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Regional mapping of vegetation structure for biodiversity monitoring using airborne lidar data

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ABSTRACT

Vegetation structure is identified as an important biodiversity indicator providing the physical environment that generates, supports, and maintains forest biodiversity. Airborne lidar systems (light detection and ranging) have the capacity to accurately measure three-dimensional vegetation structure, and have been widely used in wildlife habitat mapping and species distribution modeling. Large–area structural inventories using lidar-derived variables that characterize generic habitat structure have rarely been done, yet would be helpful for guiding biodiversity monitoring and conservation assessments of species at regional levels. This study provides a novel approach for processing regional-scale lidar data into categorical classes representing natural groupings of habitat structure. We applied cluster analysis on six lidar-derived habitat-related variables to classify vegetation structure into eight classes for the forested areas of ten natural subregions in boreal and foothill forests in Alberta, Canada. Structure classes were compared across different natural subregions and under anthropogenic/non-anthropogenic disturbance regimes. We found that the Lower Foothills Natural Subregions had the most complex vegetation structure, and wildfire was the most prevalent disturbance agent for all classes except for the rarest class (i.e. stands with high standard deviations of height and low canopy cover) which was more heavily altered by timber harvesting. This data product provides continuous, regional mapping of vegetation structure directly measured from lidar, with a spatial resolution (30 m) relatively finer than what was provided by polygon-based forest inventories. This vegetation structure classification and its associated spatial distribution address the fundamental issue of habitat structure in biodiversity monitoring. It can serve as a base layer used together with species and land cover data for forest resources planning, species distribution and animal movement modeling, as well as prioritization of conservation efforts on critical habitat structures.

1. Introduction

Vegetation structure is considered an important component in wildlife and forest management (Noss, 1990; McCleary and Mowat, 2002; Lindenmayer et al., 2006). For example, forest canopies mediate microclimate, provide perching, nesting, foraging, and covering habitats for many animal species, and influence food quality, diversity and accessibility (Hamer and Herrero, 1987; Johnson et al., 2002). Forest structure is also inextricably affected by disturbance regimes, especially wildfire, harvesting, and road development, which may favour certain species while discouraging others (Tews et al., 2004; Devictor et al., 2008; Boutin et al., 2009; Desrochers et al., 2012). Forest horizontal and vertical structures have therefore been identified as essential biodiversity indicators across a broad range of forest ecosystems around the world (Ozanne et al., 2003; Chirici et al., 2011; Gao et al., 2014). In general, forest species diversity is positively associated with vegetation structural diversity because different vertical strata and structural heterogeneity of forest stand provide ecological niches for species of various habitat specializations (MacArthur, 1958; Hunter, 1999; Culbert et al., 2013). This linkage between forest biodiversity and forest structure is a central assumption in ecosystem-based management approaches to forestry, where forest managers attempt to maintain the diversity of forest structural attributes at both landscape and stand scales in order to maintain forest biodiversity (Hunter, 1993).

MacArthur (1972) identified productivity, climatic stability, and habitat structure as three primary drivers of biodiversity whose effects can be reflected in three aspects: composition, structure, and function (Franklin et al., 1981; Noss, 1990). Spectral information acquired from optical remote sensing data has been widely used to assess compositional and functional components of biodiversity over broad spatial scales (Cohen and Goward, 2004; Duro et al., 2007; Coops et al., 2008; Schuster et al., 2015). Habitat classifications based on land cover types (Wessels et al., 2000; Franklin et al., 2001; McDermid et al., 2009; Riggio et al., 2013), and habitat suitability indices derived from vegetation productivity and seasonality (Nilsen et al., 2005; Coops et al., 2008)

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have contributed significantly to species distribution models and animal movement studies. As opposed to correlations with spectral indices, the structural component of biodiversity has principally been assessed through forest resource inventories that require labor-intensive field surveys and/or aerial photo interpretation (Fensham et al., 2002; Hyde et al., 2006; Clawges et al., 2008; Nijland et al., 2015b). In addition, resource inventories submitted by multiple forest management stakeholders may lack consistency in interpretation standards, update schedule, and aerial coverage when collectively used for large-area habitat mapping (McDermid et al., 2009). Moreover, vegetation height estimates from photo interpretation are reported at the polygon level where the within-polygon variations in height and structure are not readily assessed (Culbert et al., 2013). More detailed, fine-scale mapping of vegetation structure is needed to allow a broader range of biodiversity values to be included in forest management planning.

Airborne lidar (light detection and ranging) is an active remote sensing technology that can accurately measure three-dimensional vegetation structure (Lim et al., 2003). Lidar-derived canopy height, canopy height variation, and canopy cover metrics have been used widely in forest ecological studies to determine or predict a number of important forest attributes, including: forest vertical layering and overall architecture (Maltamo et al., 2005); forest successional stages (Falkowski et al., 2009); vegetation strata and forest genera (Morsdorf et al., 2010; Kim et al., 2011); tree species abundance (Ewijk et al., 2014); forest volume, biomass and carbon storage (Zald et al., 2014); vegetation regeneration; and response after timber harvesting (Nijland et al., 2015b).

Although lidar technology cannot directly measure forest biodiversity, previous studies have examined the hypothesis that vegetation structure is an important indicator of species diversity as postulated by MacArthur and MacArthur (1961) and Erdelen (1984). Species

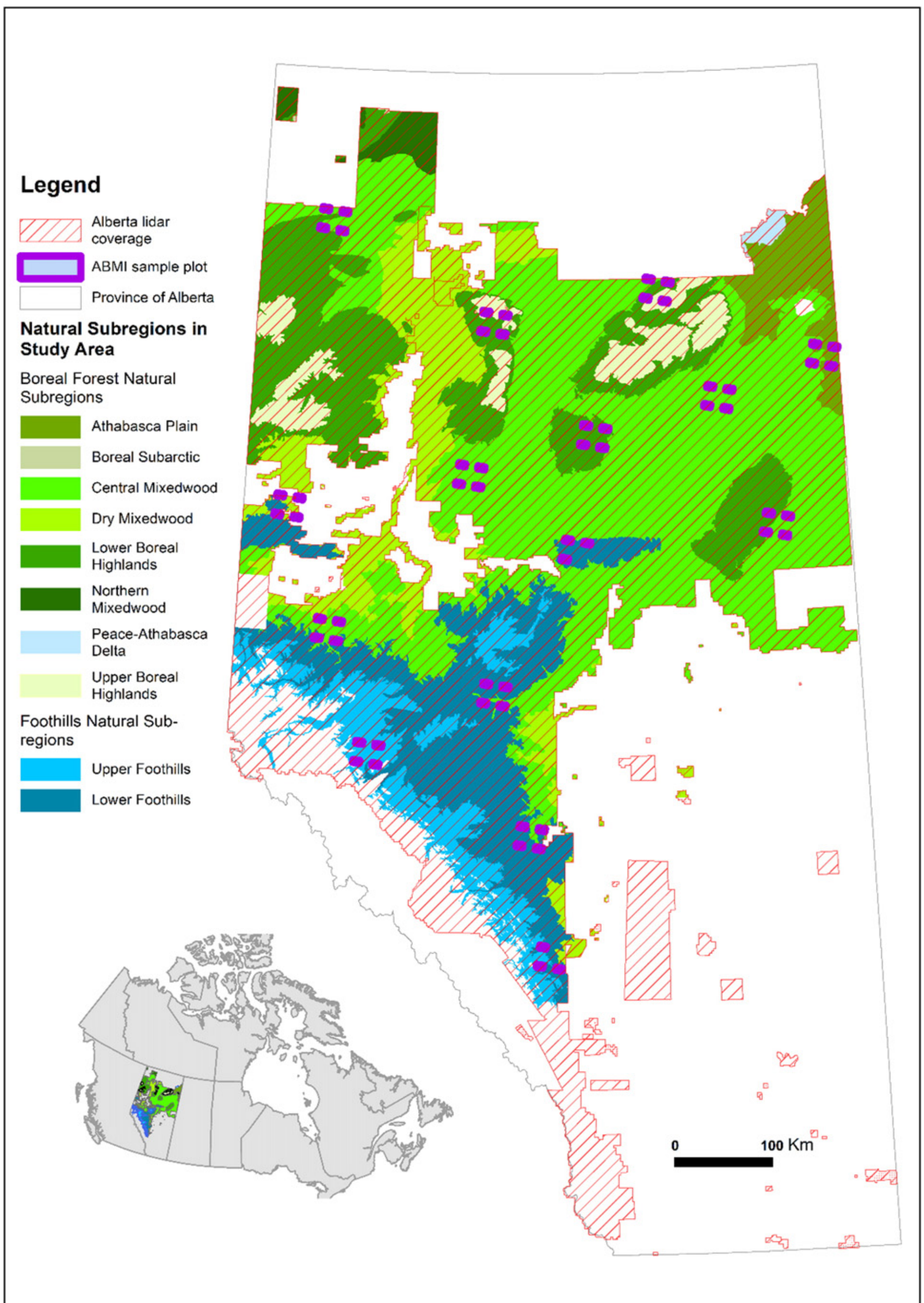

Fig. 1. Boreal and foothills forest and associated natural subregions within the Government of Alberta's lidar data coverage.