Forest Ecology and Management 410 (2018) 84–94

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Management implications of varying gap detection height thresholds and other canopy dynamics processes in temperate deciduous forests

Jean-Francois Senécal[a,*], Frédérik Doyon[b], Christian Messier[b]

[a] Centre d'étude de la forêt, Département des sciences biologiques, Université du Québec à Montréal, Montréal, Québec H3C 3P8, Canada
[b] Institut des sciences de la forêt tempérée (ISFORT), département des sciences naturelles, Université du Québec en Outaouais, Ripon, Québec J0V 1V0, Canada

ARTICLE INFO

Keywords:
Canopy gaps
Gap dynamics
Multi-temporal LiDAR
Temperate forest
Partial cutting
Canopy height erosion
Canopy gap detection height threshold
Old-growth forest

ABSTRACT

Gap dynamics is the main process by which forest renewal happens in many forest biomes in the world. Under the classical gap dynamics model, only canopy gaps are considered as a dynamic zone. It is also assumed that gapless canopy height change is either uncommon or unimportant for forest dynamics, even though its frequency has never been quantified. In the temperate deciduous forest biome of Quebec, Canada, forest management uses selection cutting to emulate gap dynamics, but little is known about the differences in canopy dynamics between unmanaged and managed forests. Here, we investigated five canopy height change processes: three generating positive height change (canopy growth, gap closure and gap filling) and two generating negative height change (gap creation and canopy height erosion) using multi-temporal LiDAR data in unmanaged and managed (by partial cutting) forests at different periods during the last 24 years. Canopy height erosion, which is canopy height reduction without gap formation, was very common in all studied forests, whatever the gap detection height thresholds used. This canopy process was often more frequent than new canopy gaps and as important in terms of canopy volume reduction. Gap closure rates suggest that canopy gaps will remain more frequent in managed forests 30 years after cuts compared to unmanaged forests. Our results show that it will take at least 30 years after cuts for natural canopy dynamics to recover. We also show that measurements of canopy dynamics processes are sensitive to canopy gap detection height thresholds. This sensitivity is clearly limiting the reproducibility and the comparability of studies in gap ecology.

1. Introduction

In many forests around the world, canopy gaps are crucial to the renewal of forests as they provide environmental conditions that favour establishment and growth of many tree species (Canham, 1988; Kern et al., 2012) due to increased light and below-ground resources (Beckage and Clark, 2003; Caspersen and Saprunoff, 2005). Although canopy gaps have been studied for decades (Jones, 1945; Runkle, 2012; Watt, 1947), the concept has always been somewhat unclear since gaps do not exist exactly as physical objects; canopy gaps are abstract constructs that are used to study canopy structure or canopy structure change, and multiple attempts have been made to describe and define gaps.

The classical conceptual definition that has been most commonly used is probably Brokaw's «treefall gap» that describes a gap as the projection of a hole in the forest canopy extending through all levels to a height threshold of two meters above ground (Brokaw, 1982). Other definitions have been proposed over the years, such as the "expanded gap" (Runkle, 1982). In the majority of previous gap studies, the gap detection method and its threshold parameters were determined based on research objectives and expert knowledge of the forest dynamics of the study sites. However, the choice of specific height threshold parameters, like height of the vegetation in the canopy openings or minimum size of the opening, influences the results and limits repeatability of these studies (Barden, 1989; Brokaw, 1982; Lobo and Dalling, 2014). These subjective choices have limited the ability to compare results across studies, particularly those relating to upscaled landscape patterns or processes, like the gap turnover rate (Després et al., 2017). Even repeated analyses of gap dynamics such as those using multi-temporal LiDAR data are not immune to these subjective choices, although they ensure that canopy openings result from a decrease in canopy height.

Gap studies are based on a gap vs. non-gap dichotomy as part of the detection protocol, which reduces canopy structure complexity to two classes (Lieberman et al., 1989). However, as mentioned by Lieberman et al. (1989), "the forest canopy is not a swiss cheese". It has been pointed out that most methods/thresholds used may have led to the study of a limited set of forest canopy height reduction events

---

[*] Corresponding author.
E-mail addresses: senecal.jean-francois.3@courrier.uqam.ca (J.-F. Senécal), Frederik.Doyon@uqo.ca (F. Doyon), christian.messier@uqo.ca (C. Messier).

https://doi.org/10.1016/j.foreco.2017.12.029
Received 30 August 2017; Received in revised form 15 December 2017; Accepted 18 December 2017

(Nadkarni et al., 2008). It is, in fact, possible to observe tree death without gap creation (Brokaw, 1982; Connell et al., 1997; Young and Hubbell, 1991), and yet this pattern has not been carefully recognized and investigated as a canopy dynamics phenomenon. Most studies have focused on the role of gaps in forest dynamics where the forest is seen as a group of spatially localized stems under a canopy, instead of looking at it as a collection of leaves forming a 3D structure from above. To our knowledge, no study has quantified the occurrence of tree death without gap creation and its effect on canopy dynamics.

Understanding canopy dynamics and its associated effects on tree communities is particularly relevant with the increased use of the concept of emulating natural disturbance, even though it has been misused in some cases (Kuuluvainen, 2009; Landres et al., 1999; Seymour et al., 2002). Emulating natural disturbance has been the cornerstone of the ecosystem management paradigm (Gauthier, 2009). Many forest ecologists have recommended the use of partial cut silvicultural systems, like selection cutting or irregular shelterwood, for mimicking the gap disturbance regime (Majcen, 1994; Raymond et al., 2009; Seymour et al., 2002). However, it has been suggested that managing temperate deciduous forests with selection cutting might not be an adequate way to emulate the natural disturbance regime of this biome as the spatio-temporal patterns of trees and shrub structures in selection cut forests differ from those in unmanaged old-growth forests (Angers et al., 2005; Doyon et al., 2005), and because partial cuts often do not create the microsites necessary for seedling establishment (Bolton and D'Amato, 2011). The objective of this paper was to describe and compare the canopy processes of managed (by partial-cutting) and unmanaged forests using multi-temporal airborne LiDAR data. We hypothesized that canopy dynamics will be different between managed and unmanaged forests. We expected that the positive and negative growth processes would balance each other out in unmanaged forests while the growth processes would be positive for managed forests after partial cutting. We also expected less gap creation but greater gap closure in managed forests until a certain period after the cut when canopy processes start to become similar in both managed and unmanaged forests. Finally, we wanted to verify the sensitivity of observed patterns in canopy processes to the gap detection height threshold.

2. Study area and methods

2.1. Study area

The study area was located in the south of the province of Quebec, Canada. Nine sites subjected to selection cuts and one unmanaged site were located in the Papineau-Labelle wildlife reserve (45°59′N, 75°20′W). Two other unmanaged sites were located nearby in the ecological reserve of the Forêt-la-Blanche (45°44′N, 75°16′W). The partially cut stands had been subjected to selection cuts at different times over the last 25 years (1993, 1995, 1998, 2000, 2004 and 2008). One additional site was subjected to diameter limit cuts, a type of partial cut to cull the bigger trees, in 1985, followed by a selection cut in 2012. The history of human-caused disturbances for the other managed sites is unknown. However, it is likely that there was some form of high grading performed there in the past (Angers et al., 2005). The study area used in the analysis is comprised of 827 ha and 352 ha of partially cut and unmanaged stands, respectively (Table 1). Climatic conditions are very similar on all sites. The average annual temperature in the study area varies from 2.5 to 5 °C, with a growing season (daily average over 5.6 °C) of 180–190 days (Robitaille and Saucier, 1998). Mean annual precipitation ranges from 900 to 1000 mm with a third falling as snow. The dominant tree species in the area are sugar maple (*Acer saccharum* Marsh.) often in combination with American beech (*Fagus grandifolia* Ehrh.). Other notable tree species are basswood (*Tilia americana* L.), Eastern hemlock (*Tsuga canadensis* (L.) Carrière), red maple (*Acer rubrum* L.), white ash (*Fraxinus americana* L.), balsam fir (*Abies balsamea*), white elm (*Ulmus americana* L.) and yellow birch (*Betula alleghaniensis* Britt.). Also common in the understory are shrubs from species such as ironwood (*Ostrya virginiana* (Mill.) K. Koch), striped maple (*Acer pensylvanicum* L.) and saplings of the shade-tolerant tree species. Understory shrubs and saplings are characteristic of the structure of old-growth forests (Després et al., 2014). All study sites are mature uneven-aged forests. To the best of our knowledge, the unmanaged forests have not suffered noticeable stand-level catastrophic or anthropogenic disturbances in the last 200 years. However, the study area was affected by the North American ice storm of 1998, receiving between 40 and 100 mm of freezing rain, causing light to severe damage to forest stands in the study area (Chabot, 1998). Furthermore, beech bark disease (Houston, 1994) has been present in the study area for several years, causing mortality and defects on large beeches. These events might have led to a higher than normal level of advanced regeneration, although normality is highly subjective when speaking of mature or old-growth forests (Pesklevits et al., 2011).

2.2. LiDAR data processing

Two LiDAR datasets were used in this study. The first airborne discrete-return LiDAR dataset was acquired in September 2007 using an Optech ALTM 3100 instrument operating at an average altitude of 1300 m. Average point density was over two returns per m^2, maximum half-scan angle was 20°, scan rate was 41 Hz, and line spacing was 750 m (for a targeted 50% overlap between strips). The second airborne discrete-return LiDAR dataset was acquired in August 2013 with an Optech ALTM Gemini instrument operating at an average altitude of 650 m. Average point density was over four returns per m^2, maximum half-scan angle was 18°, scan rate was 55 Hz, and line spacing was 261 m (for a targeted 50% overlap between strips). Preprocessing of the LiDAR data was accomplished with the Terrascan software package (Terrasolid, Leppävaara, Finland). This process included data cleaning, bird hit removal, and classification of LiDAR points as ground surface hits using the morphological properties of the point cloud. The LiDAR data was supplied as 2×2 km square tiles.

The canopy height models were generated following the guidelines of Vepakomma et al. (2008). The multi-temporal LiDAR data was first co-registered to ensure that there were no significant systematic planimetric errors. As there was no systematic shift, a digital terrain model was created at a 50 cm resolution from the combination of points classified as ground returns in the two LiDAR datasets. The lowest value was assigned to the pixels in which ground points fell. Pixels with missing values were interpolated by inverse distance weighting using the combined ground points and a power of two for the weighted average. The digital surface models of 2007 and 2013, representing ground elevation above sea level, were produced using the same procedure, but with the highest height of LiDAR returns in each pixel instead of the lowest. The canopy height models (CHM) of 2007 and 2013, high-resolution raster representations of the height of vegetation above the ground, were then obtained by subtracting the digital terrain model from the corresponding digital surface models. A height change image was produced by subtracting the 2007 CHM from the 2013 CHM. Positive values were interpreted as canopy height growth and negative values as canopy height loss.

The study areas were delimited within the 2×2 km square tiles to obtain relatively homogeneous and comparable characteristics, such as species composition, site history, topography and a minimum continuous area of 42 ha. The bodies of water were removed. We classified the sites into three management categories: the unmanaged forest sites (UMF), the sites partially cut between 1993 and 2004 as the old selection cut sites (OSC), and the sites partially cut in 2008 and 2012 as the recent selection cut sites (RSC). We analyzed OSC separately from the RSC because cuts were performed in the latter sites between the 2007 and 2013 LiDAR data acquisitions. Thus, any height loss observed in the RSC is predominantly due to cuts, while those in the OSC are not.