

Assessing forest gap dynamics using remotely sensed digital height models and GIS

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Abstract

Canopy gaps play an essential role in continuous cover forests, as they have a strong effect on regeneration dynamics and species composition. However, canopy gaps have been widely neglected in current monitoring and planning practices, which might be caused by the fact that mapping of canopy gaps from the ground is labour-intensive, tedious, and error prone.

An approach to automated canopy gap delineation based solely on canopy height information was developed and evaluated within a Geographic Information System. Remote sensing can provide the required data enabling surveys of canopy gaps over large areas. Digital height models of sufficient resolution can be derived from laser scanning (LiDAR) or softcopy photogrammetry using digitized CIR imagery and digital terrain models. These techniques provide very accurate height models for large areas with a minimum of human interaction. Based on the digital height models not only the number, size and distribution of gaps were analyzed but also other ecological parameters describing the morphology of the canopy surface. Data taken at for dates facilitate to study the dynamics of canopy gaps and canopy morphology, which has not been possible on a large scale so far.

Introduction

Canopy gaps play an essential role in continuous cover forests, as they have a strong effect on regeneration dynamics and species composition. They have been investigated in a number of studies, but predominantly mapped terrestrially (cf. Runkle, J.R., 1982; Barden, L.S., 1989; Runkle, J.R., 1992; Leibundgut, H., 1993; Emborg, J., 1998; Tabaku, V. & Meyer, P., 1999). Only a few studies used remotely sensed data to map canopy gaps (cf. Brunig, E.F., 1973; Tanaka, H. & Nakashizuka, T., 1997; Fox, T.J., Knutson, M.G. et al., 2000; Fujita, T., Itaya, A. et al., 2003; Nuske, R.S., 2003). Canopy gaps and the canopy surface, especially, have been widely neglected in current monitoring and planning practices. This might be due to the fact that terrestrial as well as analogue photogrammetric measurements are particularly problematic in dense broadleaved stands. Blackburn and Milton (1996) conclude that automatic gap detection and large scale studies of gap dynamics will contribute to an enhanced ecological comprehension.

High resolution Canopy Height Models (CHM) can be used to study the morphology of the canopy layer, including canopy gaps. A CHM is usually given by an array of grid points representing the height of the vegetation, excluding the terrain. These CHMs may come from different sources. At the moment there are two main sources of high resolution CHMs of considerably large areas.

The most precise way to measure heights of forest canopy surfaces is to use an airborne LiDAR system (Baltsavias, E.P., 1999). Since some of the laser pulses penetrate the vegetation, a Digital Terrain Model (DTM) and a Digital Surface Model (DSM) may be derived from the same dataset through appropriate filtering. The use of LIDAR data for forest applications is documented in a number of studies (Koch, B. & Friedlaender, H., 1999; Diedershagen, O., Koch, B. et al., 2003; Lim, K., Treitz, P. et al., 2003). This method has a lot of potential, but is still far from being widely accepted, mainly because of its still high costs.

The derivation of DSM from aerial photographs by means of digital photogrammetry is a less expensive alternative that also offers other advantages. Since the use of aerial imagery is an old and widely used remote sensing technique, most of the German forests are covered as part of the standard forest inventory in a ten year cycle. Aerial imagery, thus, enables retrospective studies of the dynamics of forest canopies, and quantitative analyses of large areas. But, in order to build a CHM from this type of data, a DTM from another source is needed, since digital photogrammetry is only capable of calculating the height of the uppermost surface.

Based on the CHM, not only stand heights (cf. Nuske, R.S. & Nieschulze, J., 2004), but also number, size, and distribution of canopy gaps can be obtained. Appropriate methods for a highly automated process based on remote sensing and GIS will be developed. Gap delineations of four points in time are then used to study the dynamics of canopy gaps.

Materials and Methods

Study Site

The study area “Limker Strang” is situated at 51°24' N and 9°24' E in southern Lower Saxony, Germany. For comparability reasons, the same boundaries used in previous studies done at the same site (Tabaku, V., 1999; Tabaku, V. & Meyer, P., 1999) were chosen (cf. Figure 1).

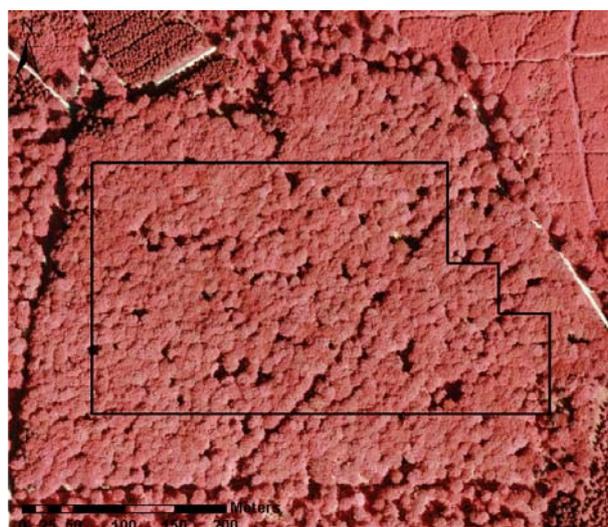


Figure 1 CIR-Image with study site boundaries.

The study site covers an area of 10 ha and the altitude ranges from 384 to 420 m above sea level. The area has a slight exposition towards the WNW- and ENE-Directions. The area has a suboceanic climate. The stand stocks on a medium to deep brown soil with bedrock of New Red Sandstone. This results in a moderate nutrient supply and a moderately moist to moist water supply (Lamprecht, H., Göttsche, G. et al., 1974; Otto, H.-J., 1991). The considered forest is a 153 year old unmanaged European beech stand (*Fagus sylvatica* L.), with only one main canopy layer. The stand is mainly closed but has gaps in some regions due to windthrow and previous salvage logging.

Aerial Imagery

CIR aerial photographs from four dates were used (cf. Table 1). The flights were done with sufficient overlap during the vegetation period to provide a stereoscopic view on the canopy surface. For each date, a stereopair covering the study area was chosen for derivation of a DSM. The aerial photographs were provided as diapositives and scanned for further processing. The chosen resolution of 0.40 ± 0.05 m corresponds to the accepted opinion that the spatial resolution for photogrammetric vegetation measurements should be 0.1 to 0.5 m (Hall, R.J., Franklin, J.F. et al., 1998; Gong, P., Biging, G.S. et al., 2000; Herwitz, S.R., Sandler, B. et al., 2000). Details of the georectification and the achieved precision are given in table 1.

Table 1 Image and georectification details.

Date of Flight	Nominal Scale	Spatial Resolution [m]	Total Number of GCPs	Number of Stereo-GCPs	X-RMSE [m]	Y-RMSE [m]
Aug. 1989	1:10500	0.36	16	4	0.87	0.74
Sept. 1992	1:600	0.22 (0.44)*	16	5	1.48	1.23
Aug. 1998	1:13000	0.45	12	3	1.69	1.56
Sept. 2000	1:6000	0.20 (0.40)*	15	4	1.24	1.27

(* values in brackets show the resolution after resampling)

Extraction of the Canopy Height Model

The digitized and rectified stereopairs were used to automatically derive DSMs using digital photogrammetry methods. The matching algorithm employed by OrthoEngine (Pcigeomatics, 2003) is based on image correlation, where homologous pixels are identified and the elevations are calculated based on their parallaxes. A postprocessing including noise removal and interpolation was carried out to enhance the quality of the DSM. The noise removal is used to discard any outliers or artefacts which may be in the DSM. A bilinear interpolation fills holes in the DSM that result from the matching or noise removal process.

The result is a digital image which represents a landscape and its components, such as trees and buildings, by height above sea level. The ground elevation level must be subtracted in order to obtain canopy heights. In this study, a DTM provided by the cadastre service of Lower Saxony is employed. The difference in elevation yields a CHM.

Canopy Gap Delineation

Our gap definition follows Runkle's definition (1992), which defines a canopy gap as an area within a forest where the canopy is noticeably lower than in adjacent areas. The minimum gap area in this study was set to 20 m², without an upper limit. The gap dynamic was studied using the gap delineations of four different stereopairs. Superimposing the four gap delineations gives an impression of the change of the gaps over time. This combined gap delineation can be further investigated using a GIS.

Different methods of automatic canopy gap delineation were tested in a previous study (Nuske, R.S., 2003). The adaptive median threshold was found to be most suitable. This method classifies that area as a canopy gap, which is lower than a reference height minus a certain range given by variability of the neighbourhood.

To create a reference height that is not influenced by the still to be detected gaps, the median of the height values of a moving window is used. The window has to be at least twice as large as the largest expected canopy gap to ensure that the median always represents a height value of the upper canopy. The interquartile distance serves as a fast and easy to calculate measure of dispersion. Hence, the classification threshold is calculated as the median minus the interquartile distance. The classification is based only on the distribution of the height values of the neighbourhood.

Results

The automatic gap delineation was compared to a manual gap delineation done with an analytic stereoplotter (cf. Figure 2). The canopy gap dynamics is shown in table 2 and figure 3.

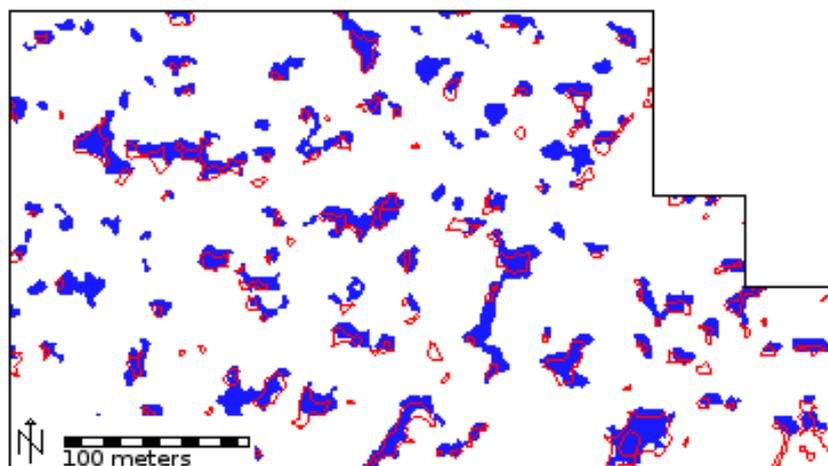


Figure 2 Automatic canopy gap delineation (blue area: automatic gap delineation; red polygon: manual gap delineation).

Table 2 Area based canopy gap characteristics.

Year	Gap Density [N/ha]	Gap Area [%]	Gap Size			
			\tilde{x} [m ²]	\bar{x} [m ²]	s [m ²]	max [m ²]
1989	12.6	11.8	60.3	93.6	88.3	521.3
1992	10.7	10.9	61.0	101.6	109.4	646.8
1998	10.4	12.3	64.5	118.4	144.5	800.9
2000	10.8	9.8	55.6	91.4	101.6	523.5

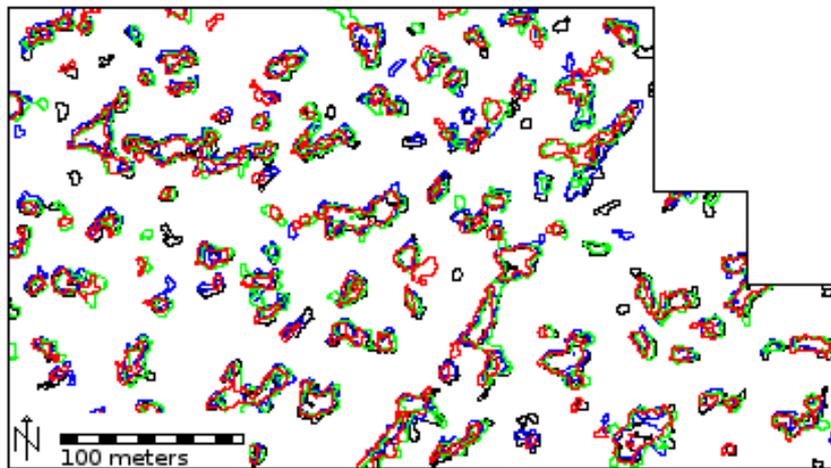


Figure 3 Canopy gap dynamics (black: 1989, blue: 1992, green: 1998, red: 2000).

Discussion

The Analysis of canopy surfaces can be automated using aerial imagery, digital photogrammetry, and a GIS. Because of the automation, this methodology can be applied on a large scale. It is a rather low-cost approach, using the software package OrthoEngine from PCI Geomatics (Brostuen, D., Sutton, S. et al., 2001) and the open source software GRASS GIS, which run on a standard PC. Although no high-tech equipment was chosen, we were able to produce results comparable to studies done on analytic stereoplotters.

The gap delineation approaches were assessed by means of a reference gap delineation based on the same stereopair. The manual delineation using an analytical stereoplotter was chosen as reference, because it was the gap delineation with the highest quality available. The comparison of the automatic gap delineation with the reference delineation showed only some differences. The shape of the gaps in both delineations matches approximately. All larger gaps delineated by the human interpreter were also detected by the automatic approach. The two delineations differ as regards the smaller canopy gaps. Some of the small manual delineated gaps were missed, but in general the automatic approach tends to find too many small gaps. This mismatch might be due to the limits of the human interpreter having particular problems judging the existence of very small gaps. On the other side the very simple gap delineation approach applied in this study does not handle small gaps too well. The lower limit of 20 m² gap area was chosen to represent a gap created by a large broken off branch. Since small gaps do not have a substantial influence on the forest

ecosystem, it might be a good idea to increase the minimum gap size. That would not diminish the ecological relevance but could reduce the discrepancy of the two delineations.

The gap area found in this study is somewhat high (cf. Table 2) compared to other studies carried out on the same site, where values range from 3.0 to 11.0 % (Spellmann, H., Meyer, P. et al., 2003). This might be caused by the different methodologies or by different gap definitions. However, one can see in Figure 3 that some of the smaller gaps vanish in the course of time and others appear. At a closer look, it is evident that more gaps vanish than arise. However, the larger gaps also tend to shrink, although this is harder to notice because of their fuzzy boundaries. The total gap area has a clear decreasing trend (cf. Table 2). The decline of the number of canopy gaps is reflected in gap density. These results agree with other studies in the same area (Spellmann, H., 1991). These findings also agree with theoretical considerations that mature beech stands tend to close gaps via vertical growth of gap neighbouring trees and height growth of understorey trees (Meyer, P., Tabaku, V. et al., 2003).

The demonstrated technique ensures reproducible results for large areas and at different points in time. Aerial photographs, which are the basis of this method, are raw information, and therefore independent of different measurement schemes. Thus, this method can be regarded as a very robust monitoring scheme. Aerial photographs of the studied stand taken during the last decades do not only enable studies on gap dynamics but also further ecological studies such as dynamic crown cover and dynamic stand structure, which have not been possible so far.

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