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Discrete return lidar-based prediction of leaf area index in two conifer forests

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ABSTRACT

Leaf area index (LAI) is a key forest structural characteristic that serves as a primary control for exchanges of mass and energy within a vegetated ecosystem. Most previous attempts to estimate LAI from remotely sensed data have relied on empirical relationships between field-measured observations and various spectral vegetation indices (SVIs) derived from optical imagery or the inversion of canopy radiative transfer models. However, as biomass within an ecosystem increases, accurate LAI estimates are difficult to quantify. Here we use lidar data in conjunction with SPOT5-derived spectral vegetation indices (SVIs) to examine the extent to which integration of both lidar and spectral datasets can estimate specific LAI quantities over a broad range of conifer forest stands in the northern Rocky Mountains. Our results show that SPOT5-derived SVIs performed poorly across our study areas, explaining less than 50% of variation in observed LAI, while lidar-only models account for a significant amount of variation across the two study areas located in northern Idaho; the St. Joe Woodlands (R^2=0.86; RMSE=0.76) and the Nez Perce Reservation (R^2=0.69; RMSE=0.61). Further, we found that LAI models derived from lidar metrics were only incrementally improved with the inclusion of SPOT 5-derived SVIs; increases in R^2 ranged from 0.02–0.04, though model RMSE values decreased for most models (0–11.76% decrease). Significant lidar-only models tended to utilize a common set of predictor variables such as canopy percentile heights and percentile height differences, percent canopy cover metrics, and covariates that described lidar height distributional parameters. All integrated lidar-SPOT 5 models included textural measures of the visible wavelengths (e.g. green and red reflectance). Due to the limited amount of LAI model improvement when adding SPOT 5 metrics to lidar data, we conclude that lidar data alone can provide superior estimates of LAI for our study areas.

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1. Introduction

The foliage component of a forest canopy is the primary surface that controls mass, energy, and gas exchange between photosynthetically active vegetation and the atmosphere (Fournier et al., 2003). A thorough characterization of leaf area index (LAI; the ratio of half of the total needle surface area per unit ground area) can therefore provide valuable information about nutrient cycling, hydrologic forecasting, and biogeochemical processes in a forested ecosystem. As a key vegetation structural characteristic that drives many vegetation functions, LAI is a primary parameter used in ecophysiological and biogeochemical models to describe plant canopies (Chen et al., 1997). For example, process-based models such as BIOMASS (McMurtrie & Landsberg, 1992), FOREST-BGC (Running & Coughlan, 1988) and RHESSys (Band et al., 1991) use LAI as a primary or intermediate variable for forest growth and productivity. Additionally, LAI is often employed as a critical calibration variable for remote sensing datasets to differentiate vegetation characteristics over a wide range of biomes (Coops et al., 2004). LAI has also been used to characterize forest radiation regimes and the amount of light available to the understory in tropical (e.g. Rich et al., 1993; Vierling & Wessman, 2000) and temperate conifer (e.g. Law et al., 2001a) and deciduous forests (e.g. Ellsworth & Reich, 1993). Given the role of LAI in determining many forest ecosystem processes, several techniques have been developed for rapid LAI estimation.

The most commonly employed methods for estimating LAI across landscapes rely on the relationships between LAI and various manipulations of spectral information from aircraft or satellite-based imagery. A significant amount of research has been dedicated to quantifying the connections between spectral vegetation indices (SVIs) that associate foliar composition in the visible red waveband, which is absorbed by *chlorophyll a* and *b*, and the near-infrared waveband, which is scattered by plant cellular structures. The normalized difference vegetation index (NDVI) (Rouse et al., 1974) and the simple ratio (SR) (Birth & McVey, 1968) are the most frequently used SVIs to estimate LAI for a variety of ecosystem types including coniferous forests (Chen et al., 1997; Curran et al., 1992), grasslands (Friedl et al., 1994) and deciduous forests (Coops et al.,

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