ESTIMATING FOREST PRODUCTIVITY OF MANMADE CONIFEROUS FOREST STANDS USING LOW DENSITY LIDAR

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ABSTRACT:

The site index, defined as stand height at a specific age (40 years in Japan), is used to assess forest productivity. We estimated the site index of Hinoki cypress (*Chamaecyparis obtusa*) for forest productivity using low-density airborne LiDAR. LiDAR data were acquired along a 20-km long (100-m wide transect in the eastern part of Shikoku Island at low density (1 pulse m^{-2}) and with a small footprint (20 cm). Within the transect, we set plots that included non-forest, small forest, and large forest areas, and measured tree height. Laser pulses for use in a digital canopy height model were extracted for each plot, and the following LiDAR indexes were calculated: average, maximum, minimum, 10, 20 ... 90 percentiles, standard deviation, and coefficient of variation. A linear regression analysis was performed between the LiDAR indexes and stand height. Stand height had the strongest relationship with the LiDAR index for the first-pulse 80 percentile. We were able to estimate forest productivity in a large area using stand height from the LiDAR data, stand age for a forest GIS, and the site index equation.

1. INTRODUCTION

The development of practical methods for measuring forest carbon stock, absorption, and emission in large areas has become increasingly important for forestry under the Kyoto Protocol. Forest carbon stock and carbon absorption by forests depend on forest productivity of the site, even if species, stand age, and operation are the same. The site index, defined as stand height at a specific age (40 years in Japan), is used to assess forest productivity in man-made coniferous forest stand yield tables (Forestry Research Institute of the Forestry Agency 1957). In general, it is difficult to study the site index, because it contains a large amount of field plot data. Here, we demonstrate that low-density LiDAR can be used to measure forest stand variables precisely (Kodani and Awaya 2008), which will allow precise data to be obtained for a large area.

The objective of this study was to estimate the forest productivity index of Hinoki cypress (*Chamaecyparis obtusa*) in man-made coniferous stands using low-density LiDAR.

2. METHODS

2.1 Study site

We established a transect 20-km long and 100-m wide that traverses the western part of Shikoku Island (Fig. 1). Most of this transect is national forest area. Airborne LiDAR data for the transect were obtained on September 2002 by the Asahi-koyo Corporation. Flight height above the ground was 1000 m, laser density was 1 pulse m^{-2}, the footprint was approximately 20 cm, and the first and last pulses were recorded. A digital terrain model (DTM) was generated by Asahi-koyo using the last-pulse data. A digital canopy height model (DCHM) was generated using the difference between the laser pulse data and the DTM.

We set plots within this transect that contained non-forest areas and small to large forest stands of a man-made coniferous forest of Sugi (*Cryptomeria japonica*) and Hinoki cypress (*Chamaecyparis obtusa*, n = 24). The plot was 15-m wide and 15-40-m long, depending on tree density. We measured stem diameter at breast height (DBH) and tree height in the plots. Two points on the plots were surveyed using differential GPS Trimble Pathfinder Pro (Trimble Inc. USA) for more than 10 min.

Figure 1. Map of the transect in the western part of Shikoku Island.

2.2 Estimating average stand height using low-density LiDAR

High-density LiDAR can detect single trees and measure variables of each tree (Hyyppä et al. 2001), whereas low-density LiDAR cannot detect individual trees, but is suitable for observing large areas and uses a different analytical method. In the latter, the subject is not a tree, but a forest stand, and the

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method uses statistical analysis to obtain stand data. The cost of high-density LiDAR is higher than that of low-density LiDAR.

We estimated forest stand variables using regression analysis, i.e., calculating coefficients of determination between forest stand variables and airborne LiDAR indexes and selecting the best airborne LiDAR index. The following airborne LiDAR indexes have previously been used: average, maximum, minimum, 10, 20, ...and 90 percentiles, standard deviation, and coefficient of variation (Nelson et al. 1988, 2004; Næsset 1997, 2002; Tsuzuki et al. 2006). In the present study, airborne LiDAR indexes were calculated as described below. The first and last pulse laser data of DCHM were extracted from each plot, and indexes of maximum, average, minimum, standard deviation, and coefficient of variation were calculated. The quantiles corresponding to the 10, 20, ... and 90 percentiles were calculated from a cumulative histogram of airborne LiDAR DCHM in each plot.

2.3 Estimating the site index

The site index is defined as forest stand height at a specific age. The specific age used in Japan is usually 40 years. The site index is calculated using a guide curve (Eq. 1) and a site index curve (Eq. 2; Avery and Burkhart 1988, Nishizawa 1972, Parde and Bouchon 1988):

$$\text{Log } Hd = b0 + b1/t \quad (1)$$

$$\text{Log } S = \text{Log } Hd + b1(1/t - 1/40) \quad (2)$$

(where S: site index, Hd: stand height, t: age)

The site index curve for Hinoki cypress was calculated using empirical yield tables from the Shikoku National Forest Agency (Forestry Research Institute of the Forestry Agency 1957), where stand height in the site index is taken as the average of dominant trees. In the yield tables, the trees are classified as thinned or not thinned according to selection criteria for thinning from below. The dominant trees are defined as those that are not thinned, and these are used to calculate the site index. However, in our regression analysis between average of dominant trees and the average of all trees, the gains were approximately 1 and the offsets were approximately 0 in Hinoki cypress (Eq.3). Therefore, we used the average of all trees to calculate the site index.

$$y = 1.01\,x + 0.06 \quad (3)$$

(R^2 = 0.997, x: average tree height、y: average dominant tree height)

The Shikoku National Forest Agency established 400 permanent sample plots for developing a more precise yield table and surveyed these at 5-year intervals from 1982 to 2005. The field plot data for Hinoki cypress were selected for the present study. The variables from the site index curve were re-calculated using the plot data and found to be approximately the same as the original variables (Kodani et al. 2009).

To calculate the site index, data for stand height, stand age, and forest species are needed. National forest GIS data were used to obtain stand age and forest types. Quickbird images and air photos were interpreted to obtain more detailed forest types and forest species.

3. RESULTS AND DISCUSSION

3.1 Estimating average stand height using LiDAR

A linear regression analysis was performed between the LiDAR indexes and average stand height (Table 1). Average stand height had the strongest relationship with the index of the first-pulse 80 percentile (R^2 = 0.908, p = 0.000). We estimated the average stand height using the LiDAR data and this regression line.

3.2 Estimating the site index using LiDAR and GIS data

The site index of Hinoki cypress was estimated using the average stand height from LiDAR, the stand age of the forest from GIS, and the site index curve. Figure 2 shows the average stand height and site index for the same location. The average stand height was smaller than the site index where stand age was lower than the specific age, whereas average stand height was larger than the site index where stand age was higher than the specific age. These results correspond to the definition of the site index curve.

The Hinoki cypress stand was extracted by interpretation of the Quickbird images and air-photos. The frequency histogram of the site index and stand age was calculated for the transect. The average site index in the transect was 13.5, nearly the same (13.7) as the average for the site index. Most site index data were normal, but the histogram included smaller and larger locations that were outside the range of the site index curve data.

Three error factors were obtained. First, when stand age was much less than the specific age, it was difficult to correctly estimate the site index. Second, the average stand height from the LiDAR data contained errors: the average stand height was too small in several places, especially areas of bush from 10 to 30 years old, although the stand was confirmed to be growing well according to the stand age and image interpretation. As the laser was unable to detect the ground in the bush site, average stand height would be estimated to be smaller. Third, when the forest type or species was misinterpreted, the site index was also erroneous. Photo interpretation can easily distinguish between coniferous forest and broadleaf forest, but has difficulty in separating man-made coniferous Sugi and Hinoki cypress forest stands. Sugi grows faster than Hinoki cypress, and when Sugi was misinterpreted as Hinoki cypress, the site index became much larger.

In conclusion, we have developed a method to estimate forest productivity using low-density LiDAR. Future forest stand volume, carbon stock, and carbon absorption could be estimated more precisely by combining the forest yield table, site index, and low-density LiDAR data. Remote sensing can be used to measure the present variables and to estimate the future stand state using an ecological model.

Forest yield tables are a classical tool in forestry practice, and many forest growth models have been developed and used. However, these models are not suitable for combining with low-density LiDAR because they use stand density variables, which low-density LiDAR cannot estimate precisely (Kodani and Awaya 2008). For further study, a forest growth model incorporating low-density LiDAR should be developed.

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*English titles are tentative translations of the original Japanese titles.

Table 1. Coefficients of determination between average stand height and LiDAR indexes.

First Pulse	Average	Maximum	Minimum	STD	CV				
	0.883	0.893	0.045	0.696	0.493				
	h10	h20	h30	h40	h50	h60	h70	h80	h90
	0.741	0.887	0.897	0.900	0.902	0.904	0.907	0.908	0.906
Last Pulse	Average	Maximum	Minimum	STD	CV				
	0.716	0.893	0.000	0.816	0.007				
	h10	h20	h30	h40	h50	h60	h70	h80	h90
	0.806	0.791	0.782	0.781	0.775	0.773	0.776	0.773	0.773

(STD: Standard Deviation , CV: Coefficient of Variance, h**: ** percentile)

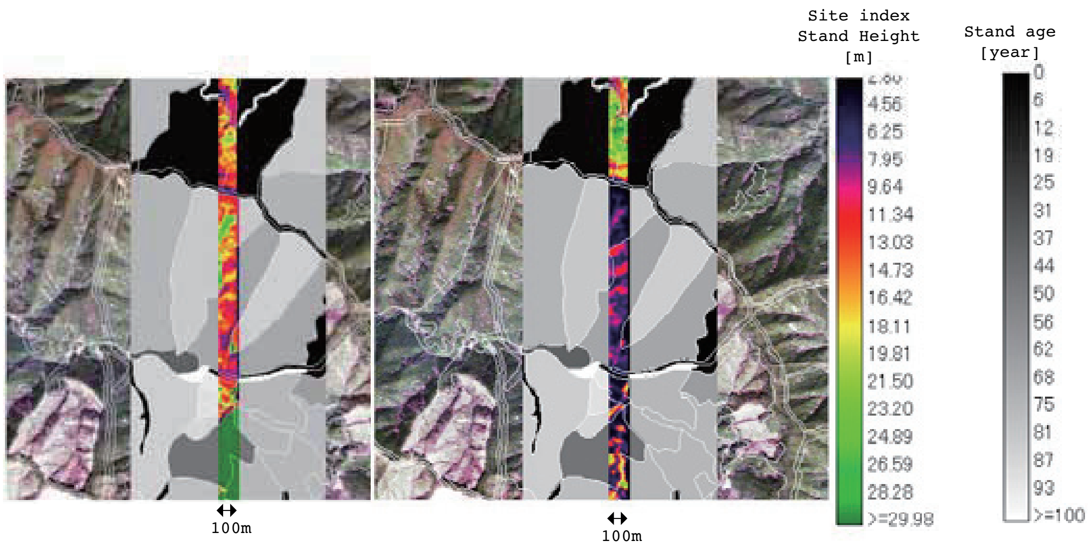

Figure 2. The site index and average stand height obtained using low-density LiDAR (background color image: QuickBird true color, background gray image: stand age, Left: site index; Right: average stand height).

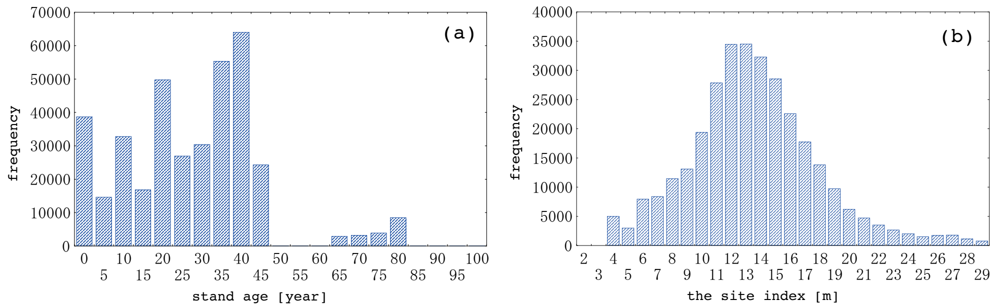

Figure 3. Frequency histogram for Hinoki cypress in the transect (a: stand age, b: site index).