Study Plan, Sierra Nevada Research Center
vs 2.06.07

1. Project Title

1000 years of forest history in the Glass Creek Watershed, eastern Sierra Nevada

Interpreting the influence of fire, climatic change, and environmental change on subalpine forest structure and composition

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Review
Original proposals were reviewed (anonymously) and funded by USFS PSW Regional Office, Ecosystem Staff ($24.3K) 1997, and PSW Internal Competitive Grant ($20k) 1998

2. Problem Reference
Sierra Nevada Research Center RWUD:
Problem 3: Climate and Landscape Change

Specific goals of Problem 3 include:

- Evaluate climate-induced changes in species composition, range distributions, forest structure, and function at century scales in the high Sierra Nevada

- Identify the role and magnitude of climate as an ecological architect relative to other landscape forces

- Provide meaningful and useful interpretations and applications to ecological restoration, conservation and management

3. Literature Review and Background
Climate change and its effects on ecosystems are key current topics of ecological research and pressing challenges for natural-resource management and conservation (Millar and Brubaker, in press; Millar, 2004; Millar & Woolfenden, 2001, 1999a, b). Despite the anthropogenic component to current climate change, pre-historic, “natural” climate change and associated ecological responses afford critical context for understanding the range of natural variability and the dynamics of forest systems. Climate change has been little comprehended as a natural driver of ecological change, and misassumptions abound of effects being simple, linear, and equilibrium responses. Increased understanding of climate’s role as a “macro-disturbance” agent will enable better estimates of future impacts on forests, and improved forest management planning in the Sierra Nevada and elsewhere.
To assess the relative influence of climate requires that its effect be partitioned from fire and other natural disturbances as well as human land-uses. We are undertaking an integrative watershed-scale forest-history study of the upper Glass Creek watershed as part of a larger set of studies in this area that seek to understand the nature of forest response to climate. The purpose of the current study is to reconstruct the forest history of the upper Glass Creek watershed as a means of evaluating the relative ecological influences driving dynamics in a typical montane eastside mixed conifer forest. Related studies in the Glass Creek Watershed and adjacent areas include:

1) elucidation of climate-driven lodgepole pine (*Pinus contorta*) colonization of montane meadows and former snowfield openings (Millar et al., 2004a);
2) development of a 3500-year climate chronology and age-class/demographic reconstruction of limber pine (*Pinus flexilis*) (Millar et al., 2004b, c);
3) identification and dating of a “ghost forest” perched discontinuously above current treeline that includes species no longer growing in the eastern Sierra and growth forms/rates no longer extant (Millar et al., in prep; 2004b, c);
4) high-accuracy dating of the last Glass Creek eruption (Inyo Crater chain) by tree-ring analysis (Millar et al., in prep; 2004b, c);
5) interpretation of 3000 years of floristic and fire history from pollen and charcoal in sediment cores from Glass Creek Meadow (Woolfenden, 2003).

While fire, insect, and disease do not appear to have significantly influenced subalpine forest development in the upper elevations of our study area, making climate signals easier to detect, successional disturbances are confounding in mid-elevation forests of the watershed. To partition the relative influence of climate on these mid-elevation forests, therefore, we must also understand the role of fire in forests that include western white pine (*P. monticola*); mixed Jeffrey pine (*P. jeffreyi*)/lodgepole pine/western white pine/red fir (*A. magnifica*); and pure Jeffrey pine. Limited and mostly anecdotal fire-history information is available for these eastside forest types. A small study of fire-history in the Glass Creek watershed from fire-scarred trees (Stephens, unpublished: primarily lodgepole pine, *P. contorta*) and in the Jeffrey pine forests at lowest elevations (King, unpublished report) in the watershed revealed a complex and variable fire-pattern (Fig. 1). This suggests the need for intensive study of fire history as part of reconstructing the dynamics of the upper Glass Creek watershed mixed conifer forest.

![Figure 1](image.png)

Figure 1. Fire scars from preliminary study of mixed Jeffrey pine/fir in the Obsidian Dome region, below upper Glass Creek watershed. Live trees sampled in a 60 ha area yielded a 400-year growth record and a relatively asynchronous fire record. Although fire scars were collected from both old-growth live trees with external fire scar evidence, and from stumps (1960s harvests), all fire scars were found to fall between 1813 and 1881. Contrary to expectation, some of the fires appear to have occurred during the early growing season. From: Unpublished pilot study. John King, 2003.

Charcoal analyses from sediment cores complement fire-scar studies in reconstructing past fire regimes. Our preliminary analysis of charcoal in sediment cores taken from Glass Creek meadow (Woolfenden, 2003) indicates a range of fire inputs from forests both near and distant to the meadow.
Study Area

Location & Land-Use History
The upper Glass Creek watershed (Mono County) lies along the eastern escarpment of the Sierra Nevada, California, and, together with Deadman Creek watershed, composes the headwaters of the Owens River. (Fig. 2). Elevations range from 3536 m at San Joaquin Mtn to 2670 m at the base of Glass Creek Meadow. San Joaquin Ridge forms the Sierra crest locally, and is a relatively low pass (at Minaret Summit, elev 2764 m) between east-flowing Owens River and west-flowing Middle Fork of the San Joaquin River. Whitewing Mtn (elev. 3051m) is a distinct, flat-topped peak that projects eastward from the main Sierran crest.

![Figure 2. Overview map of the study area. Glass Creek meadow and watershed (northern headwaters of the Owens River) are south of June Lake, CA.](image)

The Glass Creek Watershed has been the focus of a series of intensive ecosystem management projects by the Inyo National Forest (INF) over the last decade. Through collaboration with national forest staff, we use Glass Creek watershed as a model landscape unit for integrating historic and climate research into national forest management, a decision that led to the area being chosen as one of five case studies in the Sierra Nevada Ecosystem Project (Millar, 1996, Millar & Woolfenden, 1999a). The INF landscape analysis for this area (USFS, 1997), in which we participated, emphasized restoration of pre-European forest structure and disturbance regimes. This goal is brought forward in the current INF Scenic-Deadman Ecosystem Health Project (USFS, 2003). That project proposes a 20-year, 7,000 ha fuel reduction program using SN Forest Plan Amendment treatments (DFPZs and SPLATs), and includes the three forest types adjacent to the Glass Creek watershed (western white pine, mixed pine/fir, and Jeffrey pine. The primary purpose of the Ecosystem Health Project is to treat fuels through the use of prescribed fire with a goal of restoring fire regimes and forest structures more characteristic of historical conditions. Our continuing research in the Glass Creek Watershed assists the INF in determining appropriate goals for conservation and restoration, and more broadly, clarifies the value of incorporating climate dynamics in restoration planning.

The Glass Creek watershed also includes areas that have long been under consideration as Research Natural Area (Cheng, 2004), and thus, our studies assist in the review and information base of these candidate areas.

Current Forest Types
Plant communities in the Glass Creek watershed follow typical eastern Sierra elevational zonation, with local variations on limits. Tundra vegetation occurs above 2990 m on San Joaquin Ridge and Whitewing Mtn. and includes diverse shrub and herb assemblages above treeline. Bare rock dominates over plant cover. Below this is the whitebark pine (*Pinus albicaulis*) forest type, which extends from local treeline at
2700 m to 2990 m. The lower two-thirds of the whitebark pine type comprise upright trees that form dense clusters and occasionally continuous forest canopies. These grade into a broad zone of shrub (krummholz) form of whitebark pine that extends to treeline. Occasional outliers of whitebark pine occur above the general treeline in sheltered areas around rocky outcrops. Locally these occur on the slopes below the summits of Whitewing Mtn and San Joaquin Ridge. Because of the cold climate, the scattered tree growth, limited ground fuels, and co-occurrence of lightning with precipitation, fire is ecologically unimportant in this zone.

Mixed subalpine forest assemblages occur below the whitebark pine zone. These vary over space as a result of ecological tolerances of the species that grow in this elevation zone. The subalpine types include varying proportions of western white pine (*P. monticola*), lodgepole pine (*P. contorta*), limber pine (*P. flexilis*), mountain hemlock (*Tsuga heterophylla*), and red fir (*Abies magnifica*). In the Glass Creek watershed, assemblages include the lodgepole pine/red fir/mountain hemlock type (elevation range: 2750-2880 m). Given that red fir is a common dominant species in forest types of the western Sierra Nevada, its presence and extensive cover in the Owens River headwaters region are unusual in the eastern Sierra Nevada. This situation appears to result from the low Sierran gap of the San Joaquin Ridge, which provides access for wet Pacific storms to cross the divide, and also serves as a west-east biogeographic corridor. The limber pine forest in the region is a rare outlier limited to one small population on the granite slopes of North Point, which forms the northern ridge of the watershed, at elevations from 2680-2990 m. Lodgepole pine/whitebark pine forests grow from 2450 – 2700 m in the region, and form the lowest of the subalpine types. The role of fire in the subalpine types varies by site and tree/fuel conditions, and ranges from significant (lodgepole pine) to minor and localized (upper elevations).

The subalpine forests grade into Jeffrey pine (*Pinus jeffreyi*) type, which grows from 2300-2600 m. These forests are unusually extensive in Mammoth-Mono region, again assumed to result from passage of storms and propagules across the relatively low San Joaquin crest. Pinyon pine woodlands (*P. monophylla*) forms the lowest elevation forest type, at elevations from about 2500 m and extending to 1500 m in the western Great Basin. Fire is naturally common in these forest types.

**Climate**

The contemporary climate of the Glass Creek Watershed is montane Mediterranean with long dry summers and cool winters. Precipitation occurs primarily in winter from Pacific frontal storms that move eastward depositing snow orographically over the western Sierra. Gradients of precipitation and temperature are steep and the eastern slopes of the Sierra Nevada generally are in a rainshadow. The position of the Glass Creek watershed relative to the low San Joaquin Ridge crest, however, allows moisture-laden clouds to move farther east at this latitude than elsewhere along the range. Summer moisture occurs sporadically from Gulf-origin monsoon influence, which reaches near its northern limit in this area. Summer temperatures range from warm/moderate at high elevations to hot east of the crest; atmospheric humidities are very low throughout the region. The closest weather station is at Lee Vining, CA (37 57N, 119 07W, elev 2097 m), 285 m lower than the base of the watershed. Thirty-year averages for several climate variables are available from this station (WRCC, 2004) as are modeled data (PRISM, Daly et al., 1994) for the Glass Creek watershed general area.

The primary time of interest for paleoclimate in this study is the last 1000 years. The early part of this period is known as a time of significant global climate change, known as the Medieval Climatic Anomaly (MCA). Whereas many parts of the world experienced deviations up to 1°C warmer during this time, the primary effect in the Sierra Nevada appears to have been decreased available moisture for plants, although it is not clear what the interaction with temperature and snowpack retention was. Stine documented two extensive droughts, at AD 900-1112 and AD 1200-1350 (Stine 1994), evident in the central and eastern Sierra. Climate models derived from tree-ring variability in the southern Sierra Nevada indicate that temperatures were slightly warmer than average during this time (Graumlich 1993). Our work modeling climates based on the intersection of climate space for the species found on Whitewing Mtn during the MCA indicates that, relative to present, the MCA period was much warmer and wetter, especially in winter (Westfall and Millar 2004). Although ecosystem responses in the Sierra Nevada to MCA have not been widely studied, those documented suggest changes in fire regime...
(Swetnam 1993), treeline elevation, and tree growth (Graumlich and Lloyd 1996), and increases in abundance of firs (Abies) in high-elevation communities (Anderson 1990).

The MCA ended abruptly in the late 1300s, as climates cooled globally during a five-century period (AD 1400-1900) known as the Little Ice Age (LIA). In the Sierra Nevada significant glacial advances (Clark and Gillespie 1997) and reversals in some of the ecosystem responses (Lloyd and Graumlich 1997; Anderson 1990; 1993; Swetnam 1993) characterized the LIA. Twentieth century warming has been widely documented worldwide as well as in western North America and the Sierra Nevada (Millar et al., 2004a). In general, the century reflects a rebound from the LIA, with increasing temperatures, especially minimum temperatures, and increased precipitation. Notable also in the 20th-century are increases in extreme climate events, including those related to the ENSO cycle as well as multi-decadal modes such as the Pacific Decadal Oscillation (Millar et al., 2004a).

**Geologic Context and Volcanism**

Cenozoic granitics underlie most of Whitewing Mtn, together with small areas of Tertiary volcanics that underlie all of San Joaquin Ridge. Thick deposits of Quaternary tephras dominate all but a few surfaces of the watershed. These derive from episodic eruptions of the adjacent Mono Craters and Inyo Craters chains. Related to the Long Valley volcanic system and east-west crustal extension, the two chains consist of multiple magmatic and phreatic eruptive centers, each about 15 km long, and aligned along north-south trending fractures that extend from near Mammoth Mtn across the Long Valley caldera rim to Mono Lake (Fig. 2). The relatively uniform rhyolitic lavas formed a series of eruption episodes that date from ca 30,000 yrs to 640 yrs and younger (related island eruptions in Mono Lake eruptions dated ca 140-220 ypb) (Wood, 1984; Sieh and Bursick 1986).

Eruption centers adjacent to the Glass Creek watershed include vents of the northern Inyo Craters: Wilson Butte, Obsidian Dome, Glass Creek Flow, North and South Deadman Flow, and their subsidiary vents. The three most recent eruptive episodes occurred ca 6,000 yrs ago, ca 1250-1400 yrs ago, and ca 550-820 yrs ago (Miller, 1985). The Glass Creek and South Deadman vents blasted in southwesterly directions toward Glass Creek watershed, with Glass Creek vent erupting directly into the watershed (Miller, 1985). Glass Creek tephra can be mapped 190 km to the south, covered a total area of 9,000 km², and ranged in depth within the Glass Creek watershed from 8m on Whitewing Mtn to less than 1m along the San Joaquin Ridge (Miller, 1985).

Ages for the most recent Glass Creek and South Deadman eruptions were derived from radiocarbon dating of wood and charcoal in the tephra and minimum tree-ring dating of trees growing on the tephra. They range from 530 ± 100 yr. B.P. to 720 ± 60 yr. B.P. with a tree-ring date of A.D. 1472 (Wood, 1977; Miller 1984, 1985). For South Deadman the ages range from 510 ± 100 yr. B.P. to 770 ± 120 yr. B.P., with a tree-ring date of A.D. 1369 (Miller, 1984). Our dendrochronological work on deadwood resulting from the latest Glass Creek vent eruptions indicate the event occurred in late summer or early fall 1350 CE (Millar et al., in prep; 2004b, c).

4. **Objectives**

The overall objective of the project is to compile vegetation (forest), fire, volcanism, and climate history for the Glass Creek Watershed, analyze relative roles of fire and climate as drivers of forest dynamics, test the usefulness and limitations of historical variability as a restoration tool, and develop additional conservation, restoration, and management guidelines that align with documented historical forest dynamics.

Questions:
1. What is the species composition, age, and distribution of the upper Glass Creek watershed mixed-conifer and subalpine forests?

2. What is the fire history of the mixed-conifer forest, what does it explain about fire behavior and changes over time in fire regimes in this area?
3 What are the relative roles of fire, climate, volcanism, and historic land-uses in influencing forest structure and composition?

5. Methods

Forest History Reconstruction
1. Grid Definition and Plot Center
For purposes of forest history reconstruction, the following area within the upper Glass Creek Watershed is defined: The northern boundary follows Glass Creek. The eastern boundary coincides with the eastern edge of the wet meadow portion of Glass Creek Meadow, and begins at the eastern edge of the forested slope where forest meets barren tephra along the slopes of Whitewing Mtn. The southern boundary follows treeline on the slope of Whitewing Mtn. The western boundary follows the ephemeral drainage from Deadman Col into Glass Creek Meadow.

Sample plots are located at grid corners, which are the intersections of rows (parallel with contours) and columns (perpendicular to contours). The grid will cover the entire forested study area as described above. Plot centers are located every 400 ft (122 m) along rows and columns. Not every plot center may be appropriate for use, thus the actual sampling pattern may become rectangular rather than square.

A Base Row (Row 1) will be measured and clearly marked/recorded to lie just within the forest border south of the meadow edge. A Base Column (Column 1) will be similarly marked upslope along the eastern edge of the forest area. Plots are numbered upslope (south) along Columns from the Base Row 1. Rows north of the Base Row (as needed) are numbered consecutively in negative order. Similarly, additional Columns added as necessary along the sparsely forested flanks of Whitewing Mtn would be numbered consecutively in negative order eastward from Column 1.

2. Plot Sampling, Tree Plots
Sample plots are located at Row/Column grid corners and plot centers will be marked with orange plastic tent stakes. Plots are given unique numbers as well as Row/Column ID. At each plot, date, crew, slope %, slope aspect (azimuth), and forest condition and type are recorded. Declination is 17E. For the forest study area described, the approximate number of tree plots will be 75.

The tree plot is a fixed 20 ft (6 m) circular plot centered on the plot center (grid corner). Trees included in the tree plot are: Standing trees either live or dead that are at least 2 in (5 cm) in diameter measured 18 in (46 cm) from the tree base (on slopes, measure tree base as sideslope). To be included, a tree’s basal center must be within the radius of the plot, regardless of whether the crown is within the plot. Downed and dead trees are included if their basal centers likewise are/were within the plot, and if the wood is sound enough to be cored.

Plot trees are numbered in consecutive and clockwise order. For species that grow in stem clusters (whitebark and western white pines), use the same letter to indicate tree stems that belong to a cluster – e.g., number as 1a, 2a, 3a for 3 stems in cluster a). Tag two largest trees within plot with tree #, plot #, row and column #s. Record azimuth and distance to each tree from plot center.

For each tree so described within each plot, measure and record the following:

1. species id
2. live, dead, upright or down
3. diameter at 18 in (46 cm)
4. diameter at 4.5 ft (1.4 m)
5. note firescars, insect damage, or other wounds
6. using increment borer, remove one core from each tree at 18 in (46 cm) height from base, attempting to reach pith.

Where large, old-growth red fir or western white pine are close to (< 500 ft [152 m]) but outside the plot as defined above, take data and increment core as for plot trees. Label as OUTPLOT trees.
Record fuels within each tree plot as length and diameter of all stems (tree size as defined above) lying within tree plots.

Record species composition of shrub and subshrubs present in the plot.

3. Plot Sampling, “Seedling” Plots
Within each tree plot, measure and record one seedling plot. The seedling plots are 11.8 ft (3.6 m) radius (0.01 ac [0.004 ha]), centered over the tree plot center. Trees (“seedlings”) are recorded only if within the seedling plot and < 2” (5 cm) at 18 in (46 cm) height, or are less than 18 in (46 cm) in height. Note that although the trees may be small, they may not be young, hence the label “seedling” is used only as a labeling convention.

Record number of seedlings per species in each seedling plot. Additionally, the seedlings should be classes as < or > 18 in (46 cm) in height. Indicate number of seedlings in each species/height class. For whitebark pine, note each cluster of stems by a letter and then indicate number of seedling stems within each cluster.

Randomly select two seedlings per seedling plot > 18 in (46 cm) in height and cut cross-sections at least 1 in (2.5 cm) in diameter at ground level and at 18 in (46 cm). These will be used to develop a regression for age to coring height. Record heights of each seedling.

Fire History

Tree-ring samples, photographs, and GPS readings will be collected from externally visible fire-scarred trees, including live trees, dead snags, and logged stumps. The sampling design calls for the collection of fire scars from 40 total trees per forest type, with replicates from at least two stands per forest type. Transverse wedges will be removed from trees by cross-cut saw or chain saw, with priority given to trees with multiple scars. Stumps and snags will be inspected for fire scars and sampled when the wood is found to be adequately solid. Within 20 m of each sampled fire-scarred tree, two increment cores will be extracted from a live tree of similar type for chronology development and cross-dating purposes. Each tree-ring sample will be prepared using standard dendrochronological techniques. Fire scars will be identified by the presence of charcoal deposits and xylem in growth patterns. Pilot work has resulted in useful preliminary chronologies to date the dead wood of local species in this region. Published chronologies are also available from more distant parts of the Sierra Nevada to further verify dating. Direct sample comparisons, skeleton plotting techniques, and cross-dating quality control through standard software (COFECHA, Holmes 1983) will be used.

Every fire scar will be dated if possible, and, based on anatomical inspection of the scar, an estimate made of fire-event seasonality. Fire dates will be tallied by species and location to allow analysis of spatial extent and synchronicity of occurrences.

6. Application of Research Results

We expect outcomes from the proposed work both to basic science and landscape-scale management and conservation. We anticipate that partitioning the relative roles of fire, climate, volcanism, and land-use in influencing forest structure and composition will improve understanding of forest dynamics and thus prescriptions for restoration broadly. The role of climate as an ecological architect has been especially difficult to comprehend and isolate from other drivers of change. Given the long-standing status of the Glass Creek Watershed as a landscape emphasis area on the INF, we anticipate that our forest history reconstructions and partitioning drivers of change will improve management understanding and prescriptions for this and similar forest areas.

We expect the fire scar and charcoal analysis parts of the study to provide currently unavailable fire regime knowledge in the eastside pine and fir types. Although information exists for ponderosa pine and
Jeffrey pine distant from the eastern Sierra Nevada, our pilot tests and preliminary results indicate that the localized climate, soils, forest communities, topographies, and environmental histories of these sites have influenced fire histories in different ways from distant locations. Results from the proposed study (sited on volcanic soils) will provide a comparison to a Jeffrey pine study presently underway (Stephens) at three granitic sites in the northern Sierra Nevada; that research was designed to compare fire history in fire-suppressed forests to unmanaged forests on granitic soils of the Sierra San Pedro Martir (Stephens, 2001; Stephens et al., 2003). Specific to our ongoing climate studies in the Glass Creek area, we expect the fire history information to help us discern the effects of fire in adjacent forests from the effects of volcanic eruptions, and climate variability. The fire-history information proposed here will contribute directly to implementation of the collaborative and longterm Scenic-Deadman Ecosystem Health Project of the Inyo National Forest currently ongoing.

Research results will be presented in appropriate scientific journals, such as Ecology, Forest Science, or Canadian Journal of Forest Research. Additional opportunities to present the work orally and in posters at appropriate scientific meetings will be sought. Implications of forest dynamics and relative roles of climate and fire will be communicated into conservation guidelines through journals and other outlets more appropriate to a management audience, such as Fremontia, and Ecological Applications.

7. Safety and Health

Standard procedures determined by the SNRC Safety Committee will be followed (see SNRC intranet). Field and Office Job Hazard Analyses and Emergency Evacuation Procedures on file for Millar research team pertain to and adequately cover safety procedures for this project.

None applicable; Special Use Permit from Inyo National Forest issued 6/97.

Local USFS Contacts:
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Tom Higley, Supervisors Office, Inyo National Forest, Bishop, CA
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9. Personnel Assignment, Time of Completion, and Cost

Millar, Principal Investigator. Oversight and supervision for all aspects of the study, including project design, justification, grant applications, field work, data analysis, communication, quality control, field and office safety, and publication/dissemination.

Westfall: Principal Co-Investigator. Primary input on field and statistical design, analysis, and statistical interpretation. Assists and reviews study plan, participates in and advises on field techniques and lab analyses, provides input and review on manuscripts.

Delany: Laboratory Analyses (ring measurements, data input, basic statistic analyses), and assists in development of graphics for publications, posters, oral presentations.

King: Field Assistance (mapping, measurements) and assistance/input to ring measurement of difficult sections, interpretation of ring measurement results for dendroclimatic analyses.

Stephens: PI for fire history study, oversight for all aspects of that phase of the project.

Woolfenden: PI for pollen study; oversight for all aspects of that phase of the project.

Time needed for completion:
Fieldwork: Completed  
Lab Analyses: Completed  
Statistical Analysis: Mostly complete, 3 months  
Manuscript Preparation & Review: 4 months  

Remaining cost: Salary for time above for Millar, Westfall & Delany; King donates time to this project.

10. References and Additional Bibliography


