Growth and Demography of Pinaleño High Elevation Forests

RJVA 07-JV-11221615317

Performance Report

Laboratory of Tree-Ring Research and School of Natural Resources and the Environment

University of Arizona

Principal Investigators: Donald A. Falk and Ann M. Lynch

Prepared by:

Christopher O'Connor, School of Natural Resources and the Environment

Donald A. Falk, School of Natural Resources and the Environment

Ann M. Lynch, Rocky Mountain Research Station

Craig P. Wilcox, Coronado National Forest

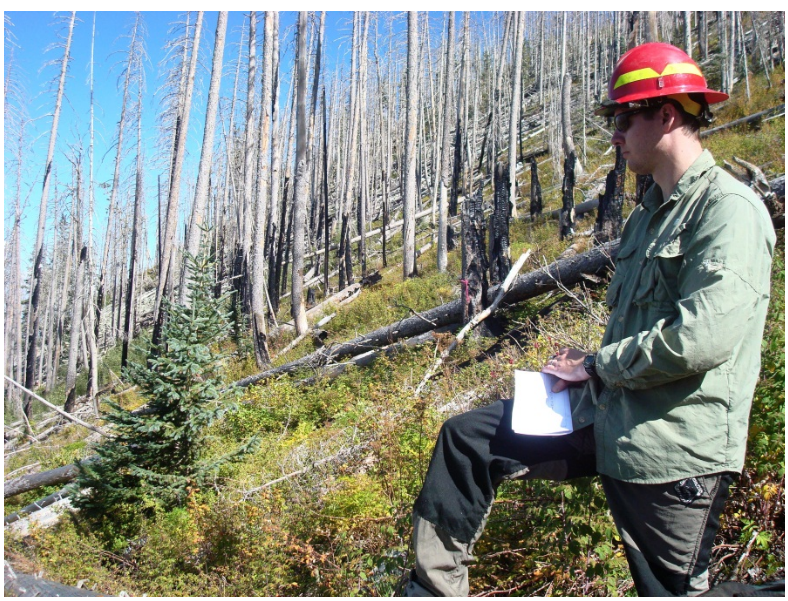
Thomas W. Swetnam, Laboratory of Tree-Ring Research

Tyson L. Swetnam, School of Natural Resources and the Environment

Submitted to:

U.S. Forest Service, Rocky Mountain Research Station

24 November 2010



This report summarizes project activity and progress through 26 October 2010.

This report includes narrative and data regarding:

1. Project location and staffing.
2. Project objectives.
3. Field sampling design and protocols.
4. Bark beetle outbreak reconstruction fire history collections.
5. Landscape modeling component application.
6. Collections management.
7. Relating remote sensing to site productivity and tree growth.
8. Collaboration.
9. Research plan for next report period.

Appendices:

A. Summary of presentations and outreach.
B. Bark beetle reconstruction field sampling protocol

Project location and staffing

The Project is managed in the in the Fire and Restoration Ecology laboratory (FREL) at the School of Natural Resources and the Environment (SNRE) of the University of Arizona. Facilities and staff support are also provided by the Laboratory of Tree-Ring Research (LTRR). Faculty from the School of Geography and Development (SGD) are assisting with remote sensing applications. Field facilities and site access have been provided by the Coronado National Forest (N.F.).

Donald **Falk**, Associate Professor in the School of Natural Resources and the Environment, serves as Principal Investigator and Project coordinator, and directs the FREL. Dr. Falk holds joint appointments in the LTRR and the UA Institute for Environment and Society.

Ann **Lynch,** Research Entomologist for the US Forest Service Rocky Mountain Research Station (RMRS) is coinvestigator on the Project and is serving as a scientific advisor for development of the insect study, sampling design, field protocols, and analysis.

Christopher (Kit) **O'Connor**, Graduate Research Associate with the School of Natural Resources and the Environment, is a doctoral student leading research activities on the Project. Mr. O'Connor is responsible for planning, coordination of field and shop work, data acquisition and analysis, preparation of reports, and communicating results generated from the Project.

Craig **Wilcox**, Forest Silviculturist for the Coronado National Forest, Safford Ranger District is serving as technical advisor and is responsible for the FS field crew providing supplemental datasets and research plots for the Project. Mr. Wilcox also coordinated the LiDAR flight over the Pinaleño Mountains and is developing management applications for the remote sensing dataset.

Matthew **Littrell**, Forester for the Coronado National Forest, Safford Ranger District served as crew leader for the USFS LiDAR field inventory team. Mr. Littrell coordinated and led plot inventories for the LiDAR ground proofing effort, developed maps for both field crews, and provided logistical support to the University of Arizona field crew. Mr. Littrell curates the LiDAR crew database that will be shared between the Coronado Ranger District and the University of Arizona.

Alex **Arizpe**, Graduate Research Assistant with the school of natural resources, provides technical support for the Project in the FREL. Mr. Arizpe's responsibilities during the reporting period have included design and maintenance of the master Project database, map and GIS management, and participating in field sampling.

Rachel **Loehman**, Research Scientist at the USDA Forest Service, Rocky Mountain Research Station at the Missoula Fire Sciences Laboratory, is technical liaison for calibration and developing tree to landscape-level inputs for modeling vegetation and disturbance interactions in the Pinaleño Mountains.

Robert **Keane**, Research Ecologist with the USDA Forest Service, Rocky Mountain Research Station at the Missoula Fire Sciences Laboratory; is the developer of the FIRE BGCv2 Software package and serves as technical advisor for model simulations and interpretation.

Thomas **Swetnam** is serving as scientific advisor to the Project, including assistance in the field, laboratory, and analysis.

Tyson **Swetnam** developed the sampling grid, led field collections in 2008, and served as technical aide for field collections.

Denise **Laes**, contractor with the USDA Forest Service Remote Sensing Applications Center (RSAC) and data specialists Brent **Mitchell**, and Steven **Dale** provided post processing of the LiDAR raw data and provided a series of products to begin spatial analysis.

Robert **McGaughey**, Research Forester for the Pacific Northwest Research Station developed FUSION software for visualization and analysis of LiDAR data and is technical consultant on the integration of LiDAR and field data sets.

Brian **Enquist**, Assistant Professor in the Department of Ecology and Evolutionary Biology at the University of Arizona is serving as a technical consultant for integrating LiDAR spatial measurements to site productivity and annual tree growth at stand to landscape scales.

Project objectives

The project goal is to understand how multiple disturbance events including fire, insect outbreaks, and climate variability interact in space and time, and how they combine to influence forest species composition, spatial structure, and tree population dynamics in high elevation forests of the Pinaleño Mountains. Information from each of these components is needed in order to understand the events and processes that resulted in contemporary forest conditions, and to guide management plans toward restoration of a sustainable healthy ecosystem during a period of potentially rapid climate change. The objectives of this agreement are to understand the demographic nature of contemporary tree populations, to understand the frequency and spatial extent of historic disturbances that resulted in contemporary forest conditions, and to develop detailed spatial and temporal histories of fire and bark beetle outbreaks in high elevation ecosystems of the Pinaleño Mountains.

The Project is composed of four main elements:

1. Tree population demography
2. Fire history
3. Forest entomology
4. Modeling of disturbance and species interactions

The original agreement and first and second amendments provide for the spatially-distributed and explicit tree population demography and fire history aspects of the project for the dry mixed-conifer, wet mixed-conifer, and spruce-fir vegetation types. The third amendment addressing the entomology component was implemented the summer of 2010. Progress to date on these aspects is reported here. The fourth component is a synthesis of the three amendments to the agreement and addresses links between demography, disturbance, and climate to increase the understanding of prior and potential future disturbance interactions.

Field sampling design and protocols

We coordinated all sampling with the Safford Ranger District and the University of Arizona Police Department (UAPD), complying with all applicable safety procedures. Field crews used UA vehicles and carried 2-way radios in addition to a Forest Service hand-held programmed with local frequencies including the Mt Graham International Observatory (MGIO) Access Road frequency. When sampling in Refugium areas, crews observed radio protocol for the access road. The crew was based at Columbine Work Center.

Field sampling over the summer of 2010 followed a newly developed protocol for bark beetle plots described in Appendix B, Bark Beetle Outbreak Reconstruction Protocols for 2010. Protocols are designed to be faster and more targeted than demography sampling protocols, specifically addressing synchronized mortality of host trees attacked by the spruce beetle (SB) *Dendroctonus rufipennis* and western balsam bark beetle (WBBB) *Dryocoetes confusus*. Synchronized growth release in non-host Douglas fir, aspen, and southwestern white pine located in and around spruce-fir forest will be used to corroborate outbreak events affecting canopy trees. In contrast to fixed size plots used for demography and structure sampling, bark beetle plots use a fixed tree number system to directly compare growth and vigor of host Engelmann spruce (SB) and cork bark fir (WBBB) to non-host tree species through the use of paired comparisons between ten host and ten non-host trees. Host tree susceptibility to infestation is driven by several factors; however the primary limitations to successful attack are bole size, density of available hosts, and proximity to a source of beetles. These traits are addressed in the sampling protocol by limiting the size of trees to be sampled to above 15 centimeters DBH, considered a minimum diameter necessary for successful brood development (Samman and Logan 2000), and by individually georeferencing each of the twenty sampled trees on a plot, allowing analysis of stem densities by species in relation to total area encompassing the twenty trees on the plot. Larger trees and intact stumps were preferentially sampled to extend the length of available time series of spruce beetle outbreaks.

Bark beetle damage sampling grid. The supplemental bark beetle sampling grid was confined to areas above 9,300 ft. elevation comprised of at least a minor spruce component to the overstory. Plot locations were based on the LiDAR secondary sampling grid where possible to combine insect sampling with age structure and other sampled plot characteristics (Figure 1). New plots were installed along the periphery of the demography and structure grid, offset by 500 meters to improve the distribution of plot slope and aspect within the spruce-fir forest. Twenty three bark beetle plots were installed in June, July, and September 2010.

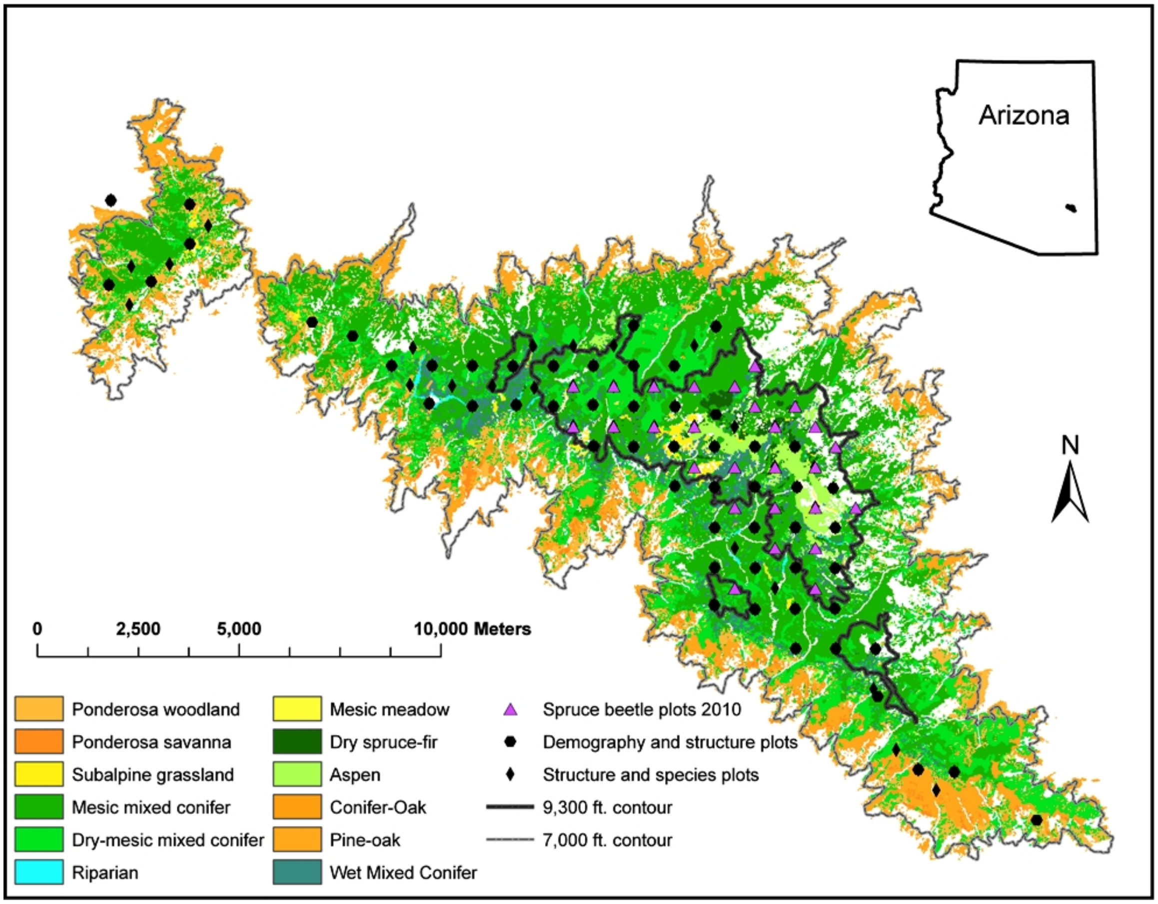


Figure 1 Gridded sampling plots in the Pinaleño Mountains summer 2010. Triangles indicate spruce beetle plot locations in relation to demography and structure plots and additional structure and species plots completed by the LiDAR crew. Forest species associations are provided by the LANDFIRE national database.

High elevation fire history. Sampling for fire history information was conducted within and near grid points as well as off-grid locations. Fire history sampling over the summer of 2010 was focused on the spruce-fir forest type and surrounding wet mixed-conifer forest, parts of the mountain considered under-sampled over the summers of 2008 and2009. An additional 56 fire history samples were added to the 106 samples collected in 2008 and 2009 for a total of 162 samples recording 978 scars. Fire scar collection sites are well distributed across the dry and wet mixed conifer and spruce-fir forest types (Figure 2). In addition to known fire and bark beetle outbreaks, we expect to be able to develop an interpolated surface among grid points giving the relative distribution of fire events over the last several hundred years.

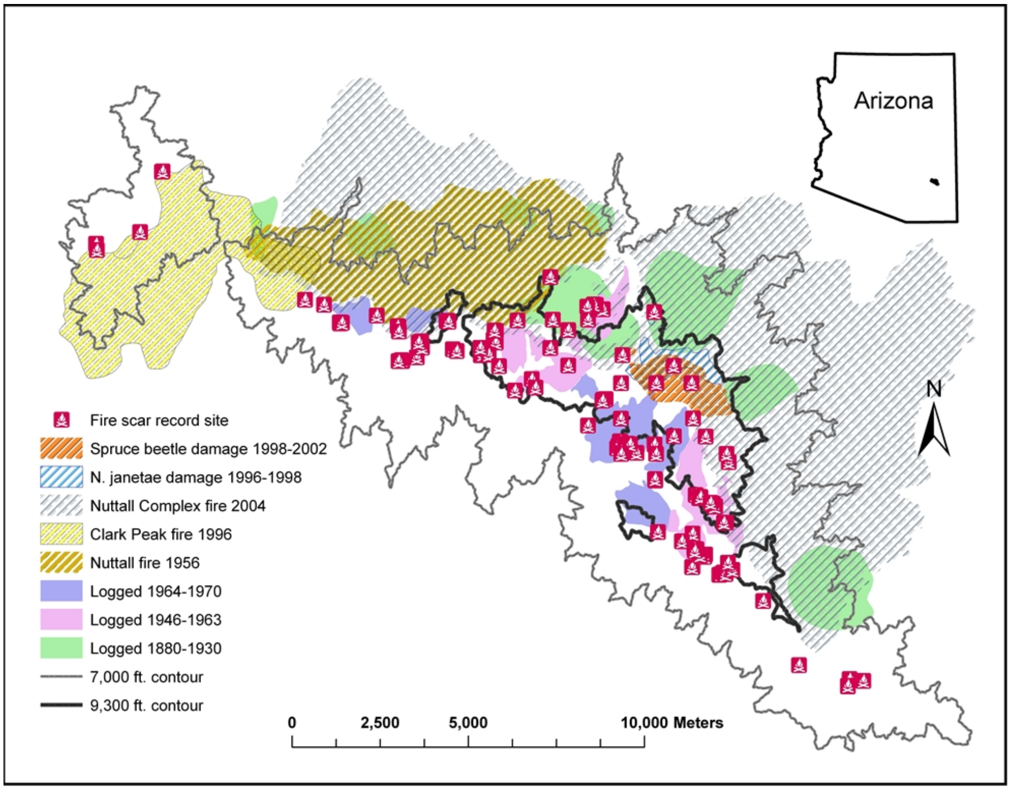


Figure 2. Distribution of fire history sampling points and known fire, bark beetle, defoliator, and logging events within the sampling area.

Intensified sampling for bark beetle damage, fire history reconstruction, stand age classes and species distributions in the spruce-fir forest type increases the resolution and connectivity of available data in this sensitive forest type. Tree age, metrics, and condition classes from the beetle-damage plots will be pooled with demography plot material to extend the coverage of demographic and disturbance information to the area between demography plots on the kilometer-spaced sampling grid. A total of 2,432 increment bored and cut samples from 1,756 trees have been collected to date.

Figure 3. Field Sampling 2010. Clockwise from upper left: the Bark beetle plot sampling protocol called for 1) increment coring of live trees and 2) chainsaw sampling of snags and stumps. Netbook computers used to record information about a Southwestern white pine fire scar sample directly into Microsoft Access. A multi-stemmed Douglas-fir killed in the 2004 Nuttall Complex fire poses a challenge for finding a tree establishment date.

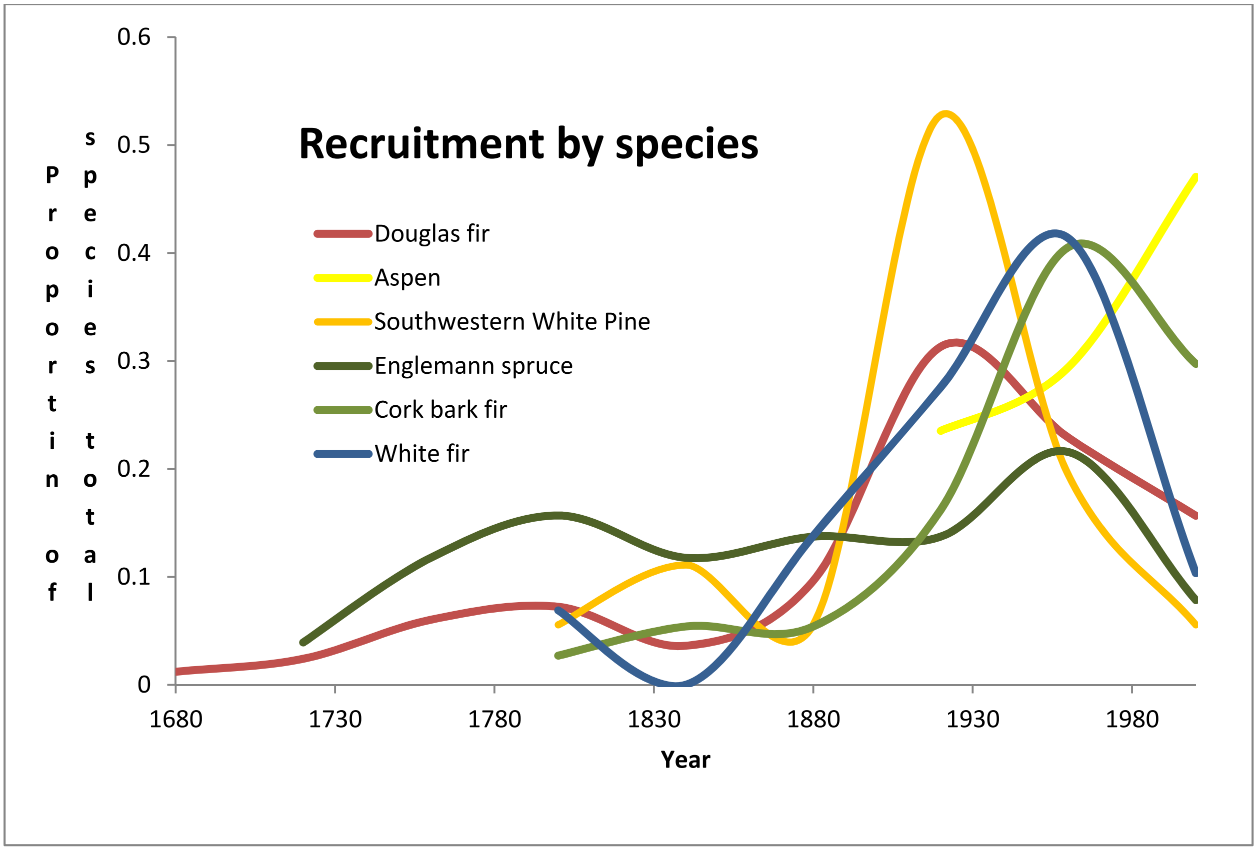


Figure 4. Species recruitment over time based on demographic reconstruction of 24 wet mixed conifer and spruce-fir plots. Data are for all trees > 5 cm DBH, pooled for all plots. The Y-axis is scaled to the proportion of total trees by species. Inner ring dates used for seedling establishment are not corrected for sampling height, however all samples are taken within 20 cm of root crown.

Preliminary results

Species recruitment trends

Analysis of 24 age structure plots along the central ridge of the Pinaleño Mountains suggests a series of recruitment pulses over the last 320 years (Figure 4). Ponderosa pine was excluded from this analysis because only six trees were sampled from these upper elevation sites. Data for this analysis does not include seedling and sampling counts (trees 1-20 years of age), so the right-most tail of the plot may be misleading. Two recruitment pulses for Douglas fir are evident in the late 18th century and in the 1920s. Southwestern white pine shows a small recruitment pulse around 1840 and a large pulse between at the start of the 20th century. Engelmann spruce appears to have relatively constant recruitment with small pulses around 1800, 1880, and 1940. White fir recruitment climbed consistently from about 1840 until a peak in the 1960s when it leveled off and began to decline. Cork bark fir had a small recruitment pulse in the 1840s and a large pulse around 1940 before tapering off to present. Aspen recruitment in the upper elevation plots has increased from a low ~1900 to a current high population following the series of recent fires in 1956, 1996, and 2004.

Reconstructed fire events

Fire history reconstruction is still in an early phase, however collections have already yielded fire scar dates as early as 1546 from mid-slope ponderosa and southwestern white pine. We expect to be able to reconstruct the spatial extent of major fires (occurring in 25% of samples within a site) by interpolating fire occurrence between fire recording trees similar to the methods used by Farris et al. (2010).

Ring width measurements to be used in detection of growth release and suppression events in the upper elevation Spruce-fir forest type are approximately 60% complete. We will be conducting ring width measurements on all datable wood from each of the 76 plots to analyze for broad-scale patterns of growth-suppression and release related to disturbance and climate factors.

Modeling interactions between multiple disturbance events from tree to landscape Scales

Introduction

Many factors influence stand composition and structure in western forests. Site potential for any given species is related to characteristics that limit growth such as water, sunlight, soil depth, soil structure, nutrient availability, and temperature; as well as individual plant adaptations to physical processes such as drought, fire, wind, and extreme heat or cold. Site potential maps combine specific location information with the physical requirements for a series of plant communities to develop a database of potential climax plant communities such as the national LANDFIRE database. These maps provide a planning tool for forest managers as well as an important calibration and bounding tool for simulation of landscape vegetation.

The factors that keep a landscape from reaching its climax vegetation are more difficult to map and may be more important to understand the current species mix and future changes in plant communities. Biological factors such as competition from other plants, physical damage caused by insects, pathogens, parasites, animals, and human activities such as logging, site development and management activities such as fire suppression are important consideration for an understanding of current and future stand conditions. While many plants are adapted to live under a given set of physical constraints, it is the specific disturbance history that determines the current species mix in any given forest. In the spruce-fir forests of the Rocky Mountains and Ponderosa pine grasslands of the interior west, interactions between two or more disturbance agents have been studied to explain current species composition found on the landscape (Veblen et al 1994, Bebi et al 2003, Bigler et al 2005, Parker et al. 2006.)

New developments in species occupancy modeling are connecting individual tree-based biogeochemical (BGC) models that simulate plant processes such as growth, carbon allocation, reproduction, competition and mortality with spatially explicit, dynamic landscape models that integrate stand and landscape level processes such as climate, fire, insect outbreaks, parasites, and human activities. Models such as FIREBGCv2 are capable of simulating dynamic changes in species distributions over time on a spatially distinct landscape at a daily time step over a period of decades to centuries. We propose to use FIREBGCv2 to investigate the effects of interactions between multiple biological and physical processes on individual species and species assemblages at plot, stand, and landscape scales (Figure 5).

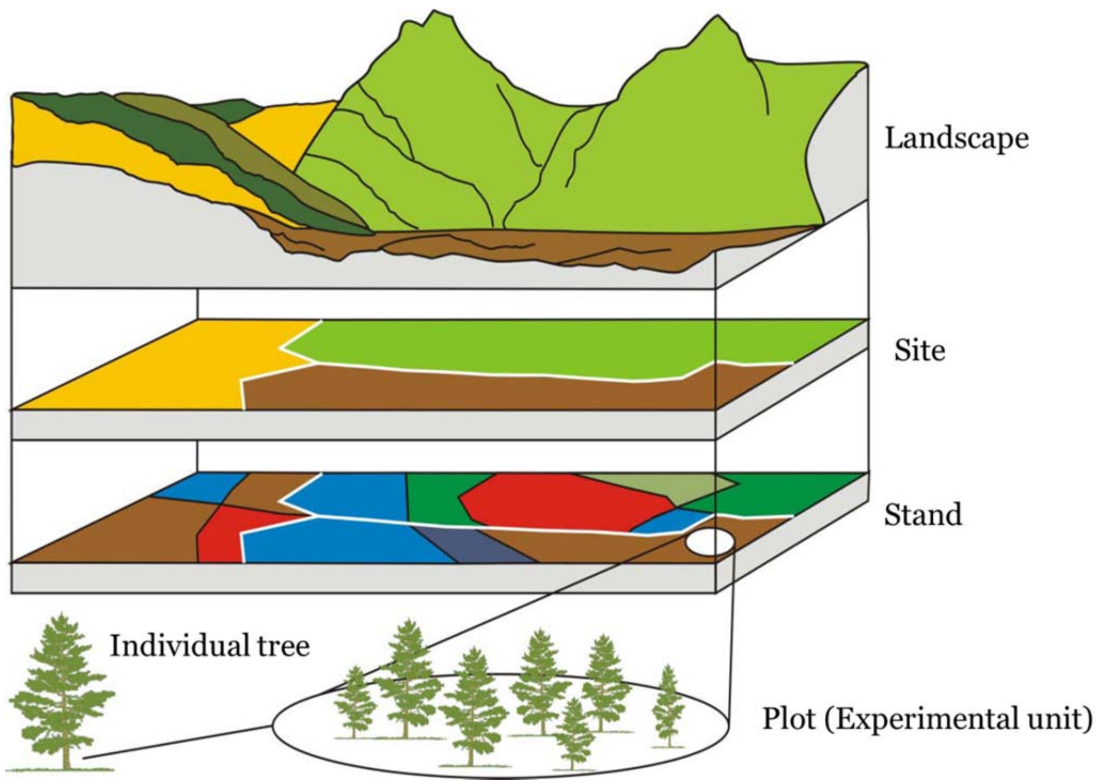


Figure 5. The five scaling components used by FIREBGCv2 model to examine interactions between tree growth processes, site characteristics, and dynamic events such as fire, insects, climate change, or management interventions.

Through this modeling exercise we will examine 1) how interactions between fire, insect outbreaks, climate, and human land uses shape forest composition and structure; 2) how these interactions have changed with increased human land use pressures and warming temperatures over the last 100 years; 3) what effect natural and human disturbances are likely to have on stand composition and structure in the future; and 4) what management actions would be appropriate to restore resilience to the forest under future climate scenarios.

Methods

Model Parameterization

We will develop a database of species parameters for each of the major stand component species in the Ponderosa-Oak woodland, dry mixed conifer, wet mixed conifer, and spruce-fir forest types. Individual species parameters will come from the list of ecophysiological measurements for inland western trees compiled by Korol (2001) and Hessl et al. (2004). Additional species parameters for Northern Arizona will be provided by Daniel Laughlin at Northern Arizona University. Missing parameter values will be input from the most specific of: 1) parameterized species with similar ecological characteristics (Minore 1979), 2) mean western forest parameters (Hessl et al. 2004), or 3) generalized parameters for deciduous or coniferous forests for BIOME-BGC. The four general forest types will be broken into subgroups represented by three or more field plots based on dominant and co-dominant species classes, differences in soils, site potential (LANDFIRE), elevation, age structure, and fire return interval.

3.2.2 *Simulation Initialization*

We will develop two raster layers based on the boundaries of the landscape above 8000 ft. elevation. A buffer of one kilometer will be used to allow the spread of dynamic events into and out of the simulation area. An initial site layer will be generated based on LANDFIRE outputs cross-referenced with plot conditions at the 76 ground truthed plots inside the study area. The simulation will be bounded by a site potential layer developed from the LANDFIRE database including the one-kilometer buffer. Plot and tree measurements from representative stand types will be transferred to the FIREMON database format for direct input to plot parameter files of FIREBGCv2. Fine fuel loading estimates will be based on Brown’s lines and coarse woody debris loading will be estimated from plot photos using the Photoload method (Keane and Dickinson 2007, Sikkink and Keane 2008, Sikkink et al. 2009).

Once initial parameters are entered for the study area, model initiation will generate the initial series of values (allocation of carbon and nitrogen in each modeled tree, pooled stand parameters, etc.) scaled from plot to landscape level. These outputs will serve as the initial values for simulation modeling that will change over time. Model initiation outputs will serve as the first error check for formatting and consistency of input files.

3.2.3 Model Calibration

We will initiate the model with tree ages and stand parameters reconstructed from 1950 (the date of earliest consistent weather station records) and run the model forward to present day. Temperature and precipitation records for the Pinaleño Mountains date to the 1990s, however lower elevation records for the area are available for the period of interest. Mountain Climate Simulator (MTNCLM) will be used to generate interpolated weather files for multiple points within the simulation varying by elevation and aspect. We will compare records from the last 55 years of measured tree ring widths, sapling growth, tree mortality, fire, and bark beetle outbreaks, to simulated growth and plot changes based on initial conditions and modules incorporating reconstructed weather, fire, and insect outbreaks to calibrate the simulation and identify any errors in parameterization inputs. Input parameters can be modified for a range of potential values to determine the sensitivity of the model to different initial conditions and accumulated disturbances over time. We will use the sensitivity analysis to adjust model inputs until the simulated landscape is similar to the actual landscape in species composition, density, tree ages, heights, and seedling/sapling composition. After the period of model calibration, we will run five iterations of 500 years (to ensure time for a complete fire rotation in the spruce-fir forest type) for each future scenario. Scenarios will include a series of weather input files that reflect IPCC climate predictions, management regimes that incorporate thinning, controlled burning, wildfire use, or continued fire suppression. These scenarios will be used to examine the interactions between climate and management actions on fire, insect outbreaks, species composition, and stand structure over a long time series.

We are in the process of species parameterization and development of current and potential vegetation layers to constrain the simulation and expect to begin trial calibration runs over the winter of 2010-2011.

Collections management.

Data: Field data collection followed the 2009 electronic data format. By the end of the summer 2010, all field collected data were checked and entered in the MS Access database. A separate laboratory samples database was developed for tracking the sample processing progress and recording laboratory-derived information from samples.

Samples: Cut sections and increment cores are stored and processed at the University Of Arizona Laboratory Of Tree-Ring Research. Demography and fire history specimens are stored by plot location so that entire plots are processed through the shop and analyzed on microscopes as a group. All (1716) increment cores collected over the summers of 2008, 2009, and 2010 have been mounted and surfaced, and cores from 26 of 76 plots have been dated. Approximately 60% of the 685 chainsaw-cut samples have been mounted and surfaced and 10% have been crossdated. Ring-width measurements have been competed for 22 of 76 plots to date.

Relating site potential, stand characteristics, and tree growth.

Through a collaborative project between students and faculty in the University of Arizona School of Natural Resources and the Environment, Laboratory of Tree-Ring Research, and Department of Ecology and Evolutionary Biology, we will be examining the relationships between site potential and stand characteristics derived from the remotely sensed LiDAR data acquired by the USFS in 2008, and annual tree growth increments collected at the 76 plot sampling locations. We hope to develop a relationship between annual site productivity potential, measured tree growth, and the series of limiting factors (competition, drought, insects, fire, logging, etc.) that hinder trees within a given site from maximizing potential resource use. This will be a pilot project exploring the possibility of scaling individual tree growth characteristics up to stand and landscape scales.

Members of FREL continue to participate in U.S. Forest Service sponsored conference calls and meetings as collaborators toward future funding proposals, decisions about deliverables for the LiDAR dataset, and the development of cooperative databases. Outcomes from each of the four outlined components as well as the LiDAR and tree growth characteristics studies will be useful for planning and implementation of the Pinaleño Ecosystem Restoration Project and other Coronado N.F. projects.

Collaboration.

Over the winter of 2009-2010, the University of Arizona and USFS LiDAR crews coordinated development and data checking for a shared plot-structure database for use by both collaborating groups. The Project continues to benefit from close working collaboration among the primary partners, including:

University of Arizona:

- School of Natural Resources and the Environment (SNRE)
- Department of Geography and Regional Development (GRD)
- Laboratory of Tree-Ring Research (LTRR)
- Department of Ecology and Evolutionary Biology (EEB)

U.S. Forest Service:

- Coronado National Forest (CNF)
- Region 3 Forest Health Protection
- Remote Sensing Applications Center (RSAC)
- Rocky Mountain Research Station (RMRS), Forest & Woodlands Ecosystems Program
- RMRS, Fire Fuel & Smoke Program
- Fire Science Laboratory (FSL)

Research plan for next report period.

Demography reconstruction We will continue sample processing and construction of age distributions. Plot and species age distributions will be compared with known fire, insect outbreak, and logging events to attribute drivers to stand and species age structures.

LiDAR processing We will examine age-structure regression relationships with plot-level LiDAR information.

Fire history we will continue fire event reconstructions in each of the forest types and begin spatial analysis of fire events for fires recorded in 25% or more of trees in a given area. Fire years will be checked against seedling recruitment dates and snag death dates to corroborate fire occurrence in each forest type.

Begin calibration of FireBGCv2 Landscape model application We are collaborating with Robert Keane and Rachel Loehman also at the FS at the Fire Science Laboratory on calibrating tree species tables for southwest forests to begin exploratory runs of the newly developed landscape model FireBGCv2.

Reconstruction of historic spruce beetle activity We will begin analysis of measured ring widths to identify common periods of growth release and suppression in the spruce-fir forest type. Growth releases in non-host and small spruce trees will be compared with large tree and stump mortality dates to reconstruct past outbreak event periods, frequencies, and spatial extents.

References

Bebi, P., Kulakowski, D. & Veblen, T., 2003. Interactions between fire and spruce beetles in a subalpine Rocky Mountain forest landscape. *Ecology*, 84(2), 362-371.

Bigler, C., Kulakowski, D. & Veblen, T.T., 2005. Multiple Disturbance Interactions and Drought Influence Fire Severity in Rocky Mountain Subalpine Forests. Ecology, 86(11), 3018-3029.

Hessl, A.E. et al., 2004. Ecophysiological parameters for Pacific Northwest trees. Gen. Tech. Rep. PNW-GTR-618. Portland, OR.

Keane, R.E. & Dickinson, L.J., 2007. Development and Evaluation of the Photoload Sampling Technique, Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Korol, R.L., 2001. Physiological Attributes of 11 Northwest Conifer Species, Ogden, UT: Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Minore, D., 1979. Comparative autoecological characteristics of northwestern tree species: a literature review, Pacific Northwest Forest and Range Experiment Station, U.S. Department of Agriculture Forest Service.

Parker, T.J., Clancy, K.M. & Mathiasen, R.L., 2006. Interactions among fire, insects and pathogens in coniferous forests of the interior western United States and Canada. Agricultural and Forest Entomology, 8, 167-189.

Sikkink, P.G. & Keane, R.E., 2008. A comparison of five sampling techniques to estimate surface fuel loading in montane forests. International Journal of Wildland Fire, 17, 363-379.

Sikkink, P.G., Lutes, D.C. & Keane, R.E., 2009. Field guide for identifying fuel loading models, Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Veblen, T.T. et al., 1994. Disturbance Regime and Disturbance Interactions in a Rocky Mountain Subalpine Forest. Journal of Ecology, 82, 125-135.

Zhang, Q., Alfaro, R.I. & Hebda, R.J., 1999. Dendroecological studies of tree growth, climate and spruce beetle outbreaks in Central British Columbia, Canada. Forest Ecology and Management, 121, 215-225.

Appendix A
Summary of presentations, outreach and awards

Lynch A.M., Wilcox C.P., Falk D.A. 2008. Ecology and management issues in mixed-conifer forests in the Pinaleño Mountains of Arizona. Invited presentation, Mixed-Conifer/Aspen Ecology and Management Workshop, 20-21 February 2008, Santa Fe NM.

Lynch A.M., Falk D.A., O'Connor C.D., Swetnam T.L., Koprowski J.L., Fitzgibbon R.A., Swetnam T.W., Wilcox C.P. 2010. Entomology & disturbance ecology research in the Pinaleño Mountains of southern Arizona. U.S. Forest Service, Rocky Mountain Research Station, All-Scientists' Meeting, 23-25 March 2010, Fort Collins CO.

Lynch A.M., O'Connor C.D., Swetnam T.L., Falk D.A., Wilcox C.L., Laes D., Anhold J.A., Loehman R.A., Koprowski J.L. 2010. Unraveling disturbance interactions in the Pinaleño Mountains. U.S. Forest Service, Rocky Mountain Research Station, All-Scientists' Meeting, 23-25 March 2010, Fort Collins CO.

Swetnam, T.L., O'Connor, C.D., Falk, D.A. and Wilcox, C.L. 2009. Mapping forests in 3-D, Applications of vegetation mapping from aerial lasers. , University of Arizona Student Showcase Research Exposition. Tucson AZ. November 6-7, 2009.

O'Connor, C. D., Lynch, A. M., Falk, D. A., Swetnam, T. W. and Loehman, R. A. 2010. Forest disturbance interactions in the Pinaleño Mountains: learning from the past to understand the present and plan for the future. Western Forest Insect Work Conference. Flagstaff, AZ, March 2010.

O'Connor, C. D., Lynch, A. M., Falk, D. A., Swetnam, T. W. and Loehman, R. A. 2010. Pinaleño Demography Project Teasing Apart Complex Disturbances in Western Forests. Tree-Ring Day. University of Arizona Laboratory of Tree-Ring Research. March 29, 2010.

O'Connor, C. D., Minor, J. J., 2009-2010. University of Arizona School of Geography and Development. Guest Lecturer, Geography 303 Field Study in Environmental Geography. May 2010, and September 2010. Tucson, AZ.

O'Connor, C. D. 2010 US Forest Service Rocky Mountain Research Station and Northern Arizona University School of Forestry. International Bark Beetle Workshop. August 10-14, 2010. Flagstaff, AZ

O'Connor, C. D., Lynch A. M., Falk, D. A. 2010. Laboratory of Tree-Ring Research Lecture Series Invited Speaker.Summer 2010 Field Sampling in the Pinaleño Mountains. University of Arizona Laboratory of Tree-Ring Research. September 2010.

Public Outreach Instructor, Laboratory of Tree-Ring Research and University of Arizona College of Science. Second Saturday's Downtown. Tucson, AZ. October 9, 2010.

O'Connor, C. D. 2010-2011 Biosphere 2 Science and Society Fellow. Web link: http://www.b2science.org/earth/outreach-society-2011.html

Wilcox C., Anhold J., Laes D., Mellin T., Falk D., Koprowski J., Merrick M., Swetnam T., O'Connor C., Lynch A., Alanen. 2009. LiDAR basics and overview of mapping the vegetation structure of the Pinaleño Mountains. Using LiDAR Workshop, National Advanced Fire and Resource Institute, 17-19 August 2009, Tucson AZ.

Wilcox C., Anhold J., Laes D., Mellin T., Falk D., Koprowski J., Merrick M., Swetnam T., O'Connor K., Lynch A., Alanen. 2010. Pinaleño LiDAR: New tool for forest restoration. Workshop presentation. Western Forest Insect Work Conference, 5-8 April 2010, Flagstaff AZ.

Appendix B

Bark beetle Outbreak Reconstruction Protocols for 2010

Pinaleño Forest Structure and Demography Project

Authors & Affiliation

Christopher O'Connor, School of Natural Resources

Ann M. Lynch, Rocky Mountain Research Station

Donald A. Falk, School of Natural Resources

May 28, 2010

Spruce beetle plot methods:

We will install a series of twenty-five additional insect-damage plots within and along the perimeter of know outbreaks and along the central ridge of the Pinaleño Mountains in both burned and unburned spruce-fir forest. Insect damage plot sampling protocols are designed to be faster and more targeted than demography sampling protocols, specifically targeting synchronized mortality of host trees attacked by the spruce beetle *Dendroctonus rufipennis* and synchronous growth release of non-host cork bark fir, Douglas fir, aspen, and southwestern white pine located in and around stands dominated by Engelmann spruce. Insect damage plots will be limited to stands with a recent spruce component to aid with the reconstruction of contemporary and and historic spruce beetle outbreaks. New plots will be centered at a single tree (live or dead) with DBH greater than 30 cm and will sample twenty trees per plot, including the ten nearest spruce (beetle host) and ten nearby non-spruce (non-host) trees with a DBH greater than 15cm. The shade tolerance of spruce and fir hinder the accuracy of diameter to age relationships so the lower size limit of trees sampled in the protocol is based on susceptibility to bark beetle attack (Samman et al. 2000). We expect the majority of living trees that experienced bark-beetle related growth release due to canopy opening in the 1950s, to be 15cm diameter or greater after 60 years growth, however this assumption will be tested in the demography plots. In the spruce-fir forest type, existing plots on the 1000 m grid occur primarily in the Nuttall-Gibson complex and Clark Peak fires, so samples from these plots are almost entirely charred and either beetle or fire-killed. Samples from plots burned in the 1996 Clark Peak Fire and 2004 Nuttal-Gibson Complex Fire will be useful to study the effects of historic beetle outbreaks, however charring of the outer wood will limit the quality of information available to study contemporary insect disturbances. Twenty-five additional gridded plots (500 m center), including 12 burned and 13 unburned sites, and six targeted non-gridded plots in unburned forest will be used to characterize bark beetle activity throughout the spruce-fir forest including documented outbreaks from 1949-1952 and from 1998-2003 (Figure 1). Many of the beetle-killed trees are thought to have been defoliated by *Nepytia janetae* (1996-1999) or spruce aphid (1999-present). Tree ring records will be used to determine the time of tree stress, potential stressor (whether it is related to drought, defoliation, or bark beetle attack), and what influence the multiple outbreaks may have had on one another.

Plots will be located on multiple slope positions (ridge top, shoulder, mid-slope, and valley base) and on representative aspects (N, W, S, E) whenever possible to aid model calibration.

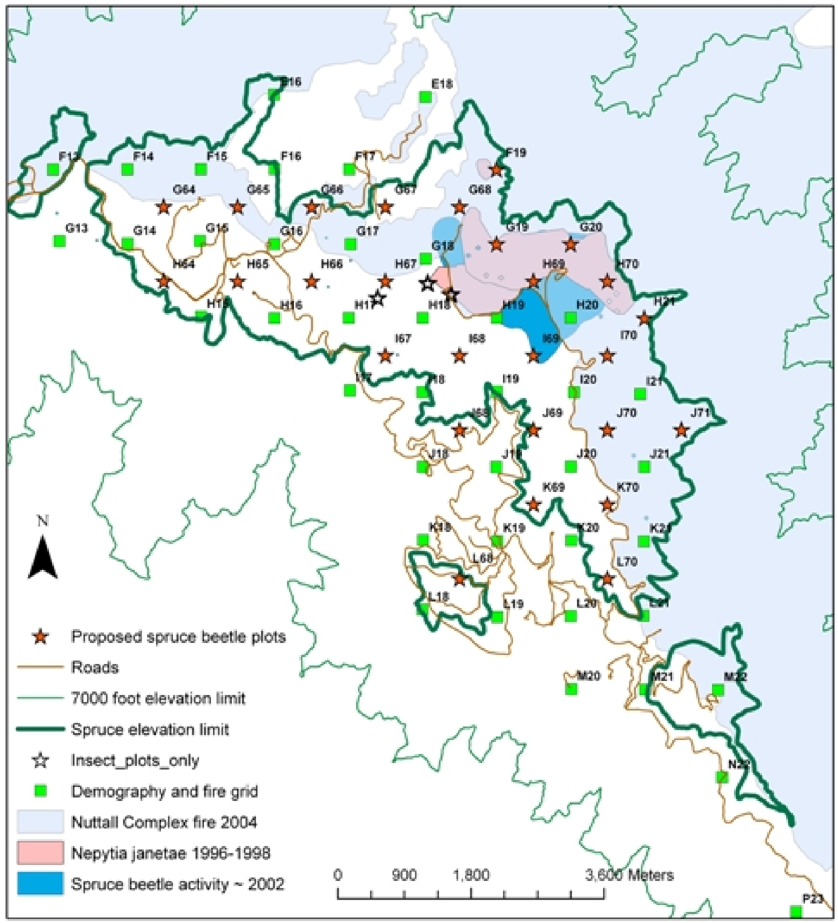


Figure 1. Proposed bark beetle sampling plots located in the spruce-fir forest of the Pinaleño Mountains. Red stars indicate additional plot locations to be added to the forest demography and fire sampling grid (green squares).