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Philippe Balandier, A. Marquier, Noémie Gaudio, L. Wehrlen, E. Casella, et al.. Methods for describing light capture by understorey weeds in temperate forests: consequences for tree regeneration. Final COST E47 conference Forest vegetation management towards environmental sustainability, May 2009, Vejle, Denmark. p. 73 - p. 75. hal-00468643

HAL Id: hal-00468643

https://hal.science/hal-00468643

Submitted on 31 Mar 2010

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Forest Vegetation Management – towards environmental sustainability, N.S. Bentsen (Ed.), Proccedings from the final COST E47 Conference, Vejle, Denmark, 2009/05/5-7, Forest and Landscape Working Papers n° 35-2009, 73-75.

Methods for describing light capture by understorey weeds in temperate forests: consequences for tree regeneration

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Introduction

The amount of light reaching the forest understorey is one of the main environmental factors controlling the success of seed germination, seedling establishment and growth of trees in temperate forests. Forest operations like thinning lead to an increase of light availability that promotes the development of the ground vegetation, graminoids, forbs and shrubs, which may affect tree regeneration (Balandier et al. 2006). These plants can intercept a significant fraction of the available light in the understorey and the resulting light available for tree seedlings can vary greatly, depending on species identity and abundance in the ground flora. Although quantifying competition for light between species is of great interest to forest managers, assessing light capture by vegetation having such a complex structure still faces many technical challenges.

Direct light measurement by sensors

Many sources of variability are combined and contribute to the very patchy structure of light under the different forest strata, these include: variability in space and time due to the structure and seasonal growth of the forest overstorey, variability due the understorey species phenology and development, and of course ecological site conditions (Fig. 1). Consequently many light sensors are needed to describe those heterogeneous systems which is a time consuming and expensive process.

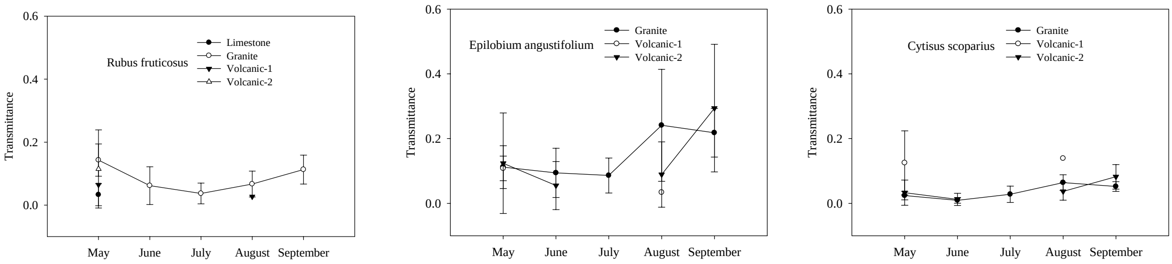

Figure 1: Seasonal evolution in 2005 of transmittance (light measured under the canopy divided by light measured above the canopy) measured at soil level with a linear PAR sensor 0.8-m long (Decagon device) under three colonizers of gaps in temperate forests, on different sites and soil substrates, Auvergne, France.

Indirect light measurement by hemispherical photographs

Hemispherical photographs could be more convenient to characterize light interception under different species (Fig. 2), but the method has drawbacks that are similar to hemispherical photographs used for assessing the overstorey (Balandier et al., 2009). These are the need to have a well contrasted photograph with no over-exposure and the subsequent difficulty in classifying pixels in sky or vegetation. For plants in the understorey an additional difficulty is that it is difficult getting a sharp image for both the understorey and the overstorey vegetation.

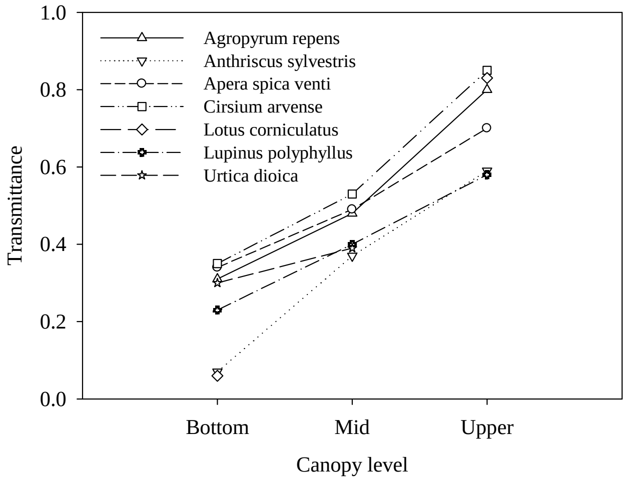

Figure 2: Estimated values in light transmittance within contrasting canopy vegetation in an open field near Rostock, Germany. Measurements were recorded with a CI-110 hemispherical lens (CID Inc., USA).

Indirect light assessment by plant reconstruction and modelling

Mathematical methods dealing with plant architecture are being developed to model light capture by a range of plants including tree seedlings in contrasting understorey situations. Whilst many models have dealt with light transmission through forest overstorey the understorey vegetation is rarely considered (Lieffers et al. 1999). Among the different possibilities, two main approaches are generally considered, firstly an analogy with the physics of turbid media and secondly the use of plant mock-up and image computation.

The Beer-Lambert law of light extinction in a turbid medium has been used considering the leaves divided in infinitely small particles. Canopy architecture can be described as a grid of 2D or 3D voxels resulting from a spatial discretisation of the space occupied by the canopy (Fig. 4). Leaf area density in a voxel is assumed to be uniformely and randomly distributed, so that Beer's law is used at the voxel scale. However a true canopy is sometimes far from this theoretical assumption and different solutions have been proposed to account for a non-uniform leaf distribution in space (i.e., leaf clumping, Varlet-Grancher et al. 1993).

Plant mock-ups can also be used to calculate light interception by image processing. The principle is often to project the image of the mock-up in a given direction as viewed by a camera. Then the ratio between the projected area by the total leaf area of the plant (STAR, Silhouette to Total leaf Area Ratio) is an estimation of light interception efficiency in a given direction. This STAR value multiplied by the incident light amount above the canopy in the same direction gives the amount of light which is intercepted or transmitted by the plant. It can be integrated on different sun directions to account for a daily sun path or the whole sky hemisphere. If different colours are used, the STAR can be calculated only for pixels with a given colour (projected area for a given colour) and hence different plants can be distinguished as well as light sharing between them (Fig. 3, 4). Three-dimension plant digitising to build mock-ups is very time consuming and consequently cannot be used extensively. However fig. 4 shows that the turbid medium approach can lead to acceptable results, particularly for dense or continuous understorey cover (*i.e.* a low value of STAR).

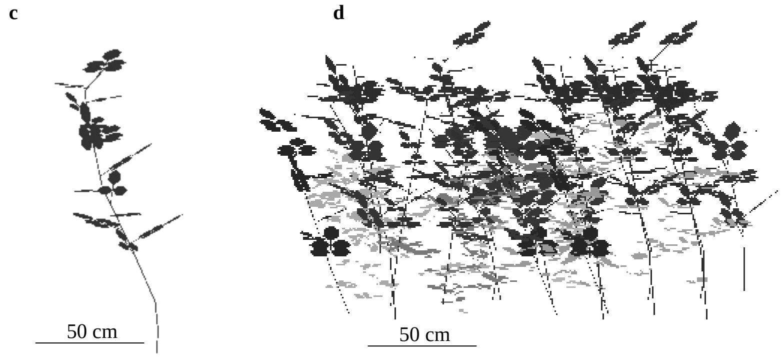

Fig. 3. Examples of plant mock-ups used to compute light sharing between raspberry (*Rubus idaeus*) and beech (*Fagus sylvatica*) seedlings. Lateral view of isolated raspberry and lateral view of a scene with 6 beech seedlings (in grey) 50 cm from each other with a systematic network of raspberry (in black) between beeches, i.e. a raspberry plant every 50 cm.

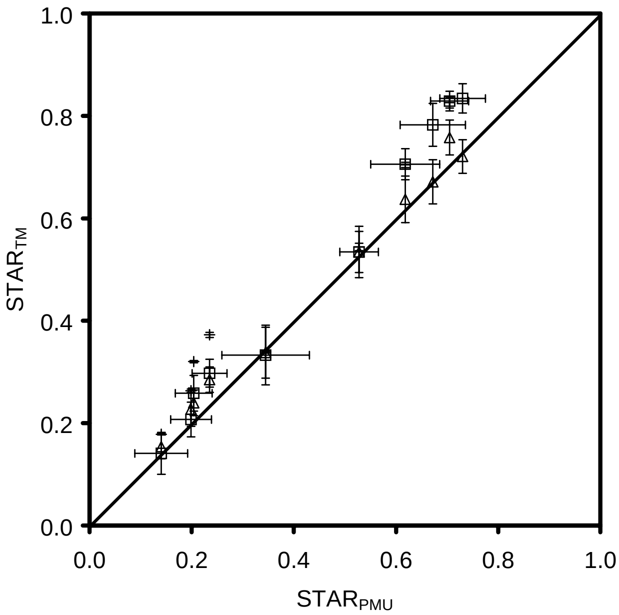

Fig. 4. Comparison of the STAR value of beech seedlings in association with raspberry computed from images (fig. 3) of plant mock-ups ($STAR_{PMU}$) and from turbid medium simulations ($STAR_{TM}$): square: 1D turbid medium model; cross: two-layer model; triangle: 3D turbid medium model. (Mean and standard-deviation computed on 6 seedlings).

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