Occupation of Canopy Space in European Temperate Old-Growth Forest observed by TLS

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1. Introduction

Forests are intrinsically three-dimensional systems with complex vertical structure, much stronger than in any non-forest terrestrial ecosystem. Canopy disturbances, tree regeneration, tree growth and competition (especially aboveground competition for light) all take place in real 3D space. These processes cannot be explicitly represented and understood by two-dimensional forest census/stem-mapping, as different tree species can have different requirements and growth strategies (species traits) including significantly different crown sizes, shapes and plasticity (Krůček at al. 2019). Different species also often occupy the canopy space in different height-levels thus forming a species-specific and site-specific vertical canopy stratification.

While traditional tree census (Condit 1998) is still indispensable field-research approach, terrestrial laser scanning (TLS) can effectively provide its valuable superstructure and complement the tree base coordinates by real three-dimensional description of individual trees (Calders et al. 2018). Such data can be easily used for description and quantification of canopy space occupation and vertical canopy stratification (Hess et al. 2018), which is due to the historical lack of data for many natural forest types still unavailable or based on sparse and imprecise measurement techniques (Apostol et al. 2018).

Here we introduce computationally straightforward approach for description of canopy space occupancy and its vertical stratification at the stand level using TLS data. It has a potential to bring a new level of knowledge about occupation of the canopy space by different tree species and tree-individuals and to answer fundamental questions such as:

i) What is actual canopy space occupation and its vertical distribution in various forest types?
ii) What is the vertical hierarchy of species and how it varies with site conditions?
iii) What is a frequency and magnitude of inter-specific and intra-specific crown-to-crown interactions and how it varies with changing observation scale?

2. Data and Methods

2.1 Study Sites and Data

On each of the three research plots several hectares of the stand have been scanned by terrestrial laser scanner Leica ScanStation P20. At each plot data from 1ha have been post-processed up-to tree segmentation using the 3DForest software (Trochta et al. 2017). The individual tree clouds have been linked to tree census data to get the record of tree status (live/dead, complete/fragmented), field-measured reference DBH and species. The three sites cover the altitudinal gradient from lowland floodplain forest (alluvial hardwood) of Ranšpurk (mean altitude of 153m) through sub-montane beech dominated Žofín forest (alt. 780m) to montane spruce-beech forest of Boubín (alt. 1095m). All research plots represent natural forests left to spontaneous development, the latter two are original forests with no or negligible historical direct human impact (Vrška and Adam 2009).

2.2 Methods

In the segmented point cloud the crowns of all individual trees of DBH $\geq$ 10cm were automatically delineated in the 3DForest software. The canopy/crown point cloud was normalized into heights above the ground and voxelized in gradually increasing resolutions: 0.25m, 0.5m, 1m. Every voxel was

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labelled as occupied if included at least one crown point. Along with that a unique tree ID was recorded for each occupied voxel. According the tree ID the data from the tree census database were linked to individual occupied voxels, so we could analyse co-occupation of voxels by different trees, species, etc. All voxels occupied by individual trees were summed to provide canopy occupancy statistics (Table 1). For calculation of total percentage of occupied space the 2% of the highest filled voxels were omitted.

3. Results and Discussion

Volume (and share) of occupied canopy space naturally changes with the voxel size used. In alluvial floodplain forest it ranges from 4.7 m^3 per m^2 for 0.25m voxel size to 14.6 m^3 per m^2 for 1m voxel size (Table 1, Figure 1a). More enlightening thus might be relative comparison between different sites observed in the same resolution (Figure 1b,c,d). Somewhat surprisingly, total mean canopy volume in the Ranšpurk floodplain forest is quite the same as in the Žofín beech dominated forest - almost 9 m^3 per m^2 for 0.5m voxel size (Table 1). However, as the aboveground canopy space in Žofín forest is occupied up to higher levels (up to 45m), relative mean occupation of canopy space there is lower than in Ranšpurk (Table 1, Figure 1). In other words, in the floodplain forest where tree heights can only exceptionally exceed 36m, similar total canopy volume is packed into a smaller space than in monodominant beech forest.

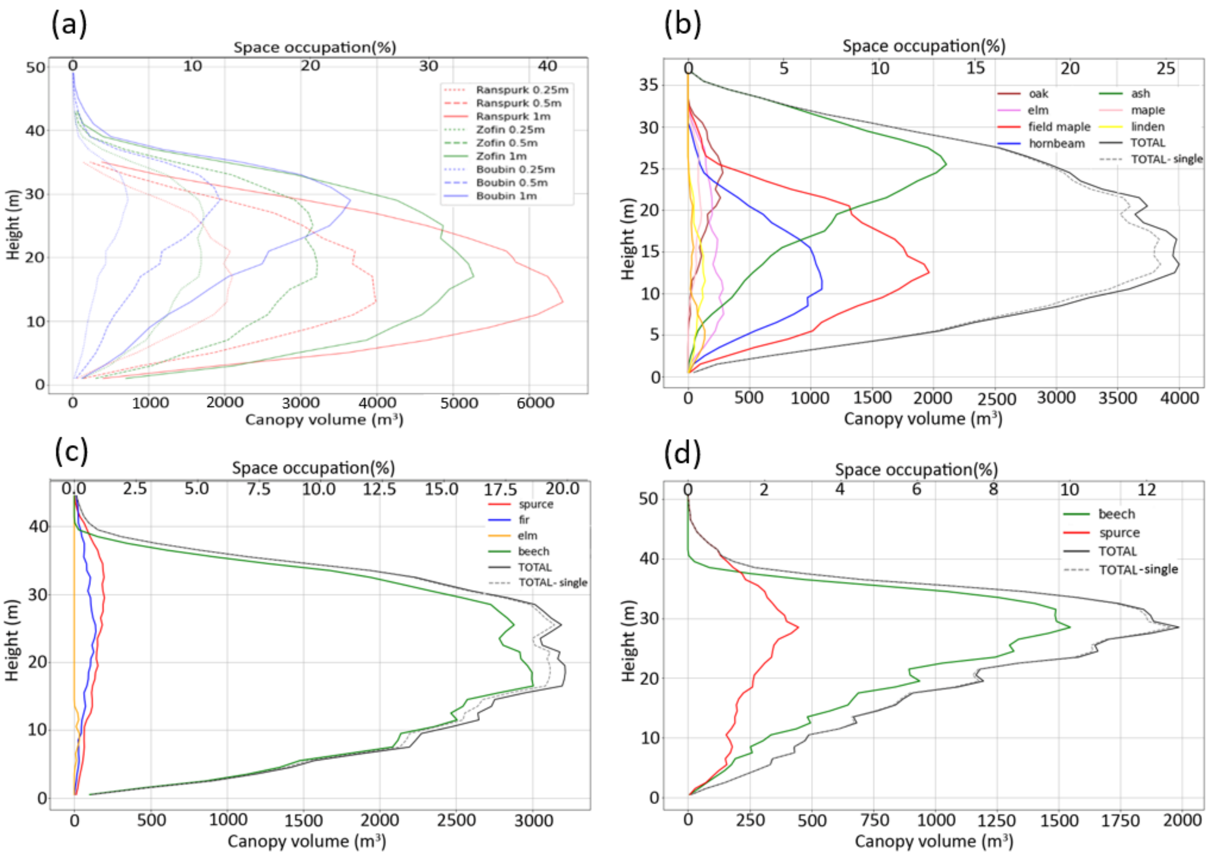

Figure 1: Comparison of vertical distribution of occupied canopy space in all three sites using different voxels sizes (a); and canopy space occupation by different tree species observed through 0.5m voxels in alluvial hardwood forest of Ranšpurk (b), beech dominated sub-montane Žofín forest (c) and montane spruce-beech Boubín forest (d).

Contrasting tree species richness of the two sites very likely plays an important role in this thanks to niche complementarity effect, leading to higher space occupation efficiency (Hess et al. 2018). While in Žofín about 90% of occupied forest canopy is formed by European beech, Ranšpurk forest canopy is composed of narrow-leaved ash (35%), field maple (34%), and hornbeam, accompanied by other four less common tree species (Figure 1b,c). Ash forms the upper canopy layer peaking in about 26m above ground, while field maple and hornbeam dominate in the lower canopy layer with the peak between 10 and 15m above the ground. All species together however form unimodal vertical canopy space occupation, not dissimilar to that of beech dominated Žofín forest.

Table 1. Canopy volume density and relative canopy space occupation observed at different scales (voxel sizes) in the three study sites.

Study	Canopy volume density (m^3/m^2)			Space occupancy (%)		
Site	vox. 0.25m	vox. 0.5m	vox. 1m	vox. 0.25m	vox. 0.5m	vox. 1m
Ranšpurk	4.7	8.9	14.6	9.2	17.6	28.7
Žofín	4.6	8.8	14.5	7.7	14.8	24.4
Boubín	1.4	3.8	7.8	2.4	6.3	12.9

Effect of higher space occupation efficiency may be observed also at the fine scale of individual voxels. Canopy voxels of 0.25m size are in species rich floodplain forest co-occupied by more than one tree crown in 1.2% of cases, while in beech-dominated Žofín forest it's about 0.7% of cases.

Somewhat different picture may be observed in the spruce-beech montane forest of Boubín, where the canopy volume is formed of three-quarters of beech and one quarter of spruce, both peaking around 30m above the ground (Figure 1d). Spruce having long crowns spanning from few meters above the ground up to 51m. Although beech is about 10m shorter, it also fills mostly the upper half of the canopy space. Overall, the canopy volume is less than half of the two other sites (Table 1), due to several reasons as higher abundance of spruce, predominance of big trees with less understory, harsher climate and thinning effect of 2008 Emma wind disturbance.

4. Conclusions

Presented method provides direct quantitative and qualitative description of forest canopy occupancy and may be used as a standard approach for comparison of forest canopy in different forest types, species mixtures, management approaches and/or before/after silviculture measures or natural disturbances. Recent advances in processing drone lidar data (Krůček et al. 2020) promise possible up-scaling of the approach beyond the level. On the contrary, when focused on individual trees, the approach may be used for unprecedented quantification of local "canopy niche" of particular trees/species and their canopy interactions.

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