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Remotely sensed measurements of forest structure and fuel loads in the Pinelands of New Jersey

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Abstract

We used a single-beam, first return profiling LIDAR (Light Detection and Ranging) measurements of canopy height, intensive biometric measurements in plots, and Forest Inventory and Analysis (FIA) data to quantify forest structure and ladder fuels (defined as vertical fuel continuity between the understory and canopy) in the New Jersey Pinelands. The LIDAR data were recorded at 400 Hz over three intensive areas of 1 km^2 where transects were spaced at 200 m, and along 64 transects spaced 1 km apart (total of ca. 2500 km^2). LIDAR and field measurements of canopy height were similar in the three intensive study areas, with the 80th percentile of LIDAR returns explaining the greatest amount of variability (79%). Correlations between LIDAR data and aboveground tree biomass measured in the field were highly significant when all three 1 km^2 areas were analyzed collectively, with the 80th percentile again explaining the greatest amount of variability (74%). However, when intensive areas were analyzed separately, correlations were poor for Oak/Pine and Pine/Scrub Oak stands. Similar results were obtained using FIA data; at the landscape scale, mean canopy height was positively correlated with aboveground tree biomass, but when forest types were analyzed separately, correlations were significant only for some wetland forests (Pitch Pine lowlands and mixed hardwoods; $r^2=0.74$ and 0.59, respectively), and correlations were poor for upland forests (Oak/Pine, Pine/Oak and Pine/Scrub Oak, $r^2=0.33$, 0.11 and 0.21, respectively). When LIDAR data were binned into 1-m height classes, more LIDAR pulses were recorded from the lowest height classes in stands with greater shrub biomass, and significant differences were detected between stands where recent prescribed fire treatments had been conducted and unburned areas. Our research indicates that single-beam LIDAR can be used for regional-scale (forest biomass) estimates, but that relationships between height and biomass can be poorer at finer scales within individual forest types. Binned data are useful for estimating the presence of ladder fuels (vertical continuity of leaves and branches) and horizontal fuel continuity below the canopy.

Keywords: Single-beam LIDAR; Forest biomass; Ladder fuels; Fuel loads

1. Introduction

LIDAR (Light Detection and Ranging) systems utilize lasers and detectors in various configurations to make accurate measurements of platform to surface distances. LIDAR techniques have been used on a variety of platforms to estimate forest height and canopy structure (e.g., Harding et al., 2001; Lefsky et al., 2002a; Nelson et al., 2003a). Specific applications have been to produce forest carbon inventories (Lefsky et al., 2002b; Nelson et al., 2003b; Patenaude et al., 2004), quantify leaf area and its distribution through the canopy (Parker et al., 2001; Riaño et al., 2004), and estimate structural changes during forest succession (Parker & Russ, 2004). Recently, LIDAR techniques have been used to estimate fuel load parameters for forests (Andersen et al., 2005; Riaño et al., 2003), including understory height, crown bulk density, and crown fuel mass, key parameters used in fire behavior models such as FARSITE and BEHAVEPlus (Andrews et al., 2003; Finney, 2004).

LIDAR represents an important tool for wildfire managers in forested regions. However, one of the problems in using more complex LIDAR products (i.e., scanning LIDAR) and their platforms is that they are expensive and beyond the scope of most wildfire management agencies. Our objective was to use a relatively simple LIDAR system constructed from “off the

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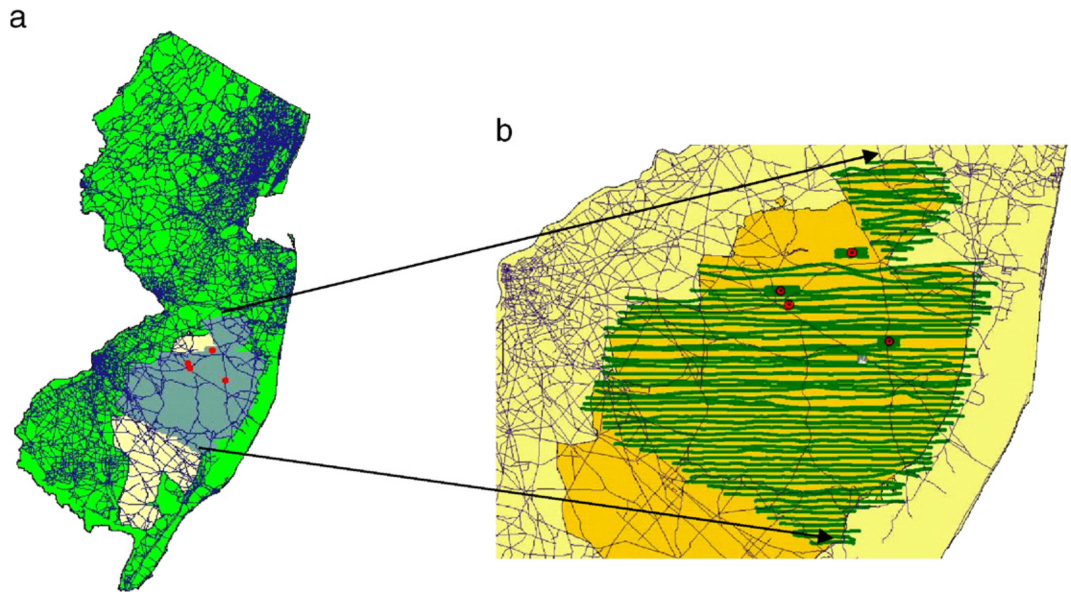

Fig. 1. The Pinelands of New Jersey (blue) and intensive study areas (red dots). LIDAR flight lines were spaced at 1 km over the Pinelands and at 200 m over the intensive study areas. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

shelf" components which can be flown on a platform that would be available to many fire managers to estimate two key fuel loading parameters, total tree biomass and the presence of ladder fuels. We define "ladder fuels" as fuel consisting of foliage and branches that produce vertical continuity between the understory and the canopy. Ladder fuels are important for fire behavior because they facilitate the transition of surface fires to the canopy, where they are much more difficult and expensive to suppress. We used forest census data that is available locally and on the internet (Forest Inventory and Analysis data; http://fia.fs.fed.us). Specifically, we used single-beam, first return profiling LIDAR measurements made by a helicopter owned by the New Jersey Forest Fire Service (NJFFS), intensive biometric measurements made on 1 km^2 grids, and Forest Inventory and Analysis (FIA) data to characterize forest structure and ladder fuels in the New Jersey Pinelands.

2. Study area

Study sites are located in Burlington and Ocean Counties in southern New Jersey. The Pinelands encompass 1.1 million acres of pine, oak and wetland forests, covering 23% of New Jersey (Fig. 1). The climate is cool temperate, with mean monthly temperatures of 0.3 and 23.8 °C in January and June, respectively (1930–2004; NJ State Climatologist). Mean annual precipitation is 1123±182 mm. The terrain consists of plains, low-angle slopes and wetlands, with a maximum elevation of 62.5 m. Soils are derived from the Cohansey and Kirkwood Formations (Lakewood and Sassafras soils), and are coarse-textured, sandy, acidic, and have extremely low cation exchange capacity and nutrient status (Tedrow, 1986). Despite the widespread occurrence of sandy, well-drained, nutrient-poor soils, upland forests are moderately productive and fuels accumulate rapidly (Pan et al., 2006).

Upland forests comprise 62% of forested lands in the Pinelands, and are dominated by three major communities; oak dominated forests with scattered pines (Oak/Pine), pine dominated forests with oaks in the overstory (Pine/Oak), and Pitch Pine dominated forests with Scrub Oaks and shrubs in the understory (Pine/Scrub Oak) (Lathrop & Kaplan, 2004; McCormick & Jones, 1973; Table 1). All upland forests have moderate to dense shrub cover in the understory, primarily *Vaccinium* spp., *Galussacia* spp., *Kalmia* spp. and *Quercus* spp., and sedges, mosses and lichens are also present. Upland forests are of major concern to fire managers, because dense residential developments and key transportation corridors occur adjacent to these flammable forests.

3. LIDAR measurements

LIDAR data were collected in mid-April, 2004 during leaf-off conditions for deciduous species. Sixty-four east/west flight lines spaced 1 km apart (total of ca. 2500 km^2) were generated using a GIS database, and then flight line coordinates were downloaded to the onboard GPS system on a Bell Jet Ranger

Table 1
Major forest types in the Pinelands of New Jersey and their extent (adapted from Lathrop & Kaplan, 2004)

Forest type	% of landscape	Area (km^2)
Upland forests		
Oak/Pine	19.1	725.5
Pine/Oak	13.1	497.0
Pitch Pine/Scrub Oak	9.6	365.3
Wetland forests		
Pitch Pine lowland	12.3	468.1
Mixed hardwood/conifer	8.6	326.0
Hardwood swamp	6.0	228.1
Atlantic White Cedar swamp	1.4	53.0