Accurate estimates of 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, fire impact, and ecological modeling.

Disruption of the frequent, low-intensity fire regime has increased fire hazard from intense stand replacement crown fires in fire dependent mixed conifer forests of the southwest USA \cite{Covington and Moore 1994, Westerling et al 2006}. Fire suppression, industrial logging, and unregulated livestock grazing have significantly increased surface fuel load, stand density, and a shift in dominance to fire-intolerant tree species since Euro-American settlement \cite{Cooper 1960, Covington and Moore 1994, Moore et al 2004, Fule 2009, Huffman et al 2015, Strahan 2016, Rodman et al 2016}. In addition to historic land use activities, increasing temperatures, extended fire seasons, and earlier snowmelt will likely continue to intensify the size and severity of wildfires in Western U.S. forests \cite{Flannigan 2000, McKenzie 2004, Westerling et al 2006}.

The recent occurrence of large, un-characteristic high-severity fires in the southwestern US have increased public concern and support for forest and fire management \cite{Schultz et al 2012, Schultz et al 2014}. The selected study regions are managed under 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, part of the network of Collaborative Forest Landscape Restoration Programs established by the Public Land Management Act of 2009 (Title IV, Forest Landscape Restoration), 2009 Kaibab Forest Health Focus, 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), the states, and local communities \cite{AZ, Mast et al 1999}. A number of restoration treatments have been implemented at the landscape scale, other treatments are still in planning stages.

Ongoing restoration of fire-frequent pine and mixed-conifer forests throughout the western United States is one of the most extensive and expensive forest restoration programs ever undertaken. Hundreds of thousands of hectares of public lands are being treated with prescribed fire and mechanical thinning each year at significant cost; 1.1 million ha of public forestlands were treated in the western United States in the period 2004–2008 alone (Schoennagel and Nelson, 2010).

Rising fire suppression costs and potential threats to ecological and human values posed by large and severe wildfires have created a sense of urgency (Spies et al., 2006) and provided the motivation for federal legislation to facilitate fuel reduction and forest restoration activities, including the Healthy Forest Restoration Act of 2003 and Title IV of the Omnibus Public Land Management Act of 2009, which established the Collaborative Forest Landscape Restoration Program. Restoring characteristic fire regimes and forest structures are central objectives of most restoration and fuel reduction projects in fire-frequent forests throughout western North America (e.g., Gaines et al., 2010; Roccaforte et al., 2010).

Historical reference conditions have long been used to guide the restoration of degraded ecosystems. However, a rapidly changing climate and altered disturbance regimes are calling into question the usefulness of this approach. As a consequence, restoration goals are increasingly focused on creating communities that are resilient to novel environmental stressors and emphasis is being placed on defining functional targets through the use of plant traits. While changes in forest structure and composition have received much attention, long-term changes in stand-level functional traits are not well understood. Strahan (2016) argue that a focus on restoring optimal functional trait combinations may be as important as managing ecosystem structure for restoring resilient ecosystems. Silvicultural treatments such as thinning and prescribed burning aim to reduce overall tree densities, \*\*\*.

Restoration treatments are based largely on applying the concept of reference conditions and the natural range of variability, defining targets based on historical forest structure and composition (Roccaforte et al 2015). Synergistic effects of climate change, altered fire regimes, and land use are also likely to alter the regime of other forest disturbances, such as insect and disease outbreaks \cite{Seidl 2017}. Forests are expected to experience conditions outside of their natural range of variability, resulting in the emergence of novel combinations of environmental conditions and disturbances \cite{ Hobbs et al 2006, Hobbs et al 2009}. further \*\* needs for monitoring ecological responses and assessing efficacy of restoration treatments under new processes and \*\* \cite{ Hobbs et al 2006, Hobbs et al 2009}.Need for monitoring to evaluate ecological conditions and guide management prescriptions, assess effectiveness of treatments and adapt restoration treatments and hazardous fuels mitigation strategies, inform land use planning, stakeholder discussions.

Repeating extensive ground-based forest inventories is time consuming, labor intensive, and expensive. Additionally, the interspersion of a mix of land ownership in the forest management unit adds to the expenses and challenges of accessing plots representing the full region \cite{Dyson??}. Utilizing lidar data and other remote sensing techniques 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, even difficult to reach regions, 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 \*\*\*?

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 and two new lidar acquisitions. When new lidar acquisitions become available, the ability to use relationships developed from existing data to update lidar-based forest inventories can result in substantial savings from reduced field data collection efforts.

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