ASSESSING POST-FIRE TREE MORTALITY AND BIOMASS CHANGE BY INTEGRATING LIDAR AND HYPERSPECTRAL DATA

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ABSTRACT

Accurate characterization of post-fire changes in tree mortality and carbon storage is critical in understanding and simulating future forest responses to wildfires in response to climate change. LiDAR remote sensing has been successfully used to estimate aboveground biomass (AGB) in undisturbed forests, but few studies focused on effects of burn severity on post-fire tree mortality and AGB. Specifically, it is not clear how burn severity would affect forest mortality and post-fire AGB patterns in mixed forests in Eastern U.S. In this study, we examined short-term changes in tree mortality and AGB across a burn gradient in a Pine Barrens ecosystem in the Eastern United States, using field observations, LiDAR and hyperspectral data. Results show that fusion of LiDAR and hyperspectral images can characterize key forest ecosystem attributes at fine spatial and spectral resolutions, and provide consistent and accurate estimation of post-fire forest conditions at landscape scales. Both post-fire mortality and AGB are highly correlated with burn severity, and we found a linear relationship between burn severity and post-fire AGB. Our results can be used to predict post-fire mortality and AGB changes and provide quantitative evidence for informed forest fire management in similar ecosystems in the U.S.

Index Terms— Lidar, biomass, hyperspectral, Pine Barrens, wildfire, burn severity

1. INTRODUCTION

Wildfires significantly affect forest ecosystems in terms of tree mortality, species composition, biomass dynamics, ecosystem function and services across the globe [1, 2]. Accurate characterization of burned effects on ecosystem carbon dynamics is key for improved simulation and prediction of future forest responses to wildfire, in the face of potential climate changes [3-6]. However, acquiring plot data to assess fire effects is time-consuming, expensive and can only be collected in limited locations. Using remote sensing datasets that are then related to field-measured variables is a more cost-effective method for extrapolating field measurements over broad temporal and spatial scales. Advances in remote sensing techniques such as Light Detection and Ranging (LiDAR) and hyperspectral instruments provide high spatial and spectral resolution measurements of forest over large areas. Increasingly, LiDAR has been used to quantify and study canopy gaps, patch dynamics and carbon storage within forests; while hyperspectral images can provide information related to forest species and health. The combination of LiDAR and hyperspectral data has great potential to solve complex issues related to ecosystem change [5, 7].

In this study, we sought to integrate LiDAR and hyperspectral data to assess the burn effects on forest mortality and AGB in a mixed-forest in the Eastern U.S. We characterized forest AGB by linking field measurements with LiDAR derived metrics, and use machine learning algorithms to predict landscape level AGB. We mapped forest mortality with hyperspectral data and then further analyze the relationship between burn severity and tree mortality and AGB, as shown below.

2. DATA AND METHODS

Various remote sensing data were used in this study to examine the effects of burn severity on tree mortality and carbon storage in the study region. 1-meter resolution burn severity map for the study area was produced by Meng et al. (2017) using WorldView-2 imagery, pre- and post-fire acquired on July 17, 2011 and September 13, 2012, respectively. For more details see Meng et al. (2017). Post-fire LiDAR and hyperspectral data were acquired from NASA Goddard's LiDAR, Hyperspectral and Thermal (G-LiHT) Airborne Imager during June 8-15, 2015. The G-LiHT platform integrates LiDAR hyperspectral and thermal instruments in one system to measure vegetation structure, foliar spectra and surface temperature at very high spatial resolution (~1m) [8]. Common lidar metrics such as height, density, fractional cover and return statistics were calculated to examine post-fire forest structural change. Detailed lists of height metrics include: height bincentiles of 10, 20, 30, 40, 50, 60, 70, 80, 90; relative height density for heights fall into the intervals (unit is meter): [0, 0.5), [0.5, 1), [1, 1.5), [1.5, 3), [3, 6), [6, 9), [9, 12), [12, 15), [15, 20), [20, 30), [30, 40), which count points which fall into height intervals divided by the total number of points and scaled to a percentage; intensities related variables such as maximum, average and minimum intensities. The canopy cover was calculated as the number of first returns above 1.37-meter (breast-height) divided by the number of all first returns and output as a percentage.

In the spring of 2016, forest inventory data were collected within and around the burned areas of the Crescent Bow fire (Figure 1). A stratified random sampling approach was adopted to collect forest inventory information from 15-meter by 15-meter fixed area field plots, capturing burned effects across the study area. The main stratifications in this sampling approach was based on the moderate resolution MTBS burn severity map [9] and five plots were established and measured within each strata of the burn severity map (unburned, low, moderate, and high). For each plot, we measured diameter at breast height (DBH) for all trees with diameter >2.5cm, and also recorded species, crown conditions, crown position, canopy height, and crown base height.

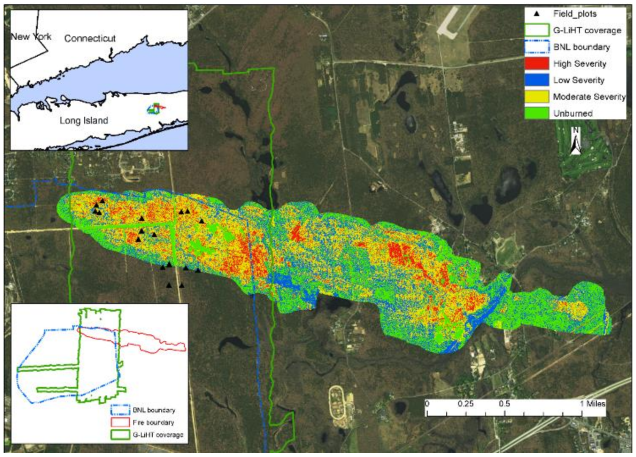

Figure 1. Map of study area showing burned area location in the Pine Barren Ecosystem in Long Island, New York. Our study area consists of locations within the Lidar acquisition boundary that were burned in the Crescent Bow fire on April 9, 2012. 1-meter spatial resolution burn severity map for the Crescent Bow fire was produced by Meng et al. (2017).

We used allometric equations developed for oak and pine species in the study area [10] to calculate the AGB of each tree. We applied allometric equations for each tree onsite and aggregated plot level AGB by summing up each tree's AGB within the plot boundary. Only trees with DBH larger than 10cm were included in the calculations.

For landscape level AGB modeling, we used plot-level AGB at five modeling radii (7.5m, 10.0m, 12.5m, 15.0m and 17.5m) and LiDAR metrics as the response and predictor variables, respectively. We then trained a Random Forest algorithm to predict wall-to-wall AGB values for the full LiDAR coverage area. Then we overlaid the high spatial resolution burn severity data, hyperspectral based mortality map with the AGB map, and analyzed the relationship between burn severity and tree mortality and AGB.

3. RESULTS

3.1. LiDAR-derived AGB (aboveground biomass)

Using the Random Forest algorithm, we modeled the landscape-level AGB by linking measured plot-level AGB with LiDAR metrics and apply this relationship to areas with LiDAR coverage. Across the five modeling footprint radii, AGB was predicted best by using the canopy density LiDAR metric. We found a decreasing R^2 from 0.77 to 0.67 in predicting AGB from a radius of 7.5m to 17.5m. Based on this result, the regression model for 7.5m radius was employed to map AGB in our study area (Figure 2).

Figure 2. Lidar derived aboveground C density map for the study area.

3.2. Effects of burn severity on tree mortality

We analyzed the effects of burn severity (unburned, low, moderate and high severities) on tree mortality using tree live or dead information derived from the hyperspectral data. Results show that percentages of dead trees increase as burn severity increased (Figure 3), with less than 3% survival in the high severity burns, followed by less than 30% and 60% of live trees after low and moderate burn severities, respectively.

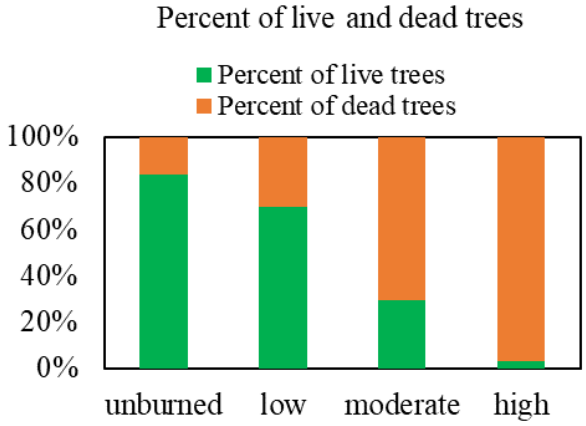

Figure 3. Percentages of live and dead trees for unburned, low severity, moderate severity and high severity burns.

3.3. Relationship between burn severity and post-fire aboveground biomass

Integrating results from high spatial resolution burn severity mapping, LiDAR-derived biomass and tree mortality from hyperspectral data, we modeled the relationship between AGB, burn severity and dead tree fractions, which shown in Figure 4. AGB changes were highly correlated with burn severity and the relationship can be expressed in a linear model with an R^2 of 0.73.

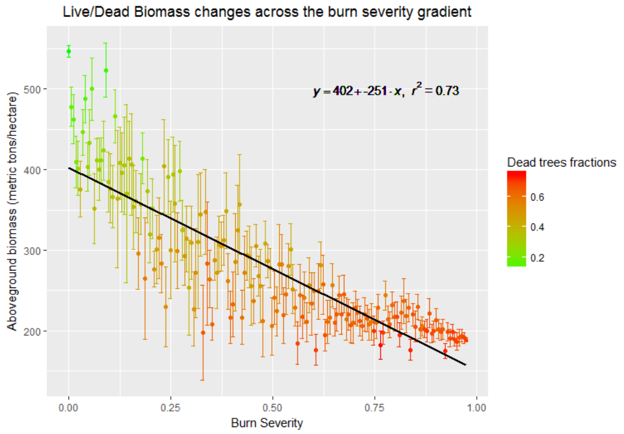

Figure 4. Changes of aboveground biomass following burn severity and tree mortality fractions in the study region.

4. CONCLUSIONS AND DISCUSSIONS

Integration of LiDAR and hyperspectral data was effective in characterizing tree mortality and AGB at fine spatial resolution, with reasonably good accuracy. Tree mortality rates increased as burn severity intensified. Post-fire forest AGB was negatively related to burn severity and this relationship can be expressed as a linear model with R^2 of 0.73. While these results are encouraging, more efforts are still needed to further understand the species-specific effects of burn severity in the mixed forest ecosystem, e.g., responses of fire-tolerant and fire-intolerant species. In addition, results from this study could help with the prediction of future tree mortality and biomass change, and forest managers may also benefit from this quantitative relationship for more informed fire management, especially in fire-prone ecosystems such as eastern, U.S. Pine Barrens.

5. ACKNOWLEDGMENTS

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