent test data. Even numbered flight lines contained measurements from 141 stands (113 pine , 26 spruce and 2 birch dominated) and odd numbered flight lines 163 stands (116 pine, 44 spruce and 3 birch dominated).

Measurements were made 9.–10.6.1992 in dry weather with incidence angle of 3^o off nadir at C–band. A near–vertical incidence angle was needed to measure the vertical distribution of backscattering sources of forest canopies and to measure the tree height as accurately as possible. In order to slightly decrease the strong direct reflections from the ground and to improve the stability of the ground backscatter measurement, the incidence angle was tilted to 3^o off nadir. A dual–antenna configuration (one antenna for transmitting and another for receiving) was used in the experiment to achieve better isolation between the transmitter and the receiver and consequently, a higher system sensitivity. The measurements made using VV–polarization were used in the estimation of the tree species proportions . In order to be able to fly along the designated flight lines, GPS navigator was attached to the HUTSCAT. To localize HUTSCAT data, coordinates and the corresponding time were recorded at one second intervals.

4. PREPROCESSING AND FEATURE EXTRACTION

Before model development, radar data were pre–processed. The amplitude calibration within the spectrum was made according to Hyyppä (1993). The range calibration constants were checked before flight. The GPS coordinates and the corresponding time were transferred to the geographical information system, in which a map of the test site and information by stands were available. The GPS was calibrated by using reference points and targets with exactly known coordinates. Using video images, localization accuracy was determined to be 10 metres. The intersections between forest stands and flight lines were defined. The times of intersections were recorded.

The purpose of preprocessing is to enhance the interpretability of profiles and remove noise. First profiles (one example is presented in figure 3a) were transformed using logarithmic transformation (common logarithm) (figure 3b) and then values smaller than threshold were set to zero (figure 3c). The purpose of feature extraction is to normalize profiles so that they are comparable and they can be used to estimate tree species proportions. This was done by dividing the profile to five pieces and computing mean value for each piece. These five features describe the intensity of backscatter and the shape of profile. Sixth feature was the length of non–zero part of profile, giving approximate value for tree height (figure 3d). Second set of features were computed by dividing the first five features by their sum, so these features describe only the shape of profile. In the end, the mean values of features of each forest stands were computed from each flight line.

5. ESTIMATION OF TREE SPECIES PROPORTIONS

The estimation of tree species proportions was performed using multilayer perceptron neural network (Widrow and Lehr 1995) with error backpropagation training algorithm (Werbos 1995). During the training process, input patterns (i.e. extracted features) and corresponding desired output patterns (i.e. tree species proportions) are presented to neural network. The purpose of error backpropagation algorithm is to adjust the weights so that the squared error between computed output patterns and desired output patterns is minimized. Computer software called Stuttgart Neural Network Simulator (SNNS) was used in this study.

Training data was acquired from even numbered flight lines. Because of small number of forest stands and for the need for large training data, 30 profiles taken randomly from each stand were averaged and this was repeated several times. Then training data was "equalized" according to the main tree species, in other words profiles were copied so that there were approximately same number of pine, spruce and birch dominated profiles. In the end, there were 1579 profiles in training data. In this way, training data represents the same statistical distribution as the mean values of forest stands computed from even numbered flight lines, but they are at the same time statistically independent. The mean values computed from even and odd numbered flight lines were used as test data.

Different neural network configurations were tested. In each case, the number of nodes in input layer and output layers were same, six and three. The most simple network had thirteen nodes in one hidden layer, so network structure was 6–13–3 nodes. This configuration is based on Kolmogorov's theorem (Kurkova 1995). The other networks were larger; 6–19–3, 6–6–5–3, 6–7–6–3 and 6–9–9–3 nodes. This was done to test the differences between different network configurations.

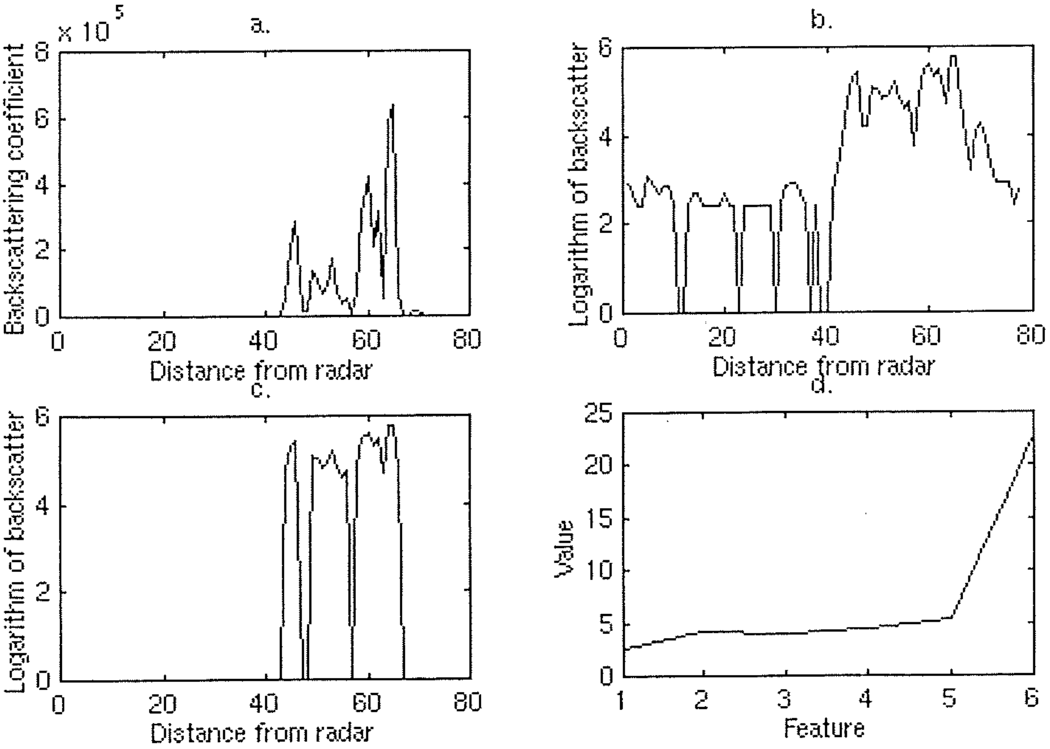

Figure 3. *The processing and feature extraction of profile: a. original profile, b. the effect of logarithm transformation, c. noise removal and d. feature extraction.*

The different networks were trained using training data and the mean values of the forest stands from even numbered flight lines were used as test data in training. The mean values computed from odd numbered flight lines were used as independent test data. The training process were repeated several times for each network to find suitable parameters. The aim was to cut the training to situation where the mean squared error of both training and test data were minimum. Then the tree species proportion were estimated for the forest stands from even and odd numbered flight lines.

Estimated proportions were compared to ground truth and following descriptive values were computed: the mean of the error (ME), the mean of the squared error (MSE), the mean of the maximum difference (MMD), the overall accuracy of the main tree species classification and average accuracies for ech tree species. The error for forest stand is defined as follows:

$$E = \sum_{i=1}^{3} (e(i) - c(i)),$$

where $e(i)$ is the estimated tree species proportion of tree species i, $c(i)$ is the correct tree species proportion of tree species i and tree species are: $i = 1$ is pine, $i = 2$ is spruce and $i = 3$ is birch. The squared error for forest stand is defined as:

$$SE = \sum_{i=1}^{3} (e(i) - c(i))^2.$$

The maximum difference is defined as:

$$MD = \operatorname*{MAX}_{i=1}^{3} (e(i) - c(i)).$$

The forest stands were also classified according to their dominant tree species and error matrix was computed. The overall accuracy is the probability of correct classification (Sotkas et.al. 1992):

OA = (sum of diagonal elements in error matrix / number of all pattern vectors) * 100

The average accuracy of class i is probability that pixel belonging to class i taken randomly from reference data has also same class i as corresponding pixel in classified data and pixel taken randomly from classified data belonging to class i has same class i as corresponding pixel in reference data.

AA_i = 2 * diagonal element of class i / (column sum of class i + row sum of class i)

6. RESULTS

The overall performance of different network configurations were surprisingly similar. When intensity–features were used, the mean error varied from 0.29 to 035 and 0.39 to 0.41, mean squared error varied from 0.11 to 0.15 and 0.15 to 0.19, and mean of maximum difference varied from 0.16 to 0.18 and 0.19 to 0.22 for even and odd numbered flight lines. Overall accuracy of main tree species classification varied from 82.4% to 86.3% and 77.6% to 81.1%, respectively. Average accuracies of different classes were about 90% and 85% for pine dominated forest, about 70% and 68% for spruce . Average accuracies for birch varied considerably, from 0% to 80%, due to poor training data because of small number of birch dominated forest stands.

When shape–features were used, the mean error varied from 0.32 to 0.34 and 0.38 to 0.40, mean squared error varied from 0.12 to 0.14 and 0.14 to 0.17, and mean of maximum difference varied from 0.16 to 0.18 and 0.20 to 0.22 for even and odd numbered flight lines. Overall accuracy of main tree species classification varied from 83.0% to 86.3% and 79.6% to 82.6%, respectively. Average accuracies of different classes were about 90% and 87% for pine dominated forest, about 67% and 70% for spruce. Small differences between different network configurations indicate that the simplest and smallest network designed according to Kolmogorov's theorem work reasonably well. When shape–features were used, the differences between different network configurations were smaller that using intensity–features.

Largest errors in tree species proportions are due to low stem volume within forest stands. This kind of stands are logging clearings and sapling compartmets where trees are small. Or stem volume is low because of poor soil, e.g. pine dominated stands in peatlands or rocky soil. Some errors in spruce dominated stands are probably due to strong backscatter from tree tops and same time decreasing the backscatter from ground and lower parts of trees, so the result is similar to pine dominated forest. The results of birch dominated stands were poor, but this is at least partly because of low number of stands (3) and these stands are saplings or peatlands. In mixed stands, especially if there are two tree species with approximately equal proportions, the estimation of tree species proportions can be difficult.

There are numerous studies conserning classification of tree species using airborne instruments such as AVIRIS (Martin et al. 1998), digital orthophography (Duhaime et al. 1997) or multispectral videography (Thomasson et al. 1994). Due to the different methodologies and regional characteristics, detailed comparison is extremely diffucult. Despite the difficulties in comparison, the presented method seems to be very promising, especially since the same data includes information about canopy structure and tree height.

7. CONCLUSIONS

Presented method to estimate the tree species proportions seem to work rather well. Feature extraction was performed using two methods which were quite similar. Different neural network configurations were tried and differences between them were small. Shape–features performed little better because the differences between different networks were smaller. In this case the overall accuracies of the main tree species classification varied form 83.0% to 86.3% for even numbered flight lines and 79.6% to 82.6% for odd flight lines. The mean error varied from 0.32 to 0.34 and 0.38 to 0.40, respectively. Largest errors are due to low stem volume, because stand is in the beginning of its production cycle (clearing or sapling) or soil is poor.

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