Canopy and gap dynamics analysed using multi-temporal airborne laser scanner data in a temperate deciduous forest

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Abstract

Forest measurement using airborne laser scanner makes it possible to obtain detailed information of canopy surface including its roughness and its applicability for the studies of gap dynamics in natural forest is considerably high. This study aims to compare multi-temporal canopy surface conditions using multi-temporal airborne laser scanner data and to extract gaps in a canopy for the clarification of gap dynamics in a temperate deciduous forest. The study was conducted in the 6-ha (300m*200m) permanent plot in the Ogawa Forest Reserve. The laser scanner data were acquired on 24 August 2001, 14 April 2002 and 9 August 2005. Digital canopy models (DCM) were created from the data in 2001 and in 2005. Gaps were extracted from each DCM using the threshold, which was decided from the vertical distribution of heights above the ground where lasers reach. Gap dynamics are classified into four patterns, i.e., appearance, enlargement, reduction, and disappearance, and the number of gaps for each pattern was strongly affected by the gap size. For the gaps that were classified into the reduction and the disappearance, their annual decreased areas (S_{diff}) could be described using their gap sizes (S_{gap}) as $S_{diff} = 1.03 S_{gap}^{0.64}$ (R^2=0.75).

Keywords: airborne laser scanner data, canopy, digital canopy model, gap dynamics

1. Introduction

Natural disturbance is one of most important factors for the structure and succession of forest communities (White, 1979; Pickett and White, 1985). Gaps in a canopy that occur after natural disturbance alter light condition in a forest stand. Crown growth of trees that consist of canopy layer in the edge of gaps and height growth of trees consist of second layer are promoted by the appearance of gaps. Nevertheless the importance of gaps to understand forest dynamics, it is difficult to evaluate them quantitatively from the ground observation. In previous studies, the methods to detect gaps from multi-temporal DSM derived from stereo-pair aerial photographs (Nakashizuka *et al*., 1995; Tanaka and Nakashizuka, 1997; Itaya *et al*., 2004; Ticehurst *et al*., 2007) and from the difference between a past aerial photograph and a late high-resolution satellite image (Clark *et al*., 2004) were proposed. In these methods, however, there is a likelihood that the difference of shade between aerial photographs or images in different seasons leads to mis-interpretation of gaps particularly in steep slopes. Measurement of forest using airborne laser scanner makes it possible to obtain detailed information of canopy surface including its roughness and its applicability for the studies of gap dynamics is considerably high. This study aims to compare multi-temporal canopy surface conditions using multi-temporal airborne laser scanner data and to clarify gap dynamics in a temperate deciduous forest.

2. Methods

2.1 Study area

This study area was located in the Ogawa Forest Reserve at the southern end of Abukuma Mountains, central Japan (36°56' N, 140°35' E, 610 - 650 m above sea level). The mean annual temperature is 9.0 °C, with the highest monthly mean of 20.5 °C in August and the lowest one of −1.6 °C in February. Annual precipitation is about 1750 mm, concentrated in August and September, and there is little rainfall in December and January. Maximum snow depth is occasionally 50 cm in winter, but it usually melts away in a few days. The forest has been protected from human impact for 80 years or more. There are more than 50 woody species in it, dominated by *Quercus serrata* Murray, *Fagus japonica* Maxim., and *Fagus crenata* Blume.

2.2 Plot description and field data

The study was conducted in the 6-ha (300m*200m) permanent plot in the Reserve. This permanent plot has been established since 1987 for the long-term ecological research (Nakashizuka *et al*., 1992). All trees with 5cm of the diameter at breast height (DBH) in the plot were identified, tagged and measured. The plot was divided into 10m*10m quadrats and a pole has been put at each corner of quadrat. All trees were remeasured every four years. Detailed delineations of the stand structure and dynamics of the community are available in Masaki *et al*. (1992), Nakashizuka *et al*. (1992), and Abe *et al*. (1995).

Geographic coordinates at pole positions established at four corners of the plot and those of every 100 m-interval were positioned using a differential GPS (Ashtech Solution, USA) and they were calculated as the UTM coordinates (datum: WGS84) with the measurement data and the data of electric ground control point, which were offered by the Agency of Geographic Survey, in post-processing. Other poles were measured using a laser range finder (LaserAce 300, Measurement Devices, UK) and their geographic coordinates were calculated with the results.
The data concerning individual trees in 2001 were used for the study. Positions of trees, which formed canopy layer, were measured from a nearest pole using the laser range finder.

2.3 Airborne laser scanner data

The ALMAPS (Asahi Laser Mapping System), which consists of the ALTM 1225 or ALTM 3100 laser scanning system produced by the Optech, Canada, the GPS airborne and ground receivers, and the inertial measurement unit (IMU) reporting the helicopter's roll, pitch and heading, was used to acquire the laser scanner data. The laser scanner system transmits the laser pulse at 1064 nm (near-infrared) and receives the first and last echoes of each pulse. The elapsed time between transmittance and receipt is measured to calculate the distance between the system and the object.

The laser scanner data were acquired on 24 August 2001and 14 April 2002 using ALTM 1225, and 9 August 2005 using ALTM 3100. For the measurement in 2001, the flight altitude of the helicopter above the ground was about 250 meters and the average of the flight speed was approximately 13.9 m/sec. The pulse repetition frequency was 25 kHz and the scan frequency was 25 Hz. Maximum scan angle (off nadir) was 12°. The beam divergence was 1.0 mrad. Measurement density was 25.0 points/m^2. Therefore, the footprint diameter was approximately 25 cm and the distance between neighbouring footprints was about 20 cm. For the measurement in 2002, the flight altitude of the helicopter above the ground was about 300 meters and the average of the flight speed was approximately 13.9 m/sec. The pulse repetition frequency was 25 kHz and the scan frequency was 30 Hz. Maximum scan angle (off nadir) was 10°. The beam divergence was 1.0 mrad. Measurement density was 31.9 points/m^2. Therefore, the footprint diameter was approximately 30 cm and the distance between neighbouring footprints was about

18 cm. For the measurement in 2005, the flight altitude of the helicopter above the ground was about 500 meters and the average of the flight speed was approximately 19.4 m/sec. The pulse repetition frequency was 70 kHz and the scan frequency was 27 Hz. Maximum scan angle (off nadir) was 18°. The beam divergence was 1.2 mrad. Measurement density was 50.2 points/m^2. Therefore, the footprint diameter was approximately 60 cm and the distance between neighbouring footprints was about 14 cm. Both first pulse and last pulse were acquired to extract forest canopy and topography in rugged terrain.

Digital elevation model (DEM) and digital surface model (DSM) for the plot were prepared from the airborne laser scanner data with 25cm cell size (Figure 1). DEM was generated from the last pulse data acquired in the leafless season in 2002. Digital surface model (DSM) was generated as assigning highest value of first pulse data of each full-leaved season in 2001 and 2005 involving in each cell to the cell value.

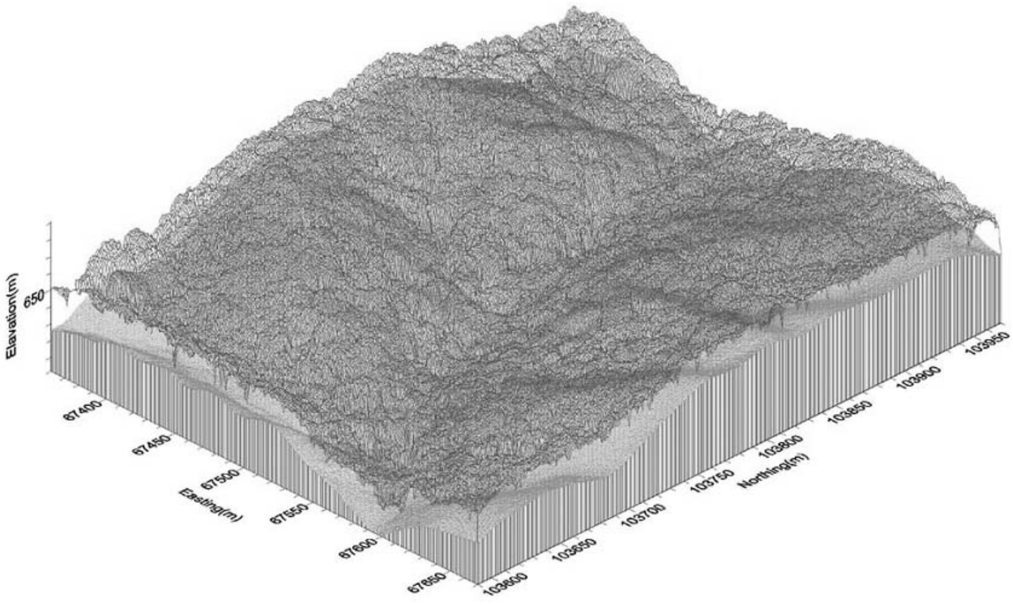

Figure 1: DSM and DEM of the study area derived from airborne laser data.

2.4 Data Analysis

Clarification of gap dynamics requires understanding of multi-temporal canopy surface condition. Digital canopy model (DCM), which delineates canopy height from the ground, was created by subtracting the DEM from each DSM of full-leaved season. The canopy heights using DCM in 2001 and 2005 were compared and change of canopy heights for 4 years from the difference between them was investigated.

Gap is defined as “open hole in canopy which occurs due to loss of crowns that consist of canopy”. While gaps appear owing to the death, uprooting, stem breakage and so on, definitions such as the size and the height are not clear (Nakasizuka *et al*., 1995). In this study, we defined the gap as the area where canopy height is lower than a certain height above the ground. Here, we assumed three thresholds to extract gaps from DCM, that is, 15 m, 10 m and 5 m. Gap size was defined as more than 1 m^2 for noise reduction. An area, which was extracted as a gap, was converted to a polygon of vector format. The area of gap of each polygon was calculated and the number of gaps and the total area in 2001 and in 2005 were investigated.

The gap dynamics are classified into four patterns, that is, appearance (Figure 2 (a)), enlargement (Figure 2(b)), reduction (Figure 2(c)) and disappearance (Figure 2(d)) in comparison with gaps of two periods. Gaps, which occur newly, come from death, uprooting, stem breakage and so on. Enlargement of an existing gap is caused by death, uprooting, stem breakage of trees around the gap and isolated tree in the gap. Reduction of a gap results from both the height growth of trees in second layer in the gap and the enlargement of crown of trees around the gap. Finally, this reduction leads to the close of gap, that is, disappearance. We investigated the gap dynamics of the study area from these patterns and the speed of gap closing against gap size.

3. Results and discussion

Mean heights of canopy derived from the DCM and their standard deviations in 2001 and 2005 were shown in Table 1. The difference of mean canopy heights was 0.48m and its slight growth was identified. While the increase of canopy height arises from height growth of individual trees as well as closing process of gaps due to enlargement of crowns that are located around gaps, the decrease of canopy height results from occurrence of new gaps. The growth of canopy height comes from the balance of them.

The number and total area of extracted gaps by threshold was shown in Table 2. The number of extracted gaps by area class using the threshold below 15 m was shown in Table 3. The number of gaps, which area was less than 5 m^2, is more than half of the total number, and the area class of 10 to 50 m^2 was next to that.

The summary of gap dynamics by area class was shown in Table 4. We selected larger area of a gap in 2001 and the same in 2005 as “area of a gap” in Table 4. We found from Table 4 that a large gap with the area of more than 100 m^2 appeared during the period. We confirmed that this gap was caused by the uprooting of *F. Japonica* M. and some stem breakages of surroundings, which resulted from the uprooting from field survey. In general, the appearances of gap, which are caused by uprooting or stem breakage near the ground trend to become large in comparison with ones from death of standing trees. Enlargement of gap could be found in all area classes, and the ratio of the number against the total number of gaps in area class was smaller in small area class. Reduction in gap dynamics patterns could be found in all area classes of gap except the smallest area class. The ratio of disappearance in the smallest area class was largest instead of the pattern of reduction. There were few gaps which area was constant during the period.

Relationship between gap area in 2001 (S_{gap}) and annual decreased area of the gap (S_{diff}) was shown in Figure 3. This relationship could be expressed as follow;

$$S_{\text{diff}} = 1.03\, S_{\text{gap}}^{0.64} \quad (R^2=0.75) \qquad (1)$$

When crown enlargement of trees around a gap is found in the process of gap closing, a gap, which has large area, are surrounded by many trees and, as a result, closing area of gap becomes large.

In this analysis, the period between two forest measurements of airborne laser scanner was only 4 years; therefore, contribution of trees in second layer or understory to gap closing process was not found. However, gap closing requires much time when gap size is large and it is considered that annual decreased area of a gap is composed of both enlargement of crowns that are located around the gap and intrusion of trees in second layer to canopy layer. Continuous monitoring of canopy condition using airborne laser scanner is required to clarify the dynamics in natural forest.

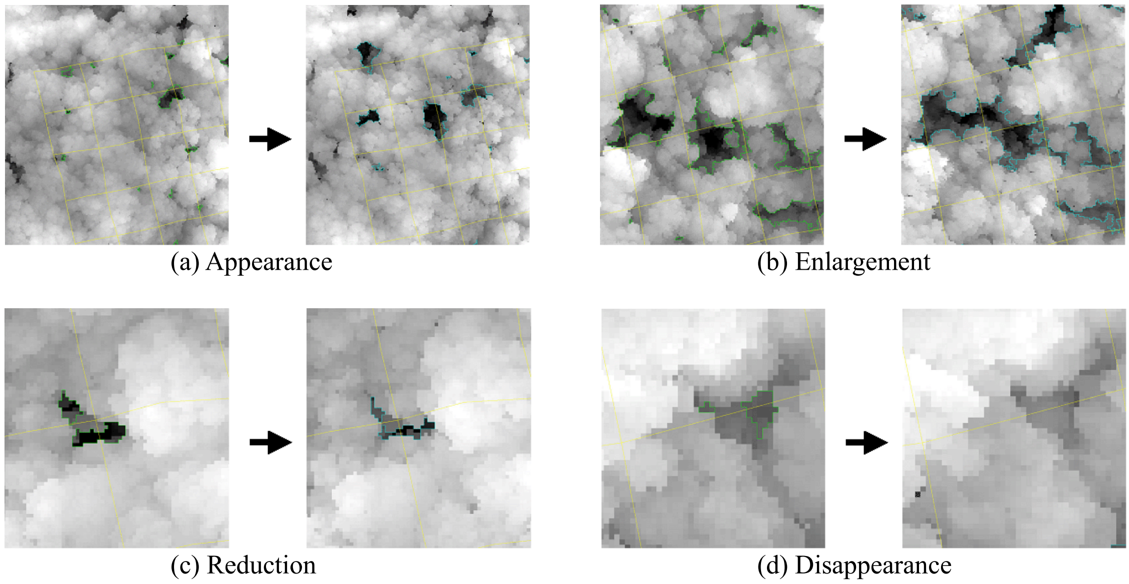

Figure 2: Patterns of gap dynamics.

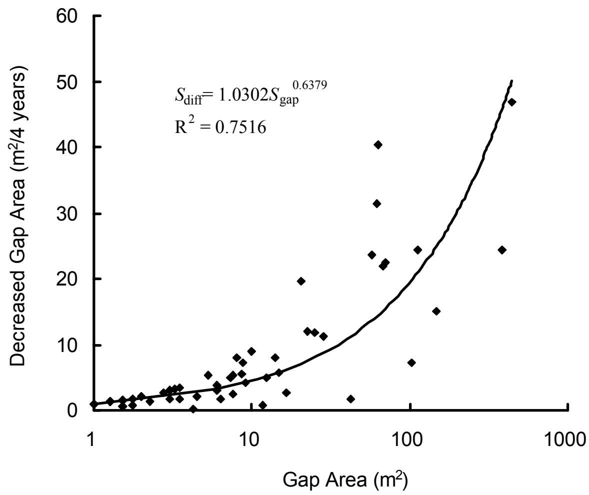

Figure 3: Relationship between gap area and annual decreased area of the gap.

Table 1: Mean heights of canopy and their standard deviation in 2001 and 2005.

Year	Mean height (m)	Standard deviation (m)
2001	22.03	3.88
2005	22.51	4.07

Table 2: The number and total area of extracted gaps by thresholds.

Threshold (m)	The number of gaps		Total area (m^2)	
	2001 yr	2005 yr	2001 yr	2005 yr
5	18	26	170	171
10	55	52	930	972
15	113	116	3048	3234

Table 3: The number of extracted gaps by area class using the threshold below 15 m.

Area of a gap (m^2)	2001 yr	2005 yr
>100	8	8
50-100	7	5
10-50	20	24
5-10	17	13
1-5	61	56
Total number	113	116

Table 4: The summary of gap dynamics by area class.

Area of a gap (m^2)	Appearance	Enlargement	Reduction	Disappearance	No change
>100	1	3	6	0	0
50-100	0	3	5	0	0
10-50	4	8	11	0	0
5-10	1	7	9	2	1
1-5	18	3	8	37	4
Total number	24	23	40	39	5

4. Conclusions

In this study, we examined to apply airborne laser scanner data to the clarification of gap dynamics in a temperate deciduous forest. The patterns of gap dynamic were classified four categories, that is, occurrence, enlargement, reduction and disappearance, and the trend of dynamics was clarified. Monitoring of canopy condition using airborne laser scanner makes it possible to evaluate gap dynamics quantitatively, and further acquisitions of airborne laser scanner data a expected to contribute to ecological studies of natural forest dynamics.

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