



Monitoring downed coarse woody debris through appearance of canopy gaps in urban boreal forests with bitemporal ALS data



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ABSTRACT

The study introduces a method for detailed mapping of downed coarse woody debris (CWD). Bitemporal airborne laser scanning (ALS) data and existing allometric equations were utilized to map the attributes and location of downed CWD. No training or calibration data were used in the process. The CWD locations were determined through canopy gaps detected with canopy height models (CHM) from 2009 and 2012. The attributes of formed CWD were derived through an individual tree detection (ITD) technique. Within the three year interval, 97.8% of all new downed trees were detected and their species group (conifer/deciduous) was classified correctly in 89.0% of the cases (Kappa 0.76). Tree-level CWD diameter and volume were predicted with an RMSE of 8.7 cm and 0.5 m³ respectively. The introduced method allows detailed mapping of CWD and can be utilized in forest planning and operational tasks in urban forest areas.

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Introduction

Accurate spatial knowledge on coarse woody debris (CWD) has various applications in forest management. CWD is recognized as one of the key components driving forest biodiversity (Harmon et al., 1986; Siitonen, 2001; Karjalainen and Kuuluvainen, 2002). Because of its important role in forest ecosystems, occurrence of CWD has been used as auxiliary information in various habitat modeling approaches (see, e.g., Martinuzzi et al., 2009; Lehtomäki et al., 2009). On the other hand, newly formed CWD, (e.g. trees downed in a storm) poses a threat to living trees potentially spawning insect outbreaks (Werleminger, 2004). In commercially managed forests, this may result in substantial economic losses due to dying trees and increment loss (see, e.g., Day and Leather, 1997).

Dying of trees may be caused for example by wind or snow, insect damage or various diseases (Kuuluvainen, 1994; McCarthy, 2001). When a tree dies it eventually falls down and relinquishes its growth space, hence leaving a gap in the forest canopy. If not removed, the trunk that once occupied the canopy remains on the forest floor as CWD. The size of the canopy gap depends on the size of the dying tree as well as the rate at which the tree dies. Storm-felled trees create canopy gaps very suddenly, whereas insect damage or disease affect over a much longer time period. When the change is more gradual, it is probable that the

surrounding trees have time to slowly occupy the growing space and thus smooth out the change in the canopy.

Traditionally, CWD inventories have been made with different sampling techniques involving manual field measurements. The traditional methods are described, e.g., in Pesonen et al. (2009) where their accuracy and efficiency in large areas were tested. The amount of CWD has also been predicted through models utilizing other forest variables. For example, Chojnacki and Heath (2002) used data from standard forest inventory plots to form regression models for the amount of dead wood in large forest areas.

Pasher and King (2009) used high resolution airborne images in direct mapping of canopy deadwood and also created indirect models for CWD utilizing image-based spectral and spatial features. However, recently CWD mapping studies have focused on the use of airborne laser scanning (ALS) data (see, e.g., Bater et al., 2009; Pesonen et al., 2008). In forest inventories, various remote sensing methods have been used for decades (see, e.g., Tomppo, 1991) and in recent years ALS-based methods have also been implemented in operational use (e.g., White et al., 2013). When compared to traditional field measurements based solely on sampled field plots, ALS-based methods can produce data with wall-to-wall coverage over large areas (see, e.g., Wulder et al., 2012). In Pesonen et al. (2009), ALS datasets were used as auxiliary information in CWD mapping and the results indicated that ALS is an efficient tool also for CWD mapping when compared to traditional means. More direct ways for ALS-based CWD detection have also been introduced, where the fallen logs are delineated directly from the forest floor. For example, Blanchard et al. (2011) utilized high

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density discrete return ALS data and object-based image analysis in assessing CWD, whereas Mücke et al. (2013) detected fallen stems from height models derived from full-waveform ALS data.

Forest attributes can be generated from the ALS data by creating predictive models between statistical metrics derived from the point cloud and ground measured forest inventory attributes (Næsset, 2002; White et al., 2013). This approach is commonly known as the area-based approach (ABA). The other way is to detect individual trees straight from the point clouds or surface models (individual tree detection, ITD) and predict individual tree attributes using existing models (Hyypä and Inkinen, 1999) or generalize field-measured reference trees over the study area (Yu et al., 2011). Both ABA and ITD techniques have been used for CWD detection. In Pesonen et al. (2008), CWD volumes were estimated with ABA from ALS data with a pulse density of 0.5 m^{-2} and predictions were validated at a resolution of 400 m^2 . Downed and standing deadwood volumes were estimated with an accuracy of 51.6% and 78.8%, respectively. However, when ABA is used to predict CWD the predictive power mainly arises from the height of the canopy, i.e., stand maturity. In mature stands, more CWD is usually present than in young stands (Krankina and Harmon, 1995). Thus, although the method may provide reasonable prediction accuracies, it is incapable of directly detecting the CWD and its spatial distribution in the area. The spatial distribution is an important factor because even single dead trunks or small loci of dead trees may comprise a biodiversity hot spot (Komonen, 2003). In Vehmas et al. (2009), height distributions were used to identify canopy gaps with CWD. This method is based on the assumption that there has been a standing tree prior to gap initiation. However, the method is incapable of verifying the pre-gap existence (or nonexistence) of a tree and the size of the CWD on the ground. Bitemporal data would be required to obtain that information.

As with any measurements, two consecutive ALS datasets with a sufficient time gap between them provide means for detecting changes in the study object. The change is the difference between the two datasets, which means that the only distinguishable changes are those that have occurred between the acquisitions of datasets compared. In the case of individual trees, changes such as tree growth can be captured (Yu et al., 2004). In addition to monitoring of living trees, change detection methods can also be utilized to monitor those trees that have been cut down (Yu et al., 2004) or damaged by snow (Vastaranta et al., 2012a,b), for example. This suggests that characteristics of newly formed CWD can also be estimated with ALS techniques.

This study describes a method for mapping downed CWD with multitemporal ALS data. Within the study, the word canopy gap is used to describe a detectable change in the forest canopy rather than an opening in an ecological sense. These canopy gaps are utilized to detect the individual fallen trees that form CWD. The amount and quality of the CWD are estimated through single trees with existing allometric equations. No training or calibration data were used. The mapping accuracy is analyzed at the tree, canopy gap, and stand-levels.

Materials

Study area

The study area is located in Finland in the Central Park of the City of Helsinki (Fig. 1). The Central Park is a recreational forest area located near the city center. Due to its location, the Central Park has an essential role in residents' recreational activities. There are about two million visits to the park every year (www.forest.fi, 2014). Because of its nature as "public space", the area also acts as a showroom for different forest management measures. As a

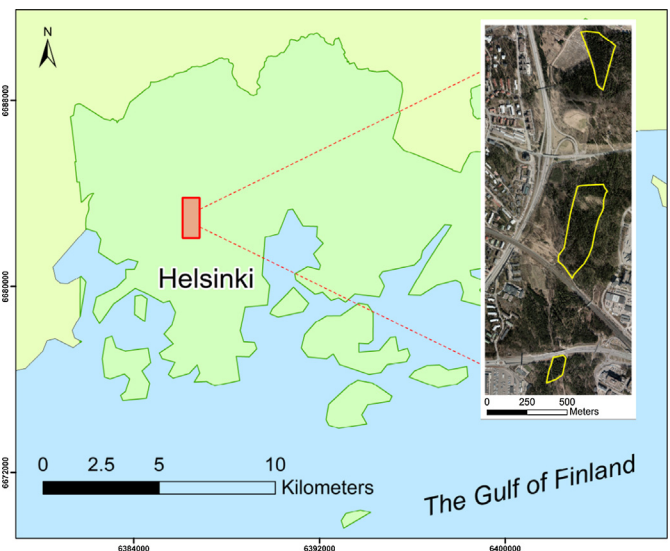


Fig. 1. Map of the study area.

result, measures carried out in the Central Park are often a subject of debate among forest users. In the case of CWD, some want every fallen tree to be left in the forest, while others want the area to be managed more like urban parks and hence demand the removal of fallen trees. From the City of Helsinki's point of view, the forests in the area are managed in order to maintain their central role in recreational activities of city residents. This means that both biodiversity and safety aspects should be taken into account. In cuttings, typically only single hazardous trees near the main trails are removed. When it comes to windthrow damage, single fallen conifers are often left in the forest, whereas groups of fallen conifer trees are removed due to Finnish legislation concerning the prevention of insect damages. In the legislation, forest owners are obliged to remove all freshly fallen or damaged Norway spruces from the forest if the total volume exceeds $10 \text{ m}^3/\text{ha}$ (Laki metsätuhojen torjunnasta 1087/2013, 6 §). Most of the fallen broadleaves are left in the forest.

The study focuses on three forest stands that have encountered storm damages of varying intensity during the study period from 2009 to 2012. The total size of the study area was 14.9 ha, consisting of 1.3, 9.6, and 4.0 ha stands. Forests in the area are dominated by Norway spruce (*Picea abies* (L.) H. Karst.), the remainder being mainly mixtures of silver birch (*Betula pendula* Roth) and Scots pine (*Pinus sylvestris* L.). No cuttings had been done during the study period but some of the conifers subject to wind throw damage had been removed. The removed fallen trees were identified from stumps.

Airborne laser scanning data sets

The remote sensing data were provided by the City of Helsinki. ALS data with a pulse density of at least 20 m^{-2} were acquired in 2009 (T1) and 2012 (T2) (Table 1). Both datasets were scanned in the spring time before the start of the growing season resulting in leaf-off data. The data were collected for general urban measurements and therefore were not optimized for measuring forest data or detecting trees. The aim of the City has been to collect uniform ALS data in terms of pulse density whereas other parameters, such as flying altitude and opening angle, have varied over the years.

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