MAPPING OF STOCK VOLUME OF DECIDUOUS BROADLEAVED AND EVERGREEN CONIFER FORESTS USING LOW DENSITY LIDAR DATA - A CASE STUDY IN THE UPSTREAM AREA OF DAIHACHIGA RIVER BASIN, GIFU, JAPAN -

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ABSTRACT: Airborne Light Detection and Ranging (LiDAR) has been used for forest biomass estimation for these two decades. Since LiDAR systems measure elevation of land surface accurately, their data are used for the most precise biomass mapping among various remote sensor data. We aimed at estimating biomass distribution in a large area using LiDAR data. The study site was selected in a part of Daihachiga river basin, which spreads 8.3 km in east and west and 2.0 km in north and south in Gifu, Japan. The area is covered by artificial evergreen conifer forest and natural deciduous broadleaved forest. Three LiDAR data, which were obtained in 2003, 2005 and 2011 with beam density about 1 point per square meter, were used to extract digital terrain model (DTM). A digital canopy height model (DCHM) was computed as the difference of DTM and digital surface model of data in 2011. Field surveys were executed in between 2010 and 2013, and stock volume of 90 plots were computed. Various canopy information such as average and standard deviation of canopy height and height at specific percentile were computed using DCHM. Correlation coefficients between the parameters and volume were examined for conifer and broadleaved forests, separately. Average canopy height showed the greatest correlation with biomass for conifer forest, however, middle height of the canopies was the best parameter for broadleaved forest. Volume estimation models were determined by a linear regression analysis by a stepwise multiple regression analysis. Stock volume was mapped using the selected DCHM parameters and the regression models. The result showed that conifer forest exceeding 600 m^3 ha^{-1} existed on the western gentle slopes, while broadleaved forests with volume less than 500 m^3 ha^{-1} spread in the eastern mountainous area mainly. The LiDAR data elucidated biomass distribution in the study site.

1. INTRODUCTION

Biomass or stem volume is an important parameter for forestry and carbon balance studies. Stem volume is the basic information for forest management and biomass is pool of fixed atmospheric carbon by plants in carbon balance studies. Biomass ranged widely by tree size in a large area. Forest survey is a hard, time consuming and costly task, and deriving forest resource information in a large area is not easy by field surveys.

Laser technology was introduced for forest measurements in early 1980's and a laser profiler revealed tree canopy height which was measureable from the air in a large area (e.g. Arp *et al.*, 1982). Various researches were executed since then to evaluate performance of laser sensors for forest measurements (e.g. Nelson *et al*., 1988; Lefsky *et al*., 1999). Improvement of the light detection and ranging (LiDAR) technology yields accurate small foot print laser data, which are applicable for precise biomass mapping (Means *et al*. 2000; Holmgren *et al*., 2003).

Most LiDAR researches analyses either conifer or broadleaved forest. Therefore, difference of LiADR performance in analyses of different forest types with different canopy shape is still unclear. Above all, analyzing both conifer and broadleaved forests is mandatory in areas with these forest types for a large area biomass mapping. We aim at analyzing usefulness and difference of performance of LiDAR data in confer and broadleaved stands, then evaluating stem volume distribution patterns in mountainous topography.

2. MATERIALS AND METHODS

2.1 Study Area

The study area was located in Daihachiga river basin in Takayama city, Gifu in the central Japan at around 36.147ºN, 137.389ºE. The study site covers mountainous area of 8.3 km in the east and west and 2.0 km in the north and south and was located in the cool temperate zone. The elevation ranged between 650 m ASL and 1600 m ASL and topography was rather steep with the average slope angle of 30 degrees.

Most forests were logged in the entire river basin about 60 years ago after the World War II according to an elderly farmer, therefore forests were relatively young in the study site. Artificial forests of evergreen conifers, which were sugi cedar (*Cryptomeria japonica D. Don*) and hinoki cypress (*Chamaecyparis obtuse Sieb. et Zucc.*), were dominant in the area below about 1000 m ASL. Some hinoki cypress stands were mixed with sugi cedar. Since foresters were recommended sugi cedar as a fast-grow species for plantation around 1950's to 1960's and hinoki cypress as worthful commercial species around 1970's to 1990's, ages of sugi cedar and hinoki cypress stands were separated clearly in the study area. Natural deciduous broad leaved forests were dominant in the area over 1000 m ASL and artificial Japanese larch (*Lalix leptolepis Gordon*) existed in the area over 1200 m ASL. The major dominant deciduous broadleaved species were deciduous oak (*Quercus mongoloca var. grosseseratta Rehder et Wilson*), Japanese white birch (*Betula platyphylla var. japonica Hara*) and Erman's birch (*Betula ermanii Cham.*) and dominant species changed by successional stages of stands. Larch were planted around 1950's for a short period. Since tree size was similar among larch stands, larch was not analyzed in this study.

Forests were classified into three types, evergreen coniferous forest (sugi cedar and hinoki cypress), deciduous broadleaved forest and larch forest using QuickBird images and digital canopy height model of LiDAR data for biomass mapping (Fukuda *et al*. 2012).

2.2 Sample Plots

Plot surveys were executed between 2010 and 2013 for deciduous broadleaves, sugi cedar and hinoki cypress. Various height classes of stands were selected and circular plots were set in relatively homogeneous part of stands. Plot radius was changed from 5 m to 17 m by tree height taking into account of numbers of sample trees in plots. Plot radius was determined to be large enough to include 40 sample trees or more. Stem diameter at breast height (DBH, cm) was measured using calipers at 1.2 m for all trees greater or equal 4 cm, however, DBH of all trees were measured in a quadrant of juvenile stands of which top layer height was less than about 5 m. Tree height (H, m) was measured using a Vertex hypsometer (Haglöf, Sweden) for all trees of which DBH was measured.

Plot center location was measured using a GPS receiver with an external antenna such as Mobile Mapper Pro or Mobile Mapper 100 (Thales, USA) for at least 20 minutes with the post differential technique. Two additional hand held GPS of Garmin were also used and the coordinate and stability of measurement was examined. Plot coordinate was also checked on digital ortho photos. If the coordinate was uncertain by checks using areal ortho photos described later, the coordinate was measured using Mobile Mapper 100 again.

During the four years, 12, 23, 55 and 3 sample plots were measured for sugi cedar, hinoki cypress, broadleaved and larch stands, respectively. Stem volume (m^3) was calculated using DBH, H of sample trees and volume equations for sugi, hinoki, deciduous broadleaves and lach which were arranged by Nagoya Regional Forestry Office of Japanese Forestry Agency. Above and below dry biomass (AGB and BGB, respectively, Mg) was calculated using DBH, specific gravity of wood for each species and allometric equations for above and below dry biomass (Komiyama *et al*., 2011). Stem volume (m^3 ha^{-1}) and total dry biomass (Mg ha^{-1}, TDB) by summing AGB and BGB were computed. The survey results are summarized in Table 1.

Table 1 Summary of sample plot surveys

Forest type	No of plots	Average DBH (cm)	Average H (m)	Stem Volume (m^3 ha^{-1})	Total biomass (Mg ha^{-1})
Sugi cedar	12	1.1 - 41.2	1.8 - 29.1	2.4 - 1068.3	2.6 - 467.1
Hinoki cypress	23	14.6 - 34.3	9.6 - 21.4	106.6 - 555.7	110.4 - 444.9
Deciduous Broadleaved	55	1.1 - 25.7	1.7 - 21.3	6.2 - 408.7	7.2 - 317.6
Japanese Larch	3	27.4 - 29.5	17.9 - 22.4	320.6 - 532.3	158.8 - 285.4

2.3 Areal Ortho Photos

Three areal ortho photos, which were taken in June 2003, September 2008 and November 2012 and were supplied by government of Gifu prefecture, were used as the reference of plot surveys and location. These ortho photos were georeferenced to the Japan Plane Rectangular Coordinate System VII (JPRCS VII) with JGD2000 as raster images with 0.5 m pixels.

2.4 Laser Scanner Data

Three airbone LiDAR scanning were executed in October 2003, July 2005 and August 2011 over the study areas, and the LiDAR data of 2003 was supplied by government of Gifu prefecture. Geometric location of airplanes or a helicopter was measured by Global Positioning System and Inertial Measurement Unit, then point data were geo-referenced to JPRCS VII. Footprint size of the three LiDAR data was between 0.2 and 0.4 cm, and beam density was 0.7 point m^{-2}, 1.8 point m^{-2} and 1.0 point m^{-2} for the 2003, 2005 and 2011 LiDAR data, respectively. LiDAR observations were summarized in Table 2. A digital terrain model (DTM) was produced as a 2 m raster image on JPRCS VII using the three LiDAR data (Fukuda and Awaya, 2013).

Gridding of digital canopy height model (DCHM) reduces height accuracy (Gaveau and Hill, 2003). Therefore DCHM were extracted for each plot as points by differencing digital surface model (DSM) of 2011 observation and interpolated terrain elevation at the beam location within each plot using the 2 m raster DTM and the bi-linear interpolation method. Various parameters were computed using DCHM for each plot as follows. A raster DCHM parameter files with 10 m resolution was also produced in the same way.

Table 2 Summary of LiDAR observations

Observation date	Contractor	Scanner	Beam divergence (mrad)	Wavelength (nm)	Flight altitude above ground (m)	Foot print size (m)	FOV (o)	Beam density (points m^{-2})
Oct., 2003	Kokusai Kogyo CO., LTD.	RAMS (EnerQuest, USA)	0.33	1064	2000 (Entire Gifu prefecture)	-	22	0.7
July 25, 2005	Nakanihon Air Service CO., LTD.	ALTM 2050DC (Optech, Canada)	0.19	1064	1200	0.24	±22	1.8
Aug. 28, 2011	Nakanihon Air Service CO., LTD.	SAKURA I (Nakanihon, Japan)	0.50	1550	600	0.30	±28	1.0

2.5 LiDAR Variables

Various LiDAR variables were examined to find useful variables for volume or biomass estimation (Means *et al*. 2000; Næsset and Økland 2002; Næsset 2004; Magnusson *et al*. 2007). Effective variables and estimation accuracy would be different by conditions such as foot print size (Næsset 2004), beam density (Magnusson *et al*. 2007), scan angle (Holmgren *et al*. 2003), tree size, canopy structure (Takahashi *et al*. 2005) and so on. Following variables (Table 3) and maximum height were calculated in reference to Næsset (2004) to evaluate useful LiDAR derived variables for artificial evergreen coniferous forest and natural deciduous broadleaved forest. Variables were computed using point DCHM in each plot, and points above the height of two standard deviations below average height were identified as canopy part in the plot. Programs of our own making were used for point DCHM generation and LiDAR variable computation.

Variables are denoted as follows. Maximum canopy height of the plot is Hmax. As for variables of all (total) points, average is THavr, standard deviation is THsd, and coefficient of determination is THcv. As for variables of points other than ground (above ground), average is AHavr, standard deviation is AHsd, and coefficient of determination is AHcv. As for variables of canopy points, average is CHavr, standard deviation is CHsd, and coefficient of determination is CHcv. As for height at each percentile, e.g. 10 percentile, is H10%. As for height at any height of each tenth, e.g. four tenth, is Hd4 and canopy coverage at this height is C4.

Table 3 Variables of LiDAR point data

Taget points	Variables					
All points	Average height	Standard deviation	Coefficient of variance			
Points other than ground	Average height	Standard deviation	Coefficient of variance			
Points within canopy part	Average height	Standard deviation	Coefficient of variance	Height at every 10 percentiles	Height at every tenth part	Canopy coverage at every tenth part

2.6 Correlation Coefficients

Tsuzuki *et al*. (2006) pointed out that stem volume is proportional to space under canopy surface theoretically. The space under canopy surface is identical to average canopy height. On the other hand, most current researches are based on double logarithmic relationship between above ground dry biomass and variables which are derived from LiDAR data including the average canopy height especially for single tree analysis (e.g. Næsset and Økland, 2002). Examining advantages of linear models for volume estimation is one of interests in this research.

Sample plots were separated into three groups by a systematic sampling according to TDB for evergreen conifer stands and deciduous broadleaved stands, separately. The smallest was split into group A, the second was group B, the third was group C, the forth was group A and all that. Correlation coefficients between the stem volume and the LiDAR data variables were computed for evergreen conifer and deciduous broadleaved forests separately for all sample plots and sample plots in each group. Points were allocated to variables to evaluate best variable for biomass estimation as follows; point 3 to the variable with greatest correlation, point 2 to the variable with 2nd greatest correlation, and point 1 to the variable with 3rd greatest correlation for all samples and three groups. The points were summed to identify variables less-affected by samples for stem volume estimation.

2.7 Regression Analysis

A multiple regression analysis by step-up procedure using Bayesian information criteria (BIC) for variable selection was executed for evergreen conifer and deciduous broadleaved forests, separately using JMP ver. 11 (SAS Institute Inc., USA). Three combinations were tested based on the 3 groups for conifer and broadleaved forests each. Samples in two groups, e.g. A and B, were used for modeling and samples in the rest group, e.g. C, were used for validation. Equations with two variables were built. A variable about canopy height was selected as the first variable in all cases. Since other height variable was usually selected as the second variable, height variable other than the first variable were removed and canopy structure variables such as crown closure or standard deviation of canopy height were left for the second variable selection. Coefficient of determination of equations were compared and a equation with the greatest coefficient of determination was selected as the best model for stem volume mapping.

Stem volume was mapped using the raster LiDAR parameters, forest type map and selected models using our own making programs. A model for deciduous broadleaved forest was used for larch according to a comparison of estimates using models for conifer or broadleaved forests. Biomass distribution pattern was visually evaluated using the stem volume map. Erdas Imagine ver. 10 (ERDAS, USA) was used for raster data conversion and ArcGIS ver. 10 (ESRI, USA) was used for creation of a figure of the stem volume map.

3. RESULTS AND DISCUSSION

3.1 Correlation Coefficient

Average height of all points (THavr) had the greatest correlation coefficient approximately greater than 0.9 with stem volume, above ground biomass and total biomass for conifer stands. While height at between four and six tenth (HD4, HD5 and HD6) had the greatest correlation coefficient approximately greater than 0.85 with the three stand variables for deciduous broadleaved forest. The result shows that effective LiDAR variable is different by forest types. As for stand parameters, the three parameters showed similar correlation for conifer forest, however, volume showed the best correlation for broadleaved forest. Specific gravity is similar between sugi cedar and hinoki cypress, therefore volume and AGB is almost identical for the case of conifer stands. On the other hand, broadleaved species have wide range of specific gravity and species composition changed widely among sample plots. These would result variation of dry biomass and caused worse correlation coefficients of AGB and TDB than that of volume. The result would support the theoretical linear relationship between canopy space and volume proposed by Tsuzuki *et al.* (2006). All correlation coefficients in Table 4 were significant ($P<0.01$).

3.2 Regression Analysis

The following equations were derived by the multiple regression analysis.

Evergreen conifer forest:

$$TDB = 18.5 \times AHavr - 216.0 \times C8 + 12.2 \qquad (1)$$

$$V = 55.2 \times AHavr + 825.4 \times CHcv - 482.4 \qquad (2)$$

Deciduous broadleaved forest:

$$TDB = 12.5 \times Hd5 - 107.0 \times C7 - 7.5 \quad (3)$$

$$V = 17.9 \times Hd5 + 1281.4 \times CC - 1324.8 \quad (4)$$

where TDB is total biomass (Mg ha^{-1}), Hd5 is height (m) at five tenth (a half) of canopy, CC is canopy closure (no unit), and C7 and C8 are canopy closure at height at seven tenth and eight tenth of canopy. V is stem.volume (m^3 ha^{-1}), AHavr is average height (H) of above ground LiDADR points, CHcv is coefficient of variance of LiDADR points hitting at canopy. The coefficient of C8 in equation (1) was not significant ($P>0.05$). Coefficient of determination adjusted for the degrees of freedom and number of sample plots are 0.903 and 22, 0.903 and 22, 0.762 and 38, and 0.849 and 38 for equation (1), (2), (3) and (4), respectively.

The results suggested that canopy structure variables of the second parameter would be effective for biomass and volume estimation, however, the significance was not high as shown the case of C8 in equation (1). If all LiDAR variables were used in the second variable selection of stepwise process, a height variable was selected as the second parameter. If two height variables were selected, it seemed to be not meaningful physically. However, standard errors in any cases of one variable equation had high correlation with LiDAR height variables. Since size (DBH, H, V and TDB) of trees and stand density are very different among trees in older stand and the difference is greater with stand age, the variation would be a function of age and canopy height which becomes greater by age. Therefore LiDAR height variables probably correlates with the standard errors in the case of one variable equation, which are variation of biomass among stands. Reducing standard error is the greatest task to improve accuracy of volume and biomass estimation.

The volume prediction tended to be slightly under estimation in dense sugi stands with high volume and slightly over estimation in hihoki stands with relatively low density. CHcv had slightly high correlation coefficient of 0.661 with stand density, and it may be the reason to be selected as the second variable. However, the error trend suggested that stand density affected on the estimation using equation (2).

Validation results showed that equations (2), (3) and (4) predicted stem volume or TDB with 1.7 % less, 5.5 % less and 3.3 % less as the average, respectively. Root mean square errors of equations (2), (3) and (4) was 12.5 m^3 ha^{-1}, 5.3 Mg ha^{-1} and 6.5 m^3 ha^{-1}, respectively. The validation suggested that the estimation was quite accurate.

Table 4a Correlation coefficients between LiDAR and stand papameters - Evergreen Conifer (All plots n=35)

LiDAR	Volume (m^3 ha^{-1})	AGB (Mg ha^{-1})	TDB (Mg ha^{-1})	Points*
Hd4	0.871	0.915	0.915	6
Hd5	0.876	0.912	0.912	8
Hd6	0.874	0.904	0.903	7
THavr	0.894	0.915	0.913	18
H40%	0.886	0.900	0.896	7

*Points: Evaluation of correlation coef. for plots of all and 3 groups. If correlation coef. is the top, 2nd and 3rd, 3, 2, 1 points were given, respectively and summed.

Table 4b Correlation coefficients between LiDAR and stand papameters - Deciduous broadleaved (All plots n=55)

LiDAR	Volume (m^3 ha^{-1})	AGB (Mg ha^{-1})	TDB (Mg ha^{-1})	Points*
Hd4	0.912	0.854	0.852	16
Hd5	0.912	0.856	0.854	14
Hd6	0.909	0.857	0.854	13
THavr	0.907	0.843	0.840	0
H40%	0.904	0.839	0.836	0

*Points: Evaluation of correlation coef. for plots of all and 3 groups. If correlation coef. is the top, 2nd and 3rd, 3, 2, 1 points were given, respectively and summed.

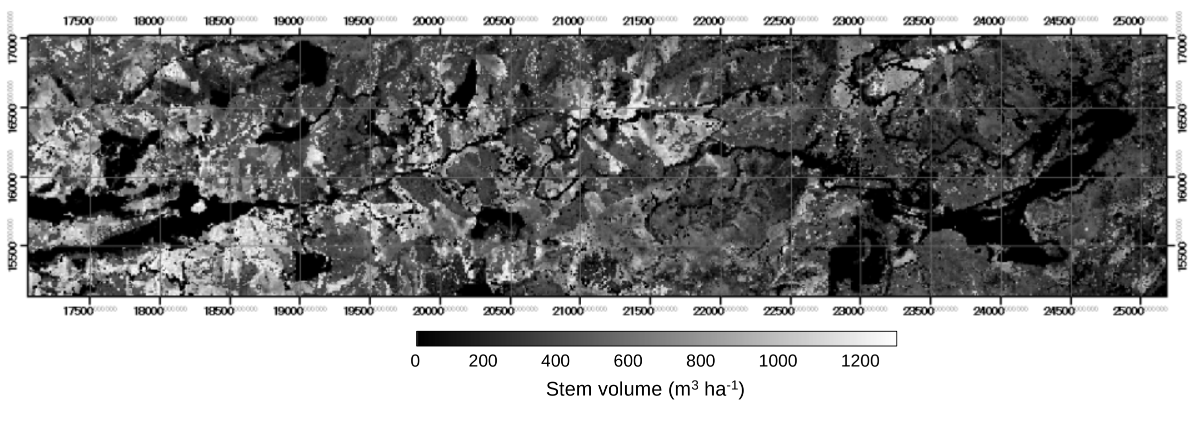

Figure 1 Distribution of stem volume

3.3 Stem Volume Distribution

According to the plot survey, stem volume of broadleaved and confer stands ranged up to 400 m^3 ha^{-1} and 1000m^3 ha^{-1}, respectively (Table 1) and there were high stock conifer forests in the study area. Forest owners cared their forests a little, therefore many of mature sugi stands are left without thinning. Above all sugi is a fast grow species. It caused unthinned dense sugi stands with high stock in many parts of Japan. A small village was located at the left (west) of study site and artificial evergreen conifer forests were common in the study area (Fig. 5). High volume areas in the west were mainly mature sugi cedar forests. On the other hand, there was no village in the eastern two third of the study area and broadleaved stands and young conifer stands were dominant. Therefore volume of these stands were small and may be less than 400 or 500 m^3 ha^{-1} according to Table 1. Fig. 5 showed this pattern very well with a few exceptions which were areas with high volume forest along forest roads in the eastern part.

4. CONCLUSIONS

Prefectural governments have forest inventory as forest registers in Japan, however, records of stand volume are not accurate in the registers. LiDAR data provided an accurate stand volume map showing volume distribution as 10 m meshes which was 0.01ha. Since stand density seemed to affect to the prediction accuracy, stem volume and biomass estimation models should be improved to be more robust. However, we confirmed the usefulness of LiDAR data regarding stock mapping.

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