Testimony of
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Hearing on
Impacts of Global Climate Change on Wildfire Activity in the United States
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Chairman Bingaman, ranking member Domenici, and members of the Committee, I thank you for the opportunity to be here and testify on the matter of climate change and wildfires. My name is Tom Swetnam, and I am Professor of Dendrochronology (which is the study of tree rings) and Watershed Management at the University of Arizona. I am also Director of the Laboratory of Tree-Ring Research. Please note that my co-author of the written testimony is Dr. Anthony Westerling of the University of California, Merced. Tony is Assistant Professor of Environmental Engineering and Geography.

Senators Bingaman and Domenici may recall that we met and talked some years ago when I was appointed by President Clinton to the first Board of Trustees of the Valles Caldera National Preserve in New Mexico. Part of the reason I was appointed to that Board was because I was raised in northern New Mexico and I know that landscape very well. I have spent a great deal of time studying forests and fires in New Mexico and elsewhere in the West – originally as a fire fighter, and for the past 27 years as a scientist.

Executive Summary

Fire is a natural and necessary part of most terrestrial ecosystems. Prior to Euro-American settlement of North America, enormous areas burned as a consequence of lightning and Native American-set fires. The largest areas burned during the warmest and driest years. However, recent fires and damages caused by them are often outside the historical range of variability, and in some cases these impacts are ecologically unsustainable. This is particularly the case in many ponderosa pine-dominated forests and drier mixed conifer forests that formerly sustained primarily frequent, low-severity surface fires. The changes we see in some of these areas now are a consequence of a "perfect fire storm" – the combination of a number of causes contributing to catastrophic fire. The ecological and watershed damages caused by some of these fires are extreme and probably irreversible. The threats to human lives and properties are increasing.

The key points of our testimony are:

- **Increasing numbers of large forest fires and total area burned in the western United States are significantly correlated with warming and drying trends.**
- **Historical land uses and management practices disrupted natural fire patterns in many western forests about a century ago, and these changes have led to dense forests and fuel accumulations that are also contributing to unusually large and severe fires in some places.**
- **Natural climate oscillations (for example the El Niño-Southern Oscillation) have also affected fire activity, but they do not fully explain the recent surge in burning.**
- **Studies using coupled global circulation and wildfire models consistently predict increased burning under scenarios of future increased greenhouse gas concentrations.**

Long-term Perspectives of Wildfire and Climate History

From many detailed studies of fire scars in tree rings, sampled in ponderosa pine-dominated forests across the West, we have learned that low severity forest fires used to burn through the understory of these forests at intervals of about 5 to 30 years. This pattern of repeated burning continued for centuries until the late 1800s, when Native American burning practices were eliminated, large herds of sheep and cattle were introduced, and government-sponsored fire suppression began. My colleagues and I have developed very similar histories of frequent, low severity forest fires from fire scars and tree rings in giant sequoia trees in California, extending back to 3,000 years before the present (**Figure 1**). Other scientists and colleagues have drilled core samples from wet meadows, bogs and lake bottoms in many places in the west. They have reconstructed more than 10,000 years of fire history by carbon-14 dating and counting the number of charcoal particles of various sizes deposited in the sediments.

Fire history studies typically find a broad range of past fire frequencies in different forest types and elevations. As you might expect, the relatively wet forests of high elevations and more northerly latitudes generally show much longer intervals between past fires (on the order of 100s of years) than the relatively dry, lower elevations where ponderosa pine dominates. Although the frequencies of past fire varied substantially from one ecosystem type to another, a general finding has been that the changes in past fire activity were well-correlated with independent reconstructions of climate history. **In particular, increased fire occurrence corresponded with warming and drying conditions. Our studies of giant sequoia fire scars and comparison with temperature-responsive tree-ring width chronologies shows that these long-term associations have existed for many centuries** (**Figure 1**).

Warmer, drier conditions are likely to promote drier fuels, which may be more readily ignited by lightning or people. Drier fuels also carry fire more rapidly across the landscape. Another general pattern of wildfires is that, the longer the typical interval between fires, the more severe and intense the fire when it occurs. For example, lodgepole pine and spruce-fir forests of high elevations in the Northern Rockies typically burned only once per 150 to 400 years. When they did burn, they burned intensely during hot, dry years. Recall the 1988 Yellowstone fires, for example. In contrast, Southwestern ponderosa pine and relative dry mixed conifer forests (like giant sequoia groves) usually burned once or twice per decade for thousands of years, and these fires were typically of low severity. The key factor here is fire frequency. At low fire frequencies fuels accumulate in increasingly dense forests over long periods, while at high fire frequencies the fuels are consumed and open forests with little fuel accumulation are maintained. **Hence, suppression of the frequent, low severity fires in forests where this type of fire regime predominated has led to unusually high fuel accumulations and increasingly large and severe wildfires.**

Although warm and dry conditions were important to increased fire occurrence, another aspect of climatic control was also important, especially in the drier, lower-productivity forests. That is the role of prior wet conditions, which served to reduce fire activity and allow fuel accumulation. **Our paleoecological and modern studies have indicated that wet/dry lagging patterns are important to regional fire patterns in some parts of the West, both in the past and today.**

Based on these findings, it is evident that both climate variations and human land uses in the past have directly and indirectly affected forest fuels and fire frequencies. **Despite local and sub-regional differences among ecosystems with different land-use histories, at the broadest-scale of the western states, including Alaska, increasing numbers of large forest**

fires in recent years are significantly correlated with warming and drying. I will come back to this key point about recent broad-scale trends in a moment, but first, I will briefly review what else we have learned about historical and natural climate and fire patterns from tree rings and documentary records.

Multiyear to Multi-Decadal Climate Variations: ENSO/PDO/AMO

Just about everyone has heard of “El Niño” since the very large event in 1982 and 1983 resulted in worldwide climate effects. This general awareness marks a revolution in climatology that has occurred in the past few decades. Thanks to many observations of ocean and atmosphere patterns and computer models, we have increasing knowledge that ocean surface temperatures, related atmospheric pressure patterns, and the jet streams have tremendous effects on climatic patterns over the continents. These patterns go through changing “cycles”, or oscillations. The word “oscillation” is used because the intervals between the highs and lows, and the magnitudes of the highs and lows are highly variable, and not fixed like the cycle of a pendulum clock. The El Niño/La Niña pattern is also known as the El Niño-Southern Oscillation – or ENSO, for short. ENSO is the best known of the ocean-atmosphere oscillations, and it operates over variable periods of about 2 to 7 years. **ENSO appears to most strongly affect rainfall and forest fire patterns in the West and Southeast, but two other ocean-atmosphere oscillations have also been identified in recent years that appear to be quite important: The Pacific Decadal Oscillation (PDO), and the Atlantic Multi-decadal Oscillation (AMO).** As implied by the names, these last two oscillations operate on decadal time spans, that is, the high and low parts of the oscillations persist for 10 years or longer.

From a combination of centuries-long tree-ring records, and careful analyses of modern climate histories and documentary records of forest fires from government agencies, a number of studies have revealed the following key findings:

- **The ENSO has important effects on wildfire occurrence, especially in the Southwest and Southeast.** In these regions, El Niño typically brings increased cool season rainfall, and forest fire activity is reduced in the subsequent fire season. Conversely, during La Niña events conditions are generally drier and wildfire activity is increased. These patterns have some predictability to them months in advance of the fire season. Consequently, the state of the ENSO is now being used by the Predictive Services group at the National Interagency Fire Center for developing seasonal wildfire ‘outlooks”.
- The Pacific Northwest and northern Rocky Mountains (in the U.S.) typically have an opposite, though weaker response to ENSO relative to the Southwest and Southeast. This means that during El Niño events it is typically drier in these regions and more fires occur, and during La Niña events it is wetter and fewer fires occur. However, it appears that during some strong La Niña events, it is generally dry throughout the West and Southeast. **The typical inverse pattern of ENSO response between the Northwest/Northern Rockies and the Southwest/Southeast has potential strategic applications in the allocation and pre-positioning of fire fighting forces, and/or emphasis on prescribed fire use in the different regions.**
- The Pacific Decadal Oscillation was first noted, in part, because of its important effects on salmon fisheries in the Northwest. The pattern itself is measured by sea surface temperatures in the Pacific Ocean, especially the northern part. **Recent studies indicate the most pronounced sub-regional effect of the PDO is in the Pacific Northwest and northern California, both in terms of rainfall patterns and forest fires.** However, there are

interesting interactions of the PDO and ENSO affecting fire and climate across the West, as might be expected because both oscillations are based on changes in the Pacific Ocean**.** For example, drought conditions and more wildfires appear to occur in parts of the West during combinations of positive (warm) phases of the PDO and negative (cool, La Niña) phases of the ENSO. Again, there may be some predictive utility of these patterns for long-term "outlooks" and forecasting wildfire hazard.

- **Findings to date suggest that the positive phase of the Atlantic Multi-Decadal Oscillation (AMO), generally corresponds with more widespread droughts and wildfires in the western US than during the negative phase.** These associations are less well understood than the ENSO and PDO patterns.
- **Finally, an important implication of the PDO and AMO patterns described above is that both of these ocean-atmosphere patterns appear to have shifted to states that favor more drought and wildfire in some sub-regions of the western US (i.e., cool PDO, warm AMO phases).** These climate patterns may have contributed to the recent surge in area burned and increased numbers of large fires in the west, but it is unlikely that they are primarily responsible. A chief reason for this conclusion is that fire-promoting decadal phases of the PDO and AMO occurred before in the past century (e.g., the 1950s and 60s), but we did not see the magnitude of increases in burning that we have witnessed recently accompanying the warming.

Modern Climate and Fire Trends

Most of the climate-wildfire patterns I have just described have been studied extensively using a combination of paleoecological, paleoclimatic, and modern documentary records. Although the paleo-records are insightful, and are the best data we have for long-term perspectives on climate and wildfire, the recent several decades is the period of time when we have the most comprehensive records for assessing climate and fire patterns. Government agencies have been keeping records on wildfire statistics since the early 1900s, but unfortunately, these records are often lacking in completeness and reliability before the 1970s. Nevertheless, this recent period has proven useful for assessing contemporary changes.

Our current understanding of recent wildfire changes in North America derive from a set of studies in Canada, Alaska, and the Western US. First, I am going to summarize the findings of the study led by my colleague Tony Westerling that we published in July of last year in the journal *Science*, along with our co-authors Drs. Dan Cayan and Hugo Hidalgo from Scripps Institution of Oceanography, University of California, San Diego. Next, I will briefly mention the published findings on climate change and wildfire in Canada, Alaska, and elsewhere.

The Westerling et al. (2006) study utilized fire occurrence records for the period 1970-2003 from federal lands in the western US, and the time series used was the number of large wildfires (i.e., exceeding 400 hectares, or about 1,000 acres). Most of the area (80%) included in this database was above 4,500 feet elevation. Hence, these data primarily reflect forested landscapes across the western US. It is important to note that these data do not necessarily reflect general wildfire patterns in the many lower elevation, non-forest ecosystem types.

The main findings are as follows:

- **There is a clear upward trend in the area burned and numbers of large forest fires in the western US, especially since the mid 1980s** (**Figure 2**, **Figure 3**, upper two plots). The area burned by large forest fires is 6.7 times higher in the latter period 1987 to 2003 than in the earlier period from 1970 to 1986 (**Figure 4**). Note, however, in a separate compilation of lower elevation, non-forest fire occurrence data that no clear trend through 2003 shows in these data (**Figure 3**, lower two plots). It is particularly notable that the largest wildfires in 50 to 100 years have occurred in a number of states in the past five years (i.e., Arizona, Colorado and Oregon in 2002, Texas 2006, Idaho and Utah 2007).

- **The trend and year-to-year variation in numbers of large forest fires is well-correlated with spring and summer temperatures over the same time period** (**Figure 5**).
- **The trend and year-to-year changes in number of large forest fires generally matches changes in the timing of spring onset, as indicated by the timing of peak runoff from extensive streamflow data in the western US.** Many more large fires occurred during years in which spring arrived relatively early than during years when spring arrived relatively later (**Figure 6**). Additionally, there are significantly more early spring occurring years after 1986 than before that time.
- The largest increase in numbers of large wildfires has occurred at middle elevations, with much of the increase above 5,500 feet (Figure 4). About 60% of the large fires in the recent period occurred in the Northern Rockies and another 18% in the Oregon Cascades, Sierra Nevada, and northern California. **This concentration of many large fire events in northern mountain areas in relatively wet forest types suggests that forest structure changes because of past land management may be less important in these areas than the effect of warming and earlier springs.** That is because these northern, wetter areas contain a large proportion of spruce-fir, lodgepole pine, and other forest types where natural fire intervals were already quite long (centuries), and so fire suppression has had less effect there on changing fuel accumulation patterns.

In addition to the Westerling et al. study, several other recently published studies point to the importance of warming temperatures in observed trends of increasing fire occurrence in the western US including Alaska (McKenzie et al. 2004, Duffy et al. 2005, Kasischke and Turetsky 2006), Canada (Flannigan et al. 2005, Gillett et al. 2004),), and possibly Russia (Goldammer 2006). Furthermore, a number of these studies have employed global circulation model (GCM) simulations of future climate under increasing greenhouse gas scenarios as input to wildfire response models. **The GCM-fire studies have consistently concluded that increasing areas burned are to be expected in coming years and decades** (Brown et al. 2004, Fried et al. 2004, Gillett et al. 2004, McKenzie et al. 2004, Flannigan et al. 2005, Westerling and Bryant 2006).

Finally, both the Arctic Climate Impacts Assessment (http://www.acia.uaf.edu/), and the ecosystem impacts assessment of the 2007 Intergovernmental Panel on Climate Change Report identified increasing wildfire occurrence as a likely response to global warming. The 1,000-plus member Association for Fire Ecology (composed of fire scientists, students, and fire managers) recently issued a declaration on climate change and wildfire, strongly expressing their professional and scientific concern over current and anticipated wildfire responses to regional and global warming

(http://www.fireecology.net/pdfs/san_diego_declaration_final_29_nov_2006.pdf).

Conclusion

Increasing wildfire problems are related to an interacting set of causes, including (1) increased forest density and fuels because of a century of fire exclusion, (2) warming climate and increasing frequency and magnitudes of droughts, (3) invasive species, such as cheat grass and African buffel grass allowing fires to spread more readily across elevation gradients, and (4) the increasing presence of people and built structures in these areas that are fire prone (i.e., the wildland-urban-interface).

Although the combination of causes listed above exist together on some landscapes, it should be emphasized that there is tremendous variability across the US, and not all of these causes and problems are present everywhere. Indeed, there are some landscapes where warming trends apparently have had little effect, so far, on fire activity. Some forests and other ecosystem types have been unaffected or little affected by fire suppression. Moreover, the importance of invasive grasses (or other non-native species), urbanization and its consequences to habitat fragmentation, and increasing ignitions by humans are paramount in some areas, and these factors may exceed the effects of climate change now and the foreseeable future.

“Natural” oscillations of the climate system, such as ENSO, PDO, and AMO will continue to operate and have important effects on drought and wildfire in the US. These ocean-atmosphere patterns impart some degree of predictability to climate and wildfire hazard months in advance of fire seasons. For example, the most recent National Oceanic and Atmospheric Administration reports on the ENSO status indicate an increasing trend toward La Niña conditions, which could spell increased drought and wildfire problems next summer, especially in the Southwest and Southeast. The effects of long-term warming trends caused by greenhouse gases on ocean-atmosphere oscillations are not well understood. Some modeling studies addressing these questions are not encouraging, suggesting that increased amplitude of ENSO might occur. Alternatively, ocean and atmospheric patterns might lock into states promoting more-or-less permanent “dust bowl” like conditions in the Southwest (Seager et al 2007).

A recent influence of warming climates and increasing drought is apparently manifest in the rising areas burned and occurrences of “megafires” (>100,000 acre burns) in many places across North America and elsewhere. Under increasing greenhouse gas scenarios, the available evidence points to a likely continuation of rising areas burned, more megafires, greater damages and costs incurred, and additional human lives lost. Not least of the mounting concerns about these trends is the likely effect of releasing more carbon into the atmosphere, and the possibility of shifting temperate and boreal forests from a net carbon sink to a net source.

Supporting Scientific Publications and Sources

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Figure 1. Giant sequoias contain detailed histories of low severity forest fires (left) within their tree rings, recorded as fire scars (right). Comparisons of fire frequency from fire-scar records in five sequoia groves with temperature estimates from bristlecone pine tree-ring width measurements (graph) show that warm periods corresponded with increased fire frequency. The fire-scar record (red line) shows a sharp drop in fires after about 1860, when livestock grazing began, but temperatures rose in the past century (Swetnam 1993).

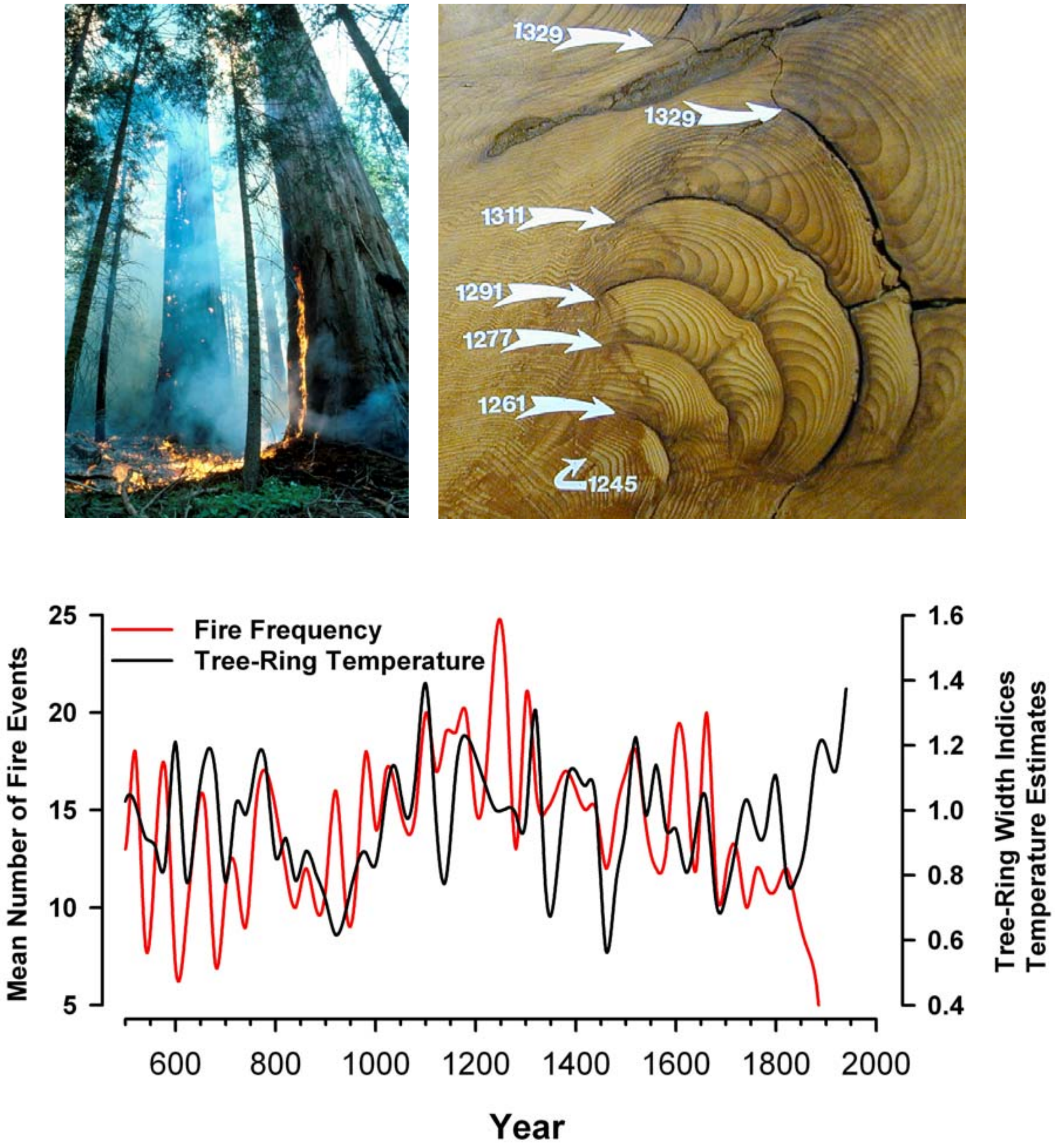

Figure 2. There is a clear trend of increasing area burned on all lands in the eleven western states, especially since the mid-1980s. Fire statistics are less complete and reliable before the 1970s. Estimates shown here are based on an adjustment of changing areas protected (included) in the land database through time (data compiled and adjusted by A. Westerling). More than 7 million acres have burned each year in the West since 2004, and nearly 6 million acres to date (September 13) in 2007.

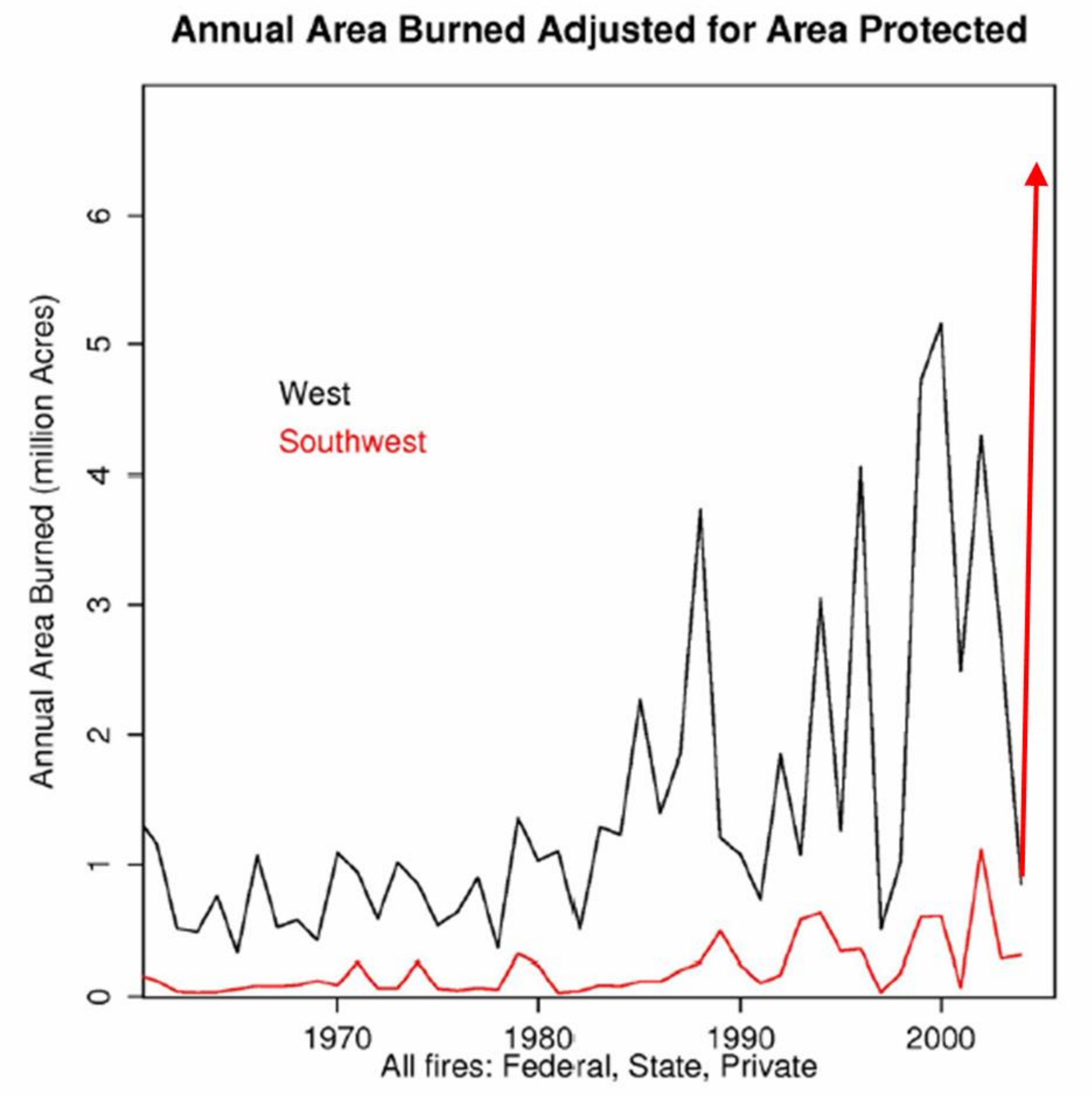

Figure 3. The numbers of large fires (> 1,000 acres) shows a distinct upward trend in the data from forested landscapes on federal lands (upper two plots), but not clear trends in the non-forested landscapes (lower two plots).

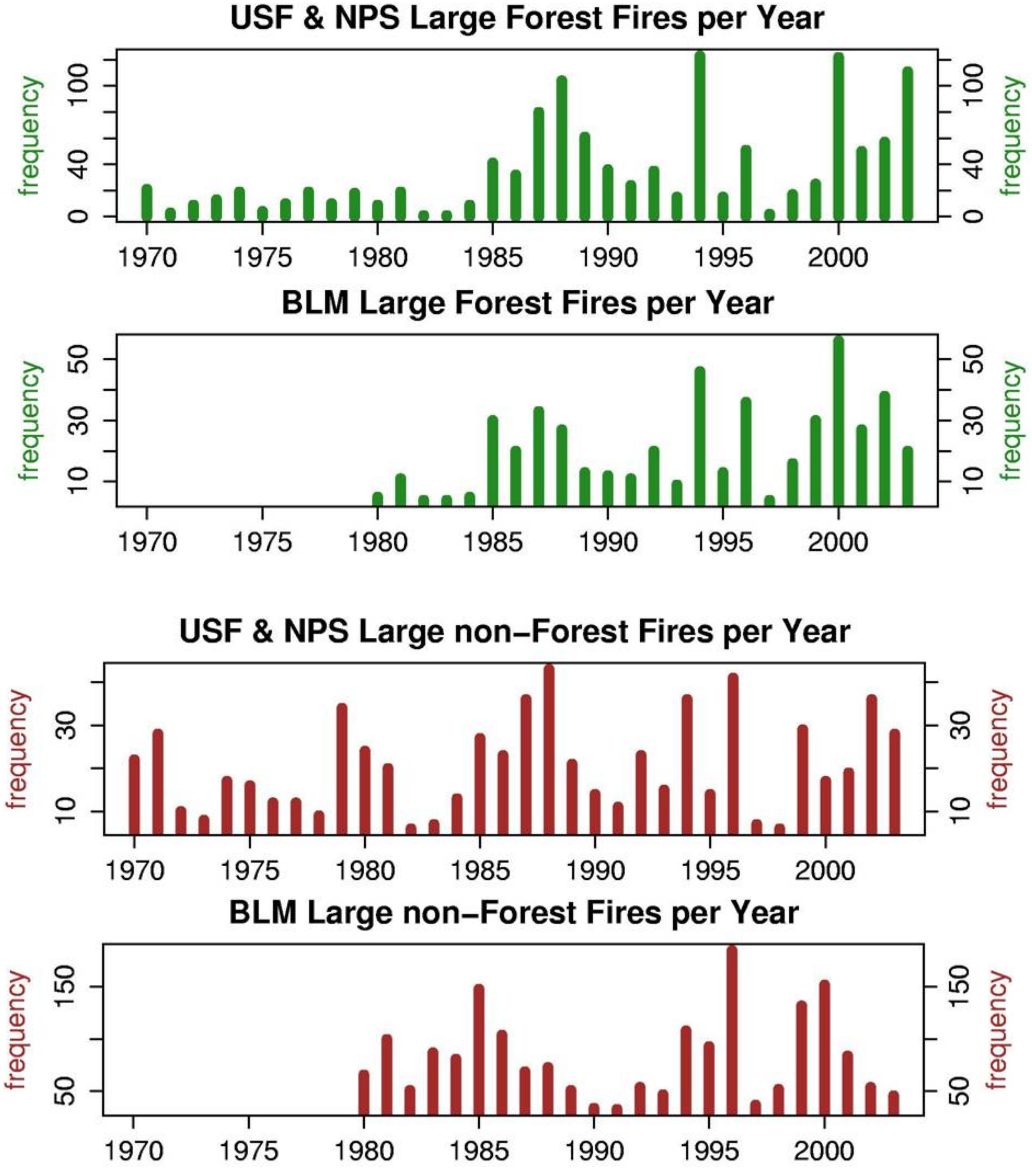

Figure 4. The relative forest areas burned in two time periods (1970-1986 versus 1987 to 2003) show clear increases in the latter period. A shift to a greater proportion of area burned above 5,500 feet elevation in the latter period is also evident.

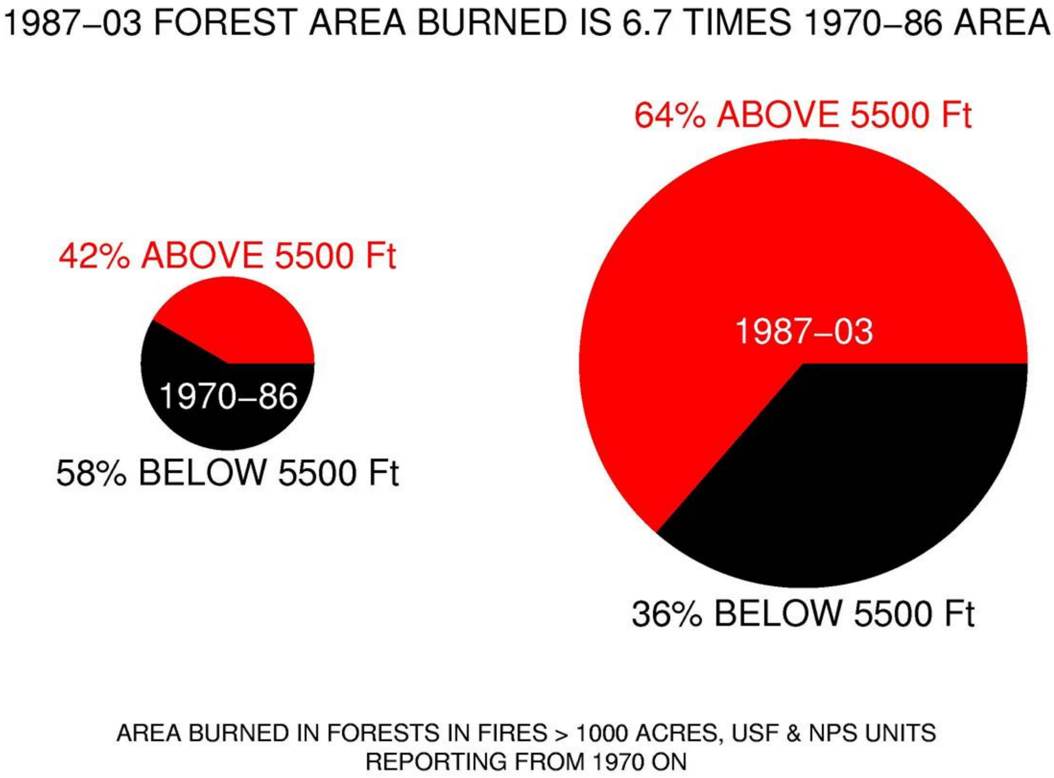

Figure 5. A. The number of large (>1000 acres) forest fires (red bars) from 1970 to 2003 is well-correlated with spring and summer temperatures (black line) (Westerling et al. 2006). The Spearman correlation coefficient of this association is 0.7, with a probability level of achieving this match by chance of one in one thousand. **B.** The timing of spring snowmelt as indicated by peak runoff in river flow data (Stewart et al. 2005). There were eight early spring event years after 1986 and only 3 such years before this time.

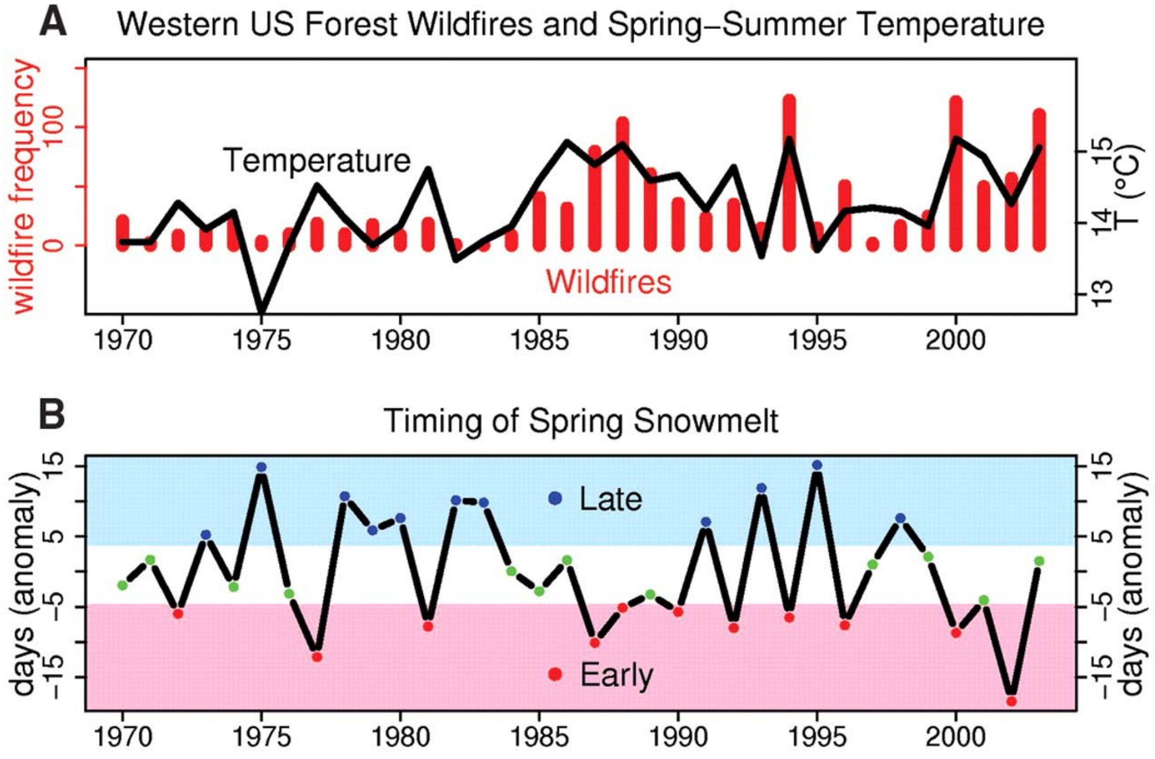

Figure 6. Many more large forest fires occurred during early snowmelt years than late snowmelt years. The size of the red circles are proportional to the area burned in the whole data set (but not to scale relative to the map).