Changes in canopy and crown structure with stand composition

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Highlights: Terrestrial laser scanning (TLS) data was used to quantify sugar maple crown metrics and local environment structure indices. It allows quantifying how crown plasticity, potential tree light interception and local environment structure are influenced by stand composition (pure vs mixed).

Key words: *TLS; Competition; Crown structure; Plasticity; Sugar maple.*

Introduction

The forest canopy structure can be defined by the position, size and shapes of each tree in a stand [1]. It is necessary to study the variations in individual tree crowns in order to understand canopy structure and its dynamics. The architecture of a tree at a given time is the result of a complex interaction between intrinsic (e.g. genotype) and external constraints (e.g. the environment) [2]. In fact, the most important environmental factor that influences tree crown structure in forests is the competition for light. This competition is usually quantified using the surrounding trees' crown dimension, size (height and diameter) and species [3]. TLS data could be used as a proxy to quantify the local environment. For instance it can provide metrics related to the shade that a given tree is subject through the woody and leafy material arrangement. The local environment varies widely according to species-specific crown shape and light acquisition strategies, and should thus change between pure and mixed stands.

Our objectives were to quantify with TLS data (i) the differences in the local environments of sugar maple trees in pure and mixed stands, (ii) the variability of crown structure between these two types of stands and (iii) the relationships between the local environment and crown structure.

Material and methods

A total of 36 co-dominant sugar maples (*Acer saccharum* Mill.) and their local environment were scanned (4 scans per tree) using a Faro Focus 3D TLS in Eastern Canada. Half of those trees were scanned in pure stands and the other half in mixed stands. We used voxelized clouds (1 point per non-empty voxel) instead of the raw point clouds in order to avoid distance to scanner bias and limit occlusion bias. Target trees were semi-manually isolated and separated from the rest of the voxelized cloud. A module in the Computree software was used to perform these isolations [4]. The principle is to select cells belonging to the tree on a 2D XY grid (i.e. a raster) computed on vertical slices of the voxel cloud. The operator starts the selection at the base of the tree by choosing the size of the slice, then selects cells belonging to the tree and repeats this step for each slice along the Z axis until the top of the tree. For each slice, delineation of the crown of a target tree is based on the changes in density of the raster that appears at the border of the crown. The local environment structure was calculated using the part of the voxelized cloud which was included in a 60° angle reverse cone starting at the crown base of the target tree (Figure 1a and b). Two indices were thus used i) a competition pressure index (CPI) based on the density of points, their height and their distance to the target tree and ii) a competition homogeneity index (CHI) calculated using the Clark and Evans aggregation index on the XY projection plan. Then, 5 crown metrics were computed to estimate the crown structure using R software (Figure 1b and c) (1) crown ratio (2) material density inside the crown (3) crown openness, defined as the angle between the axis of symmetry and the vector between the crown base point and the most external point of the crown in the XY plane (4) sinuosity, calculated as the cumulative asymmetry of polygons fitted every 10 cm along the z axis (5) volume filled, quantified by the total crown volume. CHI, CPI and crown metrics were compared between pure and mixed stands using analyses of variance. The variability of the CHI, CPI and crown metrics according to stand type was investigated using mixed effect models.

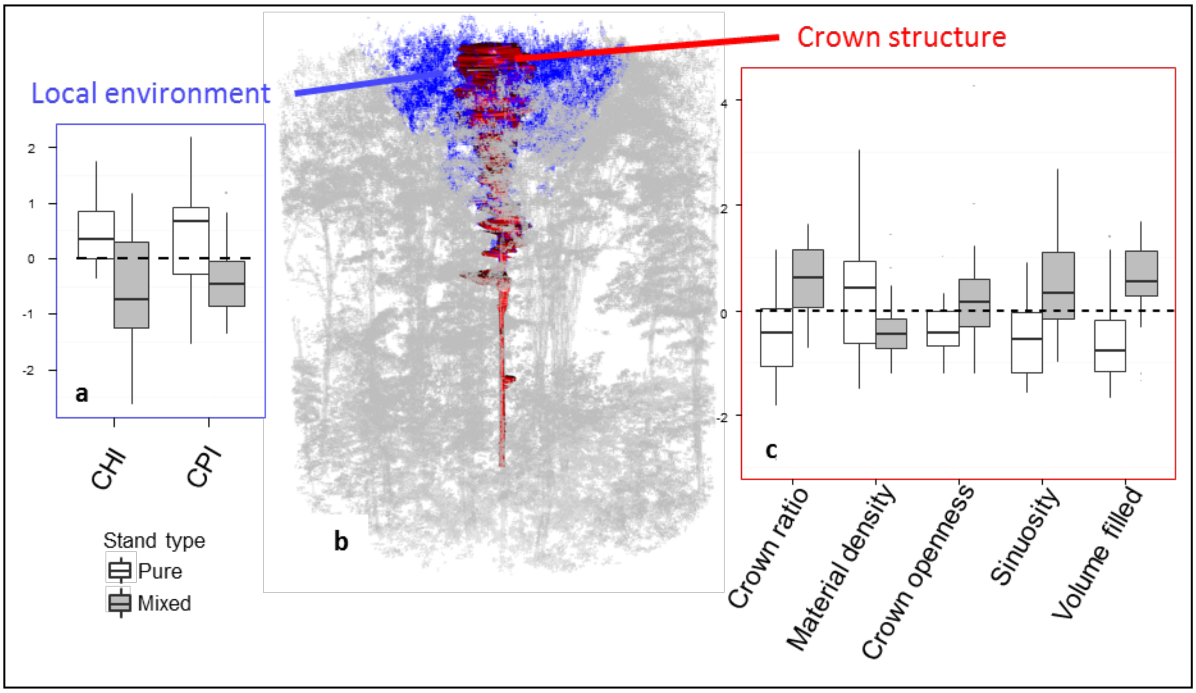

Figure 1: a) Local environment variability between pure and mixed stands b) TLS data of a target tree (red) and its local environment (blue) c) Crown metric variability between trees in pure and mixed stands

Results and discussion

Local environment variability

The CHI and CPI are lower in mixed stands (Figure 1a). The competition pressure is thus less important and the distribution of the material more clustered around trees in mixed stands. Sugar maple is a very shade tolerant species with a high light extinction coefficient [5], which could explain a higher CPI in pure stands. Similar results were observed for the shade tolerant species European beech [6]. The higher material densities inside the tree crowns observed in pure stands also supports this result. The lower CHI value in mixed stands can be explained by the high variability in crown shapes and strategies to acquire light, making the canopy more heterogeneous. Moreover, this variability and thus the potential crown trait complementarity for light acquisition could reduce the competition pressure in mixed stands when compared to pure stands.

Crown structure and implications on light interception

Statistically significant differences between stand composition (i.e. pure versus mixed) of the five studied crown metrics were observed (Figure 1c). In decreasing order of importance, trees have a higher crown ratio, filled more volume, have a higher sinuosity, a more open crown, a lower within-crown material density in mixed stands when compared to pure stands. These results should provide advantages to trees in mixed stands for increased light interception. Indeed, an increase in crown volume obviously increases the potential light intercepted by increasing the leaf area index. Moreover, higher crown openness probably increases the light penetrability in the lower part of the crown. Similar results were observed for European beech with a higher crown volume and flatter branch angles (which is similar to our crown openness) for trees in mixed stands when compared to pure stands [7]. The lower material density also suggest a more light penetrable crown in mixed stands, meaning that self-shading and self-pruning will be lower. The observed higher crown ratio in mixed stand supports this interpretation. Finally, the sinuosity is more important in mixed than in pure stands. This metric can be interpreted as the capacity of a tree to deviate from its symmetry axis in order to avoid neighbours and intercept more light.

Crown plasticity

All the crown metrics we quantified varied widely in response with stand type (Figure 1c), but also with the local environment (data not shown in the abstract). These results reveal a high sugar maple crown plasticity which could be a consequence of the feedback loop " Environment -> Growth -> Structure -> Environment" operating in forest ecosystems [7], i.e. the environment of a tree affects its growth which influences its crown structure which in return changes the canopy structure.

Conclusion

TLS data allows us to quantify local environments metrics reflecting the arrangements of material around a tree and to observe its impact on crown structure. Moreover, the three dimensional aspect of the crown structure metrics we used allow many functional interpretations, such as light interception. Validation of the tree isolation method is foreseen, as it is the basis of our results. Finally, our results could be used to further explain the potential benefits of mixed forests, at least in term of crown structure and light interception.

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