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A forest structure habitat index based on airborne laser scanning data

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ABSTRACT

Most efforts to link remote sensing to species distributions and movement have focused on indirect estimates of traits based on components of physiological and functional biodiversity. Such a view reflects one perspective on the general needs (habitat) of species. However, information on the vertical and horizontal structure of habitat may play a critical role in defining what a suitable habitat is. The development and application of highly accurate airborne laser scanning (ALS) systems, which are capable of describing the three-dimensional distribution of vegetation, have significant potential value in deriving quantitative relationships between species distributions and their habitat structure. In this paper we review the use of ALS for biodiversity studies, and propose a three-dimensional index which captures the three main components of vertical and horizontal vegetation structure: height, cover, and complexity. Once developed, we apply the index across the forested area of the Canadian province of Alberta, and compare and contrast the differences across natural subregions and land cover types. We also demonstrate how the index can be used with biodiversity data, in this case examining patterns in avian species richness. We conclude with a discussion on the potential use of the habitat structure index with other biodiversity-related research.

1. Introduction

Developing an improved understanding of species distributions and movement remains a key challenge for the conservation of biodiversity. Most frequently, biodiversity is measured by assessing assemblages of species. Home range size and shape, timing of migrations, and movement trajectories of individuals are among the most important species-specific measures, receiving constant attention in research and management over the past quarter century (Herfindal et al., 2005). Recently, the use of remote sensing imagery to track resource availability through space and time has grown in application as it offers an ideal technology to monitor and assess habitat at a variety of spatial and temporal scales (e.g., Kerr and Ostrovsky, 2003; Running et al., 2004; Potter et al., 2003; Fraser and Latifovic, 2005; Coops et al., 2008; Leyequien et al., 2007). To date, the majority of remote sensing applications to species distribution and biodiversity have been through the use of time series measures that facilitate spatial-temporal analysis of vegetation production and change (Turner et al., 2003; Myneni et al., 1998). This is most commonly based on spectral indices such as the normalized difference vegetation index (NDVI), or the fraction of photosynthetically active radiation (fPAR) intercepted by vegetation, both of which are analogous to greenness or cover (Knyazikhin et al., 1998). Potter et al. (2003) demonstrated that daily fPAR can successfully be used to monitor large-area ecosystem behavior. Nilsen et al. (2005) linked satellite measured greenness with measures of faunal diversity. Results demonstrated that the predictive accuracy of home range size was improved for 8 of 12 species using vegetation greenness. Greenness data derived from passive optical sensors such as the Moderate Resolution Imaging Spectroradiometer (MODIS), Advanced Very High Resolution Radiometer (AVHRR), Satellite Pour l'Observation de la Terre (SPOT), and Landsat series provides substantial insight into the spatial and temporal patterns in vegetation productivity. However, these two dimensional data ultimately provides only one perspective of the habitat needs and requirements of species. The physiognomy or structure of vegetation is largely ignored (Bergen et al., 2009).

Habitat structure can be defined as having both horizontal and vertical components (Bergen et al., 2009). Horizontally, changes in forest type, land cover or habitat result in patterns, which can be characterized using patch and other landscape metrics (Turner et al., 2001). Vertically, structure includes changes in vegetation

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height and biomass (Bergen et al., 2009). For a comprehensive view of habitat, species ranges and richness, and by inference biodiversity, both productivity and habitat structure must be considered in management and conservation strategies. The vertical and horizontal structure of vegetation plays a critical role in defining suitable wildlife habitat and can do so in a variety of ways. For certain species, vegetation structure relates to food quality, diversity, and availability (Hamer and Herrero, 1987; Johnson et al., 2001; Mansson et al., 2007). For example, access to high quality forage for ungulates in early successional stage forest stands, deciduous overstorey stands, or open areas with grass, forb, herb and berry species (Allen et al., 1987; Dussault et al., 2005; Munro et al., 2006) decreases the energy required for foraging and digestion, and thus maximizes energy intake. Vegetation structure also affords protection through cover which provides security against predation, protects individuals from heat stress when ambient temperatures exceed optimal levels (Schwab and Pitt, 1991), and provides refuge from deep snow during winter. Snow accumulation often adversely affects species mobility and food intake, and thus survival and reproductive rates (Cederlund et al., 1991; Mech et al., 1987; Post, 1998).

A key impediment to the inclusion of structural information into species assessments has been the lack of remote sensing data to measure local habitat structure. The development and application of Airborne Laser Scanning (ALS) systems, which measure the three-dimensional distribution of vegetation within forest canopies, has resulted in a revolution in describing, mapping, and monitoring structural aspects of vegetation (Lefsky et al., 1999). ALS utilizes Light Detection and Ranging (LIDAR) technology. LIDAR is an example of an active remote sensing tool which utilizes a near-infrared laser and detector to measure the three dimensional location of targets with decimetre accuracy. For example, in a forested environment where sunlight filters through the canopy down to the ground, LIDAR will capture the distribution of echoes reflected from stems, branches, and foliage from top of canopy to the forest floor (van Leeuwen et al., 2008; Aschoff and Spiecker, 2004; Baltsavias, 1999). Location information is provided using a Global Navigation Satellite Systems (GNSS), while platform orientation (pitch, roll, and yaw) is determined using an inertial navigation system. Together the systems allow for the precise determination of the location of reflected laser pulses. ALS relies on airborne platforms for data acquisition, with measurements typically acquired at altitudes above ground of between 500 and 3000 m (Hilker et al., 2010). ALS has been widely used for development of bare-earth digital elevation models (DEM) (Bater et al., 2009) and the estimation of forest inventory attributes (Wulder et al., 2008a,b, Reutebuch et al., 2005). Typically, these airborne systems have footprints ranging from 0.1 to 2 m (Lim et al., 2003; Wulder et al., 2008a,b), and can achieve terrain surface heights with sub-metre accuracys (Blair et al., 1994; Lefsky et al., 2002). In many jurisdictions, ALS-based estimation of tree height and canopy cover is becoming the standard by which to assess these attributes, and in most cases, are more accurate and less biased than field-based measurements (Næsset and Økland, 2002; Coops et al., 2007). In addition, by examining the number and height of the return pulses within a given area, information on the vertical profile of light penetrating the plant canopy can be derived, providing additional information on structure, such as crown shape and density. Beyond height, when compared against optical or radar data, ALS measurements have shown an excellent capacity to produce non-asymptotic biomass estimates and there have been extensive studies highlighting the accuracy of ALS to predict forest structural properties at stand and individual tree levels, including stem volume, basal-area, and height (Lefsky et al., 2002; Lim and Treitz, 2004; Nelson et al., 2004; Næsset and Gobakken, 2008; Tompalski et al., 2015). ALS data can provide specific information on forest structure, such as mid and understory cover assessment, and topographic morphological variables, such as slope, aspect, and terrain wetness (White et al., 2012; Nijland et al., 2015a,b,c), as well as predict the presence of veteran trees or snags (Bater et al., 2009). As a result, the use of ALS technology has increased for assessments of wildlife habitat. Vierling et al. (2008) provide a review of the current status of LIDAR remote sensing for wildlife habitat characterization and conclude that, although a growing number of studies highlight ALS advances, few studies have actually used the data to quantitatively address these relationships.

In this paper we further develop the concept of ALS as a tool for biodiversity assessments by proposing a broad-scale integrative index of habitat suitability derived from key components of ALS returns across the forested areas of Alberta, Canada. First, we briefly review the range of structural measurements of vegetation, with the aim of reducing the suite of possible measures to a small number of complementary vegetation metrics that capture variation in habitat structure. Secondly, we review the use of ALS data for biodiversity studies and discuss the key components of the index. Once developed, we apply the index over the forested area of Alberta. Using information on the terrestrial land cover and natural subregions of the province, we then compare and contrast the index of habitat structure across vegetation types. We also demonstrate how the index varies when compared to avian species richness and conclude with a discussion on the potential future development of the index within the context of other biodiversity-related research within Canada and elsewhere.

2. Data

2.1. Airborne laser scanning

The provincial government of Alberta, Canada, has acquired a near wall-to-wall coverage of ALS data over provincially managed forested lands. In total the coverage is in excess of 33 million ha, one of the largest ALS data compilations available globally. With these data it is possible to integrate ALS information into a structural habitat index for the region. ALS data was acquired between 2003 and 2014, with over 70% acquired from 2006 to 2008. Point densities range between 1 and 4 returns per m^2 with first return density very consistent ranging between 0.5 and 0.7 returns per m^2 The "ground" class was derived with standard processing routines (Axelsson, 2000) and used to normalize the point elevations to height above ground level. A suite of forest canopy metrics were then developed at 30 m spatial resolution using FUSION (McGaughey, 2014) software packages.

2.2. Land cover, ecological and climatic stratification

We utilized a 2010 land cover map for Alberta developed by the Alberta Biodiversity Monitoring Institute (ABMI), which is a polygon-based representation of Alberta's land cover based on a digital classification of 30 m spatial-resolution Landsat satellite imagery (Fig. 1). The land cover map consists of approximately 1 million non-overlapping polygons with a minimum size of 0.5 ha for aquatic features and 2 ha for upland features. The overall thematic accuracy of the map, as estimated by an extensive validation dataset, is 75% with the maximum of 11 classes and 88% if these classes are grouped into 5 general classes (Castilla et al., 2014).

In addition to land cover, we also utilized natural subregion stratification (Fig. 1), which separates geographically the province into six relatively homogeneous areas based on landscape patterns, notably vegetation, soils and physiographic features (Natural Regions Committee 2006). These subregions represent areas of similar climate, topography and geology. ALS data covered 3 of the