Federal wildfire response costs nearly tripled from \$1.1 billion to \$2.9 billion to response to a 70\% increase in average annual acreage of forests burned in the United States between 2000 and 2005 compared to the 1990s \cite{US GAO 2007}. Escalating costs and hazards from uncharacteristic large and high-severity wildfires have grown dramatically, and consequences of global warming are posing an ever-greater threat to forest and community health \cite{US Senate Committee on Energy and Natural Resources 2008}. Large scale efforts to restore forest resilience by creating conditions where natural ignition fires left burn do not lead to extreme fire events are underway, so that budgets are not exhausted suppressing fires \cite{Brown et al 2004, Reinhardt et al 2008, Gaines et al 2010, Roccaforte et al 2010}. The scale of required treatment, to restore enough forestland in order to get ahead of the problem and maintain restored conditions, is immense. Over 70 million acres are in need of restoration because of high fuel loadings and forest structure that is highly departed from natural conditions \cite{Brown et al 2004}; the majority are in the western United States \cite{Schoennagel and Nelson 2010}.

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, Huffman et al 2015, Strahan 2016}. In addition to impacts from 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}.

To address rising costs and threats of extreme fires to communities and landscapes, government agencies, civil society organizations, and regional and local stakeholder groups have been collaborating over the last 15 years to develop restoration strategies, identify priority areas for treatment, and implement activities \cite{Governors Forest Health Councils State of Arizona 2007, Goldstein and Butler 2010, WGA FHAC 2010}. Ongoing restoration of western US forests is one of the most extensive and expensive forest restoration programs (e.g., \cite{Schultz et al 2012}. 1.1 million hectares of public forestlands were treated in the western United States in the period 2004–2008, but these treatments still only covered 2\% of the Western US forests identified as a high restoration priority \cite{Schoennagel and Nelson 2010}. Recognizing the urgency of the problem these communities are facing, congress appropriated a consistent funding source through the Collaborative Forest Landscape Restoration Program (CFLRP, part of the Omnibus Public Land Management Act of 2009) to support and expand restoration efforts at the necessary spatial and temporal scale \cite{Schultz et al 2012}.CFLRP offers competitive awards to communities that are implementing large-scale, collaborative, cross jurisdictional restoration plans. Successful projects are able to demonstrate the degree to which restoration activities achieve stated ecological objectives, benefit communities, and reduce fire risk and costs.

CFLRP awarded projects are required to monitor social, ecological, and economic outcomes for at least 15 years after implementation begins \cite{Schultz et al 2014}. This feedback should then be used to guide future decisions in an adaptive planning cycle \cite{Ringold et al 1996,Stankey et al 2003,Stem et al 2005, Larson et al 2013}. The need for on-going monitoring is ever more important given that restoration treatments are guided by historical reference conditions and the natural range of variability \cite{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 and perhaps the emergence of novel combinations of environmental conditions and disturbances \cite{Hobbs et al 2006, Hobbs et al 2009}. Assessing the efficacy of restoration treatments under new ecological processes and conditions is essential to adapting strategies that increase resilience of desired forest systems \cite{Folke et al 2002}.

Repeating extensive ground-based forest inventories is time consuming, labor intensive, and expensive. CFLRP encourages long-term restoration treatments (10-year period) across primarily national forests, but that reach across multiple land ownerships (e.g., federal, state, tribal, and private land) to reduce fire risk to communities \cite{Schoennagel et al 2009, Schultz et al 2012}. Monitoring landscapes with many different land owners adds to the challenges and expense of accessing ground plots \cite{Dyson}. Estimation techniques that use Earth observing data provide an alternative to monitor landscapes over time \cite{Nagendra et al 2013}. The advantages of lidar-based approaches include 1) the ability to collect and process spatially explicit data representing the horizontal and vertical conditions of the landscape over large spatial extents, 2) coverage of difficult to reach terrain and properties, and 3) accurate estimation of forest structure parameters in a timely and economic fashion (reviews by \cite{Dubayah 2000, Goetz 2011,Petrokofsky 2012, Rosette 2012, Wulder 2012, Zolkos 2013}).

# Start Here

The goal of this work is to \*\*\*. No studies have attempted to build and apply a regionally developed model to new lidar acquisitions. We 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.

We test this approach using AGB as our pilot metric. In the 10 CFLRP projects now underway, the most common, and often the most urgent, treatment objective is a reduction of fuel densities through mechanical thinning, prescribed fire, harvesting woody biomass, and managing lightning-caused fire (Schultz). 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. 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 \*\*\*? Further 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}. 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. 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.

## Literature

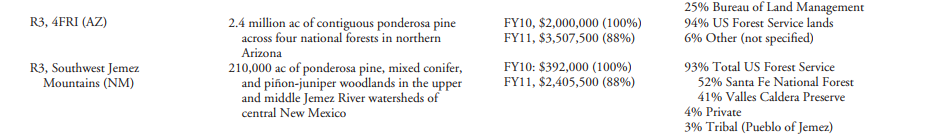
\bibitem{ Mast et al 1999}

Mast, J. N., Fule, P. Z., Moore, M. M., Covington, W. W., & Waltz, A. E. (1999). Restoration of presettlement age structure of an Arizona ponderosa pine forest. *Ecological applications*, *9*(1), 228-239.

\bibitem{ Goodale et al 2002}

Goodale et al 2002

## Study Region Notes



The 4FRI is currently CFLRP contract awarded in May of 2012 and is the largest such contract the US Forest Service has ever offered (US Forest Service 2012a). The Four Forests Restoration Initiative primary goals are to

* restore the ecosystem so that it is more resilient to fire and climate change over time,
* increase native biodiversity,
* reduce the risk to communities of wildfire, and
* promote sustainable wood products industries that can support restoration efforts and strengthen local economies.

Use mechanical thinning on approximately 50,000 acs/year to allow for increased use of both planned and unplanned fires to meet restoration objectives, ultimately mechanically treating roughly 1 million ac over 20 years; ramp up to an additional 30,000 ac of treatment per year, over and above the forests’ current program of work. Analyzing approximately 750,000 ac to identify roughly 300,000 ac of treatment for 10 years of work.

Community Forest Restoration Act of 2000, which created the Community Forest Restoration Program (CFRP) under legislation introduced by Senator Bingaman (D-NM) as part of the Secure Rural Schools and Community Self-Determination Act. In many ways CFRP is a state level version of the CFLRP. It allows for the appropriation of $5,000,000 annually for community-based restoration projects, selected through a competitive process, on any combination of federal, tribal, state, county, or municipal forestland in New Mexico. The CFRP provides federal grants of up to $360,000 over 4 years. Grantees are required to complete a multiparty assessment to report on the positive or negative impact and effectiveness of the project, including improvements in local management skills and on-the-ground results.

What is CFLRP (planning at larger scales and across jurisdictional boundaries, and the use of monitoring and adaptive management to address uncertainty (Grumbine 1994, Yaffee 1999, Butler and Koontz 2005), created to address concerns $40 million and require a 50% match by the region- Competitive funding – awarded based on ability to meet CFLRP Objectives: promote ecological, economic, and social sustainability; leverage local resources to accomplish these goals; reduce fire management costs through the reestablishment of natural fire regimes and reduction of the risk of uncharacteristically severe fires; demonstrate the degree to which restoration activities achieve ecological/watershed objectives and affect fire activity and its associated costs; and show how capturing the value of forest restoration byproducts can reduce treatment costs and support local economies.

The CFLRP requires multiparty monitoring, collaboration, planning and prioritization at landscape scales, and the competitive allocation of funding to a limited number of projects, it represents the beginning of a potential paradigm shift in forest policy in the United States. The Act is meant to encourage landscape-scale projects across multiple land ownerships, in line with the Secretary of Agriculture’s call for an “all lands” approach to land management (US Forest Service 2009), by supporting projects developed and implemented through a collaborative process that leverages local, private, and other federal resources with CFLRP funding awarded for work on National Forest System lands.

The legislation anticipates that fire suppression costs should decrease over time as a result of these projects, as should restoration treatment costs, because of improvements in efficiency and capacity of both industry and local US Forest Service units. The CFLRP also promotes a model of adaptive planning and management based on multiparty monitoring and learning. Act requires all projects to monitor social, ecological, and economic outcomes for at least 15 years after implementation begins, with this information ideally informing future decisions in an adaptive planning cycle. One of the stated purposes of the Act is to encourage a process that shows the degree to which restoration activities successfully achieve ecological objectives, reduce fire activity and management costs, and benefit local economies, while offsetting the costs to the agency of implementing treatments. [5] Thus, knowledge generation and learning are central components of the program.

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, \*\*\*.

challenges:

* build trust - as fire suppression costs continued to rise, money that had been allocated to community-supported fuels reduction projects, under both Healthy Forests Restoration Act (HFRA) in 2003 and non-HFRA authorities, was redirected to pay for fire suppression and never replenished, eroding trust with stakeholders and frustrating restoration efforts (Cromley 2005)).
* Multiparty monitoring, a key oversight mechanism for the contracts, was originally required for projects, but under the extended authority, only programmatic monitoring is required. The inclusion of a project-level monitoring requirement in the CFLRP reintroduces this as an oversight mechanism for funded projects, whether or not stewardship contracts are used. Demonstrate forest restoration is conducted with partners at scales that can meaningfully influence fire behavior and accomplish restoration goals.

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.

In the 10 projects now underway, the most common, and often the most urgent, treatment objective is a reduction of fuel densities through mechanical thinning, prescribed fire, harvesting woody biomass, and managing lightning-caused fire (Schultz). In the 4FRI -- stakeholders, with financial support from the US Forest Service, completed an assessment of small-diameter wood supply in 2008, both to assess volume and to find social agreement around harvesting parameters.