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Managing understory light to maintain a mixture of species with different shade tolerance

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ABSTRACT

Close-to-nature management of forests has been increasingly advocated. However forest managers often face difficulties in maintaining mixtures of species with different shade tolerance. In uneven aged stand management, understory light can be manipulated by modifying stand structure and composition, in addition to stand density. Using a forest radiative transfer model, we analyzed how different cutting strategies could modify light availability under the post-harvest canopy. To calibrate the model, we measured and mapped trees in 27 plots with structures ranging from secondary-successional oak forests to late-successional beech forests. We measured understory light and crown openness and verified that our forest radiative transfer model well captured the variability of understory light among the studied stands ($R^2 = 87\%$). We then compared cutting strategies varying in type and intensity and provided indications to promote the regeneration of mixtures of species of different shade tolerances. In particular, creating gaps of about 500 m^2 provided adequate light for small regeneration clumps. Cutting from below, species-specific cutting and uniform cutting were also appropriate for tree regeneration but uniform cutting required higher harvest intensity. Cutting from above slightly increased understory light and promoted more shade tolerant species.

1. Introduction

Close-to-nature management of forests has been increasingly advocated and practiced. Foresters attempt to mimic natural processes in order to produce wood and to preserve ecosystem services and diversity (Schütz, 1999). This concept is generally practiced using continuous-cover forestry systems, relying on natural regeneration, maintaining irregular stand structure and a mixture of tree species (Pommerening and Murphy, 2004; Bruciamacchie and de Turckheim, 2005; Schütz et al., 2012). The major difficulty with this system is in controlling the composition and the growth of the natural regeneration, especially of the regeneration of less shade-tolerant species.

Naturally, when they are abundant in the overstory or understory, shade-tolerant species suppress the regeneration of less shade-tolerant species in continuous-cover forestry system because canopy openings are usually limited. As a case in point, beech (*Fagus*) is a common genus in the northern hemisphere whose species are known to be very shade-tolerant and to suppress less shade-tolerant species in the absence of severe perturbation (Kunstler et al., 2005; Beaudet et al., 2007; Wagner et al., 2010; Takahashi and Goto, 2012; Ligot et al., 2013). Beech juveniles survive and invade the understory even under a closed canopy. After even a slight canopy release, that lets in 10% of above canopy light, beech juveniles thrive whereas most other species cannot survive for long (Emborg, 1998; Stancioiu and O'Hara, 2006). In understories with more than 20% of above canopy light, such as after moderate canopy release, less shade-tolerant species grow well. Nevertheless, in these conditions, beech juveniles grow faster (Kunstler et al., 2005; Beaudet et al., 2007; Takahashi and Goto, 2012; Ligot et al., 2013) and are often taller than the companion species.

Controlling understory light is therefore a key factor to regenerate mixed stands (Lieffers et al., 1999). The control of understory light with partial cuttings requires properly modifying stand

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structure and composition in addition to solely managing stand density. To date, this question of how changes in stand structure and composition affects understory light has rarely been addressed, especially for heterogeneous broadleaved forests. Only a few field experiments successfully defined levels of canopy openness suitable for the regeneration of mixed species (von Lüpke, 1998; Prévost and Pothier, 2003) while simulation studies have been limited to particular ecosystems. Cutting groups of spatially aggregated trees or creating gaps has been reported to drastically increase light availability for the regeneration in boreal mixedwoods (Coates et al., 2003; Beaudet et al., 2011), even-aged western hemlock or douglas-fir forests (Sprugel et al., 2009) or uneven-aged spruce forests (Courbaud et al., 2001; Lafond et al., 2013). Additionally, cutting understory poles and trees with branches immediately above the regeneration, or cutting from below in some way, has often been recommended for shelterwood systems as these poles and trees, unless removed, compete strongly with regeneration for nutrients, water and light resources (Nyland, 1996). Moreover, we suppose that removing shade-tolerant species increases understory light more than removing trees randomly because shade-tolerant species usually have wider, deeper and denser crowns than less shade-tolerant species (Coates et al., 2003; Beaudet et al., 2011).

We therefore attempted to explore how silvicultural regeneration treatments modifying stand structure and composition affect understory light in order to identify the best treatment to promote the regeneration of mixed species. In particular, we aimed to:

1. compare different cutting scenarios hypothesizing that, at similar levels of harvest intensity, gap creation, cutting from below, removing shade-tolerant species (species-specific cutting), cutting randomly and cutting from above induced respectively a high to low responses in transmitted light (H_1);
2. test whether our first hypothesis is general or depends on initial stand structure (H_2);
3. identify the combinations of cutting scenarios that maximize the understory area receiving 10–20% (levels favorable to regeneration of shade-tolerant species such as beech regeneration) or 20–40% (levels favorable to regeneration of mid-tolerant species) and above 40% (little light limitations for most regeneration) of above canopy light.

2. Methods

2.1. Study area

We studied light management as a regeneration treatment for acidophile medio-European beech forests (CORINE classification 41.111) mainly composed of European beech (*Fagus sylvatica* L.) and sessile oak (*Quercus petraea* (Matt.) Lieb). These forests have been managed with continuous-cover forestry systems for several decades and it has been noticed that the proportion of less shade-tolerant companion species has decreased (von Lüpke, 1998; Alderweireld et al., 2010). This underlines the failure of current practices to promote the coexistence of species mixtures. Yet, sustaining oak in beech forests, as well as maintaining mixtures of tree species in general, is important for biodiversity, forest resiliency, soil fertility, recreational and timber production issues.

The study area was located in the Belgian Ardennes (50°15′N, 5°40′E). Dominant soils are well drained brown acidic soils (WRB soil classification) of variable depth that developed on hercynian oligotrophic schist and sandstone substrates. Precipitation ranges from 930 to 1200 mm year^{-1} and the mean annual temperature is about 9 °C.

We selected 27 sites with varying stand structures and compositions and with established regeneration of oak and (or) beech. These studied stands characterized the diversity of forest structures that can be found during forest succession of early-successional oak forests to late-successional pure beech forests (Fig. 1). All of the studied stands are in public forests. With the gradual degradation of the market of small oak timber during the 20th century, they have been managed with continuous-cover forestry systems in order to progressively convert oak coppices or oak coppices with standards to high forests. Forest managers have usually maintained high forest stocking of adult trees promoting beech regeneration. Nevertheless, during the last decade, beech decay (Henin et al., 2003) has opened the canopy of some of these forests providing opportunities for the regeneration of less shade-tolerant species.

Every tree with a circumference greater than 40 cm was mapped and measured. We measured the circumference at breast height, total height (H), and height to the base of the crown for each tree. On 13 sites, we also measured at least 4 crown radii for every tree. Besides oak and beech, our data set contained 7% hornbeam (*Carpinus betulus* L.), 4% small coniferous trees (*Pseudotsuga menziessi* (Mirb.) Franco, *Picea abie*s (L.) Karst, and *Pinus sylvestris* L.), 2% birches (*Betula* pendula Erth, *Betula pubescens* Erth), and 2% other broadleaved species (*Acer pseudoplatanus* L., *Acer platanoides* L., *Sorbus aucuparia* L, and *Corylus avellana* L.).

The inventoried plots had an oval shape of variable area because they surrounded fenced areas in which advanced regeneration has been studied for a companion study (Ligot et al., 2013). Trees were measured if they were located at a distance of less than 20 m from the fence. Plot area ranged from 2070 m^2 to 10,540 m^2 with an average of 4340 m^2.

2.2. Model development and implementation

The forest radiative model named SamsaraLight was implemented in the forest simulation platform Capsis (Dufour-Kowalski et al., 2012). Courbaud et al. (2003) described a first version of this radiative model and validated it for an irregular Norway spruce stand (*Picea abies* (L.) Karst). Since 2003, the model has been improved and now enables users to model crowns with asymmetric ellipsoids (Appendix A).

We set SamsaraLight to sample 130 diffuse and 81 direct ray directions for each month of the growing period (from April to October). Ray directions are sampled at regular increasing zenithal angles with a starting value of 10° and an angle step of 15°. For every direction, parallel rays are cast at ground level in either cell centers or any other specified locations (virtual sensor). Samsaralight then identifies the interceptions of light rays by tree crowns and computes radiation attenuation using Beer's law (Eq. (1)).

SamsaraLight predicts transmitted light within a rectangular plot. Since our inventory plots were not rectangular, we developed an algorithm that added virtual trees in order to obtain a rectangular plot (Fig. 2). For each site, virtual trees were randomly drawn with replacement from the measured trees. Their location outside the inventoried area was then randomly generated. This process was repeated until the basal area of the rectangular plot equaled the basal area of the inventoried plot. The number of virtual trees created in each plot ranged between 0 and 68, and the area over which they were simulated represented on average 28% of the rectangular plot area.

2.3. Model parameterization

SamsaraLight required defining the dimensions and leaf area density of the modeled crowns. We adjusted allometric relationships using the nonlinear least squares method (R Core Team, 2013) in order to estimate missing crown radii for the six main groups of species: beech, oak, hornbeam and birches, other