Forest Ecology and Management 377 (2016) 46–54

Contents lists available at ScienceDirect

Forest Ecology and Management

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

Airborne laser scanning for modelling understory shrub abundance and productivity

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ARTICLE INFO

Article history:
Received 10 March 2016
Received in revised form 20 June 2016
Accepted 21 June 2016
Available online 29 June 2016

Keywords:
Airborne laser scanning (ALS)
Light detection and ranging (LiDAR)
Species-habitat modelling
Grizzly bear (*Ursus arctos*)
Understory vegetation

ABSTRACT

Fiber production is no longer the sole objective of forest management, with increasing importance placed on other goods and services, such as maintaining habitat quality and stand successional development. Evaluating habitat quality and understory composition across complex landscapes remains a challenge for forest and wildlife managers, but is essential for ensuring the stability of vulnerable species. In this study we investigate whether forest stand structure, as measured by airborne laser scanning (ALS), can be used to predict the abundance and fruit production (fruit count) for Canada buffaloberry (*Shepherdia canadensis*), huckleberry (*Vaccinium membranaceum*), and saskatoon (*Amelanchier alnifolia*) shrubs in southwest Alberta, Canada. We combine ALS, climate, and terrain data to build random forest models of species abundance and fruit productivity, trained on data from 322 field plots. ALS data was processed into a suite of stand structure variables, under the hypothesis that models incorporating stand structure will be more powerful than models without for describing understory shrub abundance and reproduction (fruit productivity). ALS data improved model fit for saskatoon and huckleberry abundance models, with total explained variance (r^2) ranging from 37.6 to 59.4%. Inclusion of ALS data improved explained variance between 0% and 16%, suggesting that saskatoon and huckleberry in particular were associated with overstory vegetation structure. Despite the importance of ALS in further improving explanation of shrub abundance and fruit production, terrain factors were the dominant factor affecting regional and local variation in species abundance and fruit production.

1. Introduction

Airborne laser scanning (ALS) is an emerging tool being used by ecologists to remotely measure subtle differences in the three-dimensional physical features of vegetation. Spaceborne remote sensing instruments have been used extensively for tracking spatial and temporal changes in land cover and vegetation (Turner et al., 2003). However, two-dimensional (2D) satellite imagery is limited in resolution compared with light detection and ranging (LiDAR) (Lefsky et al., 2002 1999; Wulder et al., 2008) systems, which use return times of emitted light to produce estimates of distance. Technological systems developed over the last decade have made high-resolution 3D remote sensing of forest structural features possible and increasingly economical. These aircraft-mounted LiDAR systems are known as ALS, although LiDAR and ALS terms are often used interchangeably. ALS has become an effective operational technology that provides forest managers with information useful for forest inventory and monitoring (Nelson et al., 2006; Wulder et al., 2013). The majority of ALS-derived stand attributes, like volume, basal area, and biomass, are based on height percentiles and proportions, as well as other descriptive statistics like the mean or standard deviation of point height values. As laser pulses are able to pass through canopy openings, ALS is capable of characterizing vertical structure of the forest stands (Coops et al., 2007), a useful application for forest inventory and monitoring (Næsset et al., 2004; Nelson et al., 2006). Several novel ecological applications have included fine-scale assessments of natural forest regeneration (Falkowski et al., 2009), avian habitat quality assessment (Clawges et al., 2008), insect defoliation monitoring (Solberg et al., 2006) and improved distribution models of key grizzly bear (*Ursus arctos*) forage species (Nijland et al., 2014). A review of LiDAR applications in animal and habitat ecology is provided by Davies and Asner (2014).

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http://dx.doi.org/10.1016/j.foreco.2016.06.037

ALS offers the possibility of remotely detecting understory plant species on the basis of three-dimensional canopy structure. In an early study, Korpela (2008) predicted the distribution of understory lichens from using discrete-return ALS. Martinuzzi et al. (2009) used ALS to predict presence/absence of an understory shrub layer, with classification accuracies above 80%. These innovative studies led to more advanced characterization of understory vegetation using ALS, including: mapping percentage of understory vegetation cover in ponderosa pine (*Pinus ponderosa*) forests using ALS intensity measures (Wing et al., 2012); detection and mapping of Chinese privet (*Ligustrum sinense*), an invasive plant species, using a combination of ALS and multispectral satellite imagery (Singh et al., 2015); and fine-scale predictions of understory plant species distribution (Nijland et al., 2014) from a suite of ALS metrics. However, to our knowledge, no studies have attempted to model fine-scale understory species abundance or productivity using ALS data. High-resolution characterization of stand structure may be a keystone tool in facilitating the evolution of local-scale models of species abundance.

Understory shrub productivity is particularly important for grizzly bear populations, and years of low fruit abundance are associated with an increase in grizzly bear mortality through human-wildlife conflict (Mattson et al., 1992). This may be partially ameliorated through human intervention to increase understory resource availability (Braid and Nielsen, 2015), or through climate change, which is projected to result in expanded suitable shrub habitat for some species (Roberts et al., 2014). Huckleberry (*Vaccinium membranaceum*) and Canada buffaloberry (*Shepherdia canadensis*) both represent important grizzly bear food sources (Feldhamer et al., 2003; Munro et al., 2006), while saskatoon (*Amelanchier alnifolia*) represents an important recreational food source (Arnason et al., 1981), has cultural value for First Nations peoples (Arnason et al., 1981), and serves as a secondary grizzly bear food source (Hamer and Herrero, 1987). Fire suppression has hindered growth of many understory shrubs by limiting the availability of forest openings (Hamer and Herrero, 1987), and anthropogenic disturbances may provide an alternative to fire-regulated openings by opening the canopy. However, clearcuts alone do not guarantee fruiting shrub habitat (Nielsen et al., 2004). Further knowledge on the landscape distribution of key fruiting shrub habitat could inform wildlife habitat improvements through silviculture management, such as targeting clearcuts for shrub planting or enhancements (Braid and Nielsen, 2015) or thinning in order to maximize the productivity of anthropogenic openings by encouraging understory shrub growth.

The most common method for predicting food availability is to use species distribution modelling (SDMs) to empirically relate observed presence of specific species to climatic variables, terrain variables, and other environmental variables. While species distribution modelling using climate data has found success, the resultant occupancy models do not provide an effective proxy for grizzly bear habitat quality, since they do not account for quantity or quality of available resources (Nielsen et al., 2010). While predicting site productivity is understandably difficult, improved availability of high-resolution spatial information (i.e. climatic data, ALS data, etc.) and advancements in powerful model-building methodologies provide a framework to examine and describe habitat quality in terms of factors such as fruit production in shrubs at individual sites.

Huckleberry and buffaloberry distribution are associated with low to moderate canopy cover, specific local terrain conditions (Braid and Nielsen, 2015), and low to moderate stand structural complexity (McKenzie et al., 2011). However, defining optimal canopy conditions for maximum berry production is challenging, since the relationship between canopy structure and fruiting shrub abundance depends on local landscape conditions, including soil moisture, elevation, and aspect (Nielsen et al., 2004). Interestingly, Brown and Parker (1994) provide compelling evidence that vertical stand structure, and corresponding leaf area density, is a more realistic determinant of light transmittance than simple crown closure. It is apparent that detailed information on vertical stand structure is necessary for accurate predictions of understory shrub composition and abundance. ALS technologies excel at measuring this type of spatial variation, and their capabilities in remotely measuring vertical stand structure exceed that of satellite-derived vegetative indices (Nijland et al., 2015).

In this study we investigated the usefulness of ALS data for modelling abundance of three fruiting shrubs. To do so, we combined field plot observations of three fruiting shrub species with high-resolution climate, terrain, and a suite of ALS metrics describing three-dimensional stand structure. We built models of species abundance and fruit production for these fruiting shrubs in an area of key grizzly bear habitat in southwest Alberta, Canada. We tested the hypothesis that models built with the inclusion of stand structure data (as measured by ALS) will outperform models built on terrain and climate data alone at predicting understory shrub abundance and reproduction (fruit productivity). Knowledge of this relationship could be used to inform forest management practices that could enhance site conditions, leading to increases in shrub abundance and fruit productivity.

2. Methods

2.1. Ecological and climate data

Sampling of bear foods was conducted for thirteen fruiting species across a 5065 km^2 study area in southwestern Alberta (Braid and Nielsen, 2015, Fig. 1). The study area, located approximately 125 km north of Waterton Lakes Nation Park, features variable mountainous topography and plant communities. Three hundred and twenty-two field plots were sampled for grizzly bear foods in 2012 (early July to mid-August) and 2013 (late May to mid-August), with plot locations stratified by elevation and Alberta Vegetation Inventory classes (Government of Alberta, 2005). Understory shrubs known to form part of regional grizzly bear diets were sampled in 50 m by 2 m transect belts. We recorded percent cover and fruit counts (density) for each of the three focal shrub species. The study area is characterized by variable topography and a variety of plant communities, including open and closed stands of Engelmann spruce (*Picea engelmannii*), subalpine fir (*Avies lasiocarpa*), and lodgepole pine (*Pinus contorta*). Further information on the sampling methodology and study area is provided by Braid and Nielsen (2015).

Canada buffaloberry, mountain huckleberry, and saskatoon were selected for modelling here based on their importance for grizzly bear diets and their common occurrence in sample plots (n = 27–114). Coverage and fruit counts varied greatly between buffaloberry (maximum 20.4% cover and 4616 fruit/100 m^2), saskatoon (maximum 40.6% cover and 6300 fruit/100 m^2), and mountain huckleberry (maximum 51.4% cover and 7800 fruit/100 m^2). While saskatoon represents a less important component of the Alberta grizzly bear's diet (Hamer et al., 1991), it was included here based on amount of data available (common across plots), its value for other wildlife and humans, and the fact that it is the tallest of the three species of shrubs, providing a gradient in heights from which to assess the value of ALS in predicting shrub abundance and fruit production.

Climate surfaces were from Roberts et al. (2014), which provided data from the 1961–1990 baseline period at a resolution of 300 m. This dataset is based on historical climate records interpolated using PRISM down-sampling (Daly et al., 2008) via the