ESTIMATING FOREST STRUCTURE INDICES FOR EVALUATION OF FOREST BIRD HABITATS BY AN AIRBORNE LASER SCANNER

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ABSTRACT:

Bird species diversity is affected by the vertical and horizontal diversity of forest structure; therefore, several indices of forest structure have been proposed for the evaluation of bird habitats. If these indices could be measured in a wide area by remote sensing, it would be very useful for wildlife habitat assessment. The indices that we evaluated based on whether they can be estimated from airborne laser scanning data, are as follows: the foliage height diversity calculated by five layers (FHD5) and four layers (FHD4), the sum of vegetation coverage in five layers (COVSUM5) and four layers (COVSUM4) and the crown patchness (CP). Only COVSUM5 by 1 m and 2 m width calculated from one and two flight lines of laser scanner data were correlated to those from ground truth data. The difficulty in the estimation of these indices by an airborne laser scanner that records the first and last pulses is derived from the low density of the return pulses in the middle layers. We propose a simple interpolation method to estimate the distribution of foliage in the middle layer using the information from return pulses. The indices FHD5 by 1 m and FHD4 by 2 m obtained from two flight lines data and those recalculated after the interpolation were correlated to those from ground truth data in the Pearson's correlation coefficient. CP obtained before and after interpolation from one flight line data also had relatively high correlation coefficients.

1. INTRODUCTION

1.1 Background

The conservation of biodiversity is currently one of the important roles of forestry. The management of both natural forests and plantations should take into consideration wildlife habitats.

Bird species diversity is known to be affected by forest structure; therefore, several indices of forest structure have been proposed for the evaluation of birds' habitats (Erdelen, 1984; Ishida, 1987; MacArthur & MacArthur, 1961). Higher vertical diversity of foliage distribution that can be numerically expressed based on these indices improves bird species diversity because each species can find their own ecological niche divided by feeding height. However, these indices are based on data that were measured through a field survey. Therefore, making maps of these indices in large areas is a difficult task. If these indices can be measured in a wide area by remote sensing, it will be very useful in the assessment of wildlife habitat.

Airborne laser scanners can not only measure the three-dimensional shapes of forest canopy surfaces but also the land elevation under the canopies. These scanners have recently been used to estimate tree heights in forests. Several studies have used vegetation heights measured by airborne laser scanners in the evaluation of birds' habitats (Davenport et al., 2000; Hinsley et al., 2002).

Some of the return pulses of laser beams are returns from the middle layer of the forest and undergrowth, and the estimation of three-dimensional foliage distribution from laser scanning data has also been studied (Todd et al., 2003). Therefore, laser scanning data with a high density must be available for measuring vertical forest structure.

1.2 Aim of this study

In this paper, we will demonstrate the availability of laser scanning data in the estimation of forest structure indices and propose a simple interpolation method by which to improve the accuracy of the estimated indices.

2. MATERIALS AND METHODS

2.1 Laser scanning data

The study site was an isolated forest in Kyoto City in Japan, and its vegetation type was that of a temperate mixed forest, mainly consisting of deciduous and evergreen broad-leaf trees. The laser scanning data was obtained in January 2003 when the

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leaves of the deciduous trees had already fallen. Approximately four laser fluxes per square meter were beamed from an N-TOMS II mounted on a helicopter at a height of 400 m, and the first and last return pulses were recorded. The diameter of the footprint was about 20 cm. We obtained two overlapping flight lines data.

2.2 Ground truth data

Ground truth data were 1 m × 1 m mesh vertical cross sections that were drawn on six 50-m lines in February 2003. These cross sections were drawn using a measure pole, a simple laser range finder and a measure tape; therefore, the accuracy of ground truth data was not very high but it was sufficient to calculate the forest structure indices selected in this study.

2.3 Data Analysis

Laser scanning data obtained from a flight line or two overlapping flight lines within 1 m or 2 m width on the six 50-m lines where the ground truth data were obtained, were converted to 1 m × 1 m mesh vertical cross sections after the elimination of the ground points, which were classified using a software tool called Terra Scan (Terrasolid Ltd.), and the indices of forest structure were calculated.

The accuracy of the estimated forest structure indices were checked by applying the Pearson's correlation coefficient and the Spearman's correlation coefficient to the indices calculated from the ground truth data.

2.4 Interpolation algorithm

The difficulty in estimating these indices using an airborne laser scanner that records the first and last, or only pulses, is derived from the low density of return pulses in the middle layers. Thus, using the information from return pulses, we propose a simple interpolation method to estimate the distribution of foliage in the middle layer.

Interpolation will be obtained when a blank grid cell is sandwiched by filled grid cells from both the horizontal sides of the mesh in five types as follows:

$$f_{(x-1,\, z)} = 1 \text{ and } f_{(x+1,\, z)} = 1 \quad (1)$$
$$f_{(x-1,\, z+1)} = 1 \text{ and } f_{(x+1,\, z)} = 1 \quad (2)$$
$$f_{(x-1,\, z)} = 1 \text{ and } f_{(x+1,\, z+1)} = 1 \quad (3)$$
$$f_{(x-1,\, z+1)} = 1 \text{ and } f_{(x+1,\, z-1)} = 1 \quad (4)$$
$$f_{(x-1,\, z-1)} = 1 \text{ and } f_{(x+1,\, z+1)} = 1 \quad (5)$$

where f = presence (1)/absence (0) of the return pulse
x = distance (m) along the line
z = elevation (m) of the target grid

Exceptions are allowed in two situations. Firstly, the first or only pulses are supposed to detect the top layer of the vegetation; therefore, interpolation will not be obtained when any returns are absent above the top layer. Secondly, no interpolation will be obtained when any last or only pulses exist above the top layer because we assumed that the last and only pulses are returns from the thick foliage that obstruct the light required for vegetation growth below them.

2.5 Indices of forest structure

The indices that were evaluated depending upon whether they could be estimated from airborne laser scanning data are as follows: the foliage height diversity calculated by five layers (FHD5) and four layers (FHD4), the sum of vegetation coverage in five layers (COVSUM5) and four layers (COVSUM4) and the crown patchness (CP).

The foliage height diversity (FHD) is an index proposed by MacArthur & MacArthur (1961). This index is based on the information theory and calculated using the formula given below. The more equal the proportion of vegetation coverage at every height, the higher the FHD value and the higher the bird species diversity because each species can find their own ecological niche divided by feeding height.

$$\text{FHD} = -\sum p_i \log_e p_i \quad (6)$$

where p_i = proportion of horizontal vegetation coverage in the i th layer

Although MacArthur et al., (1966) also discussed the mean of the number of layers, in several studies, these were often decided based on the authors' own viewpoint. In this study, we considered four (0-2 m, 2-4 m, 4-8 m and more than 8 m) and five (0-2 m, 2-5 m, 5-10 m, 10-15 m and more than 15 m) as the numbers of layers.

The sum of vegetation coverage (COVSUM) is an index proposed by Erdelen (1991), and this value indicates the volume of foliage. Although it was originally considered as the sum of points where vegetation is present in 600 points (50 points along a 100 m line and at 12 different heights), in this study, we used the COVSUM as the sum of vegetation coverage (%) in four or five layers along a line, because it is difficult to completely detect the presence/absence of foliage at certain heights under canopies by the double-pulse type of laser scanner.

The CP is an index proposed by Ishida (1987). This index considers both the vertical and horizontal diversity of foliage distribution. This index can be calculated from the 1 m × 1 m mesh vertical cross sections using the following formula.

$$\text{CP} = n \sum [X_i (X_i - 1)] / [N (N - 1)] \quad (7)$$

where n = total number of 2 m × 2 m blocks that were constructed from four meshes in the cross section
X_i = number of meshes occupied by vegetation in the i th block
N = the total number of meshes occupied by vegetation in the cross section

An index value of one indicates random foliage distribution, a value under one indicates equal foliage distribution and a value above one indicates clustered foliage distribution. Ishida (1987) showed that bird species diversity is high in a high-CP forest.

3. RESULTS AND DISCUSSION

3.1 Vertical cross sections by laser scanning data

According to the laser scanning data, there were four types of vertical cross sections, and each of them was obtained after interpolation. Since this data was obtained during the winter, the density of the return pulses under canopies was different for evergreen trees and deciduous trees. The canopies of the broad-leaf evergreen trees prevented a greater penetration by the laser fluxes. The leaves of the deciduous trees had fallen, but the shapes of the canopies of the deciduous trees were drawn using the return pulses from the branches.

3.2 Accuracy of estimated forest structure indices

The Pearson's correlation coefficient and the Spearman's correlation coefficient between the indices calculated from the laser scanning data and ground truth data are shown in Table 1.

No. of overlapping flight lines		1 flight line			
	Width	1 m		2 m	
	Interpolation	None	Done	None	Done
FHD4	Pearson	0.50	0.49	0.63	0.68
	Spearman	0.37	0.20	0.37	0.60
FHD5	Pearson	0.39	0.43	0.53	0.76
	Spearman	0.31	0.31	0.60	0.77
COVSUM4	Pearson	0.34	0.29	0.40	0.35
	Spearman	0.03	0.03	0.03	0.03
COVSUM5	Pearson	0.92*	0.91*	0.95*	0.94*
	Spearman	0.94*	0.94*	0.94*	0.94*
CP	Pearson	0.85*	0.86*	0.84*	0.86*
	Spearman	0.78	0.78	0.64	0.64
No. of overlapping flight lines		2 flight lines			
	Width	1 m		2 m	
	Interpolation	None	Done	None	Done
FHD4	Pearson	0.67	0.71	0.79	0.81*
	Spearman	0.49	0.60	0.71	0.71
FHD5	Pearson	0.74	0.80*	0.41	0.43
	Spearman	0.60	0.64	0.43	0.31
COVSUM4	Pearson	0.33	0.32	0.33	0.33
	Spearman	0.03	0.14	0.03	0.03
COVSUM5	Pearson	0.83*	0.83*	0.88*	0.86*
	Spearman	0.89*	0.89*	0.89*	0.89*
CP	Pearson	0.71	0.73	0.77	0.79
	Spearman	0.49	0.49	0.58	0.49

Table 1. The Pearson's correlation coefficient and the Spearman's correlation coefficient between the indices calculated from the laser scanning data and ground truth data. The asterisks indicate the correlation coefficients that are more than 0.8.

Only COVSUM5 by 1 m and 2 m width calculated from laser scanning data before and after the interpolation were highly correlated (> 0.8) to those from ground truth data in the Spearman's correlation coefficient. However, FHD5 by 1 m and FHD4 by 2 m calculated after the interpolation had a high correlation in the Pearson's correlation coefficient (> 0.8). CP by 1 m and 2 m from one flight line data also had a high correlation in the Pearson's correlation coefficient (> 0.8); especially CP by 1 m from one flight data had a rather high Spearman's correlation coefficient (0.78). Note that the numerical value of estimated indices were different from those from ground truth data; therefore, regression analysis is necessary to convert the values of the estimated indices to the values that can be compared to the values of indices from field survey. The indices that were strongly correlated in the Pearson's correlation coefficient can be converted by linear regression models.

In this study, the proposed interpolation method improved the accuracies of the estimated FHD and CP, but not of the estimated COVSUM.

4. CONCLUSION

This study has revealed the availability of a high density of laser scanning data for estimating forest structure indices. COVSUM5 and CP can be estimated from the laser scanning data in sufficient levels for testing the evaluation of the birds' habitat. FHD calculated after interpolation by the proposed method may also be available.

The laser scanning data in this study was obtained during the winter; therefore, we should examine whether these indices can also be estimated from data obtained during the summer. In addition, we should also examine the indices calculated by another number or dividing heights of layers.

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