Accurate estimates of forest structure, such as biomass, are important for forest management, diversity conservation, fire planning, and global carbon accounting \cite{Dubayah and Drake 2000, Goodale et al 2002}. Biomass provides information about the growth, health, and productivity of forests; and is a key parameter in estimating carbon stock, timber production, wildlife habitat, fire behavior and impact, and climate and ecological modeling.

The recent occurrence of relatively large, severe wildfires in southwest US fire-adapted Ponderosa pine ecosystems are partially attributed to the significant changes in the structure of these systems over the last (Weaver, 1959; Cooper, 1960; Covington and Moore, 1994, Kaufmann et al., 2000) which contribute to. Since Euro-American settlement, years fire suppression, industrial logging and tree planting, and unregulated livestock grazing have significantly increased stand density and an accumulation of biomass and dead fuels in these forests in these forests \cite{Cooper 1960, Covington and Moore 1994, Huffman et al 2015, Rodman et al 2016, Moore et al 2004}. In addition to land use histories, changes in climate such as increased temperatures, extension of fire season weather, and earlier snowmelt is further increasing fire severity and frequency in Western U.S. forests \cite{Flannigan 2000, McKenzie 2004, Westerling 2006}; further climate change will interact with and affect all disturbance dynamics of forests, such as forest diseases \cite{Seidl 2017}.

The importance of fire, and its potential for releasing carbon stored in forest biomass, has become increasingly clear (Houghton et al., 2000). To quantify the role forests play in the global carbon cycle it is necessary to comprehend how fire affects carbon fluxes (e.g. net primary productivity and decomposition), and how these processes interact and feedback on each other. This can be critical in determining fire behavior and wildlife habitat potential.

The selected study regions are all managed under a collaborative, landscape-scale, science-based initiatives aimed at restoring the structure, pattern, composition, and health of fire-adapted Ponderosa pine ecosystems. These include the Four Forests Restoration Initiative under the Collaborative Forest Landscape Restoration Program established by the Public Land Management Act of 2009 (Title IV, Forest Landscape Restoration) and the Southwest Jemez Mountains Collaborative Landscape Restoration Project. Restoration of these ecosystems is a top priority of the USDA Forest Service Southwestern Region (New Mexico and Arizona) and a number of restoration treatments have been planned and implemented at the landscape scale. Recent large burns have increased public interest in fire behavior and effects, and scientific interest in the carbon consequences of wildfires. Biomass estimates are key to making informed management decisions (thinning, prescribed burns, etc) in forest restoration efforts and general management of forest lands.

Extensive, spatially explicit forest inventories are time consuming, labor intensive and expensive. Forested land ownership in the collaborative management unit is mixed, adding to the expensive and challenge of accessing plots. Remote sensing techniques, especially with lidar data, provide an alternative to generate accurate biomass estimates and other forest biophysical parameters (reviews by \cite{Dubayah 2000, Goetz 2011, Petrokofsky 2102, Rosette 2012, Wulder 2012, Zolkos 2013}). The advantages of remote sensing include the ability to collect and process spatially explicit data over large areas in a timely and economic fashion.

Airborne laser scanners (ALS) can be broadly grouped into two categories: discrete return and full waveform digitizers. These categories can be further specified by the type of system (profiling or scanning), laser footprint size, and the number of recorded returns for each laser pulse. Previous ALS studies have demonstrated that both large-footprint waveform and small-footprint discrete return ALS data, can be used to derive measurements (e.g., tree height, crown dimensions, tree location) at the stand level [5,25,30,35] and plot level [8,19,36,37]. These direct ALS measurements can then be used in conjunction with known allometric relationships or statistical analysis procedures to estimate parameters such as diameter at breast height (DBH), AGBM, or gross volume (gV).

Lidar based biomass models outperform field based \*\* inventories (Naesset), but the financial costs associated with collecting field data to train the models can render it infeasible for estimating forest structure with new lidar acquisitions. Simulatenously, regional variation \*\*\*?

Use: Quantification of the effect of fire on carbon stocks and fluxes requires estimates of the amount of biomass in ecosystem components, including actively photosynthesizing tissues. Some of these characteristics can be used as inputs to fire behavior models, increasing our understanding of the effect of fuels on fire behavior. Others provide estimates of carbon stocks, allowing us to quantify the carbon consequences of fire. The development and use of spatially explicit maps of forest fuels can enhance our understanding and modeling of fire behavior (Perry, 1998). Hall et al 2005.

Measures of stand structure are needed to manage forested landscapes for multiple purposes, including timber production, wildlife habitat, and fire hazard. Remote sensing of forest structure has proven challenging for forest operational managers and planners, many of whom still rely on aerial photograph surveys to meet user accuracy requirements. Although moderate-resolution satellite imagery (e.g., Landsat) is reasonably sensitive to variation between managed forest stands, it is insensitive to canopy height variation within stands compared to aerial photography. Hudak et al 2006.

Regional models have been successful at accurately estimating above ground biomass forest structure using both full waveform data \cite{Lefsky et al 2002 Lefsky 2005} and discrete data from ALS instruments \cite{Nelson 2004, Naesset 2008, Asner 2012}. Little work has been done in forests of relatively low density, such as the ponderosa pine forests \cite{Hall et al 2005, Sherrill, Kim}. Sherrill et al \cite{Sherrill et al 2008} attempted to, but… No study has been conducted for temperate, fire-prone \*\*\* in the Southwest United States. Further, no studies have attempted to apply the model to new lidar acquisitions.

The goal of this work is to use discrete-return lidar data from similar acquisitions and environmental data to develop a regional lidar model to estimate above-ground biomass in \*\* in Ponderosa pine (*Pinus ponderosa*) and mixed conifer \*\* forests in the Southwest United States. We supplement the lidar based information with environmental data (topography, ecological response units, and seasonal greenness data derived from Landsat images) to explain differences in forest structure due to contrasting environmental conditions, site productivity, and species composition. We evaluate the reliability and transferability of the model derived from regression analysis using data from all sites by comparing it with independent data from each site individually and two new lidar acquisitions. Being able to use relationships developed from existing data to update lidar-based forest inventories can substantially reduce field data collection costs when new lidar acquisitions become available.

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