Forest Ecology and Management 354 (2015) 272–280

Contents lists available at ScienceDirect

Forest Ecology and Management

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

Comparing patterns in forest stand structure following variable harvests using airborne laser scanning data

Wiebe Nijland [a], Nicholas C. Coops [a,*], S. Ellen Macdonald [b], Scott E. Nielsen [b], Christopher W. Bater [c], J. John Stadt [c]

[a] Department of Forest Resources Management, University of British Columbia, 2424 Main Mall, Vancouver, BC V6T 1Z4, Canada
[b] Department of Renewable Resources, University of Alberta, Edmonton, AB T6G 2H1, Canada
[c] Forest Management Branch, Forestry Division, Alberta Agriculture and Forestry, 9920-108 Street NW, Edmonton, AB T5K 2M4, Canada

ARTICLE INFO

Article history:
Received 10 April 2015
Received in revised form 2 June 2015
Accepted 5 June 2015
Available online 11 June 2015

Keywords:
LiDAR
Remote sensing
EMEND
Boreal mixedwoods
Silviculture
Retention harvesting

ABSTRACT

Understanding landscape patterns that result from natural disturbances in the mixedwood boreal forests of Canada is a critical precursor to advancing sustainable forestry practices and ecosystem-based land management initiatives. However, monitoring changes in boreal forest structure following disturbance is difficult due to restricted access and the spatial scale at which these disturbances occur. Airborne Laser Scanning (ALS) measures the three-dimensional distribution of vegetation across large areas with high sampling intensities, enabling the detection of small changes in vegetation structure in stands of otherwise similar composition and age. In this paper we compare the suitability of three suites of ALS metrics to discriminate changes in vegetation structure across a gradient of forest harvest retention levels (100% retention (uncut control), 75%, 50%, 20%, 10%, and 0% (clear cut)) for four boreal forest stand types: conifer, deciduous, mixed, and deciduous with conifer understorey. Specifically, we focus on three key types of ALS metric: plot-based point cloud metrics, canopy volumes, and curve-fitting approaches; and evaluate the sensitivity of these metrics to changes in forest stand architecture in response to the harvest treatments or lack thereof. From the three types of metrics, height based point cloud metrics show the most significant separation by treatments and stand-types, followed by canopy volume profiles. Airborne laser scanning has strong utility for distinguishing responses in silvicultural treatments and cover types, revealing characteristics not captured by traditional measurements like crown closure or basal area.

1. Introduction

Landscape-scale distribution of forest structure, composition and age is a reflection of the influence of climate, landform, disturbance history, and stand dynamics. Human-caused disturbances, such as those associated with forest harvesting, are increasingly dominating many landscapes resulting in the need for ecological sustainability. This need has led to the rapid evolution of silvicultural practices and the development of new approaches to forest ecosystem management (Franklin and Forman, 1987; Hunter, 1992; Franklin, 1993; Bergeron et al., 2002; Burton et al., 2006). The natural disturbance-based paradigm is one example of forest ecosystem management that posits that anthropogenic disturbances specifically timber harvesting which emulate natural ecosystem processes will maintain higher levels of biodiversity (e.g., Levin, 2000; Buddle et al., 2006), habitat connectivity (Saunders et al., 1991) and habitat heterogeneity (Turner, 1989) than those that do not. Understanding landscape patterns that result from these forest management decisions is important as it allows comparisons with natural disturbance regimes, and therefore can advance sustainable forestry practices and ecosystem-based land management initiatives (Hunter, 1993; Burton et al., 2006). Prominent among the new management approaches adopted under this natural disturbance paradigm is a variety of partial harvesting approaches such as variable retention (Franklin et al., 1997; Gustafsson et al., 2012; Fedrowitz et al., 2014). Fire events typically leave structural legacies of both live and dead wood, reducing the contrast between disturbed and undisturbed stands (Hansen et al., 1991) and therefore often act as a lens through which to understand natural disturbance patterns and processes.

Emulating disturbance in forest management should occur over a range of spatial scales (Hunter, 1993; Perera et al., 2004). While

* Corresponding author.
E-mail address: Nicholas.coops@ubc.ca (N.C. Coops).

http://dx.doi.org/10.1016/j.foreco.2015.06.005
0378-1127/

landscape scale approaches in western boreal systems have received significant attention (see Andison, 2012), the inability to measure stand structural attributes, such as height canopy complexity and cover, across landscapes has been a barrier to operationally emulating disturbance at smaller spatial scales. Changes in forest management practices can be difficult to assess due to the large areal extent of operations, difficulties with access, and the sheer costs of effectively monitoring changes in stands.

Airborne Laser Scanning (ALS), or light detection and ranging (lidar), directly measures the three-dimensional distribution of vegetation elements between the top of the canopy and the ground, and is therefore particularly well-suited for describing canopy architecture (Lefsky et al., 1999). Airborne laser scanning platforms typically acquire data at altitudes between 500 and 3000 m and are cost effective over large areas when compared to ground based inventory methods (Coops et al., 2007; Næsset, 1997; Wulder et al., 2008). Airborne laser scanning simultaneously measures the three-dimensional distribution of vegetation components and terrain morphology, providing accurate, high spatial resolution information on elevation, vegetation height, cover, and vertical complexity, and other aspects of canopy structure, including canopy dimension, leaf area index and leaf density. Studies have demonstrated that the ALS measurement error for individual tree height (of a given species) may be less than 1.0 m (Persson et al., 2002) and less than 0.5 m for plot based estimates of maximum and mean canopy height with full canopy closure (Næsset, 1997; Magnussen and Boudewyn, 1998; Magnussen et al., 1999; Næsset and Økland, 2002; Næsset, 2002). Airborne laser scanning estimates of height have been shown to be more consistent than manual, field-based measurements especially over large areas and considering a range of field instruments and operators capacity and experience, ALS offers more reliable estimations of the true height of the canopies. This accuracy however is also dependent on the terrain, the density of canopies and the mission parameters (Næsset and Økland, 2002; Wulder et al., 2008; Tompalski et al., 2014).

Over the past decade, ALS technologies have progressed to a level of operational robustness where they now provide reliable estimates of crucial forest characteristics. As a result, ALS has become a common tool used in forest inventories (Wulder et al., 2013). Most of the ALS-based methods that allow for the estimation of stand biomass, volume, or basal area are based on plot-level height metrics, including height percentiles, proportions, and descriptive statistics like maximum, mean, or standard deviation of point height values (Gobakken and Næsset, 2005; Hollaus et al., 2007). However, the sensitivity of ALS data to small-scale changes in forest structure, specifically incremental forest crown removal (variable retention forestry), is less well known.

While a myriad of forest structures can be produced through variable retention harvesting, the success of these approaches can be difficult to measure and monitor. Developing an approach to detect small changes in vegetation structure in stands of similar composition and age resulting from variations in forest management practices is important because it addresses two critical gaps in our current ability to understand and monitor the influence of said practices. First, the sensitivity of ALS data to small changes in variable harvest regimes would provide forest managers with a greater understanding of the capacity of the technology to monitor sustainable management practices. Second, ALS offers the only convincing remote sensing technology for the assessment of detailed changes in forest structure resulting from harvest retention practices.

The mixedwood region in Canada includes the southern portions of the boreal forest from Quebec to the Yukon Territory, comprising a large proportion of the country's total boreal forest. It is characterized by forest stands with varying dominance by broadleaf and conifer trees. In the western boreal region, which is typified by a relatively low annual precipitation, and clay soils overlying sedimentary bedrock, the dominant natural disturbance regime is relatively large and frequent stand-initiating wildfire (see Bergeron et al., 2014). The main tree species include white spruce (*Picea glauca Moench*), trembling aspen (*Populus tremuloides Michx.*), and balsam poplar (*Populus balsamifera L.*) each of which is adapted to this disturbance regime and plays a unique role in post-fire stand dynamics (Bergeron et al., 2014). Differences in fire size and frequency are therefore key drivers of the vegetation composition, structure, and dynamics (Kneeshaw and Gauthier, 2003). Inherent variation in forest composition and structure, and the existence of experimental partial harvesting makes the western boreal mixedwood region ideal for exploration of remote sensing approaches to quantify spatial variation in vertical and horizontal forest structure.

The objective of this paper is to evaluate the sensitivity of different suites of ALS metrics within a mixedwood boreal forest containing a range of tree species associations (deciduous-dominated, deciduous-dominated with coniferous understorey, mixed coniferous with deciduous and coniferous-dominated) across a range of harvest treatments (100% retention (uncut control), 75%, 50%, 20%, 10%, and 0% (clear cut)). We focus on three key suites of metrics: plot-based cloud metrics, canopy volumes, and curve-fitting approaches. Using untreated controls and a range of harvest treatments, we examine the sensitivity of ALS metrics to changes in forest stand architecture.

2. Methods

2.1. Study area

The Ecosystem Management Emulating Natural Disturbance (EMEND) experiment was established in 1998 in northwestern Alberta to assess a range of management practices to maintain ecosystem structure and function in western boreal mixedwood forests (Volney et al., 1999), (Fig. 1). The overall design and motivation of the study is well-described by others (Lindo and Visser, 2003; Work et al., 2004; Hannam et al., 2005, 2006; Jerabkova et al., 2006; Macdonald and Fenniak, 2007) and are only summarised briefly here. The experiment is located about 90 km northwest of Peace River, Alberta, Canada (56°46′13″N, 118°22′28″W) within the Boreal Plains Ecozone (Wiken, 1986), and is 1080 hectares in size. The EMEND experiment represents a gradient of four major forest cover types: deciduous-dominated (DD: 80–95% broadleaf trees, primarily trembling aspen); deciduous-dominated with coniferous understorey (DU: 80–95% broadleaf trees with a primarily white spruce sub-canopy at 60–80% of full stocking); mixed coniferous and deciduous (MX: 35–65% of each); and coniferous-dominated (CD: 80–95% white spruce) (Volney et al., 1999; Kishchuk et al., 2014). In the winter of 1998–99, six variable retention harvest treatments were applied to three stands of each forest cover type: 100% retention (uncut control), 75%, 50%, 20%, 10%, and 0% (clear cut) with each compositional and treatment combination replicated three times. The harvesting was dispersed green tree retention with two small aggregated retention patches within each stand; harvesting equipment was confined to five metre wide machine corridors which alternated with 15 m wide retention strips.

The most recent information regarding in situ conditions of the EMEND sites suggests an understorey vegetation response threshold between the 10% and 20% retention treatments (Craig and Macdonald, 2009), with a positive correlation between the extent of understorey vegetation cover (particularly with graminoids)