EFFECT OF SPECIES ON ACCURACY OF TIMBER STOCK ESTIMATION BY AIRBORNE LASER PROFILING

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ABSTRACT: Airborne Laser Profiling (ALP) is a rather new technique used to produce a vertical canopy profile of vegetation along the flight line by measuring the distance between the aircraft and surface objects on the ground. Timber, biomass or carbon stock could be directly obtained by integrating that laser-measured vegetation profile. However, their accuracy is expected to be affected by many different factors. This study investigated the effect of species on accuracy of timber stock estimation. ALP provided the vegetation profile along seven north-south flight lines over Ehime University Experimental Forest (384 ha) with dominant species of *Cryptomeria japonica*, *Chamaecyparis obtusa* and other mixed broadleaved species. A total of 49 sample plots were surveyed along flight lines to make a regression relating ground-measured timber stock to laser-measured vegetation profile area. By using that regression, timber stock was estimated for each species component (*C. japonica* 364.2 m^3/ha, *C. obtusa* 358.8 m^3/ha and broadleaved species 427.0 m^3/ha) and entire area (397.3 m^3/ha). Then, the sample plots were differentiated by species and used to make regressions for each species. By using these species specific regressions, timber stock was also estimated for each species component (*C. japonica* 431.8 m^3/ha, *C. obtusa* 446.3 m^3/ha and broadleaved species 353.7 m^3/ha) and entire area (392.4 m^3/ha). The results indicated that for the timber stock by species the laser estimates with species specific regressions were rather different from the laser estimates with overall regression (*C. japonica* 18.6%, *C. obtusa* 24.4% and broadleaved species -17.2%), and for total timber stock they were slightly different (-1.2%). Thus, from the carbon accounting point of view, i.e. when total carbon, biomass or timber is needed, it could be accurately estimated without species differentiation. However, from the commercial point of view, the timber stock should be estimated with species differentiation.

1. INTRODUCTION

Airborne Laser Profiling (ALP) is a rather new remote sensing technique used to produce the canopy height profile along the flightline by measuring the distance between the aircraft and surface objects on the ground. Both principle and a few examples of forest measurements indicate that ALP would be a powerful tool of forest resources inventory and surpass such conventional methods as ground inventory, aerial photogrametry, or satellite imagery in accuracy, coverage, and efficiency. Maclean (1986), Sweda *et al*. (1998) and Tsuzuki *et al*. (2008) reported that timber stock, biomass or carbon stock can be directly obtained by integrating the laser-measured canopy height profile.

However, the accuracy of laser estimates is expected to be affected by many different factors, e.g. laser measurement intensity, species, stand age, or stand density. To our knowledge, although several researchers have investigated the estimation accuracy of forest variables using airborne laser scanning (Magnusson *et al*., 2007, Neasset, 2009), the estimation accuracy using airborne laser profiling is still intact. We have conducted a study to investigate the effect of laser measurement intensity on accuracy of timber stock estimation (Tinh *et al.,* 2011), and in this study, we present the effect of species on accuracy of timber stock estimation.

2. MATERIALS & METHODS

2.1. Study area & airborne laser profiling

The study area is Ehime University experimental forest (384 ha) with an altitude ranging from 500 to 1200 m above sea level. The dominant tree species area *Cryptomeria japonica*, *Chamaecyparis obtusa* and mixed broadleaved species. The area occupied by broadleaved species is about 54% mostly in high elevation areas and the rest land area is occupied by *Cryptomeria japonica* and *Chamaecyparis obtusa* with approximately equal percentages (Figure 1). The study area was flown in September, 2005 by NASA's Portable Airborne Laser System (PALS, Nelson *et al*., 2003). The laser data and concurrent video were collected along seven parallel north-south flightlines, about 200 m apart from each other. The total length of flightlines is about 26 km with average laser shot interval of 0.18 m. The laser data was used to generate the vegetation profile while the video was used in an attempt to trace the flightlines on the ground.

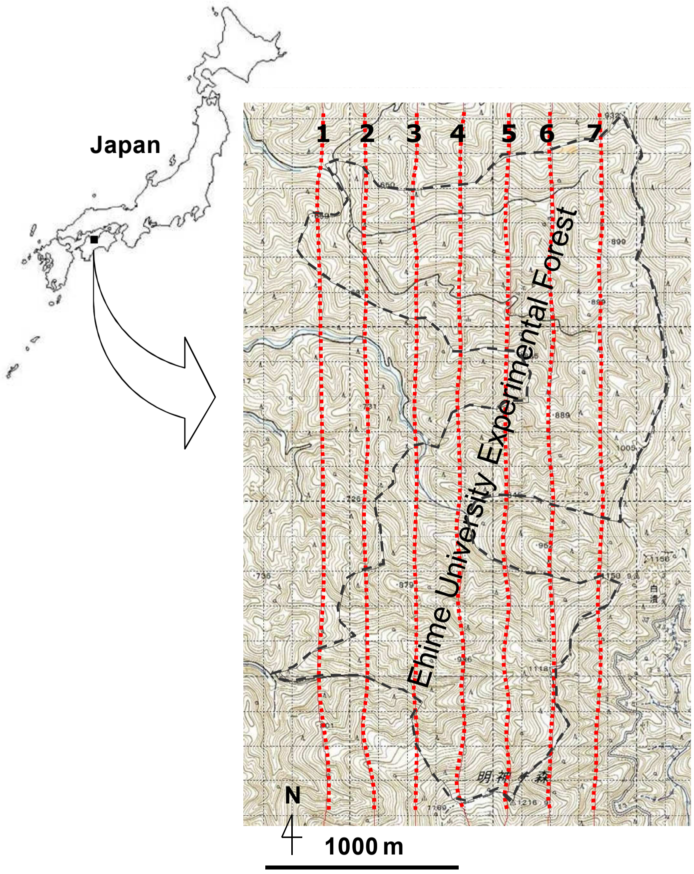

Figure 1: Study area and airborne laser profiling flight lines

2.2. Timber stock estimation

Forest timber stock was estimated from vegetation profile by classifying *C. japonica*, *C. obtusa* and Broadleaved species, calculating vegetation profile area and timber stock along flight lines by forest timber stock equations generated by ground-measured stand volume, and expanding line estimates to area (Tsuzuki *et al*., 2008, 2009). Existing inventory map of the study area with species information of 200 stands was used to judge flightline into *C. japonica*, *C. obtusa* or Broadleaved species. Forest timber stock estimation along flight line was based on regression equation

$$V = aS \tag{1}$$

where V (m^3/ha): ground-measured timber volume, S (m^2/m): vegetation profile area at a given flight distance, and a: regression coefficient (Tsuzuki *et al*., 2008).

In our previous work (Tinh *et al*., 2011), the general regression coefficient of 24.35 was determined by using the measurements of 49 sample stands. However in order to investigate the effect of species on timber stock estimation, the sample stands were divided by species and used to determined species specific regression coefficients (Figure 2).

Timber stock estimated by general regression equation was compared to the one estimated by species specific regressions at stand and forest levels.

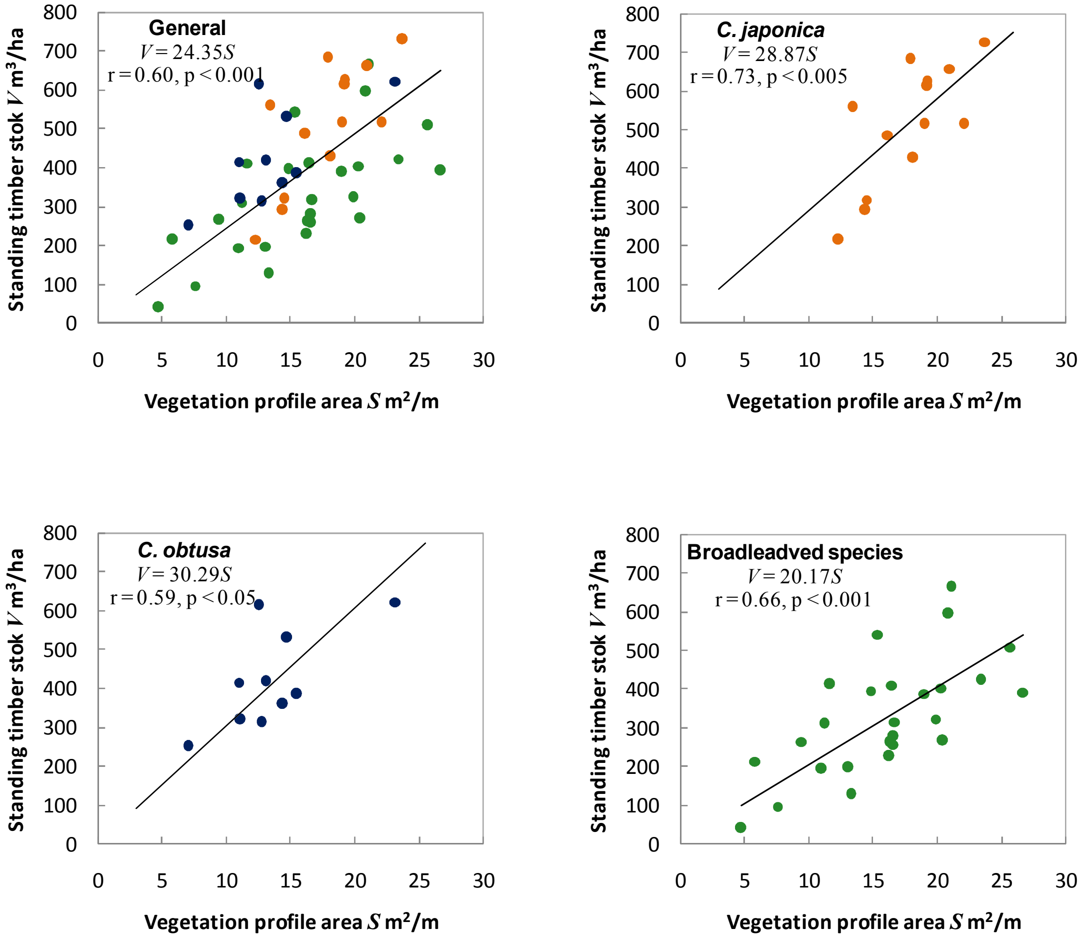

Figure 2: Regressions of standing timber stock on vegetation profile area

2.3. Ground truthing

Ground survey was conducted in sample plots established directly under airborne laser profiling flightline for generating forest timber stock equations (Figure 2) and verifying timber stock equations (Figure 3). A total of 49 sample plots consisting of 13 *C. japonica*, 10 *C. obtusa* and 26 mixed broadleaved species were surveyed along the flightlines. In each plot, stem diameter at breast height (dbh) was censused and then converted to stem volume by Forest Agency volume equations (Japanese Forestry Agency, 1970), which were modified from having two independent variables (dbh, height) into having one independent variable (dhb) by using height and dbh allometric equations made from the measurements of 167 sample trees consisting of 61 *C. japonica*, 65 *C. obtusa* and 50 broadleaved species, located in and around the sample plots. Since the laser data was collected in 2005 and sample plots were surveyed in 2008 and 2009, the plot timber volume was corrected for the increment by growth curves made from existing inventory data of Ehime University experimental forest.

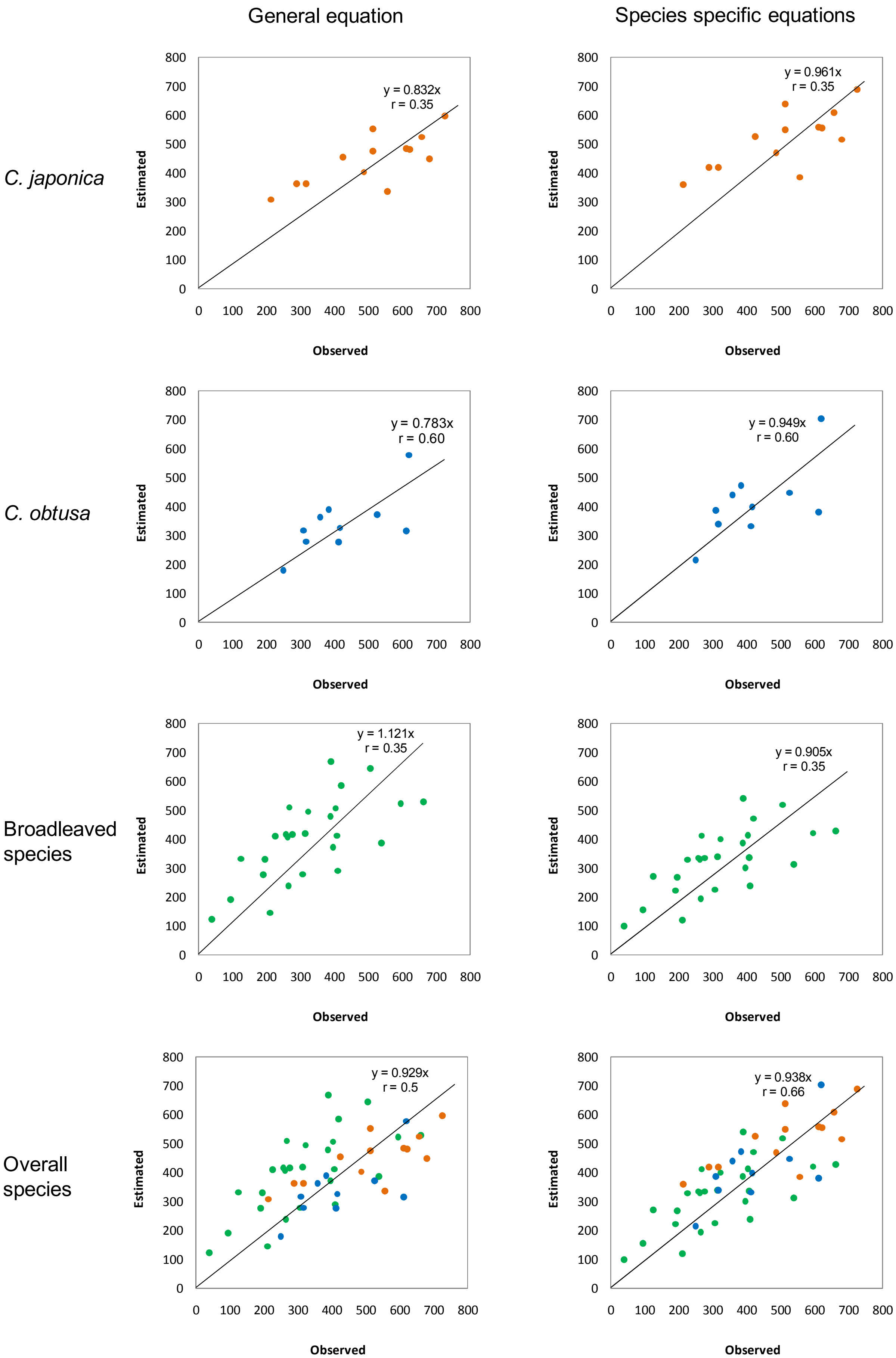

Figure 3: Regression of laser estimated stand volume on measured at ground

3. RESULTS & DISCUSSIONS

3.1. Verifying timber stock equations

Laser estimates of timber stock were compared with ground measurements. Figure 3 shows airborne laser estimates and ground measurements are nearly 1:1 at sample plots by each or overall species. This result is consistent with finding of Tsuzuki *et al*. (2009) and confirms that forest timber stock can be accurately estimated by airborne laser altimetry. However, by detail examination the timber stock estimated using general timber stock equations is about 20% smaller than ground truth for forest stands of *C. japonica* and *C. obtuse*, and about 22% greater than ground truth for forest stands of mixed broadleaved species. The under- and overestimation is canceled each other when the general timber stock equation is used to estimate the total timber stock, i.e. without species specification. This finding occurs from the differences in standing timber volume (*V*s) between conifer (*C. japonica* and *C. obtuse*) stands and broadleaved species stands although their canopy profile areas (*S*s) may be the same.

3.2. Forest timber stock: general vs. species specific equations

Since airborne laser profiling data set was classified into different categories of *C. japonica*, *C. obtuse* and broadleaved, they were used to estimate forest timber stock by using general and species specific timber stock equations alternately (Table 1). By using the general equation, timber stock was estimated for each species component (*C. japonica* 364.2 m3/ha, *C. obtusa* 358.8 m3/ha and broadleaved species 427.0 m3/ha) and entire area (397.3 m3/ha), and by using the species specific equations, timber stock was also estimated for each species component (*C. japonica* 431.8 m3/ha, *C. obtusa* 446.3 m3/ha and broadleaved species 353.7 m3/ha) and entire area (392.4 m3/ha). Since the comparison shows the laser estimates with species specific equations and ground measure is nearly 1:1 (Figure 3), we assumed the former as the actual values to evaluate laser estimates with general equations. The result shows that by using general equation, total laser estimate is rather accurate with a small difference -1.2% (Table 1) and consistent with existing figure 394.9 m^3/ha automatically calculated by a Real Forester System developed for monitoring timber stock of the study area (Takejima *et al*., 1999), while for *C. japonica* and *C. obtusa* laser estimates underestimated 18.6% and 24.4% respectively, and for broadleaved species laser estimate overestimated 17.2%. The under- and overestimation had been expected by above verifying timber stock equations. Thus, this result suggests that from the carbon accounting point of view, i.e. when total carbon, biomass or timber is needed, it could be accurately estimated by only one general timber stock equations. However, from the commercial point of view, the timber stock should be estimated by species specific equations.

Table 1: Laser estimates of timber stock (m^3/ha) by general and species specific equations and their comparison

Equations	*C. japonica*	*C. obtusa*	Broadleaved	Total
General A	364.2	358.8	427.0	397.3
Species specific B	431.8	446.3	353.7	392.4
$\frac{A-B}{B} \times 100$ (%)	-18.6	-24.4	17.2	1.2

4. CONCLUSIONS

This study has shown that forest timber stock could be estimated with the use of ALP through the regression of ground-measured timber volume upon the area under vegetation canopy profile, and the general equation could be used for total timber stock estimation while species specific equations is recommended for timber stock estimation by species. The present study is only limited to a small and well-managed area of temperate forest and thus, further investigations on larger areas and different forest types should be conducted.

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