Retrospective analysis of fir sapling growth vs. light interception

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Introduction

The natural regeneration of forests may create dense spots of young saplings, but most of these gradually die through competition for light, water and nutrients, leaving only a few individuals with better access to resources still alive. Determining the specific role of light in this plant selection process is difficult because there is no easy way to measure light interception over time during the ontogeny of a plant in its environment.

In most tree temperate species, successive annual growth units (GUs) can be clearly identified through markers such as the scars of fallen bud cataphylls (Barthélémy & Caraglio, 2007). It is therefore possible to infer the architecture of a sapling over the years from a retrospective morphological analysis of its final architecture. A few additional geometric laws can then be used to reconstruct 3D computer models of saplings at different ages and employed to calculate their light interception. The study described here illustrates how this original methodology is used for the retrospective reconstruction of fir saplings (*Abies alba* L.) at different ages and to simulate their light interception.

Materials & Methods

Experiment

Fir saplings were grown for 4 years in a nursery at Aix-les-Milles (43°30'37"N, 5°24'33"E) at an initial density of 290 plants m^{-2} under neutral shading nets that provided a light transmission level of 20% (considered representative of natural conditions), with/without water supplies in the summer (treatments hereafter referred as W and D, for “wet” and “dry”, respectively).

Measurements were made in one subplot of 33 saplings for each treatment. A comprehensive topological description was generated for all saplings at the end of their 4th year. Production year, length and diameter were noted for each GU and data were coded in accordance with AMAPMod/MTG syntax (Godin & Caraglio, 1998).

Additional measurements were made for purposes of modeling needle number, length and orientation (fig. 1a). The number of needles per GU was found to be linearly correlated to GU length both on the main stem and branches, with R^2 values of 0.68 and 0.93, respectively. Needles were arranged in a spiral pattern with a phyllotactic angle of 144° on the trunk and arranged on three planes on branches. Needle length was found to be dependent on their relative position along the GU and differed slightly with needle plane. Branch insertion angles were analyzed and simple geometrical rules were derived for reconstructing plant geometry, as illustrated in fig. 1b.

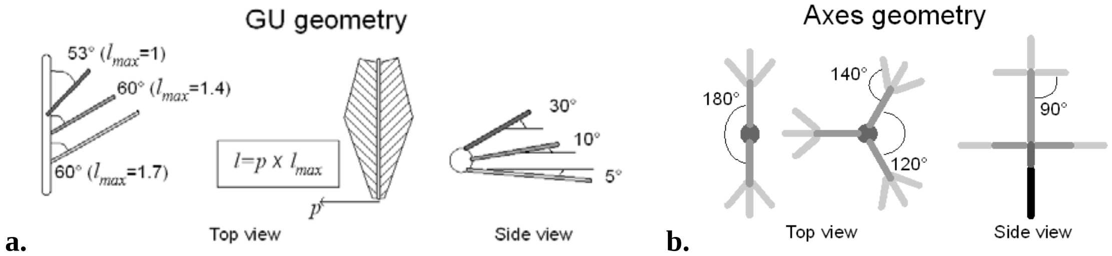

Figure 1: Rules for geometric reconstruction, (a) Growth Units geometry with the three needle planes in a gray gradient; (b) view from above and view in elevation of branches geometry with successive GU in a gray gradient.

Tools and methods

Xplo-Simeo-MMR software was used to sequence simulation steps (fig. 2): reconstruction of individual plants (Xplo), stands simulation (Simeo), calculation of light interception (MMR) and data extraction for analyses (Xplo).

Xplo (http://amap-dev.cirad.fr/projects/xplo/wiki/Xplo) is a tool used to produce 3D models of plant architecture. Users can create, edit, visualize and extract architectural data. The software is built on a formal model called "ArchiTree" inspired by MTG formalism (Godin & Caraglio, 1998), which forms the central data structure in the system. Data can be edited and extracted in an interactive and/or scripting manner (Jython/Groovy). 3D visualization is based on editable geometric rules for building the multi-scaled geometry of the plant (Fig 1 and 2c).

Simeo (Scene Implantation Manager with Edition by Outline; http://amap-dev.cirad.fr/projects/simeo/wiki/Simeo) is a multi-purpose 3D editor used to conduct studies on vegetation scenes. It provides various plantation pattern plugins that can be combined to create scenes interactively (Fig. 2d). It is designed to connect easily with other software to run calculations at the scene level. In this particular study, a connection was made with the MMR radiative model using virtual scenes reconstructed by positioning 3D fir models at their observed position and orientation.

MMR is a model implemented in the Archimed simulation platform (Dauzat *et al*., 2008) and used to calculate the irradiance of plant elements in 3D virtual scenes. The model is based on the principle that elements visible from an observer point of view will receive light from the corresponding direction (for instance all entities visible on an image calculated from the sun point of view are sunlit). To account for light received from all directions, the sky vault is divided into 46 sky sectors of equal solid angle. Total light interception is therefore derived from calculations made on 46 images, with weighting for Photosynthetic Active Radiation (PAR) intensity in the corresponding sectors. The calculated irradiance is added as a plant new attribute in ArchiTree.

In this study, light fluxes were integrated over a period from May 1st (date on which flushes are fully developed) to September 31st, i.e. the period when carbon assimilation is most active. PAR irradiance was calculated at the needle level and integrated at branch and plant levels (Fig. 2e). Total PAR intercepted per sapling over the entire period (L) was expressed in moles of photons.

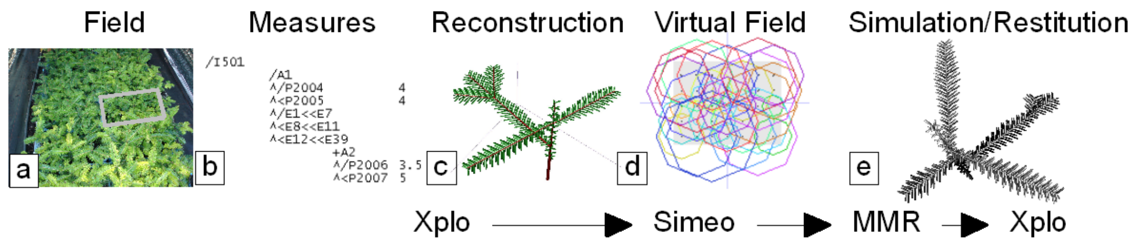

Figure 2: From plot to simulation, (a) view of a subplot in the dry (D) treatment, (b) plant architecture coded in accordance with AMAPMOD/MTG syntax (Godin & Caraglio, 1998), (c) topological and geometrical plant reconstruction with Xplo, (d) stand reconstruction with Simeo, (e) light interception calculated using MMR model and analyses by Xplo.

Results and discussion

The retrospective reconstruction of saplings was used to calculate their needle area in the 3rd and 4th years of their growth (noted A_3 and A_4, respectively) and their light interception (L) at different ages.

The results showed that sapling needle area on average more than tripled in one year for both treatments (Table 1). Marked inter-tree variability was observed for A_4, with coefficients of variation (cv) of about 0.5 and 0.4 for the D and W treatments, respectively. We therefore analyzed to what extent the area increment of individual saplings correlated with their light interception (L, as defined in materials and methods).

Given that the GUs that develop in the spring were preformed during the previous year, the needle area increment A_4-A_3 was related to sapling PAR interception in the 3rd year (L_3). A_4-A_3 was found to be highly linearly correlated with L_3 in the W treatment (R^2 = 0.70) and less correlated in the D treatment (R^2 = 0.62). However, a further analysis showed that A_4-A_3 is more closely correlated with A_3 than with L_3 in the dry treatment (Table 1). This result can be explained if we assume that the largest plants not only have greater access to light but also greater access to soil resources owing to a more developed root system. Moreover, competition for light is not intense among 3 yr. saplings which intercept less than 50% of incident light with an LAI of around 0.70 for both subplots.

Table 1: Saplings properties and inter-sapling relationships

Treatments	Needle area per sapling (cm²)		PAR intercepted (moles photons sapling^{-1})	R^2 for linear regression of A_4-A_3 versus	
	A_3	A_4	L_3	A_3	L_3
Dry (D)	26 ± 10	94 ± 45	1.37 ± 0.56	0.70	0.62
Wet (W)	28 ± 11	106 ± 46	1.53 ± 0.63	0.69	0.70

Perspectives

This preliminary study illustrates (1) how the dynamics of plants can be reconstituted retrospectively by analyzing their architecture and (2) how their individual light environment can be simulated over time. Further investigations will be carried out to test possible effects of the irradiance of individual branches on their growth (i.e. to test whether branches with the highest irradiance show greater growth).

This overall approach is well suited to analyzing the manner by which plants compete for light throughout their development and may in particular be useful for setting the parameters in functional-structural plant models related to plant reactions to their light environment.

References

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