Spatial pattern of forest resources in a multifunctional landscape

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ABSTRACT:

Forests are usually assessed as a discrete land cover type. However, we hypothesise that the resources associated with forests show diverse spatial patterns, only partially matching current forest boundaries. Therefore tree vegetation parameters related to relevant forest resources at the landscape level were assessed for the Canton of Geneva in western Switzerland. LIDAR based digital terrain and surface models at the local scale (2.5m resolution) were used to derive the tree vegetation parameters at the landscape scale (hectare resolution). Resulting rasters of 'tree vegetation cover', 'mean and standard deviation of tree vegetation height' showed that areas mapped as forests contained only 53% of the tree vegetation detected from LIDAR. A substantial amount, especially richly structured and high stands, were found outside forests, located predominantly in suburban areas. LIDAR based assessment of tree vegetation parameters confirmed that forest resources show a higher diversity in spatial pattern than is implied by the classified forest area. LIDAR proved to be an efficient technique for large scale forest and landscape assessment and monitoring.

1. INTRODUCTION

Forests provide a diverse range of products and services, ranging from the original timber production, habitat, protection, and carbon sequestration to recreation (Farrell, 2000). Each of these forest resources refers to different aspects of the forested and often times non-forested land. Hence, they are based on a specific combination of landscape parameters, or just parameter segments. In a multifunctional landscape such tree vegetation parameters relevant to the various forest resources are not evenly distributed, but show heterogeneous spatial patterns. As a consequence, also the potential forest resources vary spatially. Despite this spatial variability of tree vegetation parameters, forests are usually mapped as discrete land units (Figure 1).

We hypothesize that only a limited number of current forest resources follow discrete forest borders, while many are distributed outside or only partially inside forest boundaries. However, for the sustainable management and monitoring of forest resources at the landscape level, knowledge of the full value range within the entire landscape, and not just within a classified forest, is important (Andersson et al., 2000). To fulfil this prerequisite for sustainable forest and landscape assessment and monitoring, the third Swiss National Forest Inventory is now assessing the full range of raw data values (spatially and thematically) in its forest assessment using aerial photography. The resulting point sampling data provides quantitative estimates. However, the sampled data does not allow for spatial assessment and monitoring.

The aim of our study is to assess selected tree vegetation parameters relevant to forest resources for the entire area of interest, irrespective of a forest boundary.
As many of these parameters represent structural, i.e., geometrical aspects of tree vegetation, LIDAR was selected as the method for raw data acquisition. LIDAR has been used successfully to assess tree (Morsdorf et al., 2004; Persson, 2002) and stand (Lefsky et al., 2002; Næsset, 2002; Riaño et al., 2003; Zimble et al., 2003) attributes within forests. However, tree vegetation parameters must be assessed consistently within their full value range, i.e. in- and outside forests.

We therefore assessed and analysed the spatial pattern of tree vegetation parameters, as well as their distribution within a heterogeneous and multifunctional landscape.

2. MATERIAL AND METHODS

Spatial patterns of forest resources were investigated in the Canton of Geneva, in western Switzerland (Figure 1). According to the national mapping agency (Vector 25; Swisstopo), the study area of 282 km^2 included 11% forest and 25% urban areas with a large gradient in landscape heterogeneity, land use intensity, and urbanisation.
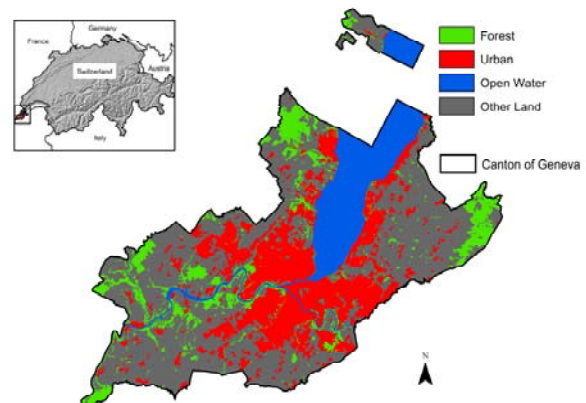

Figure 1. Geneva mapped by discrete land units (Vector 25)

The general approach for the generation of tree vegetation parameters was to first extract the tree vegetation at the local level and then derive tree vegetation parameters at the landscape level.

According to the forest definition of the Swiss National Forest Inventory tree vegetation has a minimum height of 3 meters (Keller, 2001). In that approach tree vegetation includes the full tree canopy, and not just the single point height at the centre of the tree. We used the difference between a LIDAR-based digital surface (DSM) and terrain model (DTM) to extract objects taller

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than 3m. The raw LIDAR data for the entire study area was acquired from a helicopter in May 2000 using a small-footprint LIDAR system. The resulting terrain and surface models had a grain of 1m, a horizontal accuracy of 30-40cm, and a vertical accuracy of 25cm. All data processing was performed in ArcInfo® 8.3.

In a second processing step, tall objects (>3m) other than tree vegetation were excluded based on the official building map (accuracy: 10-70cm) and secondary mapping information (constructed objects in Vector 25). In the building map the corners of the walls and not the roof are recorded, which is measured through LIDAR. This resulted in a mean horizontal discrepancy of 0.8m (n=67) between the polygons of buildings and constructed objects and the LIDAR raster data. While cubic-shaped buildings and regular houses matched well with the raster models, some farm houses with extended roofs showed larger differences. To account for the horizontal uncertainty of the DTM/DSM and the polygon maps, we resampled the elevation models first to a grain of 2.5m using the bilinear function implemented in ArcInfo® 8.3. The selected cell size represents a compromise between spatial uncertainty (cell size > DTM/DSM and map error) and spatial consistency with other raster data sets.

In the final processing chain, buildings and constructed objects were excluded from the resampled DTM/DSM, which had a difference in height greater than 3m. The cells of the resulting tree vegetation raster had a size of 2.5m and contained the height and area values of tree vegetation.

Tree vegetation parameters were then derived at a hectare scale based on focal analyses with a rectangular moving window of 100m side length applied to the generated 2.5m tree vegetation rasters. Three key vegetation parameters associated with different forest resources were generated for this investigation; 'tree vegetation cover' as an indicator for horizontal structure and general tree vegetation quantity (ex. general forest mapping, timber volume, protection, carbon sequestration), 'mean height of tree vegetation' accounting for biomass (ex. carbon sequestration, fire risk, habitat), and 'standard deviation of tree vegetation height' accounting for vertical structure (ex. habitat, recreation). The three resulting tree vegetation rasters covered the entire canton at a spatial resolution of 1 hectare.

Together, these data sets form a continuous and three dimensional parameter space, characterising the various key forest resources. To investigate the spatial relationship between the parameters, each raster was normalised using a max-min transformation. The normalised rasters were then stacked to form an RGB composite.

3. RESULTS AND DISCUSSION

LIDAR based DTM and DSM products were used to assess forest resource patterns consistently for the entire Canton of Geneva, i.e. in- and outside official forest boundaries. Relevant tree vegetation parameters related to forest resources were assessed at the landscape level based on raw LIDAR data from the local level. Hence, each hectare cell of the final tree vegetation parameters was summarised from 1600 cells (2.5m) containing tree height and area information. At the landscape level the lower spatial resolution of the resampled DTM/DSM (2.5m) did not produce significantly different elevation values compared to the original raw data (1m), but accounted for spatial uncertainties discussed in section 2. After all, the cell size of the resampled raw data (2.5m) was still smaller than and therefore homogenous with respect to the target features, i.e. tree vegetation, buildings and constructed objects.

Some overestimation of tree vegetation occurred around farm houses with extended roofs (see section 2) and geometrically complex buildings or construction objects (ex. industrial sites, overpasses etc.). But compared to the target resolution, i.e. hectares, this potential bias is negligible. Accuracy of the tree vegetation height mostly remained within the indicated uncertainty range. Only some very steep slopes along river shores resulted in an overestimation of tree vegetation height. Again, we consider this potential bias as negligible when finally shifting the focus to the hectare. But we do suggest further investigations on localised height and tree classification uncertainties, which might lead to different acquisition densities depending on the terrain and surface condition.

The assessed tree vegetation was not evenly distributed in the landscape. While forests cover 11% of the Canton of Geneva, the assessed tree vegetation based on LIDAR data resulted in a cover of 19%. Hence, only 53% of the tree vegetation was found within forest boundaries, 26% in urban and 21% in other areas. These results support our hypothesis that only a limited number of forest resources follow the spatial forest pattern (Fig. 2a-c).
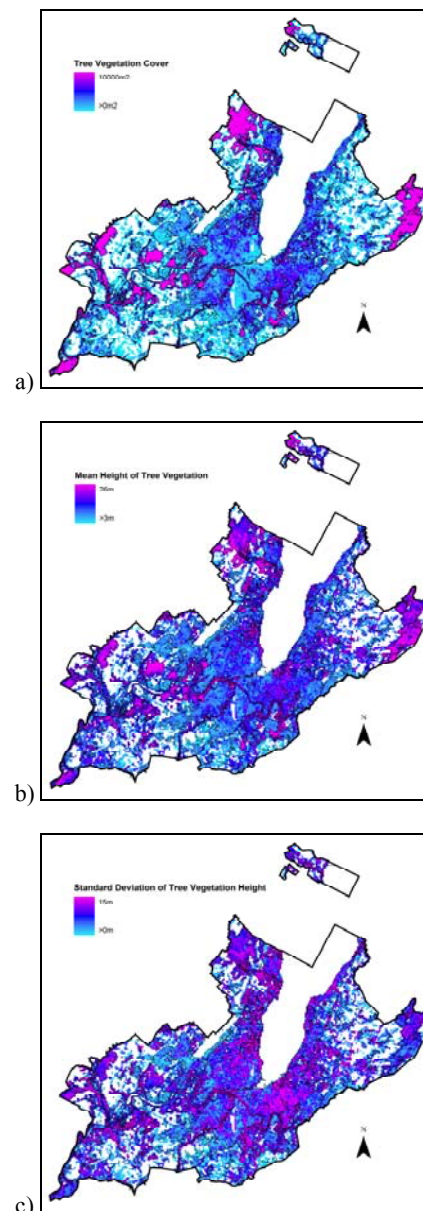

Figure 2a-c. Spatial pattern of tree vegetation parameters

In fact, only 89% of the forested area was covered with tree vegetation. This forest tree vegetation showed highest density in the study area. However, also urban and more specifically suburban areas, where tree vegetation represented 20% of the area, contained high proportions of dense vegetation, providing much potential for carbon sequestration. On the other hand, such dense tree vegetation in residential areas also represents a hazard as a heavy fuel load. Fire danger is not generally high in Geneva, but the presented approach could also be applied to Mediterranean areas, where fire is an omnipresent risk.

Forest resources based on structural diversity (ex. habitat, recreation) were strongly clumped in these suburban areas, where values of standard deviation of tree vegetation height were especially high.

Detection of vertical structure, i.e. mean and variance of height, is a characteristic trait of LIDAR. While fractional tree cover has been mapped at large scales using spectral data (Fernandes, 2004; Hansen 2003), LIDAR provides additional information on the height dimension.

The RGB composite of the tree vegetation parameters (Figure 3) confirmed that forests represent resources associated with dense tree vegetation (ex. timber production, carbon sequestration). However, considerable forest resources were found outside the official forest boundaries (ex. carbon sequestration, fire risk). Especially forest resources related to structural diversity (ex. habitat, recreation, biodiversity) were mostly found in these suburban areas outside forests.
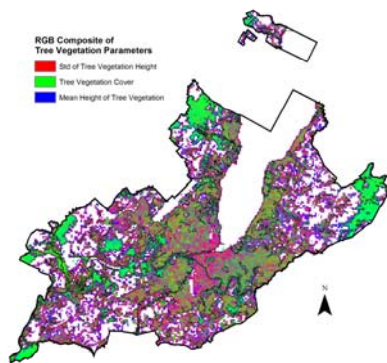

Figure 3. Spatial relationship of tree vegetation parameters represented as an RGB composite

Tree vegetation parameters showed long gradients in suburban areas. These soft boundaries at the landscape scale represent rich structured areas with a special microclimatic situation, therefore positively influencing several forest resources (ex. habitat, biodiversity, recreation). In contrast, forest borders contained rather short tree vegetation gradients creating hard boundaries.

This study showed that some of the traditional forest resources were found within classified forest boundaries. However, LIDAR-based landscape assessment also revealed great potential for further forest resources outside forests.
We therefore conclude that LIDAR data provides an ideal source for an efficient assessment of forest resources at the landscape level, therefore enhancing the planning and sustainable management of multifunctional landscapes.

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