FIRE AND CLIMATIC VARIABILITY IN THE INLAND PACIFIC NORTHWEST: INTEGRATING SCIENCE AND MANAGEMENT

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ABSTRACT: In order to manage fire regimes based on scientific information, it is critical to quantify the spatial and temporal variation in historical fire regimes, link this variation to climatic variability, and develop tools to identify fire hazard based on these linkages. This project addresses tasks 6 and 7 of the Joint Fire Science Program request for proposals 2001-1 by linking climate to fire regime characteristics and by developing spatially explicit, empirically based tools for predicting fire risks as a function of climatic conditions. *We propose a multi-scale analysis of the relationships between climate and topography and spatio-temporal patterns in historical fire regimes in the inland Pacific Northwest, using existing fire history data from the Okanogan-Wenatchee and Colville National Forests*. We will identify the primary constraints on fire occurrence and fire extent at three spatial scales. For individual points within watersheds (small scale), topography likely constrains fire sizes, and the rate of fuel accumulation constrains fire occurrence. Across 36 individual watersheds (medium scale) and three national forests (large scale), climatic variation (e.g., El Niño/Southern Oscillation and Pacific Decadal Oscillation) and extreme drought likely constrain the area burned and location of large fires. We will develop visual products that map fire hazard based on long-lead climate forecasts and our empirical analysis. These outputs will be used as inputs to the Northeastern Cascades Landscape Analysis Management and Monitoring System (NOCLAMMS) using Ecosystem Management Decision Support System (EMDS) software. By understanding how the dominant processes that drive fire regimes change across scales and incorporating this information in decision support systems, we can improve forecasting of large fire events, promote better allocation of fire suppression resources and provide assessment of spatio-temporal patterns of fire effects.

PROJECT DESCRIPTION

INTRODUCTION

In the summer of 2000, the western United States experienced the most severe fire season in the last 50 years. Wildfires, associated loss of property, and the costs of suppression have motivated much public discussion, including extensive plans to reduce fuels in western national forests in order to reduce fire hazard. However, federal land managers will need to consider the range of natural variability in past disturbance regimes when applying prescribed fire, mechanical thinning, or other methods of fuels management (Mann and Plumber 1999).

In most dry ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*) forests of the inland Pacific Northwest, fire exclusion (including suppression) has led to increased fire hazard. Prior to Euro-American settlement, these forests were characterized by frequent (3-10 years) ignitions (both native- and lightning-caused) and low to moderate intensity surface fires (Agee 1993). As a result of fire suppression, removal of fine fuels by grazing and other human activities, the structure and composition of these forests has changed, perhaps more than in any other region of North America. Horizontal and vertical continuity of fuels has increased, and these forests are considered to be far outside their historical range of variability (Agee 1994, 1998; Everett et al. 2000). A major task for scientists and managers, given the increased potential for large wildfires, is to identify the processes that control fire regimes at different spatial and temporal scales (Schmoldt et al. 1999). Accomplishment of this task would enable better long-term planning and short-term event prediction.

Broad-scale relationships between fire and climate have been studied extensively in dry ponderosa pine ecosystems in the American Southwest (Weaver 1951, Savage and Swetnam 1990, Swetnam and Baisan 1994). Prior to fire exclusion over the last century, fire regimes were closely linked to interannual variability in moisture conditions associated with the El Niño/Southern Oscillation (ENSO; Swetnam and Betancourt 1990). Large-scale climatic patterns that affect interannual and decadal moisture availability are associated with fire regimes in moisture-limited ecosystems like the Southwest (Swetnam 1993, Swetnam and Betancourt 1998, Veblen et al. 2000), but to date these relationships are poorly understood in the Pacific Northwest.

In the Pacific Northwest, climatic patterns other than ENSO may be important for fire regimes. For example, the Pacific Decadal Oscillation (PDO) is associated with decadal-scale patterns in precipitation (Mantua et al. 1997), and productivity in high-elevation forests (Peterson and Peterson 2001) and possibly large fire occurrence in the 20th century (Mote et al. 2000). In addition, continental-scale oscillations have inverse effects in the Pacific Northwest vs. the Southwest. For example, El Niño years are associated with warmer, drier winters in the Northwest but colder, wetter winters in the Southwest. Finally, drought conditions over several previous years may affect the spatial pattern and extent of fires in a given year, particularly in arid ecosystems. For example, high loadings of fine fuels arising from one or more unusually wet years may increase fire severity and extent in a succeeding dry year (Swetnam and Betancourt 1998, Veblen et al. 2000). Again, these patterns have not been studied in the inland Pacific Northwest.

At smaller scales, the spatial distribution of fuels and microclimatic gradients are likely the major influences on spatial heterogeneity of fire frequency and extent. In the east Cascade Range, topography is steep and dissected with strong west (wetter) to east (drier) gradients in precipitation. Across northern Washington, the precipitation regime changes from a Mediterranean-type pattern dominated by winter moisture to a quasi-monsoonal pattern characterized by a greater percentage of annual precipitation falling in summer, during the fire season. These environmental gradients may have strong influences on both the spatial and temporal characteristics of fire regimes.

Human disturbance, especially fire suppression, has had strong impacts on fire frequency in the western United States (Savage and Swetnam 1990, Agee 1993, Swetnam and Baisan 1994, Grissino-Mayer et al. 1995, Veblen et al. 2000). Although these changes have been documented at individual sites in the Pacific Northwest, human influence on fire occurrence over time is poorly defined. Due to the scarcity of spatially explicit fire history data, it has been difficult to assess how human activities have affected the spatial characteristics of fire regimes.

Although a few fire history studies in the Pacific Northwest have addressed topography, climate, and human land use at small spatial scales, none has identified the relative importance of each of these variables at different temporal and spatial scales (Schmoldt et al. 1999). Heyerdahl (1997) investigated the relationship between topography, climate and human land-use in the Pacific Northwest, but this study was limited to four watersheds in the Blue Mountains of Oregon. A multi-scale analysis of the processes that controlled historical fire regimes is crucial to the management of landscapes subject to future climatic variability and change. In order to address multiple controls on past fire regimes, we will:

- Quantify the relationships between fire regimes, climate and topography in the inland Pacific Northwest at multiple spatial scales.
- Determine how fire exclusion has altered relationships between climate and fire by comparing pre- and post-20th century fire regimes.
- Integrate the results of this research with decision support systems used by federal land managers to help plan fuel reduction efforts, anticipate future extreme fire years, and manage broad-scale patterns of fire effects.

Significance and Applications

The results of this study will provide relevant information for managing forest disturbance at multiple spatial scales, from watershed-scale fuels and fire management to regional fire event prediction and management (Table 1). Seasonal climate forecasts, based on patterns such as ENSO, are currently available for several months prior to the fire season. If temporal patterns in fire regimes in the Pacific Northwest can also be linked to climatic variability, then we can use climate-forecasting tools to anticipate future forest fire patterns.

Our proposed research links directly with ongoing projects at the Forest Service Pacific Northwest Research Station, (Wenatchee Forestry Sciences Lab) and Pacific Northwest Region (Okanogan-Wenatchee National Forest), funded in 2001 under the National Fire Plan (program #PNW-14). Their work addresses "Fuel reduction and forest restoration

strategies that also sustain key habitats, species, and ecological processes in fire-prone ecosystems in the interior Northwest". Our study will link to a key component of PNW-14 - multi-scale pattern (vegetation) and process (fire) research as the basis for designing appropriate stand and landscape-level fuel or fire treatments. In addition, integrating our results with an existing decision analysis process used by the Forest Service would advance the second goal of the PNW-14 research program - development and planning of operational fire and fuel reduction management strategies.

Table 1. Variables, observed patterns, and applications of the multi-scale analysis.

	Small scale (20-75 ha)	Medium scale (200-15,000 ha)	Large scale (0.5-1.0 million ha)
Application	Watershed scale fuels and fire management (sub-district level)	Fuels reduction planning and implementation (district to national forest level)	Fire event prediction and management (national forest to regional level)
Unit of Analysis	Trees/points and aspect polygons	Watersheds	National forests
Climate Variables	Reconstructions of summer precipitation and PDSI from watershed-level chronologies	Summer precipitation and PDSI reconstructions using principal components analysis of divisional climate data	Regional climate variables (summer precipitation, PDSI, PNA, ENSO, PDO)
Biophysical Variables	Aspect, slope, elevation of aspect polygons, solar radiation (30-m)	Potential vegetation, solar radiation (1-km), slope, elevation, aspect summarized by watershed	Geographic gradients of medium-scale variables over entire study area

RESEARCH METHODS

Approach

Everett et al. (2000) have produced a detailed, spatially explicit dataset of fire history from 2090 fire-scarred trees in 36 watersheds (280 ha - 12700 ha) extending from the Wenatchee National Forest in central Washington to the Colville National Forest in eastern Washington (Figure 1). The fire histories developed by Everett and others comprise one of the largest networks of fire history studies in the world. Furthermore, this data set is unique, in that all of the fire-scarred trees sampled have been geo-referenced, making spatial analysis of fire history over a region possible for the first time. Some of these data have been analyzed for individual sites, but not across broader spatial scales. Building on the work of Everett and others, we will (1) link spatial and temporal variation in fire regimes to climate and topography across these watersheds, (2) compare spatial and temporal patterns among watersheds, (3) develop empirical models of the relationships between biophysical drivers (e.g., climate and topography) and variability in fire regimes, and (4) integrate empirical results with a decision analysis process used by

forest management. We will focus on three distinct spatial scales of analysis. At each scale, key questions will direct research:

Small Scale

- Which drivers (e.g., topography, climate, fire exclusion) influence the temporal pattern of fire at each point and within topographic units?
- How do these drivers affect the synchrony of fire between points?

Medium Scale

- How do temporal and spatial patterns of fire vary between watersheds and what are the primary drivers (e.g., topography, climate, fire exclusion) of this variability?
- How do relationships between climate and fire change over time, and how do these changes vary among watersheds?

Large Scale

- What is the relationship between temporal patterns of fire occurrence and climatic variability?
- How do these relationships change along biophysical gradients associated with seasonal precipitation and temporal gradients associated with fire exclusion?

Data Compilation

Fire History Data

Low and moderate severity fires, typical of ponderosa pine and Douglas-fir forests east of the Cascade crest (Agee 1994), often kill only a portion of the cambium of living trees, leaving a scar that can be identified in cross-section. The year of the fire generating each scar can be identified and crossdated with a master chronology for the region (Fritts and Swetnam 1986). Individual trees can record a large number of surface fires, preserving a history of fire at a particular point in space. Although many factors influence the likelihood that a tree will record a fire (position of the tree on a landscape, bark thickness, lean of the tree, burning-off of previous scars by subsequent fires, and tree vigor [Swetnam and Baisan 1994]), it is possible to characterize past surface-fire regimes with a large number of accurately dated fire scar samples.

Studies relying solely on fire scar data may not detect evidence of high-intensity fires in regions where fire regimes are a hybrid of high and low severity (e.g., Shinneman and Baker 1997). However, several aspects of our data indicate that these low-elevation ponderosa pine/Douglas-fir forests were dominated by low-intensity fires for several centuries prior to Euro-American settlement: (1) the existence of very old trees (>500 years), (2) many fire-scarred trees within a small area, and (3) multiple scars per tree (up to 30+ scars on some samples; Agee 1993, Everett et al. 2000). Thus, historical fire regimes in the ecosystems sampled for this study were likely dominated by surface fires over the last few centuries and can be adequately quantified from fire-scar data.

Everett et al. (2000) generated an extensive, spatially distributed network of geo-referenced, cross-dated fire scar chronologies, ideal for spatial and temporal analysis of regional surface-fire history. Chronologies were developed in 36 watersheds located

throughout the Okanogan-Wenatchee and Colville National Forests, Washington (Figure 1). Within each watershed, aerial photographs and topographic maps were used to identify and map *aspect polygons*, delineated by aspect (northerly or southerly) and slope (flat, moderate, or steep). Size of aspect polygons ranged from 32 to 1700 ha, and the number within each watershed ranged from 2 to21. Polygons were internally stratified into four to five sub-polygons to ensure that fire scar samples were spatially segregated in the polygon. All fire-scarred trees within each sub-polygon were mapped, and between 2 and 23 "high quality" trees (with a large number of scars) were sampled for a total of over 17,700 fire scars. Sections were cut from live trees (Arno and Sneck 1977), and cross-sections were collected from stumps, snags and logs. Fire scars were prepared using standard procedures (Arno and Sneck 1977), and then crossdated (Stokes and Smiley 1968) against an independent master tree-ring chronology developed from 20-50 climatically sensitive trees within each sampling area. The year of each fire scar was determined by the position of the scar relative to the dated sequence of annual rings in the cross-section (Dietrich and Swetnam 1984).

We will archive and summarize the fire history data from all watersheds using FHX2 fire history software (Grissino-Mayer 1995). This software is designed specifically for analyzing extensive fire history databases, and creates master fire charts for individual trees and sites, allowing statistical comparisons of fire regimes over time and space. By archiving the fire history data in this format, we will facilitate comparisons with similar studies in the Southwest (Swetnam and Baisan 1996), the Sierra Nevada (Swetnam 1993) and the Colorado Front Range (Veblen et al. 2000).

GIS-based fire maps for each year in the study period will be generated based on the geo-referenced fire-scarred trees. Estimates of percent annual area burned (by aspect polygon, watershed and national forest) will be computed from these coverages (not including unsampled areas), allowing for temporal and spatial comparisons of fire regimes (see below).

Data Analysis

Climate Reconstructions

Small Scale

The key climatic variables driving past fire regimes at small spatial scales are likely summer (June – September) precipitation and Palmer Drought Severity Index (PDSI). PDSI is a composite monthly index calculated from precipitation and temperature changes (Alley 1984, Heddinghaus and Sabol 1991), and incorporates both immediate (same-year) and cumulative (multi-year) effects of drought. These climatic variables will probably differ among watersheds because of seasonal anomalies in precipitation across our study area. Therefore, we will reconstruct summer precipitation and PDSI for each watershed from local tree-ring chronologies developed by the Forest Service PNW team from 20-50 climatically sensitive ponderosa pine trees (many greater than 500 years old) in each watershed, using regression models (Cook and Kairiukstis 1990). Models will be validated using half of the observed climate record withheld from model building.

Medium Scale

For medium-scale analysis, summer precipitation and PDSI reconstructions will be developed for each climate division, using the principal components of all watershed-level chronologies within that division as predictors. This is a standard approach for broad-scale reconstructions (e.g., Cook et al. 1999) and avoids problems associated with multicollinearity in the predictors (Cook and Kairiukstis 1990). The predictive models will be validated by the same method as for the watershed-level reconstructions (see *Small Scale* above).

Large Scale

We will use existing regional reconstructions of four climatic indices with regional impacts on climate in the Pacific Northwest: (1) ENSO (Stahle et al. 1998), (2) PDO (Biondi et al. 1999), (3) PNA (Woodhouse 1997), and (4) PDSI (Cook et al. 1999), to evaluate the relationship between regional-scale fire patterns and climatic variability.

Analysis of Fire Regimes

Using the FHX2 software, we will develop a master database of fire history records for all points (fire-scarred trees), aspect polygons, watersheds and national forests. Master fire charts (Grissino-Meyer 1995) will be used for exploratory analysis of spatial and temporal patterns at multiple scales. We will calculate summary statistics for fire intervals, including: means, medians, and the Weibull median probability interval (WMPI; Grissino-Meyer 1999), minima, maxima, variance, and coefficient of variation at each scale of analysis.

Small Scale

Which drivers (topography, climate, fire exclusion) influence the temporal and spatial pattern of fire at each point (fire-scarred tree) and within each aspect polygon (topographic unit)?

For the pre-suppression period (1700-1910), patterns of fire occurrence at each point were likely constrained by fuel loadings, in which case a dispersed temporal pattern should be observed. Alternatively, aggregated or random patterns would suggest different controls (periodic climatic patterns or the influence of extreme events, respectively). We will test the distribution of fire-free intervals at each fire-scarred tree for randomness, using the Ripley's K criterion (Ripley 1981). Significant changes for the period after 1910 would suggest that active fire suppression has uncoupled fire regimes from their historical constraints. For example, fire exclusion may drive temporal patterns toward randomness by increasing the importance of extreme events associated with anomalous weather patterns.

In addition, topographic position has likely affected past ignition sources and fire spread. We will use a 2-factor analysis of variance (aspect – 2 levels, slope – 3 levels, as defined for each aspect polygon) to identify topographic differences, based on topography, in the characteristics of fire regimes (e.g., Weibull median probability interval [WMPI] or variability in fire intervals).

Table 2. Temporal and spatial patterns of fire, associated fire pattern, and drivers.

Pattern	Fire Pattern	Probable Driver
Dispersed	Fires are less likely soon after previous fire.	Fuel buildup is the primary constraint (e.g., fires will not burn in consecutive years for lack of fuel in the second year).
Random	Fires are equally likely at any time.	Dominant driver is stochastic (e.g., local extreme weather conditions responsible for most area burned).
Aggregated	Fires are more likely soon after previous fire.	Periods of favorable climate (weather) for fire, potentially corresponding to cycles of productivity and drought.
Synchronous	Multiple fires occur across aspect polygons, watersheds or regions in the same year.	Local to regional scale climate patterns, depending on the geographic extent of synchrony.
Asynchronous	No relationship between the timing of fires across space.	Climate is not an important driver; topography, fuels or human influence may be dominant.

How do these drivers affect the aggregation and synchrony of fire between points within watersheds?

We will examine synchrony and aggregation between points and across aspect polygons by a moving-window approach applied to master fire charts in two dimensions (space and time; Figure 2). The temporal distribution of multiple fire scars within and among aspect polygons will be characterized as aggregated, dispersed or random, using the Ripley's K criterion. We will vary the window size of the analysis from single trees to all trees in the watershed, but will concentrate on spatial scales that represent ecologically meaningful units: point, aspect polygon, watershed (see also *Large Scale Analysis*). An aggregated temporal pattern that is maintained over increasing spatial scale would suggest that "fire years" may be associated with climatic variables (Swetnam and Baisan 1996), and could yield clues about the temporal frequency of drivers responsible for fire occurrence.

We will use multivariate time series methods, including cross-spectral analysis (Bloomfield 1976) to identify the association between years with multiple fire scars (years of synchronous fires) and climate, using two time series: (1) the number of points recording fire for each year, and (2) reconstructions of summer precipitation and PDSI (from site chronologies).

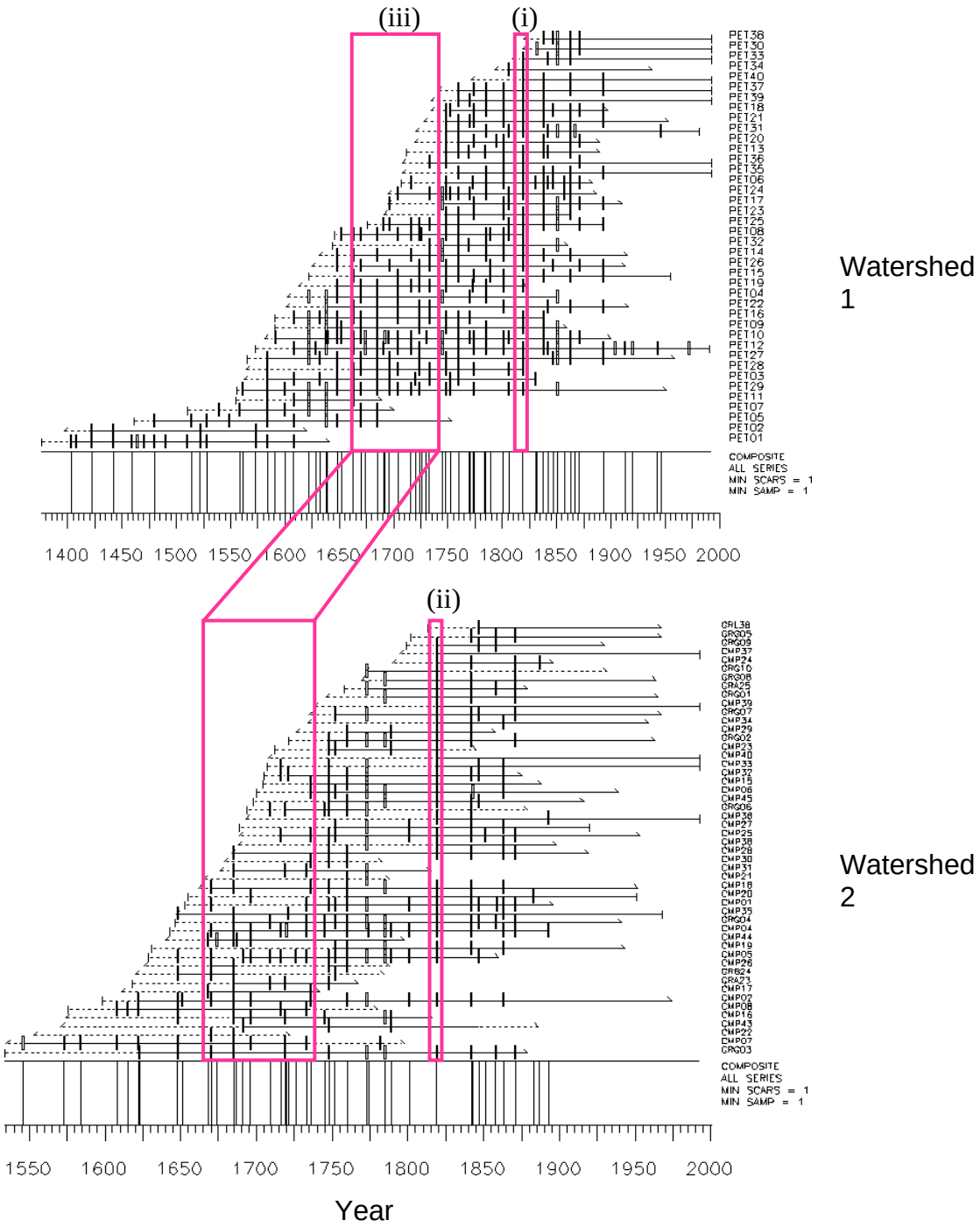

Figure 2: Master fire charts for two hypothetical watersheds. The horizontal lines are fire-scar records from individual trees and the vertical tick marks are fire-scar dates recorded on those trees. The composite graphs (long vertical lines at the base of each chart) show fire dates recorded by multiple trees. Moving window analysis (boxes define the temporal and spatial extent of the window) within a watershed (i & ii) allows us to characterize the temporal distribution of fire occurrence. Moving window analysis across watersheds (iii) allows us to identify coherence between fire years over multiple temporal and spatial scales.

Both immediate (current year) and lagged responses to climate will be examined. The *coherence* of the two time series (the analogue in the frequency domain to a correlation coefficient) should be maximized when temporal variation of the number of fires within a window is most synchronous with temporal variation in the climatic time series. The shape of the coherence spectrum may change with window size, so we will examine a complete range of window sizes from one year to 200+ years.

A strong association at one frequency suggests the influence of a driving variable across multiple time-steps. For example, if a 4-year cycle in ENSO influences fire occurrence, we should see the maximum spectral coherence at f=1/4, whereas a multi-decadal frequency would suggest the influence of PDO. If there are no periodic relationships, fire years are more likely the result of single events (e.g., one year of extreme drought).

We will use superposed epoch analysis (SEA; Swetnam and Betancourt 1998) to identify statistical relationships between climate variables and synchronous fire years (when > 10% of the trees were scarred). Mean values of PDSI and summer precipitation will be calculated for 5-9 year windows preceding and including each synchronous fire year. These values will be compared with the complete climatic record for each parameter using Monte Carlo simulations that randomly pick non-fire years, identify 5-9 year windows, calculate expected means, and provide 95% bootstrap confidence intervals (Grissino-Mayer 1995). Results will be described as the percent difference between the means of the fire and non-fire years. The 5-9 year windows of the SEA will allow us to identify important climatic signals from years preceding synchronous fire years and provide a statistical tool that can be tied to climate forecasts to help predict severe fire years.

Medium scale:

How do the temporal and spatial patterns of fire (Table 2) vary between watersheds and what are the primary drivers (e.g. topography, climate, fire exclusion) of this variability?

Sampled watersheds are spatially dispersed across gradients of environmental variables such as the timing and amount of precipitation, elevation, solar radiation, and topography. Summary statistics, results from time series analysis and SEA may differ between watersheds and these differences may reflect variation in topography and local climate. As an exploratory analysis, we will first make qualitative comparisons of watershed-scale measures:

1) Mean and variance of estimated percent annual area burned (EAAB), fire return interval, fire size, temporal pattern (aggregated, dispersed or random).
2) The degree of “coupling” of climate to EAAB or number of synchronous fires (from small-scale time-series analysis and SEA).

Next, we will develop regression models of the fire variables (#1 above), within aspect polygons, as functions of environmental variables (e.g., potential vegetation and solar flux) and topographic indices (e.g., average slope, elevation, aspect). Models will be validated by a bootstrap procedure that estimates their predictive power when applied to another sample (Efron and Tibshirani 1993). These models will quantify the relative importance of topographic and climatic factors for fire regimes in different watersheds

and provide a tool for predicting characteristics of fire regimes in neighboring unsampled watersheds.

How do relationships between climate and fire change over time, and how do these changes vary among watersheds?

We will model annual, watershed-scale fire statistics (e.g., EAAB, number of points recording fire each year) as a function of annual values of summer precipitation and PDSI (from reconstructions), using state-space models and the Kalman recursions (Brockwell and Davis 1996). This approach is a generalization of ordinary regression, which is limited to independent response variables and constant coefficients. In contrast, the Kalman recursions can be applied to autocorrelated time series and will estimate coefficients that vary over time. Successive values of a time-varying coefficient are an indication of how closely a response variable is coupled to the predictor(s) at any time step. This analysis will provide a robust summary of how strongly fire regimes are constrained by climate over the period of record (1700-1990) and how these constraints change for different watersheds.

Large scale:

What is the relationship between temporal patterns of fire occurrence and climate, and how do these change along biophysical gradients associated with seasonal precipitation and temporal gradients associated with fire exclusion?

At this scale of analysis we will (1) identify the temporal and spatial scales at which the association between fire and climate is maximized, and (2) quantify how this association changes across spatial scales and among the two time periods.

We expect watershed-level summary statistics of fire regimes (mean and variance of FRI, number of trees recording fire per year, etc.) to change along gradients represented by the geographic range of the watersheds. We will use regression to model changes in the fire statistics as a function of spatial variation in biophysical and climatic variables, (see *Medium Scale Analysis*). Given the small sample size of 36 watersheds, models will be validated by the same bootstrap procedure as for medium scale models.

We will extend the moving window/time series analysis (Figure 2) and the SEA to multiple forests, such that coherence and association between fire years and climate indices (summer precipitation, PDSI, ENSO, PDO, and PNA) can be viewed at multiple spatial scales. We will ask whether scaling laws exist with respect to aggregation and synchrony of fire events in space and time. For example, do fire events become less aggregated with increasing spatial scale? If such a scaling relationship exists, does it depend on the geographic distances among watersheds, or some other measure of dissimilarity (Milne 1988)? Similarly, with respect to the SEA, does the association between fire and climate become stronger/weaker at larger scales? Are there important thresholds or non-linear relationships that constrain the association between fire and climate in space?

We will use the results of the SEA at multiple spatial scales to evaluate the nature and strength of fire-climate relationships across the entire study area. Using significant results from the SEA, we will create correlation maps at multiple spatial resolutions, showing geographic locations where temporal relationships between fire and climatic

predictor variables (summer precipitation and PDSI, ENSO, PDO, and PNA) are strongest/weakest. These maps and the underlying associations revealed by SEA, in conjunction with climate forecasts (e.g., ENSO), will be inputs to a decision support system, creating a tool for managing fuels reduction and fire suppression efforts.

Application of Results to Decision Support Systems

We will use the Ecosystem Management Decision System (EMDS – Reynolds et al. 1996, Reynolds 1999) software, a Forest Service national standard for decision support, to integrate the correlation maps, climate data, vegetation and fuel maps with the spatial allocation of management resources. EMDS provides a knowledge-based framework for structuring multiple, spatially explicit databases in order to optimize both short- and long-term management strategies. EMDS output will be incorporated into the "Northeastern Cascades Landscape Analysis, Management, and Monitoring System" (NOCLAMMS) currently being developed by J. Lehmkuhl, P. Hessburg, K. Reynolds and others (US Forest Service, Pacific Northwest Research Station, Wenatchee WA). NOCLAMMS will provide a formal yet accessible decision tool that integrates existing and new research on landscape pattern and process, key habitats (e.g., late-successional forest) and species (e.g., northern spotted owl), aquatic/riparian systems, disturbance, and socioeconomic factors. The analysis targets the watershed scale typical of Ranger District-level forest management projects, but within the context of regional-scale patterns.

DELIVERABLES

Product	Date
On-line fire history database and associated inter-active GIS web site using ArcIMS (ESRI 2000), with GIS coverages of past fire events.	December 2001
General Technical Report: *Synthesis of fire history information and characterization of fire regimes for the three forests*.	June 2002
Peer reviewed manuscript: *How 20th century fire exclusion affects climatic constraints on fire*.	December 2002
Fire landscape analysis and planning application for managers using EMDS and NOCLAMMS.	March 2003
Workshop on fire-climate interactions for forest managers in the Pacific Northwest. The implications for prescribed fire, mechanical treatments, and other approaches to fire management at multiple scales will be addressed. EMDS and NOCLAMMS presentation and training.	March 2003
Peer reviewed manuscripts: *(1) Using decision support to plan for fire events and fuel reduction efforts, and (2) Predicting fire regimes from climate and topography: a view from multiple scales.*	September 2003
Metadata compliant with Federal Geographic Data Committee (FGDC) and the National Biological Information Infrastructure (NBII) standards.	September 2003