PROJECT SUMMARY

The Proposed Study

This doctoral dissertation research integrates ecological and dendrochronological methods to investigate the extent of natural and anthropogenic impacts on declining whitebark pine communities in Montana and Idaho. Whitebark pine is limited in distribution to high elevations in the mountains of western North America, where it has been present throughout most of the Holocene. Whitebark pine is considered a keystone species in mutualistic relationships that involve the caching of seeds by red squirrels and the dispersal of seeds by Clark's nutcrackers. These caches are a major food source for both grizzly bears and black bears, which rely on the seeds for up to two-thirds of their annual diet. The effects of 20th century fire suppression, periodic mountain pine beetle outbreaks, and white pine blister rust infestations, have led to a dramatic decline in whitebark pine communities throughout its native range. These factors, and a lack of research, have hindered the response of land managers to the dramatic decline in whitebark pine communities. Consequently, an urgency exists to implement management and restoration practices that will slow the succession of fire-intolerant species, and decrease the severity of decline in whitebark pine communities in western North America.

Intellectual Merit

Our project will be the first dendroecological research on whitebark pine that combines stand dynamics, disturbance regimes, and climate-forest health interactions in the northern Rocky Mountains. To understand the stand dynamics of whitebark pine populations, we will inventory the size, canopy class, and health of whitebark pine and associated species in overstory and understory fixed-radius plots. To obtain precise information on the disturbance regime and successional status of whitebark pine over the past few centuries, we will collect tree cores from all live and dead standing trees. This component will provide a temporal scale to the complex interactions in whitebark pine communities. The results of the dissertation research will answer theoretical forest succession and applied ecological questions: Is subalpine fir replacing whitebark pine due to the compounding effects of white pine blister rust, mountain pine beetle, and fire suppression during the 20th century? Is succession more rapid on mesic sites compared to xeric subalpine sites? Can we detect annual mortality dates of whitebark pine attributed to periodic mountain pine beetle epidemics and white pine blister rust infestations in the 20th century? And finally, using tree rings as a proxy, do linkages exist between climate and mountain pine beetle outbreaks or white pine blister rust intensity?

Broader Impacts of the Proposed Research

(1) *Benefits to society*- Currently, a combination of techniques that integrate the use of blister rust-resistant whitebark pine, prescribed fire, and forestry silvicultural techniques is being used to restore whitebark pine ecosystems. Whitebark pine dendroecological research is critical because land managers are currently making restoration decisions on limited ecological data from the 20th century. This keystone species will likely become extinct within the next two decades if restoration efforts are not successful, leading to a loss in biodiversity and population declines in grizzly bears, black bears, Clark's nutcrackers, and red squirrels.

(2) *Results disseminated broadly and collaboration with federal agencies*- This research addresses needs for restoration plans by the USDA Forest Service and the Whitebark Pine Ecosystem Foundation. The data from this dissertation research will be shared with the USDA Forest Service, the Whitebark Pine Ecosystem Foundation, and the International Tree-Ring Data Bank.

(3) *Promoting teaching, training, and learning*- Our project will be incorporated into educational programs for Tennessee kindergarten-12th grade students, senior citizen groups, and YMCA summer camps.

(4) *Participation of underrepresented groups*- The principal investigator of this research is female and we will continue to recruit underrepresented students to participate in the fieldwork and data analysis of this dissertation research.

PROJECT DESCRIPTION

1. Introduction

1.1 Doctoral Dissertation Research

This dissertation research investigates the ecology of whitebark pine communities using methods of stand dynamics and dendroecology, to provide a much-needed long-term record of disturbance and stand history in diminishing whitebark pine communities in western Montana and central Idaho. The impetus for this research is the growing concern by land management agencies over the ecological status of this keystone subalpine species.

1.2 The Ecological Status of Pinus albicaulis

Whitebark pine (*Pinus albicaulis* Engelm.) is a long-lived tree species that is found in many high elevation and subalpine forest communities of western North America (Arno and Hoff 1989). The species is restricted at its upper elevations by severe climate conditions and at lower elevations by competition from other tree species. It is a pioneer species that fills a crucial niche in watershed protection, catching and retaining snow, and stabilizing rock and soil in harsh and recently disturbed areas (Tomback *et al*. 2001).

Whitebark pine is also a food source of critical importance to Clark's nutcrackers (*Nucifraga columbiana*), red squirrels (*Tamiasciurus hudsonicus*), grizzly bears (*Ursus arctos*), and black bears (*Ursus americana*) (Mattson *et al*. 2001, Tomback 2001). Whitebark pine seeds are picked and cached by nutcrackers and squirrels, and bears rely upon these seed caches in the northern Rockies (Mattson *et al*. 2001). Cached seeds that escape predation are in turn a major source of regeneration for whitebark pine (Tomback *et al*. 2001). The availability of whitebark pine seeds directly influences the number of human conflicts with grizzly bears that result in management actions (Mattson and Reinhart 1986). During low seed crop years, more conflicts occur between grizzly bears and humans as well as high mortality rates of grizzly bears (Mattson and Reinhart 1986).

The combination of advancing encroachment by fire-intolerant species such as subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) and Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), infestation by mountain pine beetle (*Dendroctonus ponderosae* Hopk.), and the epidemic of white pine blister rust (*Cronartium ribicola* JC Fischer) have devastated whitebark pine populations north of 45°N latitude in western North America (Hoff *et al.* 2001, Kendall and Keane 2001, Tomback *et al.* 2001). Due to natural (mountain pine beetle) and anthropogenic (fire suppression and the introduction of white pine blister rust) impacts, the whitebark pine ecosystem of the northern Rockies is diminishing. If whitebark pine restoration efforts are not successful in the next 15–20 yrs, this species will become extinct (Tomback *et al.* 2001).

Ecologists recognize that natural disturbance cycles involving fire, wind, or pathogens are a normal part of most landscapes and that few ecosystems ever achieve a steady-state climax (White 1979, Bormann and Likens 1979, Christensen 1989). Tree reproduction in many forest ecosystems occurs in episodes associated with major disturbances. Thus, the distribution of ages in a population is often a sensitive indicator of the history of disturbance in a stand (Christensen 1989). Conventional models of succession show that whitebark pine dominates during early stages of succession and regenerates after stand-level fires that occur at long return intervals of 200 yrs or more (Fischer and Bradley 1987). The long lifespan (up to 1000 yrs) of whitebark pine makes it an important component of mid- and late-successional forests. Research shows that this ecosystem experiences both stand-replacing fires, which occur at long intervals and initiate forest succession, and low-severity surface fires, which occur throughout stand development and create and maintain an open canopy (Arno and Peterson 1983, Fischer and Bradley 1987). Stand replacing fires kill most trees and result in juvenile recruitment, which alters the age structure of the stand. Low severity fires produce fire scars on trees but do not dramatically change stand composition.

1.3 Biogeography of White Pine Blister Rust

White pine blister rust is an exotic pathogen first discovered in North America on a currant plant in Geneva, New York, in 1906, and it soon spread to the Great Lakes region and British Columbia. Eastern white pine seedlings that had been exposed to white pine blister rust were sold from tree nurseries in Germany and France to North America from 1890 to 1914 (Tomback *et al.* 2001). Blister rust first appeared on whitebark pine in the coastal range of British Columbia in 1926 and spread to northern Idaho by 1938 (Childs *et al.* 1938). Blanchard and Tattar (1997) report that white pine blister rust is now found throughout the entire range of five-needled pines in North America. Worsening the situation, whitebark pine is also the most vulnerable white pine species, with fewer than 1 in 10,000 trees showing resistance to blister rust (Kendall 1994). The range of whitebark pine affected by white pine blister rust is expanding and infection is intensifying.

White pine blister rust is a heteroecious rust fungi that produces several spore types and requires two host types to complete its life cycle (Blanchard and Tatter 1997, Bega 1978). White pine blister rust alternates between five-needle pines and *Ribes* species. The disease initially infests a tree through the needles and girdles branches, but can travel to the main stem, where it usually leads to girdling of the main stem and death of the tree. Currently, the degree of infestation of whitebark pine decreases southward throughout all parts of its range, including the Cascade-Sierra Nevada chain, the Bitterroot Mountains, and along the Continental Divide of the Rocky Mountains (Hoff 1992).

In Washington State, northern Idaho, northwest Montana, southern Alberta, and British Columbia, 40–100% of the whitebark pine are dead in most forest stands, and 50–100% of the live trees are infested with white pine blister rust (Tomback *et al.* 2001). Keane (1995) found that 98% of the whitebark pine communities in the Columbia River Basin have disappeared since the turn of the century. During a project to reconstruct landscape patterns of whitebark pine in western Montana, Arno *et al.* (1993) found that 14% of the stands were dominated by whitebark pine around 1900, but none of these stands were dominated by whitebark pine in the 1990's. Of the remaining live trees in these whitebark pine stands, 80% were infected with white pine blister rust, and more than one-third of their cone-bearing crowns were dead (Arno *et al*. 1993). Furthermore, the extent of forest stands with cone-bearing trees had declined by half. Because whitebark pine cones form in the top third of the tree (Kendall 1994), and blister rust kills from the top down, a tree's ability to produce seed is eliminated long before the tree dies.

1.4 Mountain Pine Beetle Ecology

Mountain pine beetle outbreaks have killed millions of *Pinus* trees over thousands of square kilometers in the northern Rockies during the 20th century (Romme *et al.* 1986). Extensive mountain pine beetle outbreaks in the northern Rockies occurred from 1920–1940 and 1970–1980 (Arno and Hoff 1989). The major hosts for mountain pine beetle include, in addition to whitebark pine, ponderosa pine (*Pinus ponderosa* Douglas ex C. Lawson), lodgepole pine (*Pinus contorta* Douglas ex Loudon), and western white pine (*Pinus monticola* Douglas ex D. Don). This native bark beetle constructs "J" shaped egg galleries in the infected tree's inner phloem. It is the phloem tissue that the larvae then feed on (Amman *et al.* 1989). The beetle galleries impede water and nutrient transport within the tree and can introduce a secondary pathogen, a blue staining fungus (*Ophiostoma* spp.) that clogs the sapwood of living trees (Kipfmueller and Swetnam 2002). The combination of beetle galleries and blue staining fungus girdles trees and cuts off nutrient flow, leading to the death of the tree. The beetles tend to selectively attack larger, older trees, which have a thicker phloem. Younger trees are usually not killed because they lack an adequate food supply for the beetles (Cole and Amman 1980).

1.5 Fire Suppression

Fire deters succession of fire intolerant tree species and maintains healthy, productive populations of whitebark pine. Changes in fire regimes due to fire exclusion have removed fire from this ecosystem, while increasing competition from fire-intolerant species such as subalpine fir and Engelmann spruce (Arno 1986, Tomback *et al.* 2001). Reintroducing fire into whitebark pine ecosystems is complicated because of abruptly changing weather patterns, scattered fuels, and short growing seasons. In the summer of 2003, wildfires burned many portions of Montana, including Glacier National Park, Flathead National Forest, Lolo National Forest, and Gallatin National Forest, and threatened many cities including Missoula, Butte, and Helena. These fires emphasize the urgency that exists among fire managers and ecologists to retrieve, analyze, and archive valuable dendroecological data now before wildfires permanently erase this information.

1.6 Research Objectives

Knowledge of the complex stand dynamics and stand history of whitebark pine ecosystems are essential to the long-term management and restoration of this declining keystone species. The primary objectives of our research are to:

1. Quantify the changing composition of whitebark pine communities in mesic and xeric sites and assess the successional status of subalpine fir and Engelmann spruce in subalpine areas historically dominated by whitebark pine.
2. Assess the long-term impacts of human-related (fire-suppression and the introduction of white pine blister rust) and natural (mountain pine beetle) disturbances in high-elevation whitebark pine ecosystems.
3. Reconstruct climate on a multi-century scale to determine the inter-relationships between climate change and anthropogenic and natural disturbance regimes present in whitebark pine ecosystems.
4. Evaluate the effects of blister rust, mountain pine beetle, and fire suppression in whitebark pine ecosystems on a landscape scale (study area ranging from central Idaho to western Montana).

2. Study Area

The fieldwork for this project will be conducted in the Lolo and Beaverhead-Deerlodge National Forests in western Montana and in the Boise National Forest in central Idaho (*Figure 1*). The highly irregular topography of the northern Rocky Mountains results in a wide range of weather conditions, as well as unique microclimates. Terrain ranges from rugged ridges and glacial features to gentle slopes.

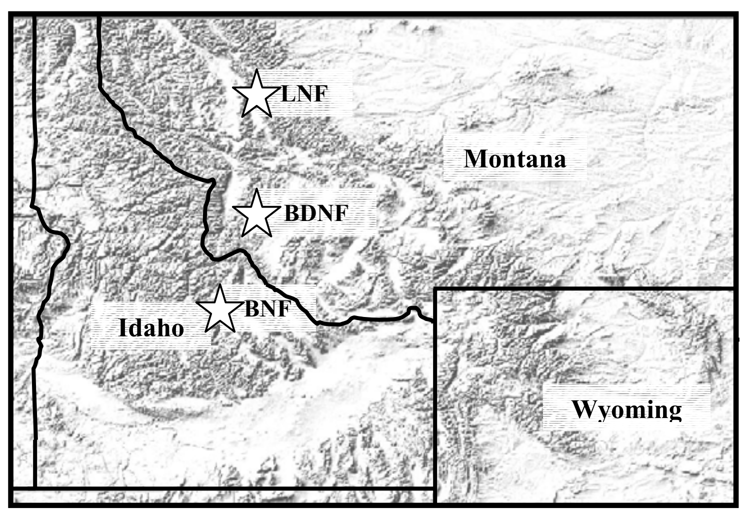

Figure 1. Study sites in the Lolo National Forest (LNF) and Beaverhead-Deerlodge National Forest(BDNF), Montana and Boise National Forest (BNF), Idaho. Map adapted from USGS (2004).

The Rocky Mountains provide a barrier to the flow of air across western North America and profoundly influence local climates. Our study areas are influenced by North Pacific weather patterns and are located in a transitional zone between continental and maritime climates (Arno and Hammerly 1984). Continental atmospheric patterns likely affect the relationship between the ecology of mountain pine beetles, white pine blister rust, and whitebark pine growth. The interacting feedbacks between these variables and climate are important for understanding changing ecosystems.

Tree species present in the high elevation (2000–3000 m above sea level) study areas include whitebark pine, lodgepole pine, subalpine fir, and Engelmann spruce. Whitebark pine occurs in open stands and small groups with other conifers in subalpine and treeline communities throughout the study area.

3. Methods

Objective 1. Quantify the changing composition of whitebark pine communities in mesic and xeric sites and assess the successional status of subalpine fir and Engelmann spruce in subalpine areas historically dominated by whitebark pine.

At each study site, we will quantify forest composition and structure using four 0.05 ha fixed-radius (r = 12.66 m) plots. We will sample three strata (vertical forest structure) of woody vegetation within each fixed-radius overstory plot. All trees greater than 5.0 cm in diameter at breast height (measured at 1.47 m) will be recorded by species and their dbh measured to the nearest 0.1 cm. Living tree crowns will be classified into four categories (dominant, co-dominant, intermediate, and suppressed), based on the amount and direction of intercepted light (Smith 1986). We will tally all saplings less than 5.0 cm in diameter but greater than 1.3 cm in diameter at ground level (dgl) in a nested 0.01 ha fixed radius (r = 5.66) plot. Seedlings (less than 1.3 cm dgl) will be tallied by species in the nested fixed-radius plots. A small number of subalpine fir saplings will be cut to determine age at ground level within each stand. We will record site characteristics such as percent slope and aspect at each overstory plot center. We will also record UTM coordinates using a GPS unit to map each study site. The length and width of dead woody debris within the overstory plots will be measured to calculate the basal area and accumulation of fire fuels on the forest floor.

We will determine whether succession is more rapid on mesic sites compared to xeric whitebark pine subalpine forests, using Euclidean distance to quantify changes in species composition through time between subalpine forest communities (Veblen *et al.* 1994). In addition, we will calculate relative dominance and relative density (Cottam and Curtis 1956), for each tree species to compare the importance of each species within a forest stand. Canopy class and diameter class distributions will also be calculated to compare both horizontal and vertical forest structure for all species at each site.

Objective 2. Assess the long-term impacts of anthropogenic (fire suppression and the introduction of white pine blister rust) and natural (mountain pine beetle) disturbances in high-elevation whitebark pine ecosystems.

Dendroecological techniques will help evaluate the age structure and tree-growth patterns to document changing stand conditions related to disturbance, stand development, or climatic variation (Payette *et al.* 1990, Foster *et al.* 1996). Dendroecological techniques can also help assess relationships between climate, site conditions, and tree growth to evaluate factors that influence the growth of a plant community (Cook and Kairiukstis 1989). Crossdating makes it possible to extend stand histories beyond one generation of trees or one major disturbance event by using narrow and wide ring-width patterns of living and dead trees (Foster *et al.* 1996). Crossdating consists of combined traditional techniques of skeleton plotting, a graphical technique of ring-width comparison (Stokes and Smiley 1968), and the use of a crossdating quality control program, COFECHA (Holmes 1983, Grissino-Mayer 2001).

Dendroecological techniques and analyses will be used to provide high-quality, temporally precise information on the ecological status of whitebark pine ecosystems. We will sample all live and standing dead trees in each plot for age using increment borers. Cores will be extracted 30 cm above ground level and multiple cores will be sampled to ensure they intercept or are near the pith. We will obtain two cores from each standing tree (healthy, declining, and dead) in each plot. Samples will be processed and prepared for dating using methods outlined in Stokes and Smiley (1968). We will measure ring widths with a Velmex measuring stage at 0.001 mm precision in conjunction with J2X software. These measurement series will then be statistically compared to ensure accurate crossdating using the computer program COFECHA (Holmes 1983, Grissino-Mayer 2001). We will standardize and combine tree-ring measurements into a master chronology using the software package ARSTAN (Cook 1985). We will date standing snags by crossdating each unknown sample with the master chronology derived from live trees, specific for each species and stand. The outermost ring of each increment core from these standing snags will provide an estimate of the year of tree death (Daniels *et al*. 2004).

Forest stand dynamics and disturbance patterns can be inferred from suppression-release patterns in tree rings (Brubaker 1987). To quantify the extent of the disturbance (fire, mountain pine beetle, or white pine blister rust) on stand and landscape scales, we will calculate releases of tree growth over time in our whitebark pine chronologies. The occurrence of releases in trees within and between study sites can identify the disturbance as either a regionally extensive or localized disturbance event (Veblen *et al.* 1994). Individual disturbance events will later be disentangled by inspecting tree cores for blue stain fungus from mountain pine beetle outbreaks and by finding declines in tree growth over a number of decades, indicating a possible white pine blister rust infestation. We will calculate minor and moderate release events, which are defined as changes in growth with respect to subsequent 10-yr growth periods (McCarthy and Bailey 1996, Nowacki and Abrams 1997, Schuler and Fajvan 1999) using a percent growth change equation:

$$\% \text{ GC} = ((\text{M2} - \text{M1}) / \text{M1}) * 100$$

where % GC is percent growth change from preceding to superceding 10-yr radial means, M1 is the preceding 10-yr mean radial growth (exclusive of the current year), and M2 is the superceding 10-yr mean radial growth (inclusive of the current year) (Schuler 1999). Major releases will be calculated using the same formula, except radial growth will be measured over a 15-yr period. Major releases will have a percent growth change over 100% for 15 yrs, moderate releases will have a percent growth change over 50% for 10 yrs, and minor releases will have a growth change greater than 25% for 10 yrs.

Objective 3. Reconstruct climate on a multi-century scale to determine the relationship of climate to the anthropogenic and natural disturbance regimes present in whitebark pine ecosystems

Meteorological data (temperature, precipitation, and the derived Palmer Drought Severity Index) for the past 110 yrs in the central mountain regions of Montana and Idaho are available from the National Climatic Data Center in Asheville, North Carolina. We will use these data for climate analysis of the whitebark pine and subalpine fir master chronologies. We will conduct response function and correlation analysis with state divisional climate records to assess whitebark pine and subalpine fir annual ring-width response to monthly average temperature, total monthly precipitation, and monthly Palmer Drought Severity Indices (PDSI) from 1895–2004 (Grissino-Mayer 1996). Lagged variables will also be created to calculate the relationship between ring width and temperature, precipitation, and PDSI in the previous year. PDSI is calculated using temperature and rainfall information in a formula designed to determine drought conditions.

To measure the preconditioning effects of monthly climate data on tree growth, we will use the program PRECON (Fritts and Shashkin 1995). PRECON is software that statistically analyzes the relationship between climate and tree-ring variation. Tree-ring chronology data are calibrated with site-specific regional or local monthly climate data using stepwise multiple regression, bootstrapped response function analysis, correlation analysis, and a Palmer Drought Severity Index growth model (Fritts and Shashkin 1995). Quantifying the preconditioning effects of climate on tree growth will help clarify the variance explained by climate versus anthropogenic and natural disturbance regimes.

Moisture stress is widely regarded as an important contributor to conifer mortality from bark beetles (Craighead 1925, Thomson and Shrimpton 1984, Safranyik 1989). Rapid beetle population expansion can be caused by a drought over a large area that predisposes forest stands to beetle attacks (Safranyik 1989). Extensive mountain pine beetle outbreaks have occurred historically in our study sites from 1920–1940 and 1970–1980 (Arno and Hoff 1989). We will use correlation and regression techniques to determine the strength of temperature, precipitation, and PDSI variables on mountain pine beetle-induced mortality in the 20th century.

Objective 4: Evaluate the effects of blister rust, mountain pine beetle, and fire suppression in whitebark pine ecosystems on a landscape scale in a study area ranging from sites in central Idaho (Boise National Forest) to sites in western Montana (Beaverhead-Deerlodge and Lolo National Forests).

By evaluating both live and dead trees, we will address both theoretical and applied ecological concepts that will help land management agencies achieve restoration goals. For all live, declining, and dead whitebark pine trees, we will note the presence or absence of mountain pine beetle galleries in the phloem on the stems of the trees in each plot. We will later examine tree cores from live, declining, and dead trees for the presence of blue stain fungus, which is inoculated by the mountain pine beetle (Daniels *et al.* 2004). If blue stain fungus is found in the tree cores, the death of the tree was caused during a mountain pine beetle outbreak.

The presence of white pine blister rust will be evaluated on the health of tree crowns (brown needles, flag branches), and on the presence of cankers on the branches and stems of whitebark pine, following the methods of the Whitebark Pine Ecosystem Foundation (WPEF 2004). We will compare sites that are heavily infested with white pine blister rust (Lolo National Forest) to stands where white pine blister rust is absent (Beaverhead-Deerlodge and Boise National Forests) to determine if there is a unique tree-ring pattern indicating when white pine blister rust first became present within the forest stands.

4. Preliminary Results

During a two-week research trip in June 2004, I led an expedition with two fellow graduate students to collect forest composition and tree-ring data in four whitebark pine-dominated stands in the Lolo and Beaverhead-Deerlodge National Forests. We cored over 500 trees and inventoried seven overstory plots, but were unable to collect data on a more comprehensive spatial scale due to lack of funding and time constraints.

In a 2003 pilot study, we found that whitebark pine in Montana are sensitive to disturbance and environmental change as shown by the variability in growth in many of our whitebark pine cross-sections. We conducted a preliminary dendroecological assessment of 20 cross-sections taken from whitebark pine stumps and snags at Morrell Mountain in the Lolo National Forest, Montana. This initial chronology provides dendroecological information for the past 475 years and has the potential to greatly improve our understanding of disturbance regimes in whitebark pine communities. The whitebark pine master tree-ring chronology (N=20) ring-width index (RWI) values ranged from 0.392 to 1.484 from 1507–1982 (*Figure 2*). The interseries correlation between the whitebark pine series (samples) was 0.522 with an average mean sensitivity of 0.242, both strong values when compared to other research in high mountain ecosystems (*e.g*. LaMarche 1974, Perkins and Swetnam 1996), suggesting whitebark pine, as a species, is likely to be sensitive to disturbance events and environmental change.

We found a strong decrease in radial growth in the past 50 years in many of the whitebark pine samples (*Figure 2*) which may be caused by several exogenous disturbances, including mountain pine beetle outbreaks, blue stain fungus, and white pine blister rust (McDonald and Hoff 2001, Kendall and Keane

2001), but more data are required to determine the landscape level impacts of these disturbance agents. We hope to investigate this decline in whitebark pine growth with other sites in the Lolo, Beaverhead-Deerlodge, and Boise National Forests to investigate the spatial scale of this pattern. We can determine whether the growth decline is caused by white pine blister rust by comparing the last 50 years of growth with our subalpine fir chronologies, which would not exhibit this pattern. The unique 50-year tree-ring pattern in our samples is the first whitebark pine study to record this growth decline in western North America.

Our successful dating of these high-elevation samples indicates that whitebark pine is a viable species to use in dendroecological reconstructions of past disturbances and environments. Using this species as a proxy, we will be able to build a more spatially comprehensive disturbance history of whitebark pine at both the stand and landscape levels in the northern Rockies.

Our whitebark pine samples were also significantly correlated ($p < 0.01$) to the Palmer Drought Severity Index (PDSI) from the previous/current year's winter. Over the past century, whitebark pine in Montana appear to be responding primarily to snowpack conditions during the previous December. The significant relationship found between whitebark pine growth and PDSI may help clarify how climate relates to the ecology of whitebark pine ecosystems (including mountain pine beetle outbreaks and the white pine blister rust disease cycle). My dissertation research will expand on the climate reconstruction research of whitebark pine by comparing the climate-forest health interactions of this threatened subalpine species on a multi-century scale. Further research and analysis will provide a regional dendroecological comparison between our study sites in western Montana and central Idaho to sites in Idaho investigated by Perkins and Swetnam (1996).

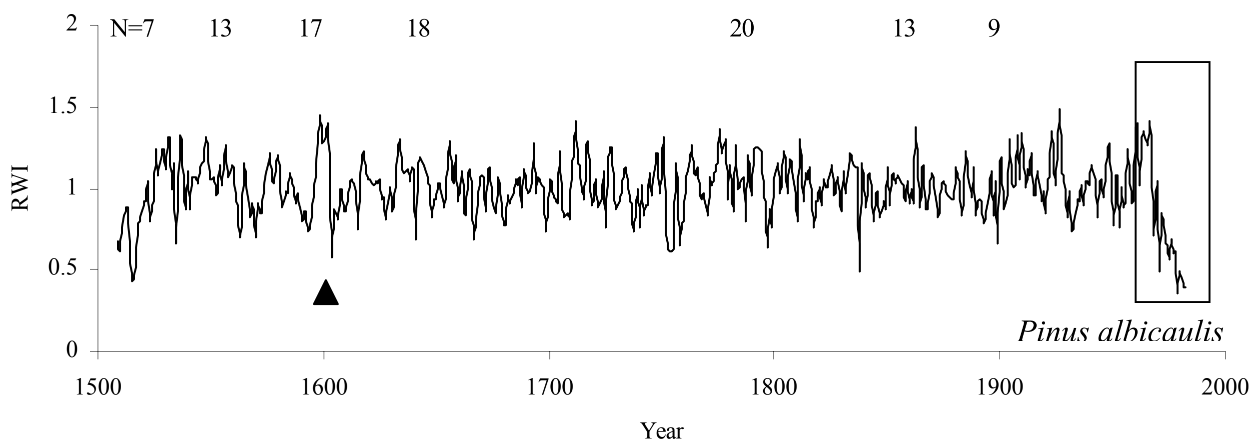

Figure 2. Master whitebark pine chronology from 1507-1982. Sample depth (N) throughout the 475-year chronology. ▲indicates the 1601 frost ring, which is a marker ring found in whitebark pine chronologies in the northern Rockies (Perkins and Swetnam 1996, Kipfmueller 2003). The boxed area highlights the recent 50-year decline in growth found in our samples.

5. Research Structure

Leading USDA Forest Service researchers from Missoula, Montana, approached Henri Grissino-Mayer at the 2003 North American Dendroecological Fieldweek to encourage a dendroecological investigation of this keystone species. While I attended "Monitoring Whitebark Pine for Blister Rust: A Methods Workshop," held by the Whitebark Pine Ecosystem Foundation and in West Yellowstone in 2004, I interacted with ecologists, foresters, and researchers from Montana and Idaho who offered advice, resources, and research sites for further whitebark pine ecological research. Communication channels and research logistics are established with USDA Forest Service researchers and ecologists in the Lolo, Beaverhead-Deerlodge, and Boise National Forests. Over the next two summers, it is feasible to inventory and core trees in 32 plots (eight whitebark pine-dominated stands with four plots in each) in Montana and Idaho.

Working closely with Federal Cooperators from the USDA Forest Service and the Whitebark Pine Ecosystem Foundation, I will select and investigate eight whitebark pine-dominated stands growing at 2000–3000 m elevation in the Lolo, Beaverhead-Deerlodge, and Boise National Forests. I have been in contact with USDA Forest Service researchers and ecologists since January 2004, developing plans for accessible research locations, expedition accommodations, and research logistics. In the Lolo National Forest, Bob Keane (Research Ecologist, Rocky Mountain Research Station) suggested three research sites that are located on remote mountain peaks accessible only by using 4-wheel drive vehicles on unimproved Forest Service roads. Cathy Stewart (Fire Ecologist, Lolo National Forest) signed our research permits and acquired necessary keys for access to these remote locations. Elaine Kennedy Sutherland (Research Biologist and Project Leader, Rocky Mountain Research Station) provided registration fees for me to attend "Monitoring Whitebark Pine for Blister Rust: A Methods Workshop," sponsored by the Whitebark Pine Ecosystem Foundation, in West Yellowstone, from June 28–29, 2004. Diane Hutton (Fire Management Officer, Beaverhead-Deerlodge National Forest) allowed us to use Forest Service housing and took me to research sites, some of which have been devastated by mountain pine beetle outbreaks in the Beaverhead-Deerlodge National Forest.

This Doctoral Dissertation Research Improvement Grant would fund two research expeditions totaling six weeks of fieldwork in July 2005 and July 2006 (*Table 1*). I would use the requested funds to cover travel for two graduate field assistants and myself during both expeditions. Our research sites are isolated and located in an area of rugged terrain with unpredictable mountain weather. We often hike 6–12 km a day, in mountain weather, with an elevation change of at least 500 m. Although the fieldwork is challenging, we are able to maximize our time in the field by camping on site and by being ready for intense fieldwork. With a three-person team, we can core 80 trees and inventory at least one overstory plot per field day. In June 2004, we conducted fieldwork for three days at each research site in the Lolo National Forest. In the Beaverhead-Deerlodge National Forest, Diane Hutton supplied us with free housing in Forest Service cabins and has promised to continue supporting us over the next two summers. We intend to expand our study into other subalpine sites in the Lolo, Beaverhead-Deerlodge, and Boise National Forests to develop a better understanding of the spatio-temporal dynamics of changes in the disturbance regimes of whitebark pine communities.

Table 1. Research schedule from 2005 – 2007.

Research Activity	SU 2005	FA 2005	WI 2006	SP 2006	SU 2006	FA 2006	WI 2007	SP 2007	SU 2007	FA 2007
Stand and Tree-Ring Data Collection	X ***				X					
Process Wood Samples	X	X			X	X				
Measure Samples		X				X				
Chronology Development			X				X			
Statistical Analysis of Stand Data			X				X			
Conference Presentations				X	X			X		
Write Dissertation								X	X***	
Submit Dissertation										X

***Beginning and end of DDR NSF funds (24 months)

6. Research Significance and Intellectual Merit

The longevity of whitebark pine trees provides an opportunity for temporally extensive tree-ring reconstructions of past disturbance regimes and ecological events. In addition, the sensitivity of many subalpine species to changes in their environment suggests whitebark pine may also be an excellent indicator of global climate change (LaMarche and Stockton 1974, Fritts 1976). The annual nature of tree-ring formation and the ability to statistically link tree growth with climate are important tools for understanding climate variability on a temporal scale (Kipfmueller 2003). Perkins and Swetnam (1996) successfully built a whitebark pine tree-ring chronology back to the 10th century, and while they found their samples difficult to date, they suggest that whitebark pine could be used to relate disturbance regimes and climate on a multi-millennial scale. This project will be the first dendroecological research on whitebark pine that combines stand dynamics, disturbance regimes, and climate-forest health interactions in the northern Rocky Mountains. The combined results of stand and tree-ring data will provide a much-needed long-term record of disturbance history in whitebark pine ecosystems in Montana and Idaho.

The University of Tennessee's Laboratory of Tree-Ring Science (LTRS), directed by Drs. Henri Grissino-Mayer, Sally Horn, and Ken Orvis, is internationally recognized as one of the leading and best-equipped dendrochronological research facilities in the United States. The laboratory is funded by the Department of Geography and the College of Arts and Sciences, and external research grants. Dendrochronological research conducted in the LTRS involves both human and natural processes that affect the environment, and has produced successful projects that include archaeology, fire history, and climate reconstruction.

7. Broader Impacts of the Research

7.1 Benefits to society- This investigation was undertaken because of a need for a better ecological understanding of declining whitebark pine ecosystems. Whitebark pine restoration efforts must succeed in the next 15–20 years in order for this species to avoid extinction, which would dramatically impact wildlife species such as the grizzly bear, black bear, Clark's nutcracker, and the red squirrel. Quantitative information on the complex stand dynamics and dendroecology of whitebark pine ecosystems are essential to the long-term management and restoration of this declining keystone species. Whitebark pine dendroecological research is important because land managers are currently making restoration decisions based on limited ecological data from the 20th century.

7.2 Results disseminated broadly and collaboration with federal agencies- Whitebark pine stand data will be shared with the Whitebark Pine Ecosystem Foundation to add to their newly-developed white pine blister rust survey data across western North America. We will provide copies of all data to the USDA Forest Service and the Whitebark Pine Ecosystem Foundation. Tree-ring data in the form of raw tree-ring measurements and chronologies will be submitted to the International Tree-Ring Data Bank (ITRDB), which is one of the premier paleoclimatic databases in the world. The ITRDB contains measurements and tree-ring chronologies for over 100 tree species from over 1500 sites around the world. This website allows researchers to easily access and download one or more of these data sets to use in dendrochronological studies. Our tree-ring data will add needed data points to the paleoclimate record in North America.

7.3 Promoting teaching, training, and learning- We will present our research findings at annual meetings of the Whitebark Pine Ecosystem Foundation and at the 7th International Conference of Dendrochronology which will be held in June 2006, in Beijing, China. Data collected during this research project will have a broad impact on not only the scientific community, but on public outreach programs in Tennessee as well. Locally, information gathered from this research will be integrated into programs run by the Tennessee Geographic Alliance and will be presented to a variety of audiences including kindergarten–12th grade students, senior citizen groups, and local summer camps (YMCA). This year, I am the Coordinator of Geographic Awareness Week (GAW) at the University of Tennessee through the Tennessee Geographic Alliance. GAW is a national program sponsored by The National Geographic Society to increase kindergarten-12th grade student awareness of geography-related issues. I will also be a guide for the Tennessee Geographic Alliance at the University of Tennessee Earth and Science Fair (7th-12th grade students) in October. I have participated in outreach tree-ring programs organized through the Laboratory of Tree-Ring Science (LTRS). This summer I helped teach students (ages 8–16) at a YMCA summer camp how to use tree rings as a proxy to study fire, climate, and land-use change. I will continue to participate in outreach programs and will incorporate our research on endangered whitebark pine ecosystems into these interpretive programs.

7.4 Participation of underrepresented groups- This dissertation research is being conducted by a female Ph.D. student who has extensive field experience. Saskia van de Gevel has served as mentor and field supervisor to ten field assistants during her graduate career at Southern Illinois University and the University of Tennessee. We will continue to recruit underrepresented students to participate in the fieldwork and data analysis of this dissertation research. We will also try to involve underrepresented students during this research from the department's Research Experiences for Undergraduates course.

Results from Prior NSF Support: Henri D. Grissino-Mayer

BCS-9809245: *Historic expansion of western juniper on near-relict sites: a dendroecological approach*, 1998–2001, $190,376. Co-PIs: Dr. Paul A. Knapp, Department of Anthropology and Geography, Georgia State University, and Dr. Peter T. Soulé, Department of Geography and Planning, Appalachian State University. Our primary objective was to determine mechanisms responsible for changes in western juniper establishment, expansion, and growth rates in relict and near-relict sites of central and southern Oregon. Our study investigated the competing roles of land-use history, climate, biological inertia, human and natural disturbances, and elevated CO_2 on western juniper forests. This study was designed to determine if western juniper trees growing under natural conditions were responding to CO_2 fertilization. Our results have been disseminated at regional and national meetings and in several peer-reviewed journals, including *Geophysical Research Letters*, *Global Change Biology*, *Quaternary Research*, *Professional Geographer*, *Journal of Climate*, and *Ecological Applications*.

BCS-0327280: *Oxygen isotope compositions of tree-ring cellulose as a high-resolution proxy record of hurricane activity*, 2003–2005, $149,999. Co-PI: Dr. Claudia I. Mora, Department of Earth and Planetary Sciences, University of Tennessee. This research currently investigates the potential use of oxygen isotope ratios of alpha cellulose in tree rings of yellow pines from southern Georgia and South Carolina as a proxy record of hurricane activity. We've developed a 227-year record of oxygen isotope compositions of alpha cellulose in slash and longleaf pine tree rings that preserves evidence of past tropical cyclone activity, seasonal droughts, and multidecadal climate oscillations and suggests the potential for a detailed record of tropical cyclone occurrence extending back many centuries. The trends in hurricane frequency closely track changes in larger-scale ocean-atmosphere circulation features, especially the North Atlantic Oscillation, which we believe may significantly moderate hurriance activity. We've presented our initial findings at national meetings, including the Association of American Geographers, the American Geophysical Union, and the Geological Society of America, and our first manuscript was recently accepted by the journal *Geology*.

BCS-0242155: *Establishing a multi-century, annual-resolution climate record from the northeastern Caribbean*, 2003–2005, $153,072. Co-PIs: Dr. Kennth H. Orvis and Dr. Sally P. Horn, Department of Geography, University of Tennessee. This research project builds on the finding that *Pinus occidentalis* Swartz, the native pine of the Caribbean island of Hispaniola, produces excellent tree rings that are moisture and temperature sensitive. Initial analyses, primarily of younger samples, has yielded a well-replicated master chronology dating to the late 1800s and continuous, non-crossdated records to the late 1500s. Many older samples remain to be analyzed. The chronology correlates positively ($r = 0.44$, $p \leq 0.001$, $n = 51$) with January–March (late dormant season) rainfall days on the windward mountain flank, and negatively ($r = -0.46$, $p < 0.001$, $n = 50$) with February–June (early growing season) temperature on the leeward flank. The latter represents, to our knowledge, the first tropical-region dendroclimatological temperature record. The primary signal apparently reflects the timing of onset of the rainy season, which is very likely teleconnected to large-scale global climate oscillations.

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