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Effect of thinning on LAI variance in heterogeneous forests

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ABSTRACT

Leaf Area Index (LAI) is a main variable controlling carbon and water fluxes. This paper estimated the effect of thinning on the spatial distribution of leaf area in French forests. While many studies have focused on average LAI, we estimated clumping and measured both average LAI and the variation around it. LAI was derived from digital hemispherical photos at three sites: an unmanaged *Fagus sylvatica* forest in temperate area (control site), a mixed Mediterranean forest of *Quercus ilex* and *Pinus halepensis*, and regeneration of *F. sylvatica* under a mature stand of *Pinus nigra* in mountainous area. LAI measurements were also made with LAI 2000 devices over 5 years (from 1994 to 1998) within forest stands dominated by either beech (*F. sylvatica* L.), by oaks (*Quercus petraea* (Matus) Liebl., *Quercus robur* (Matus) Liebl.), or by Scots Pine (*Pinus sylvestris* L.). Thinning led to a variable decrease in LAI. The coefficient of variation of LAI (CV_{LAI}) provided a useful ecological index of the level and type of thinning. For undisturbed stands, CV_{LAI} varied from 10% to 20%, corresponding to the higher average LAI values. Disturbances created by thinning increase LAI spatial variability, resulting in larger CV_{LAI} values for all stands considered. Possible explanations of these results and use in remote sensing were discussed.

1. Introduction

Leaf Area Index (LAI) is defined as the projected area of green leaves or needles per unit horizontal ground surface area (Watson, 1947; Stenberg, 2006). It corresponds to the main surface exchange of carbon and water fluxes between the forest canopy and the atmosphere. It is also a key variable driving ecosystem functioning as many processes in a forest depend on LAI, including light and rain interception (Gash, 1979), gross productivity (Davi et al., 2006b), transpiration (Granier et al., 2000) and soil respiration (Davidson et al., 2002). Therefore, LAI variability usually explains a significant part of the variability in water fluxes from stand to regional scales (Behrenfeld et al., 2001; Sellers et al., 1997; Davi et al., 2006b).

LAI is an efficient index of ecosystem functioning at various scales since it can be derived by remote sensing (Turner et al., 1999; Chen et al., 2002; Davi et al., 2006a). Average LAI is one essential biome characteristics (Asner et al., 2003). Temporal variability of spatially averaged LAI values approximated by remotely sensed vegetation indices allows characterizing ecosystem functional types (Paruelo et al., 2001).

Spatial variability of LAI was found to be correlated to evapotranspiration and soil moisture (Grier and Running, 1977; Long and Smith, 1990; Burton et al., 1991; Jose and Gillespie, 1997). Some correlations were also found with foliage nutriment content (Vose and Allen, 1988; Hebert and Jack, 1998; Davi et al., 2006b). However, LAI interannual variation between years depends essentially on disturbances induced by thinning (Le Dantec et al., 2000), wind, fire, or severe drought. Two kinds of LAI are important for modelling: (i) the LAI which governs the fraction of light absorbed and therefore the light available in the canopy and at the ground level and (ii) the LAI which controls leaf respiration and litterfall. Clumping index (CI) corresponds to the ratio between these two quantities and depends mainly on local variation of leaf area density (leaf area per unit canopy volume area). The first corresponds to that derived from gap fraction measurements, assuming that leaves are randomly distributed within the canopy volume.

Several studies investigated the effect of thinning on spatially averaged LAI and its consequences on light transmittance (Cutini, 1996), soil and tree water status (Bréda et al., 1995), throughfall (Aboal et al., 2000; Dietz et al., 2006), and nitrogen uptake and growth (Carlyle, 1998). However, the same spatially averaged LAI value may thus correspond to very different spatial distributions depending on species, climate conditions and management history. Until now, very little attention has been paid to the effect of thinning on LAI spatial distribution. LAI can be defined over a

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range of spatial support domains such as the region (10 km × 10 km), the site (≈1000 m × 1000 m), the stand (≈100 m × 100 m), the plot (≈20 m × 20 m), or at even smaller scales (e.g., trees, shoots). LAI spatial distribution can be approached using either the coefficient of variation of LAI (CV_{LAI}) or clumping index (CI) which are obviously closely related. However, their relationship will mainly depend on the scales considered. Variation of leaf area density approached by CV_{LAI} and CI may occur from the stand level to the tree, branch and shoot levels. By selectively eliminating trees, thinning practices are expected to impact leaf area density distribution at the stand to the tree levels, while branch and shoot levels will be marginally affected, except when thinning focuses on species selection. The typical footprint of individual LAI measurements when using indirect methods (Jonckheere et al., 2004) is the plot scale corresponding to a small number of trees. At the plot scale, CI will therefore detect leaf clumping between adjacent crowns and inside the crown. Conversely, CV_{LAI} computed over a series of individual LAI measurements at the stand or regional level will mainly detect variability in tree distribution over larger length scales.

Accounting for LAI spatial variability is important because of the non-linear dependency of ecological processes to LAI (Davi et al., 2006b), as well as their direct dependency on LAI spatial distribution. Indeed, in previous works, Dufrêne et al. (2005) using uncertainty analysis highlighted the necessity to account for parameters variability in process-based models: neglecting the spatial parameter variability of LAI (or other parameters) led to a Net Ecosystem carbon Exchange (NEE) overestimation of 29%. In another study, Davi et al. (2006b) have shown that NEE and Transpiration increased non-linearly with LAI, showing strong saturation for high LAI values. On the other hand, the importance of the CI in carbon models, in which the foliage is separated into sunlit and shaded leaves, has been demonstrated by Chen et al. (2003). Clumping was shown to be the first source of NEE spatial variability in a young beech stand (Davi et al., 2006b). Quantifying the dynamics of CI and CV_{LAI} after thinning is thus important to advance understanding and modelling of forest ecology.

The objective of this paper is to describe effects of thinning on average LAI and its spatial distribution characterized by CI and CV_{LAI}. For this purpose an experiment was conducted in broad-leaved, coniferous and mixed forests subjected to several thinning practices. The study considers both the stand and the regional scales.

2. Material and methods

2.1. Sites description

2.1.1. Stand scale: three sites

Three sites were used for the stand scale analysis. They correspond to particular ecosystems showing various level of complexity in terms of forest structure and species composition.

2.1.2. Lamanon

The site, located north of Marseille near Lamanon (43°42′N; 5°03′E; elevation 120 m, slope < 10°) is made of an overstory of Aleppo Pine (*Pinus halepensis* Mill.) above an understory of Holm Oak (*Quercus ilex* L.). The understorey is dominated by boxwood (*Buxus sempervirens*). Climate is Mediterranean with a mean annual temperature of 13.9 °C and a mean annual rainfall of 663 mm. Three plots were further studied north of Alpilles with a colluvial soil including: the "control" plot (30 m × 40 m), where no thinning was conducted, the Lamanon Oak plot (30 m × 30 m), where all Aleppo Pines were removed, and the Lamanon Pine plot (30 m × 30 m), where all oaks were removed. Lamanon Oak and Lamanon Pine plots were thinned in February 2006 leading to a 40% and 30% basal area decrease, respectively, for the Lamanon Oak plot (from 28 to 17 $m^2\ ha^{-1}$) and for the Lamanon Pine plot (from 30 to 21 $m^2\ ha^{-1}$). Pine dominated at 13.09 m in mean height, varying between 6.3 and 16.3 m high; Holm Oak had a mean height of 5.41 m. Hemispherical photographs were taken over a regular grid every 5 m before and after thinning leading to a total of 49 photos for Lamanon Oak and Lamanon Pine plots and 64 photos for the control plot.

2.1.3. Ventoux

This flat site (44°6′N, 5°49′E elevation 1120 m, slope < 10°) located on the southern face of Ventoux mountain is dominated by black pine (*Pinus nigra* ssp. *nigra*). Climate is typical of low altitude mountains with 9.25 °C mean annual temperature and 1068 mm mean annual rainfall. An area of 6 ha was selected over calcareous soil on a limestone regolith parent rock with a southern aspect moderate slope (Nouals and Jappiot, 1996). Adult pines were planted in 1920 and the last thinning before that of 2006 was conducted in 1981. The average tree height of pines was 19.5 m. Below the overstorey, a natural regeneration layer of young black pine and beech was growing. The beech regeneration had a large range of age and height. The average height of the three tallest beeches per cell of 400 m^2 is about 3 m. The thinning conducted in January 2006, led to a decrease from 39 down to 15 $m^2\ ha^{-1}$ for the basal area (G) and from 469 to 177 stems ha^{-1} in stem density for mature trees. The cutting was conducted using three modalities (3 × 2 ha): (i) one plot was thinned following a "seeding cut" (S) leading to a decrease of basal area of 68% (from 44 to 14 $m^2\ ha^{-1}$); (ii) another plot following "a gap cut" (G) decreases the basal area by 53% (from 37 $m^2\ ha^{-1}$ to 18 m^2); (iii) and the last plot following a "seeding cut plus a gap cut" ($S + G$) leading to a decrease of basal area of 64% (from 39 to 14 $m^2\ ha^{-1}$). Hemispherical photographs were taken at five dates: November 2005 (before the forest thinning), April 2006 (winter), August 2006 (summer), February 2007 (winter) and August 2007 (summer), every 20 m leading to a total of 148 photos for each date. At this site, we analyzed the effect of thinning not only just after the thinning in 2006, but also 1 year after in 2007.

2.1.4. La Tillaie

"La Tillaie" is a 36 ha natural forest located in Fontainebleau (48°43′N, 2°68′E, elevation 120 m) dominated by beech (*Fagus sylvatica* L.). Climate is temperate with 10.6 °C mean annual temperature and 750 mm mean annual rainfall. Soil types are luvisols and podzosols with a calcareous substratum at approximately 1 m deep and humus types ranging from mull to moder. This old forest has been protected for royal hunting since the 17th century and has not been subjected to forestry practices since that time and was considered as the control site for this study. A 80 m × 100 m plot was selected. It is characterized by a gradient in canopy openness, from a clearing in the western side to a dense pole stand in the eastern side. The average density was 659 stems ha^{-1} with a 32 $m^2\ ha^{-1}$ basal area and an average tree height of 13.5 m. Hemispherical photographs were taken in 2001 and 2002 every 10 m. A description of the site was given in Davi et al. (2006b).

2.2. Regional scale: Fontainebleau forest

Fontainebleau forest is located in a 17,000 ha mixed deciduous forest at an average elevation of 120 m (48°25′N, 2°40′E). A total of 40 plots approximately 6.5 ha were used to represent the Fontainebleau region: 12 were dominated by beech (*F. sylvatica* L.), 17 by oaks (*Quercus petraea* (Matus) Liebl., *Quercus robur* (Matus) Liebl.), 11 by Scots Pine (*Pinus sylvestris* L.). These stands