# CLIMATE CHANGE AND WILDFIRES IN THE WESTERN US: A STATISTICAL MODEL

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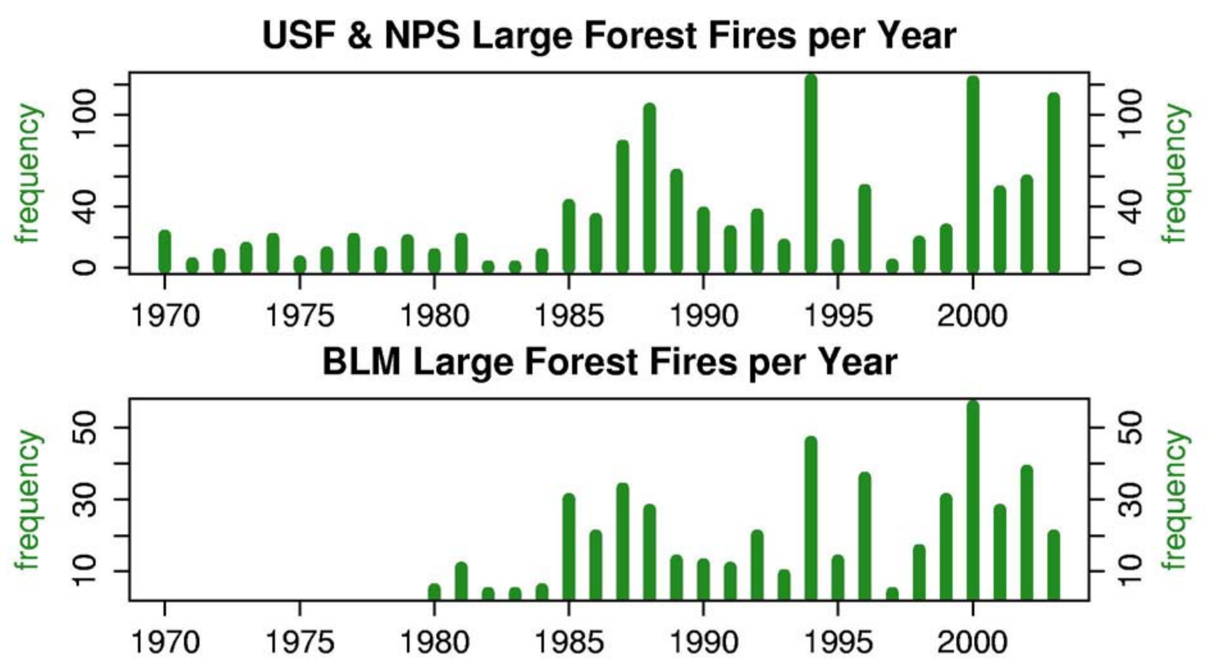
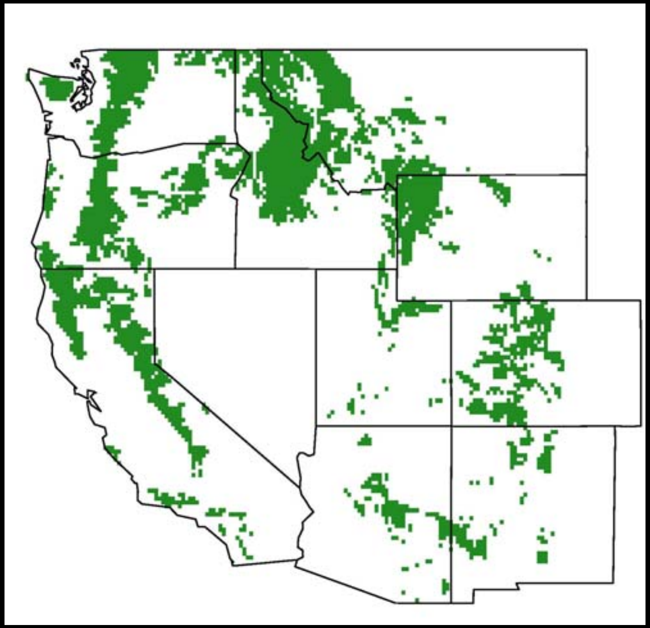
**Session title**:
Current Controversies in Forest Fire Suppression and Management



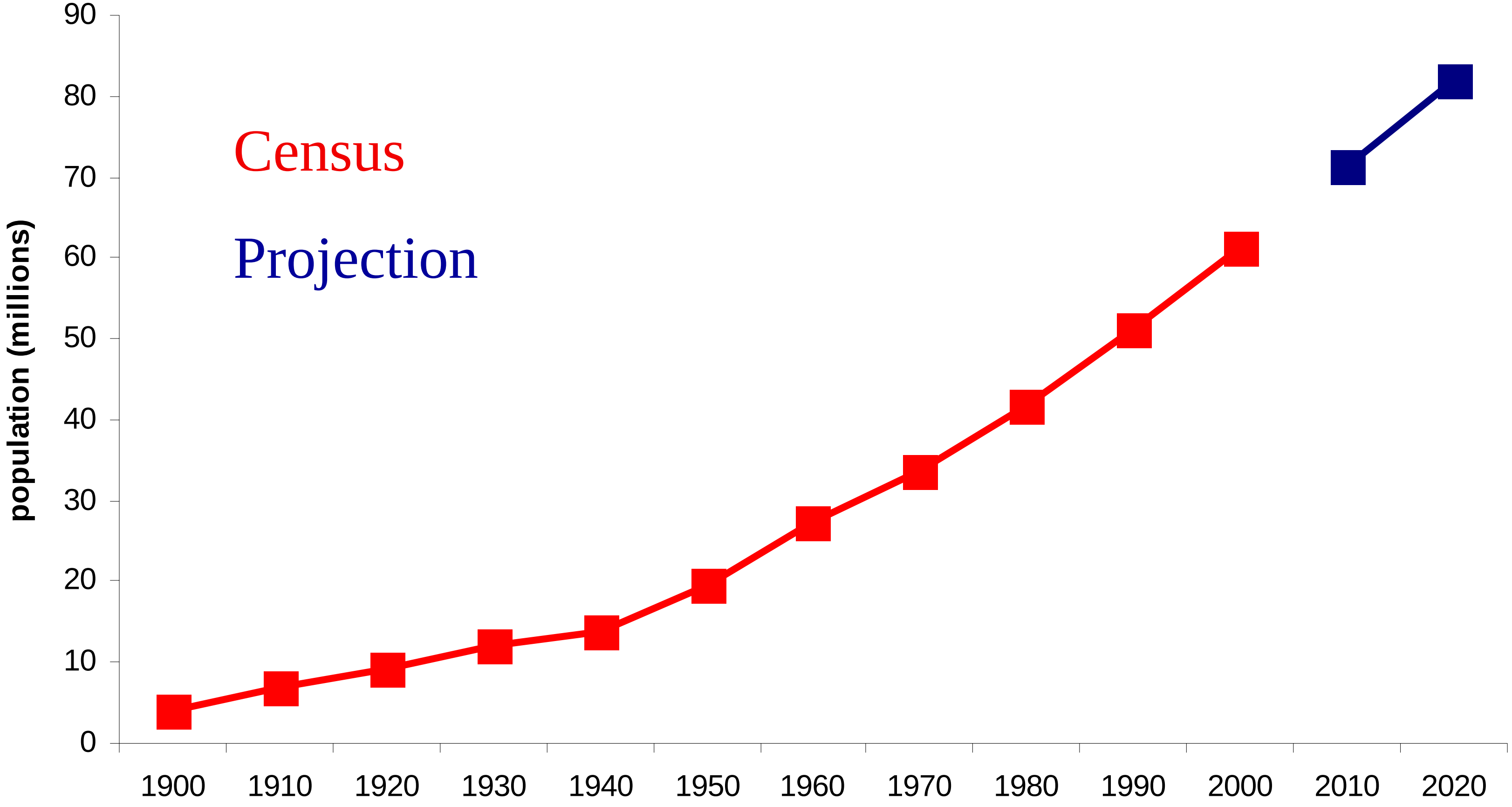

*Since the mid-1980s*

*Large Forest Wildfires Have Increased ~300%*

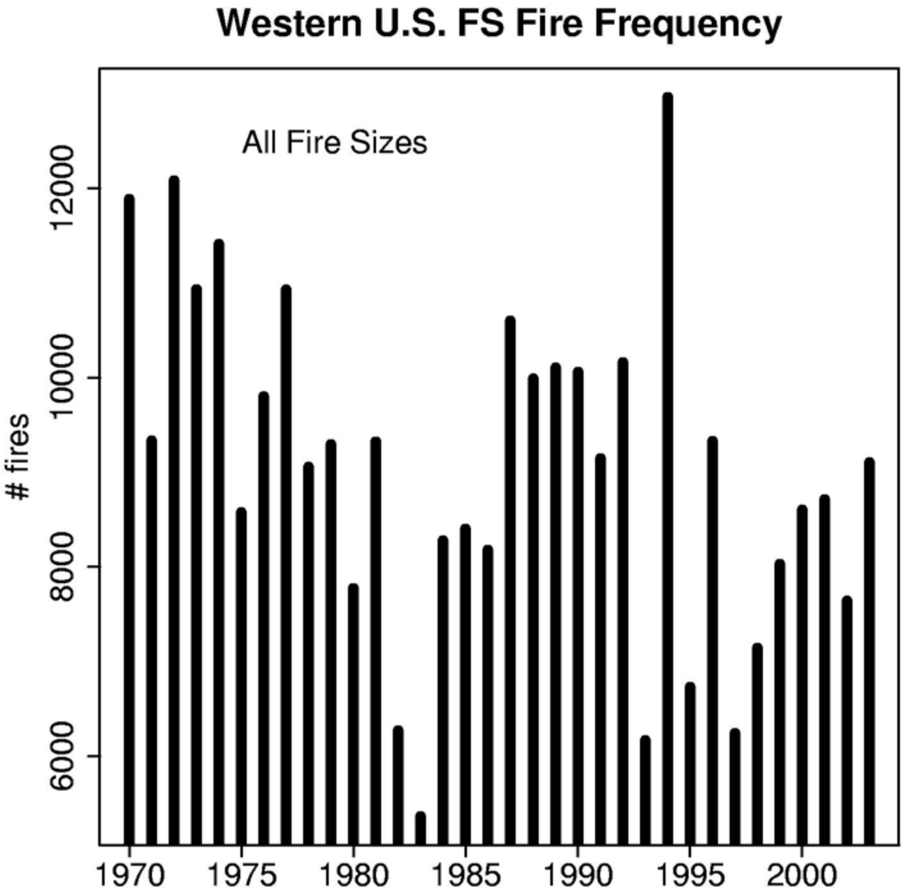


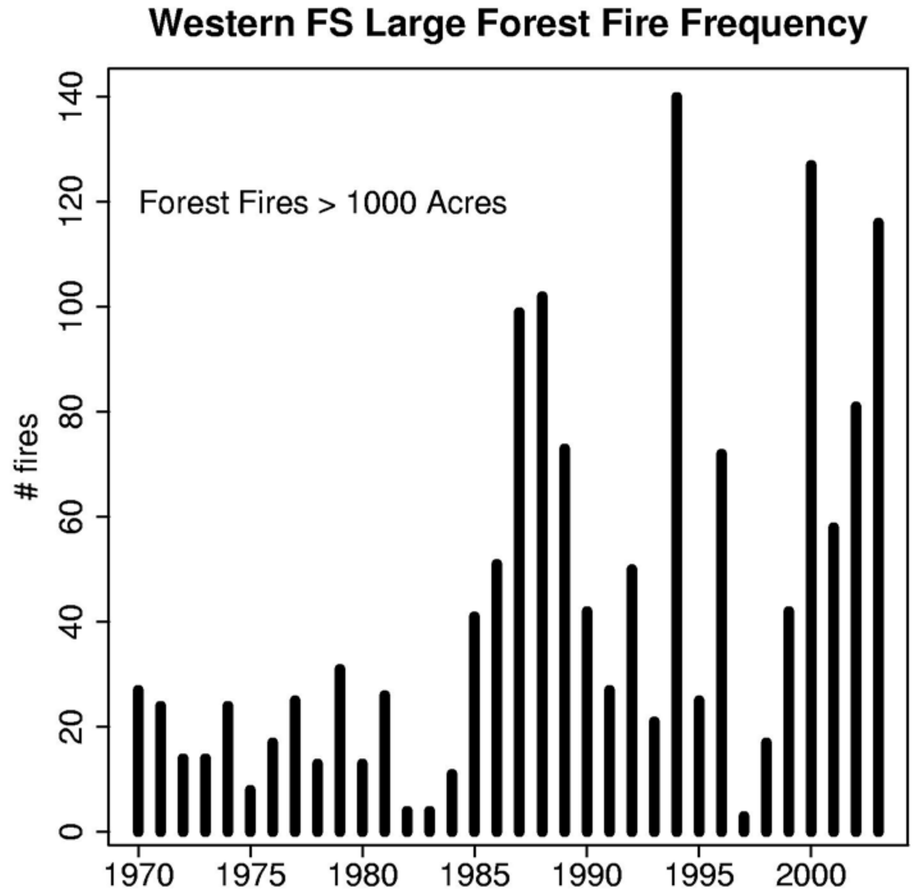
# *Population has increased …*

Western U.S. Population, 1900 - 2020

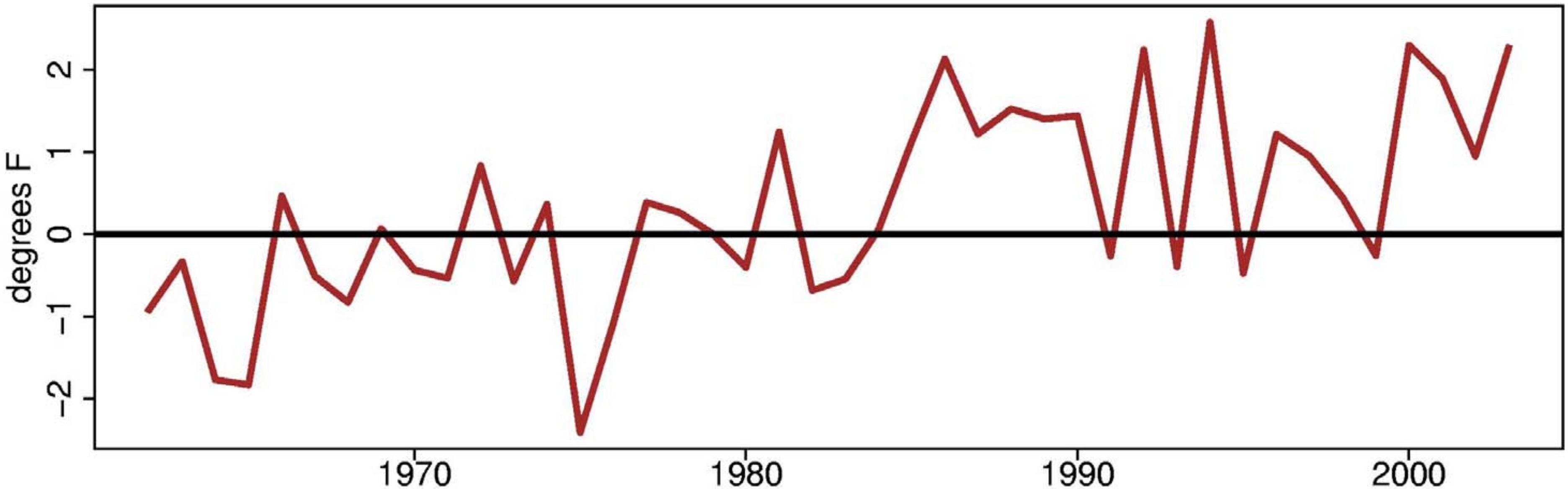


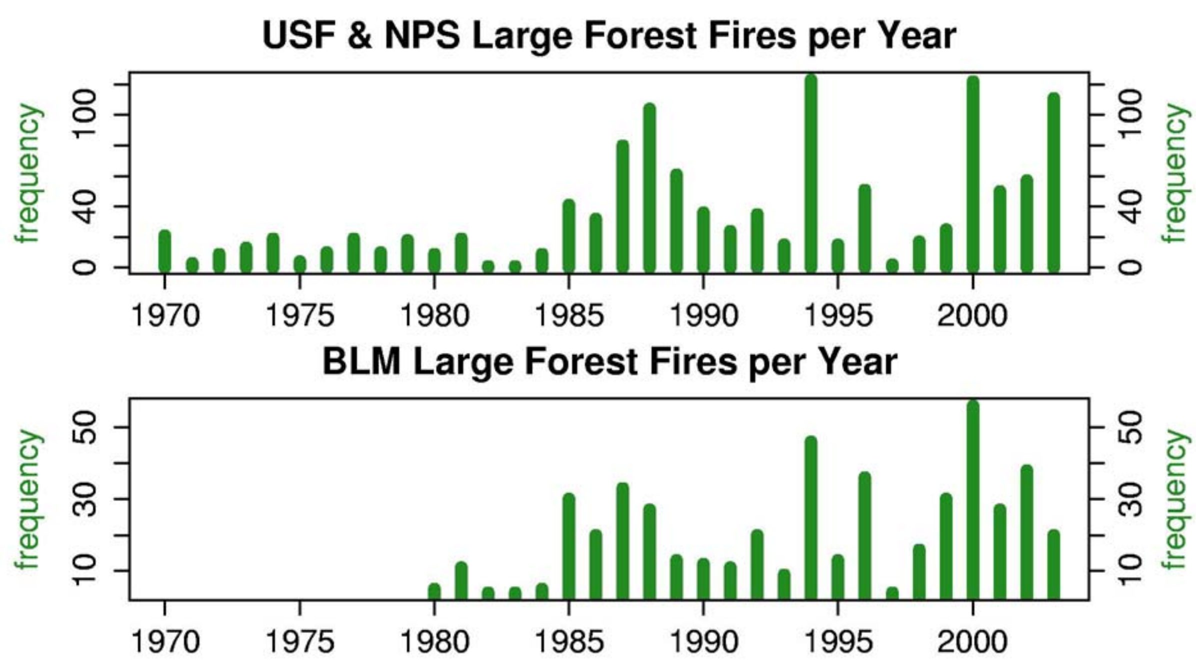
# … but total ignitions have not.



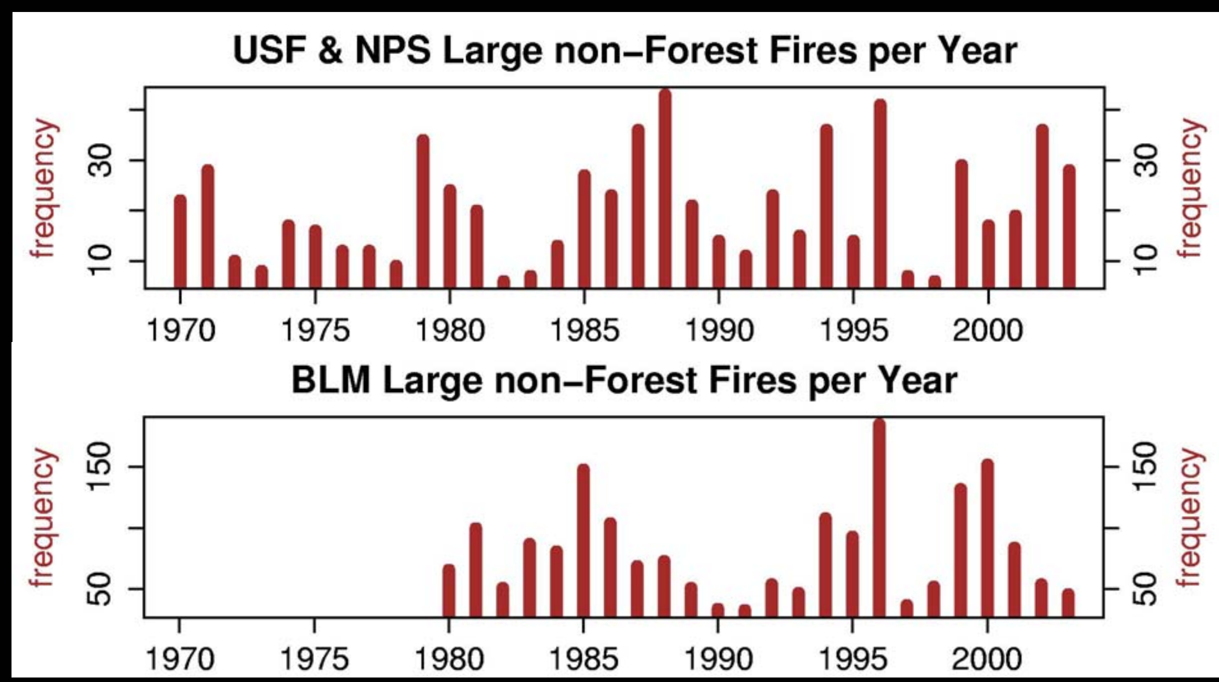
# Western US Spring and Summer Temperature

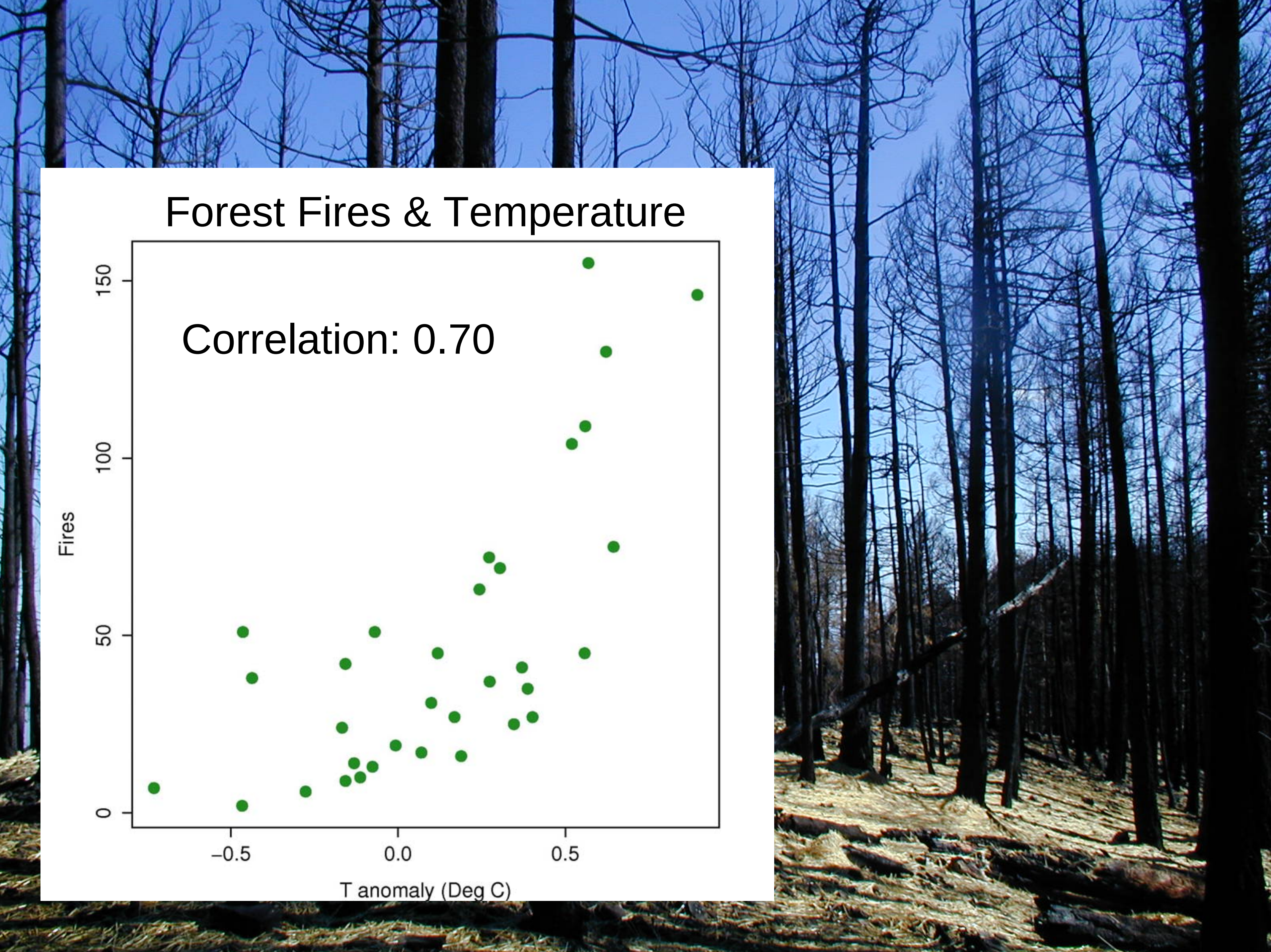




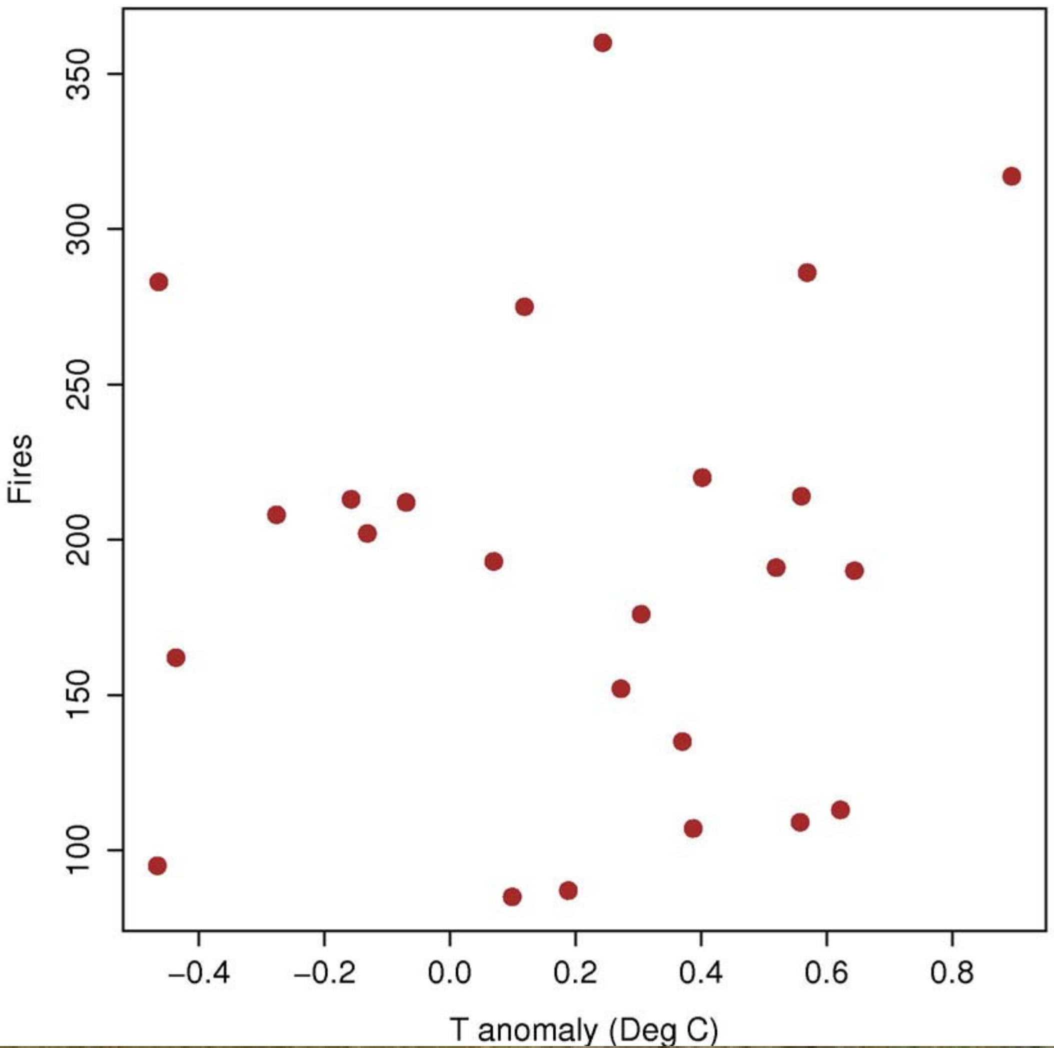

*Large Forest Wildfires Have Increased ~300%*

*Other Large Wildfires Have Not Changed Substantially*



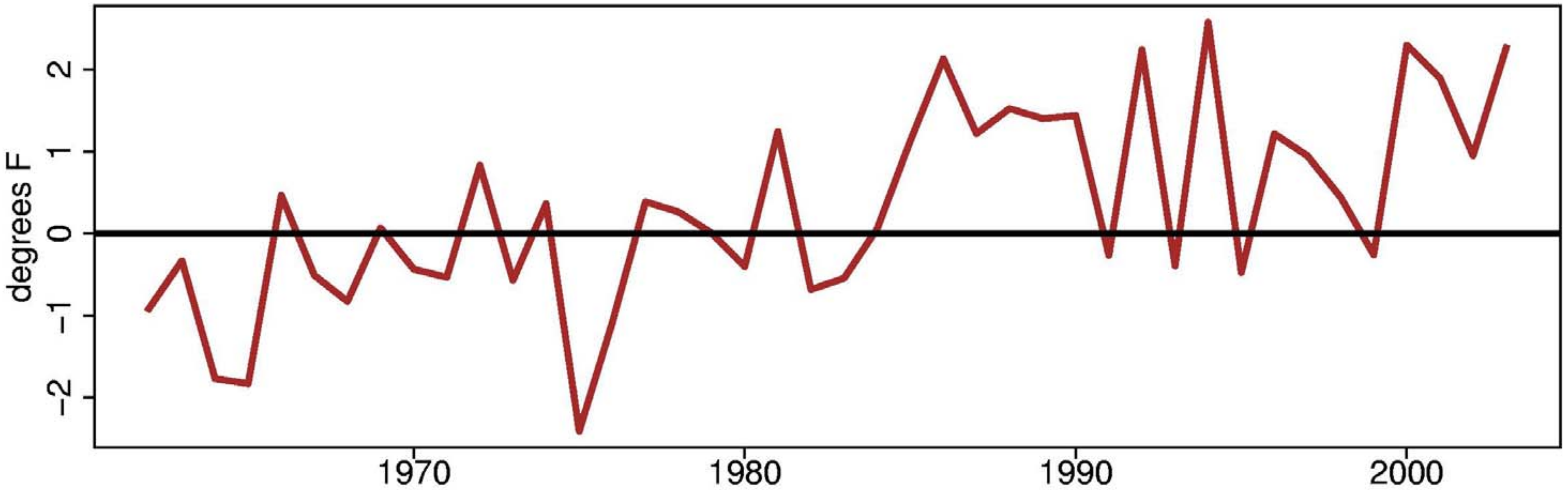

Forest Fires & Temperature
Correlation: 0.70
Fires
0
50
100
150
−0.5
0.0
0.5
T anomaly (Deg C)

# Grass/Shrub Fires and Temperature

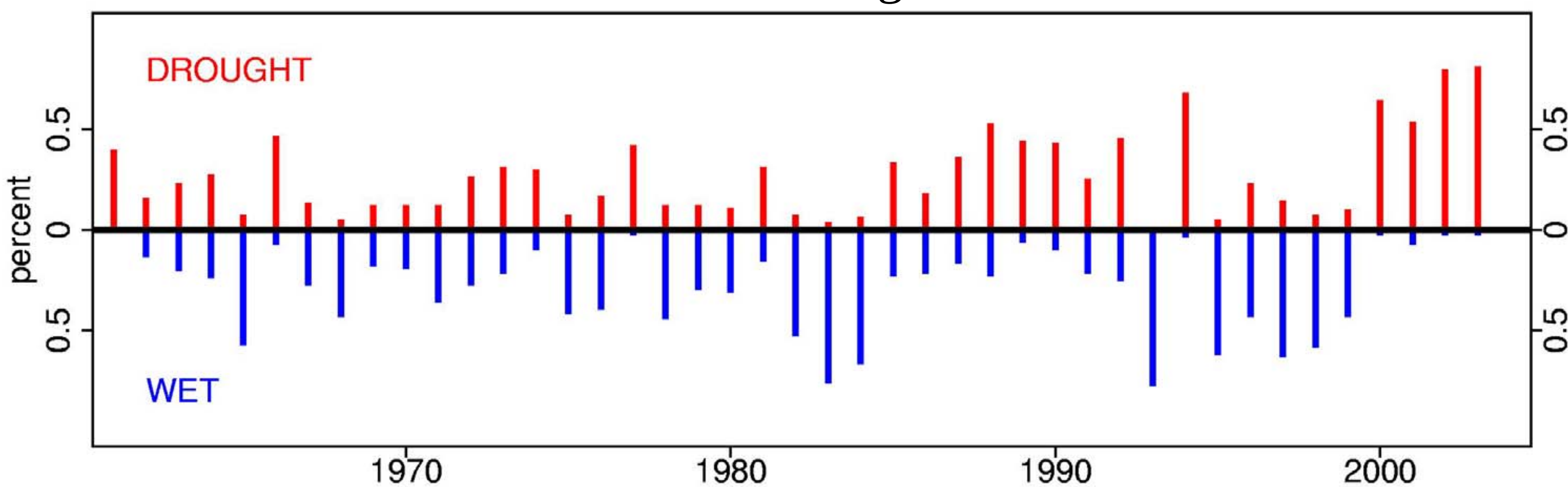


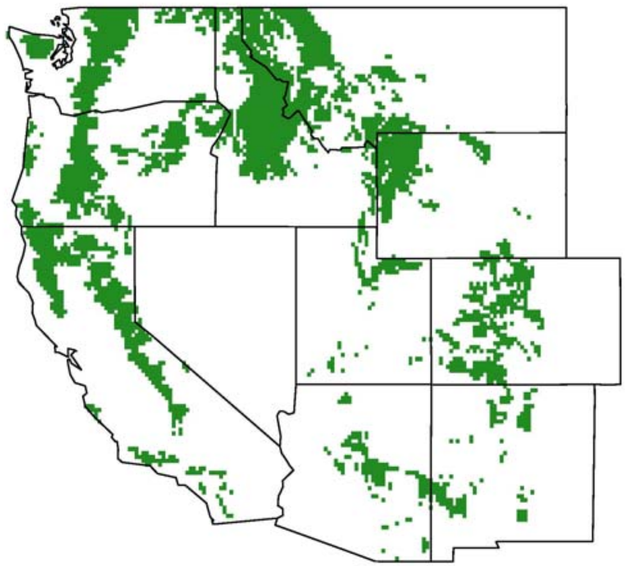

Correlation: 0.08

## Western US Spring and Summer Temperature

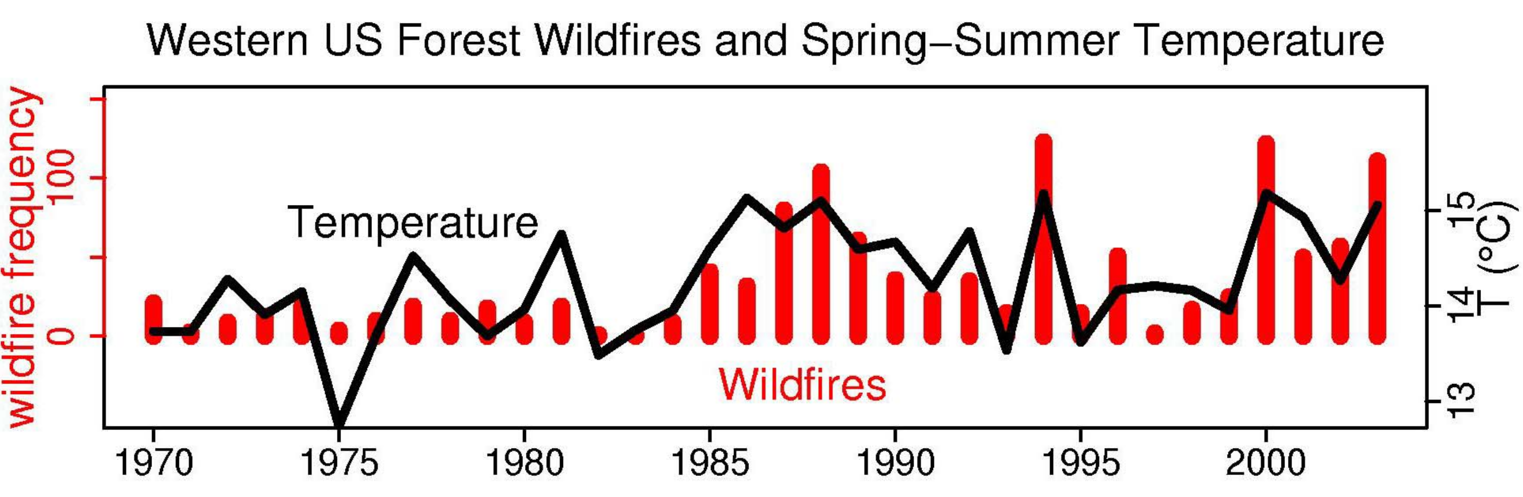



## Percent of Western US in Drought or Wet Conditions

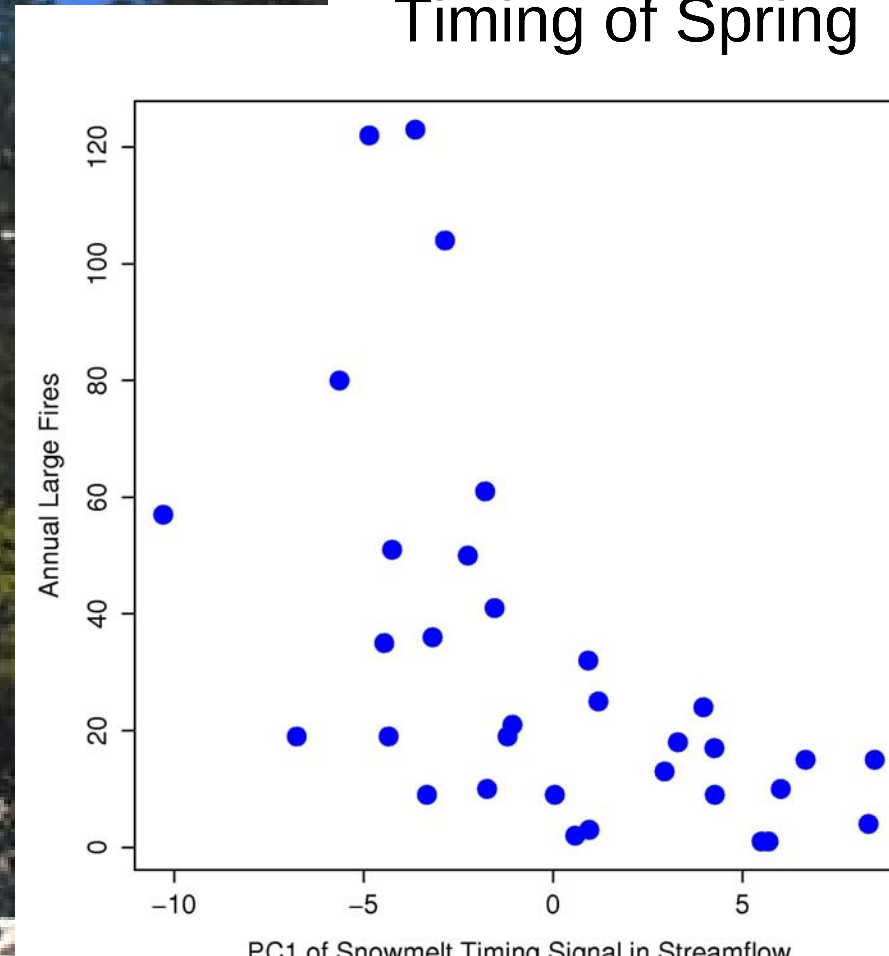




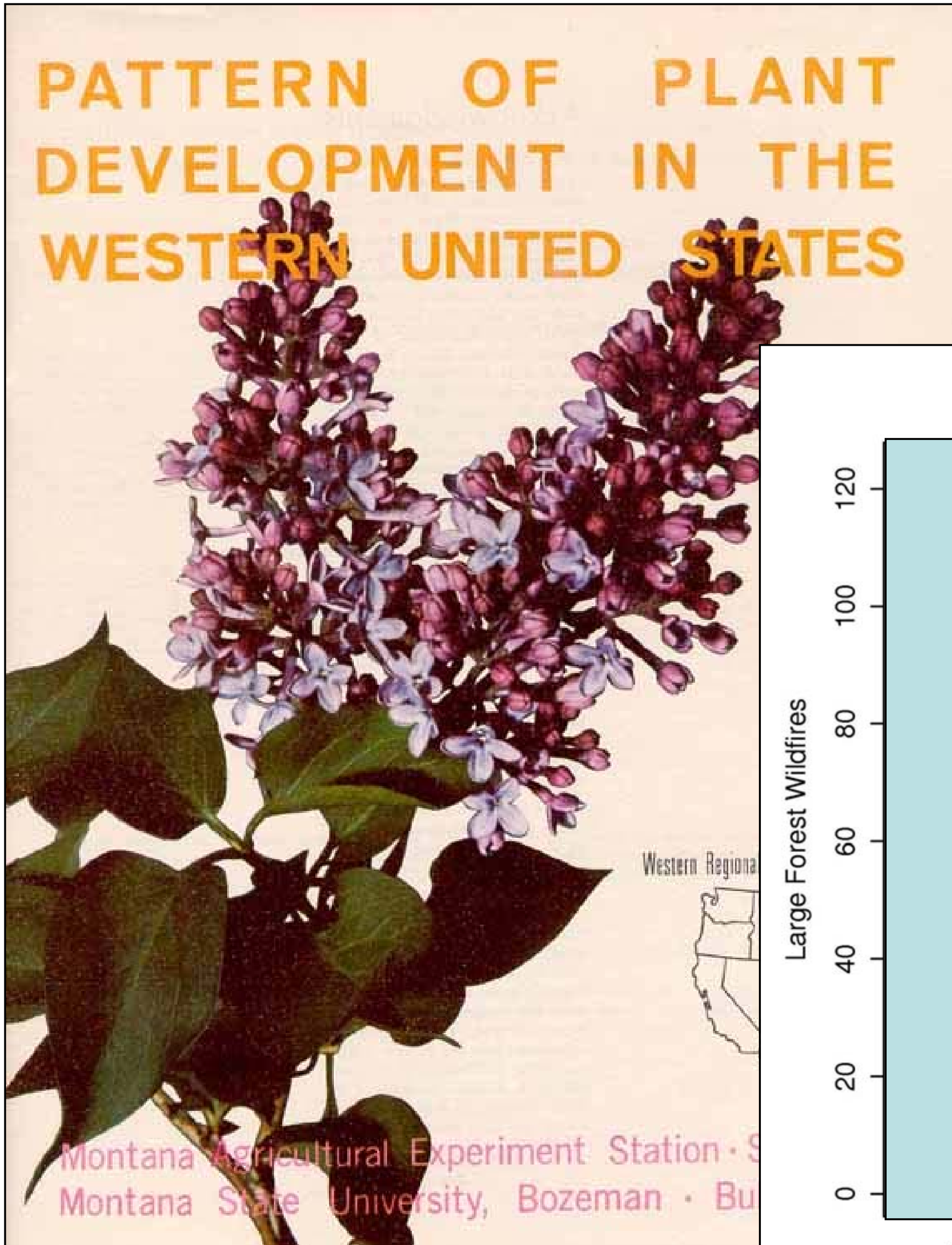
*Westerling et al, 2006 Science*

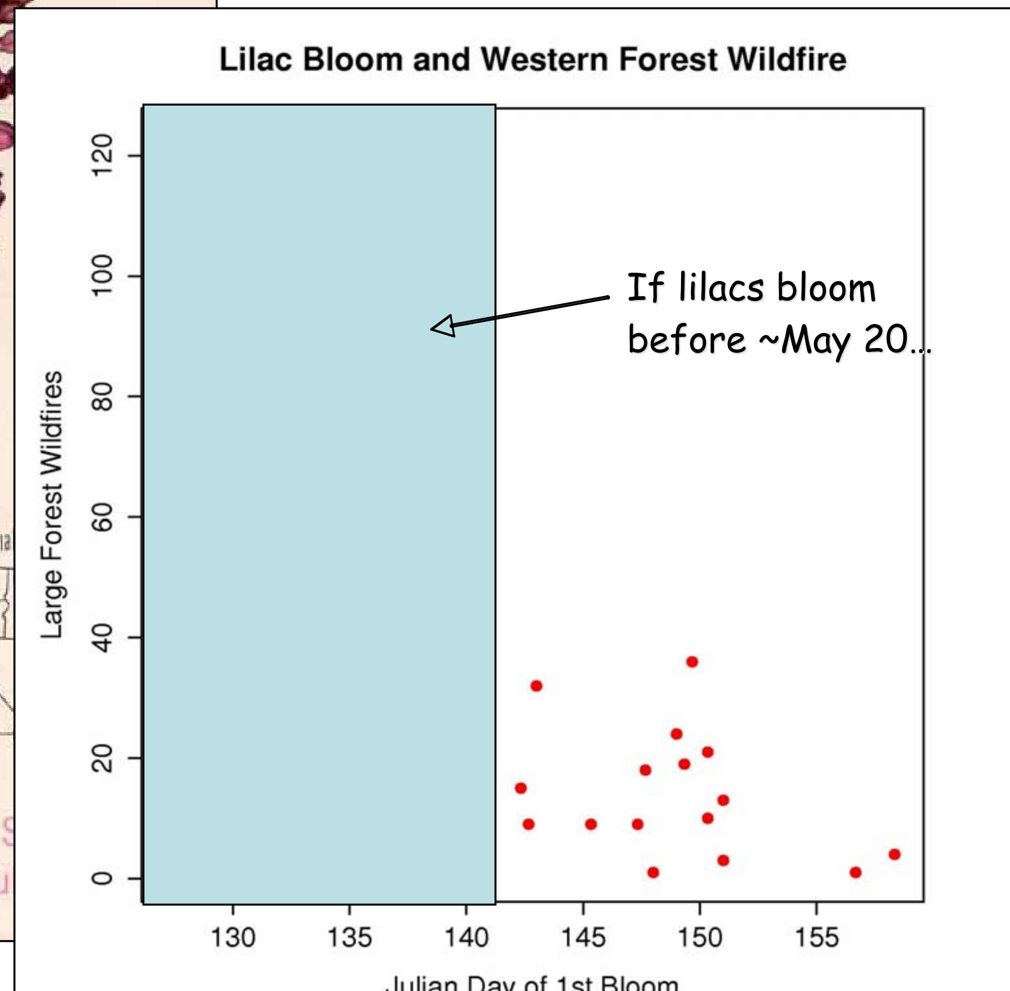


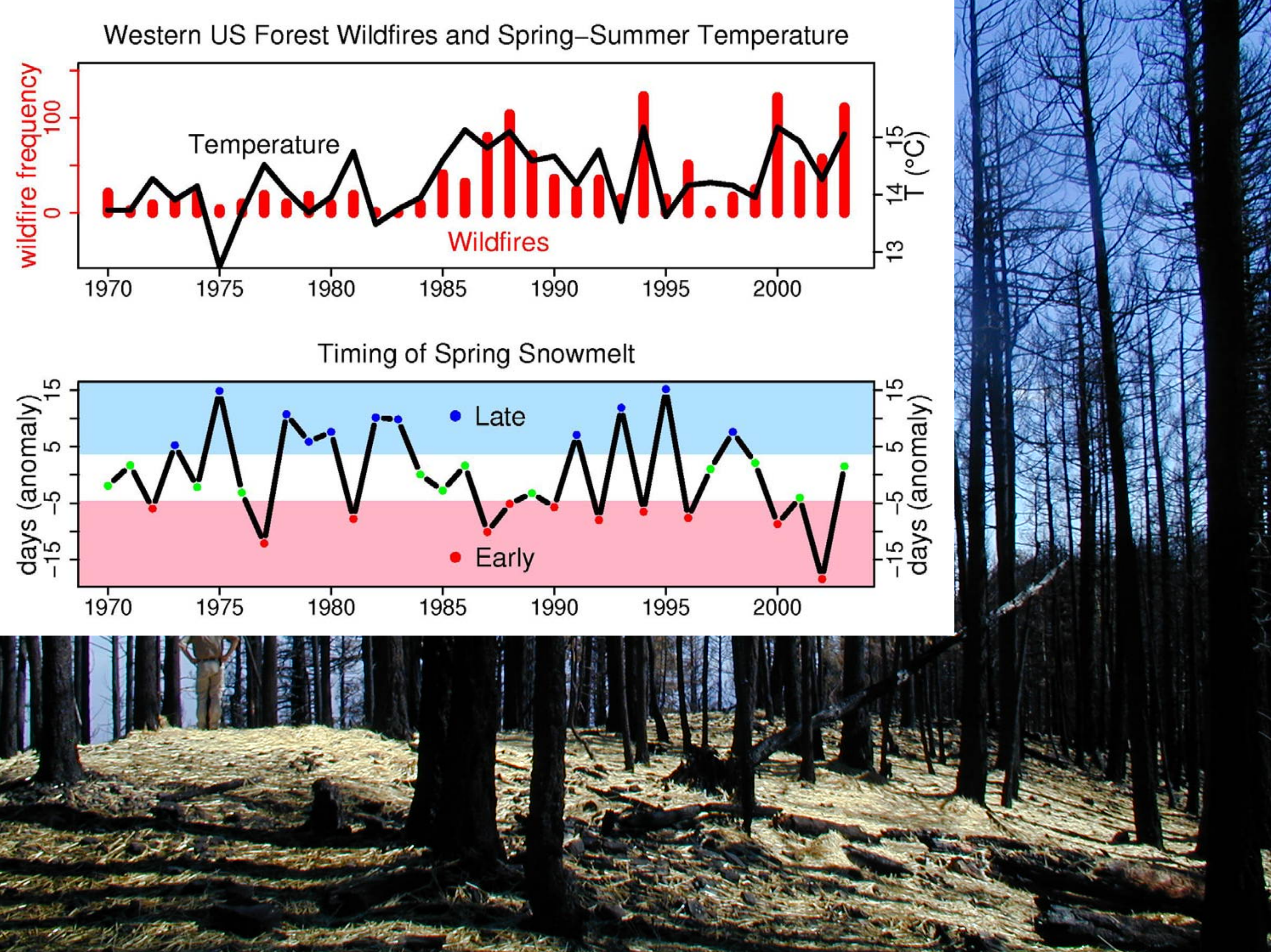
# Forest Fires & Timing of Spring

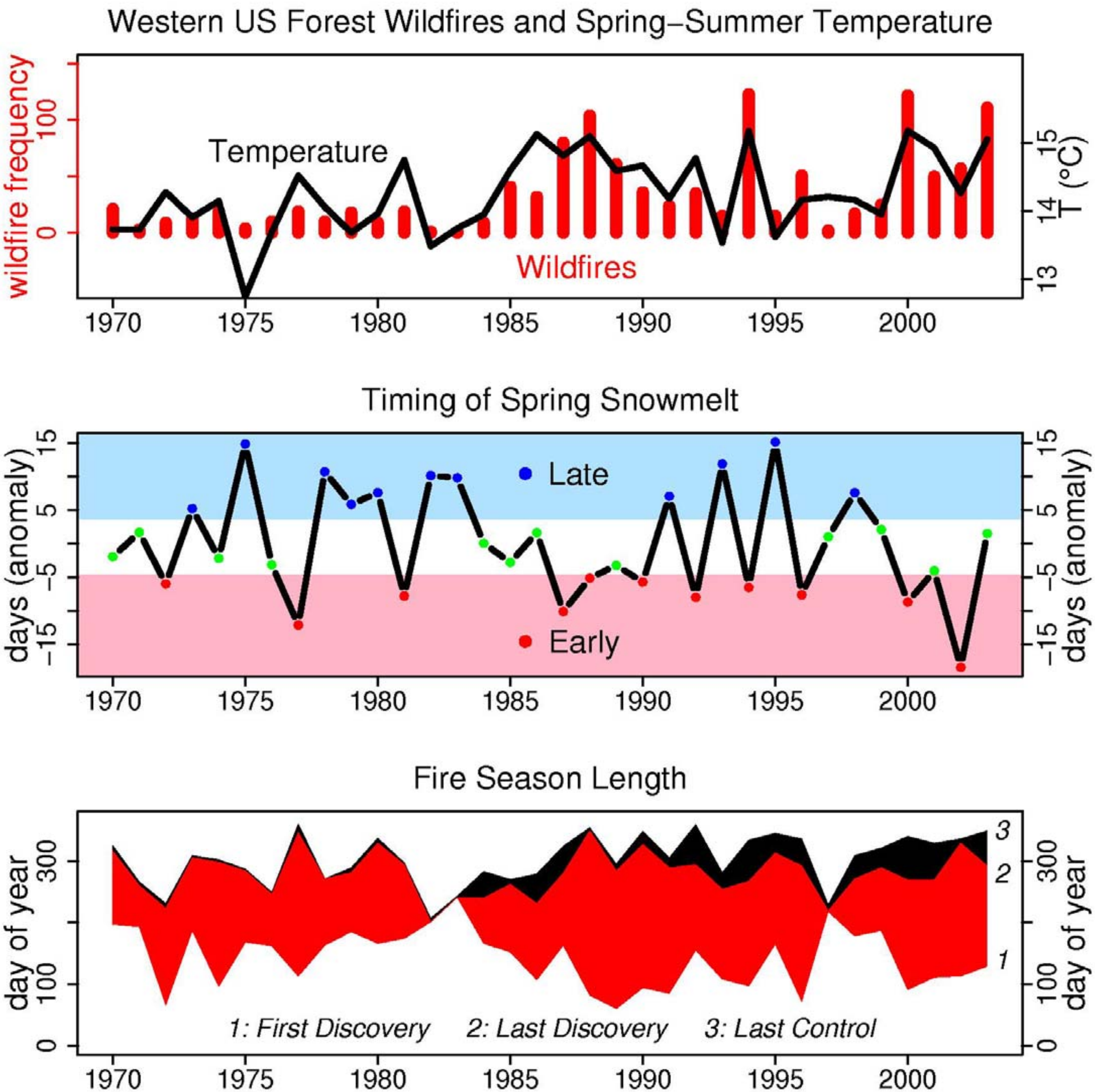




Correlation: 0.56


PATTERN OF PLANT DEVELOPMENT IN THE WESTERN UNITED STATES
Montana Agricultural Experiment Station
Montana State University, Bozeman

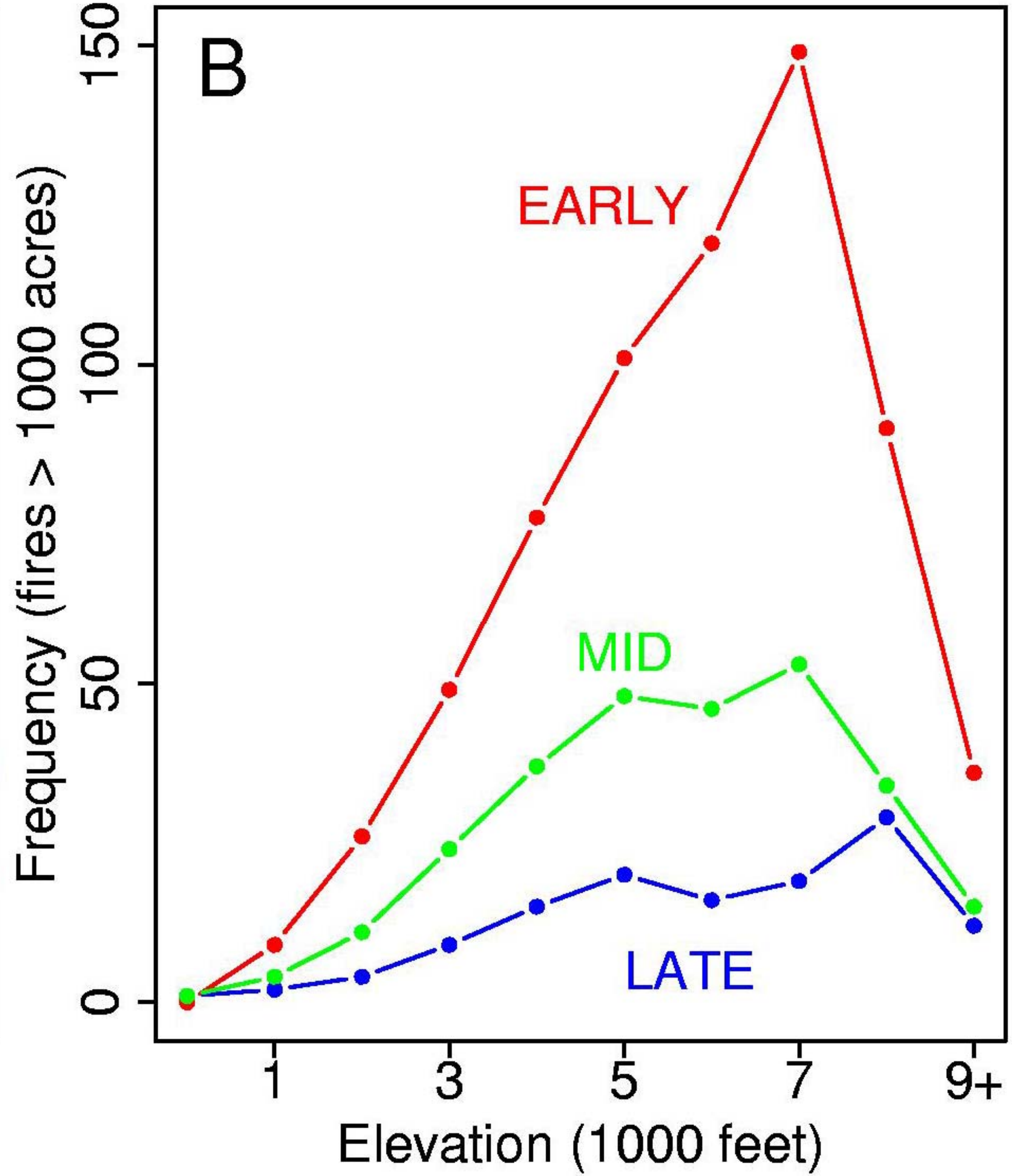

Lilac Bloom and Western Forest Wildfire
Large Forest Wildfires
0
20
40
60
80
100
120
Julian Day of 1st Bloom
130
135
140
145
150
155
If lilacs bloom before ~May 20…


Western US Forest Wildfires and Spring−Summer Temperature
wildfire frequency
0
100
Temperature
Wildfires
T (°C)
13
14
15
1970
1975
1980
1985
1990
1995
2000
Timing of Spring Snowmelt
days (anomaly)
−15
−5
5
15
Late
Early
1970
1975
1980
1985
1990
1995
2000

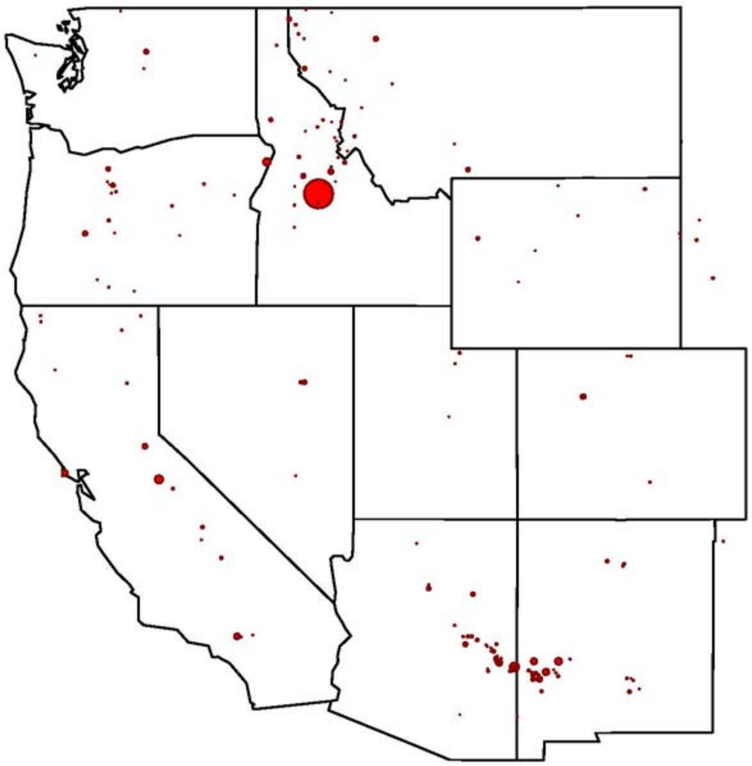

Western US Forest Wildfires and Spring−Summer Temperature
wildfire frequency
Temperature
Wildfires
T (°C)
0
100
13
14
15
1970
1975
1980
1985
1990
1995
2000
Timing of Spring Snowmelt
days (anomaly)
Late
Early
−15
−5
5
15
Fire Season Length
day of year
0
100
300
1: First Discovery
2: Last Discovery
3: Last Control
1
2
3

***Most forest fires occur in years with early Springs…***

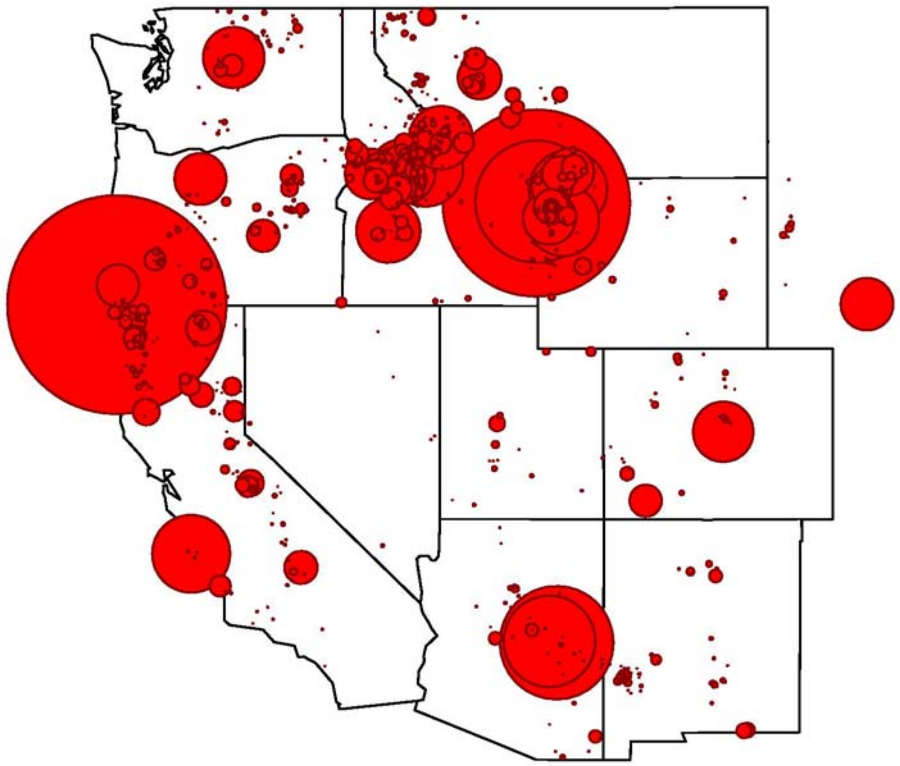
***… at elevations around 7000 feet***



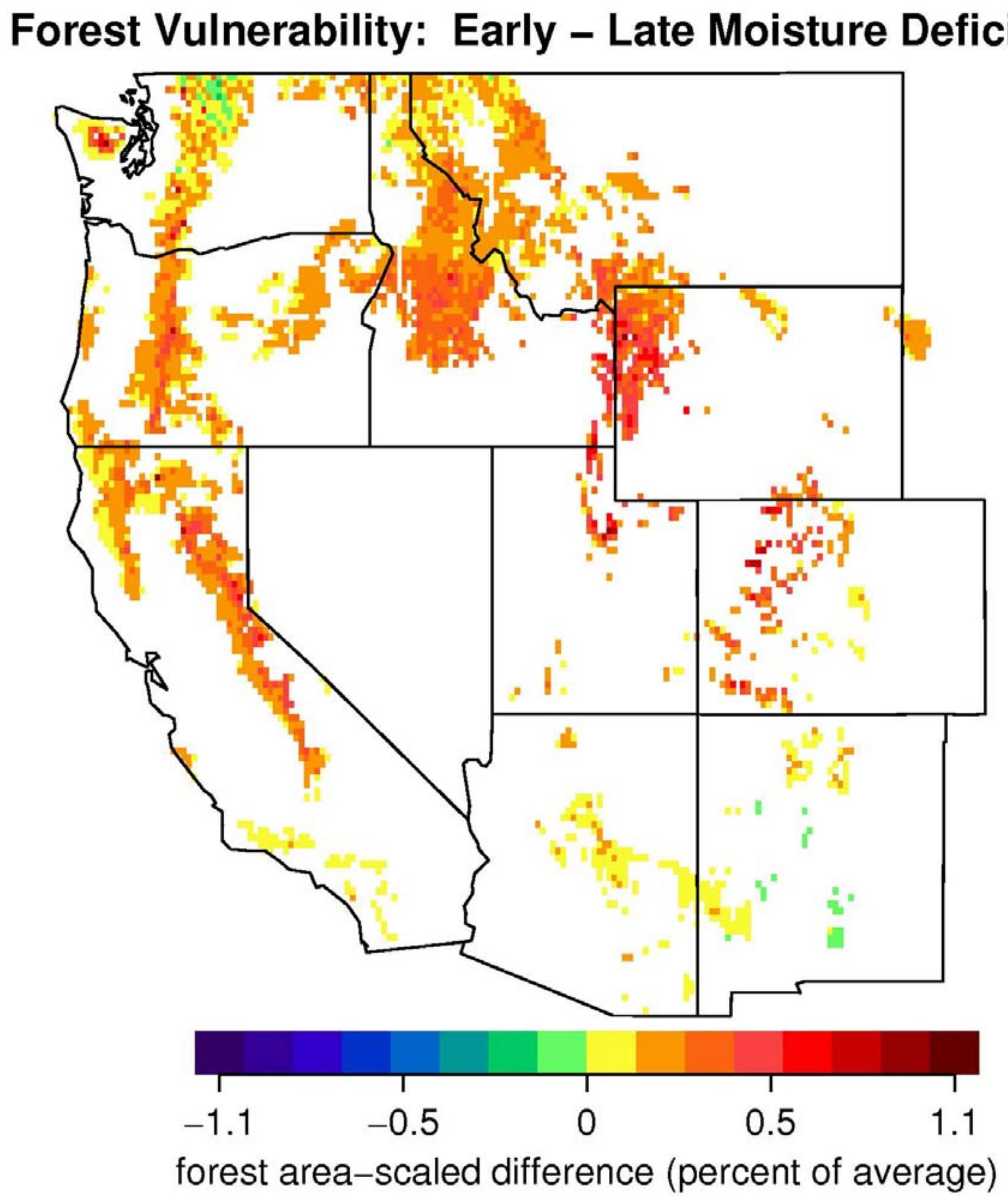
Late Snowmelt Years

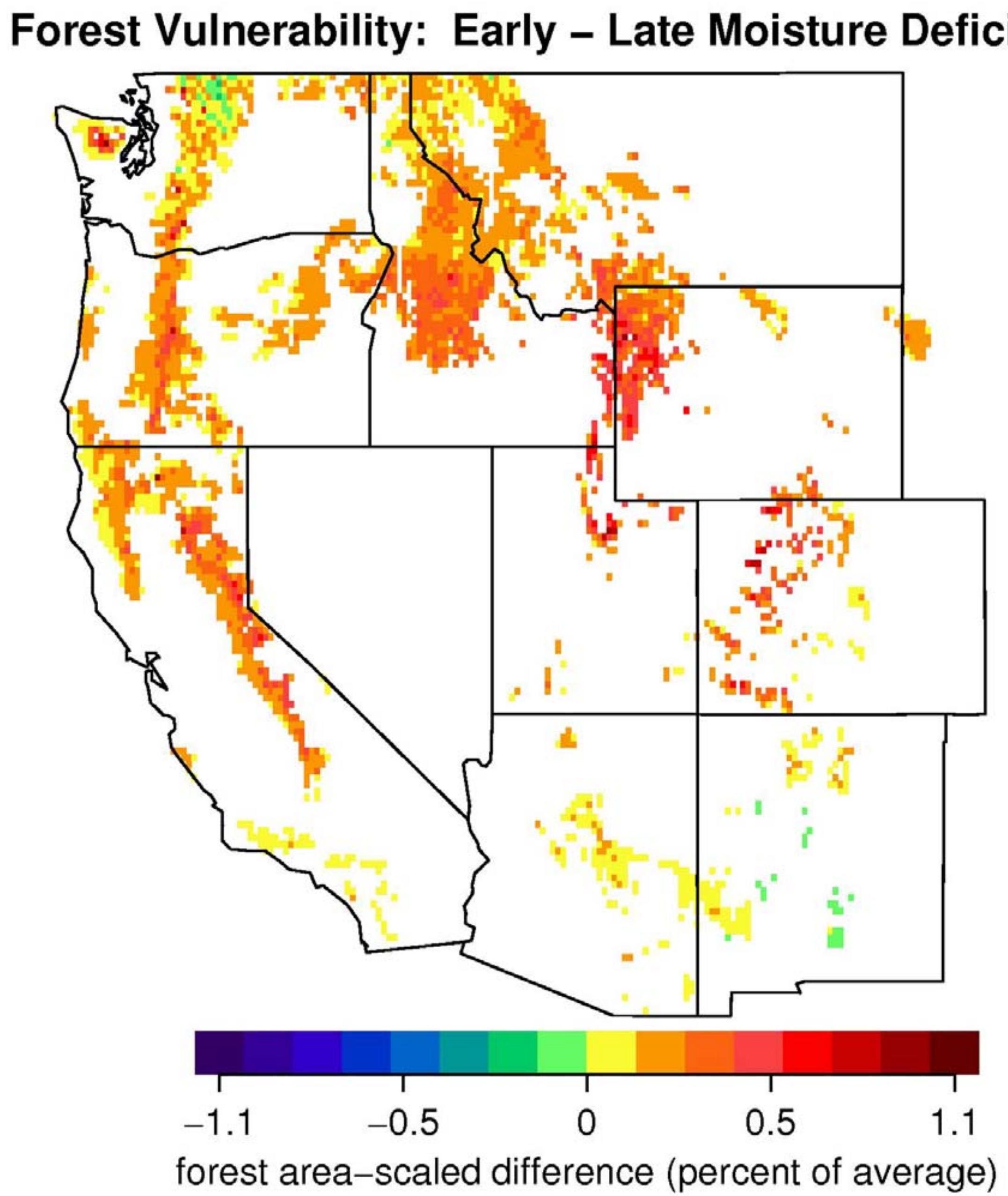


Early Snowmelt Years



1972 - 2003, NPS, USFS & BIA Fires over 1000 acres


Forest Vulnerability: Early – Late Moisture Deficit
−1.1
−0.5
0
0.5
1.1
forest area−scaled difference (percent of average)




Dry Winters

+

Warm Springs

↓

Early Snow Melt

↓

Drier Soils in Early Summer

↓

Longer Dry Season

↓

Drier Vegetation

↓

More Fires

# Why Has Forest Wildfire Increased?

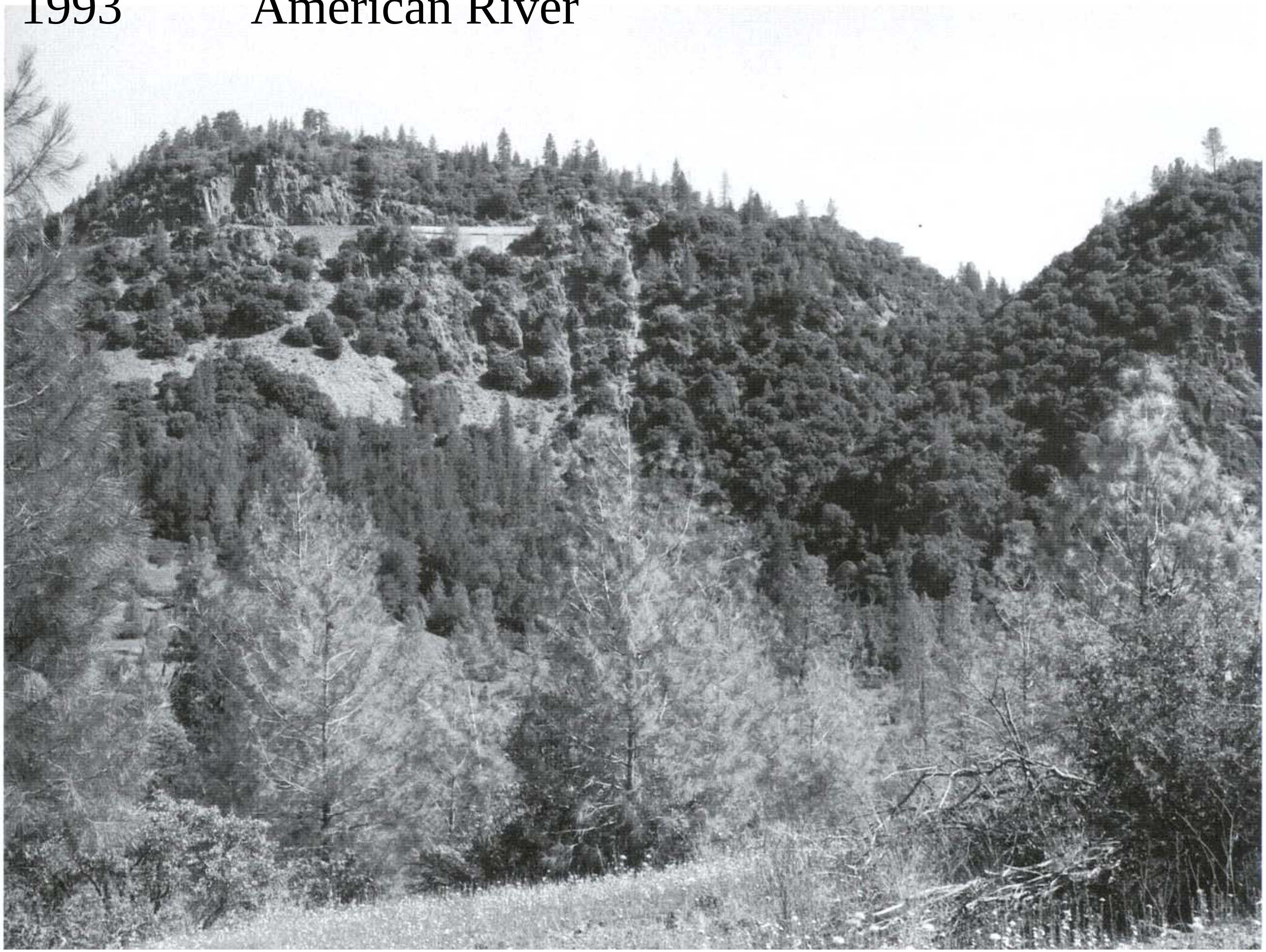
- **Management**
  - Grazing and fire suppression reduced burned area
  - Reduced burned area led to biomass accumulation in some forests
  - Increased biomass reduced the effectiveness of suppression efforts
- **Climate**
  - Forest fire activity driven by drought
  - Warming and Earlier Springs have extended and intensified the fire season in mid-elevation forests

*Consequences?*

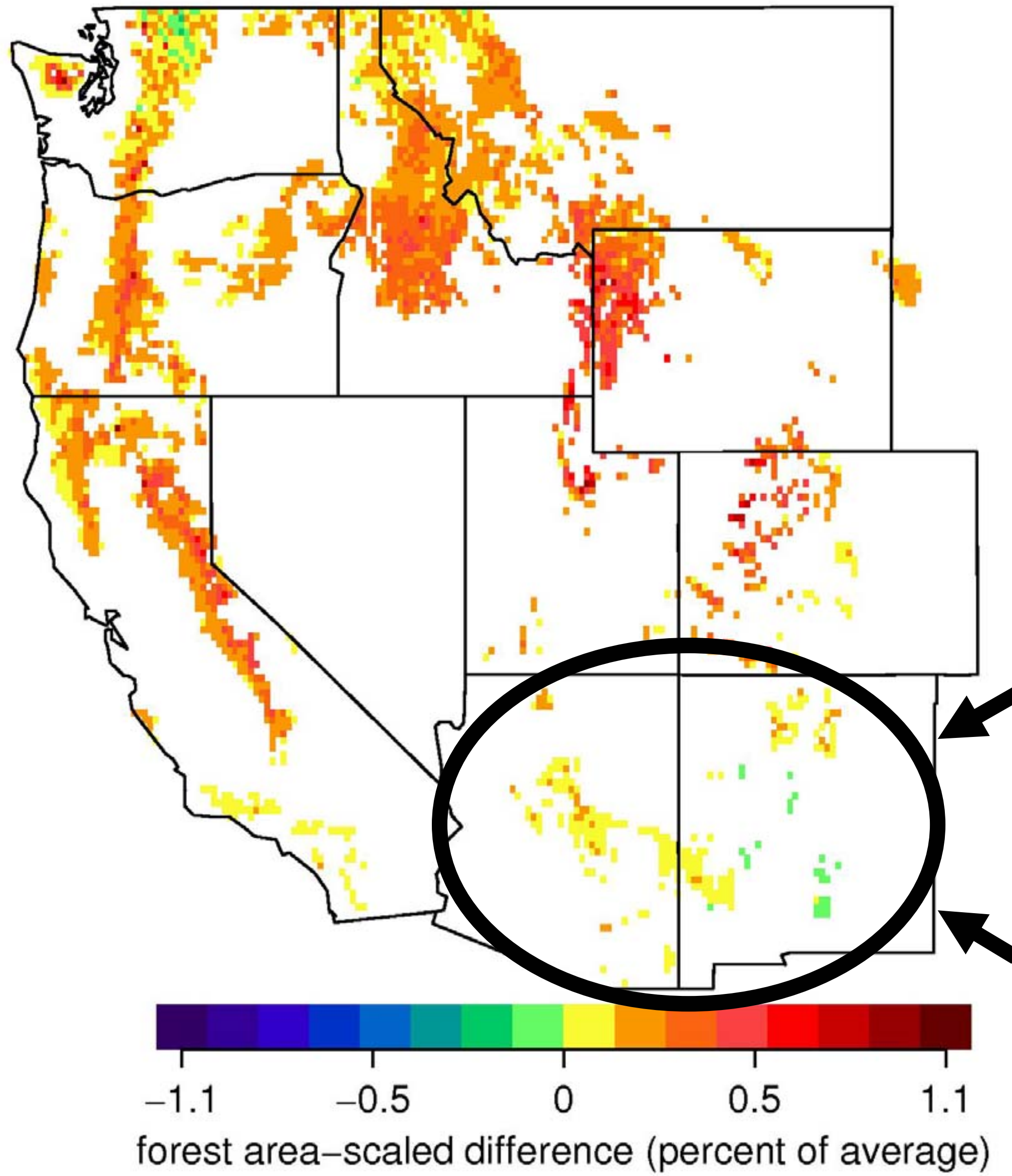
1867 American River

*Consequences? Fuel accumulation reduces effectiveness of suppression*

1993 American River

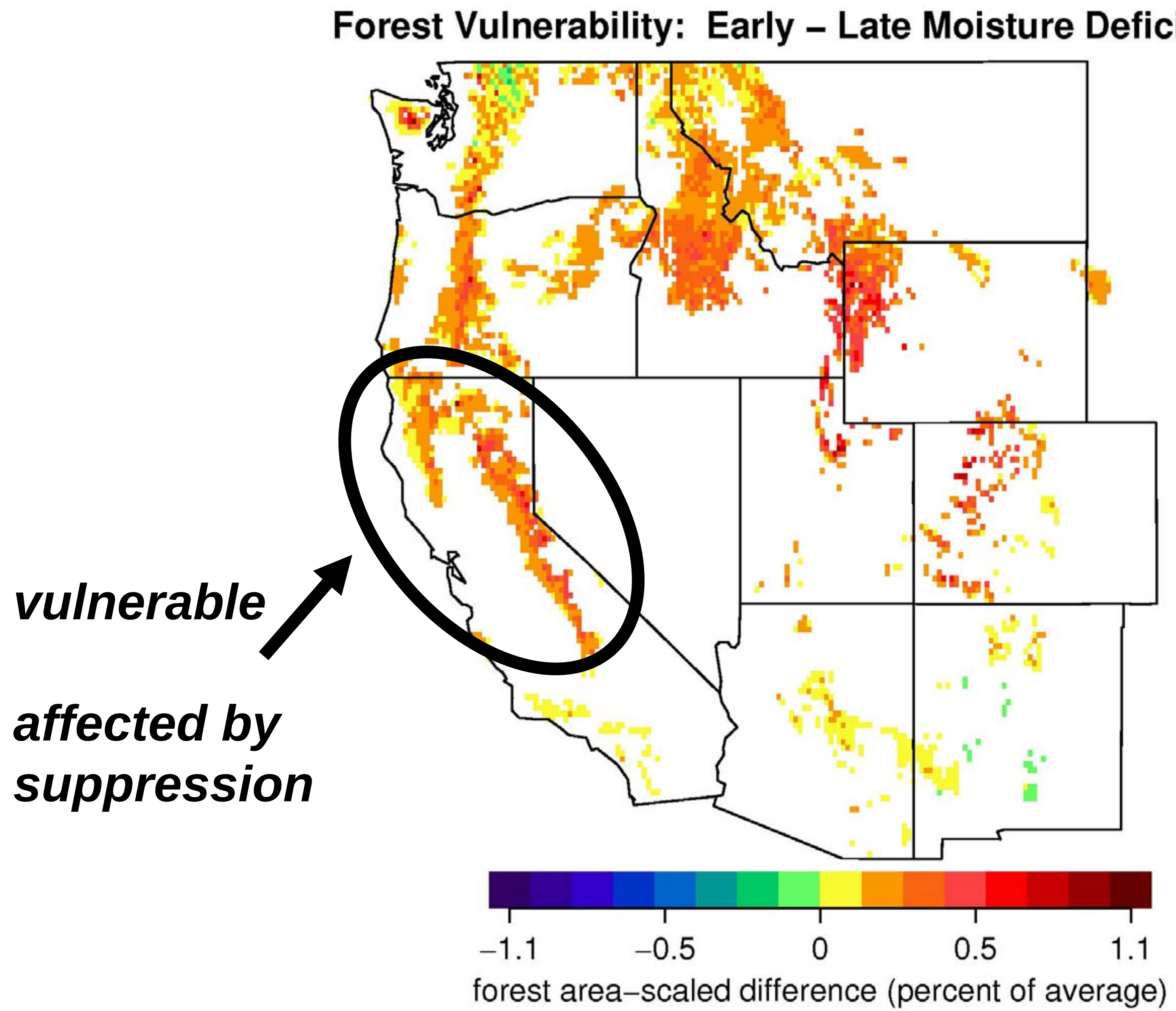


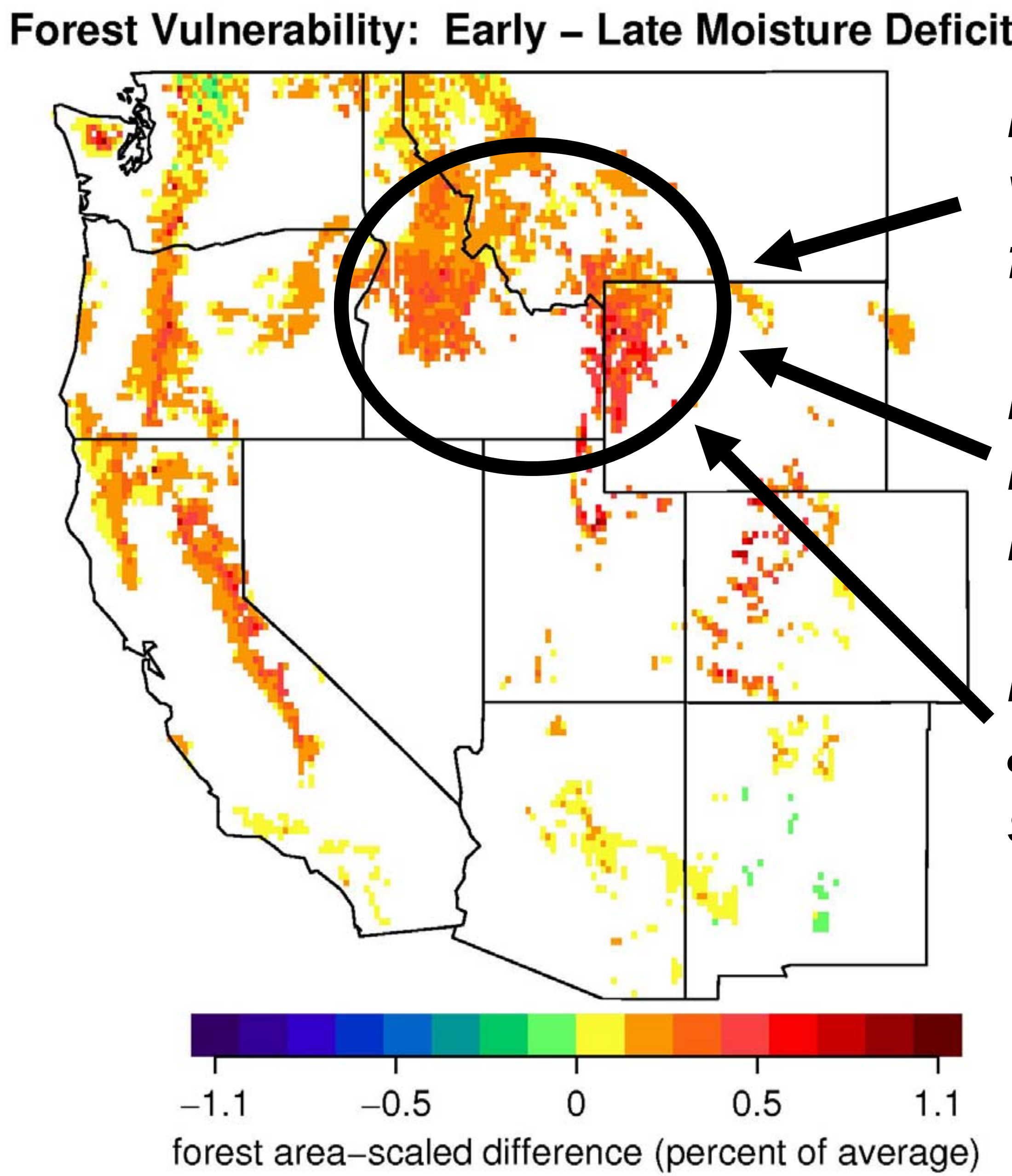
## Forest Vulnerability: Early – Late Moisture Deficit




***less vulnerable to warming***

***most affected by suppression***


Forest Vulnerability: Early – Late Moisture Deficit
vulnerable
affected by suppression
−1.1
−0.5
0
0.5
1.1
forest area−scaled difference (percent of average)




***largest vulnerable forest area***

***biggest increase in wildfires***

***risks least affected by suppression***

## **Purpose of a statistical model**

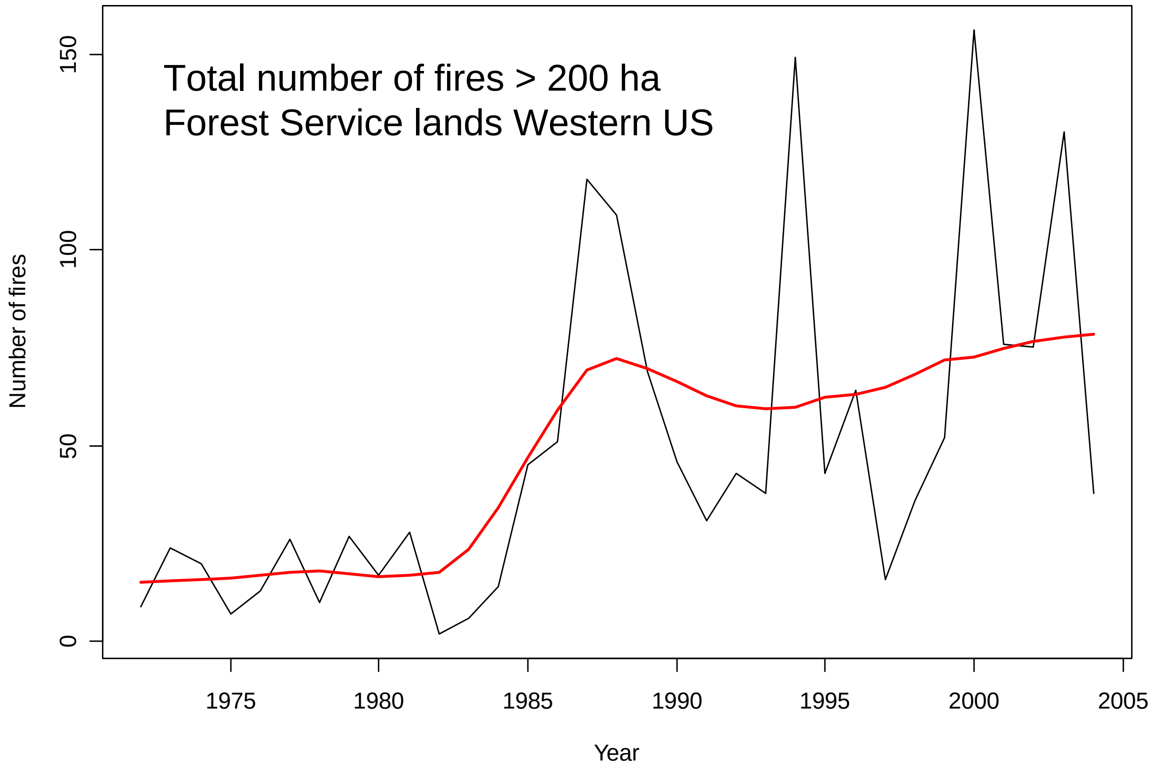
- Quantify relationships between distributions of fire sizes and various explanatory variables (e.g., climate variables)

- A quantitative statistical model may be useful for forecasting future scenarios of wildfire activity

# Data used to estimate statistical model

Response variable:

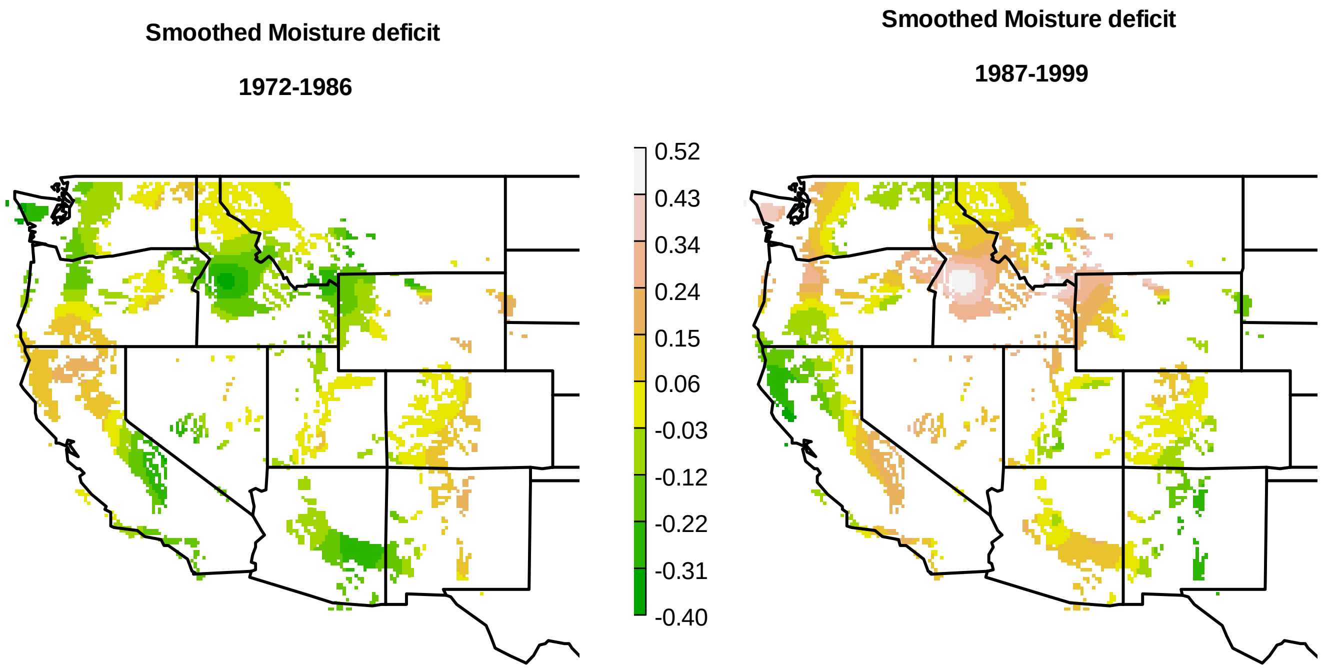
Total area burned in each 1/8$^o$ grid cells of Western FS lands for each year



# Data used to estimate statistical model

Explanatory variables:

1. Moisture deficit
2. Temperature
3. Timing of Spring
4. % forested area
5. Elevation



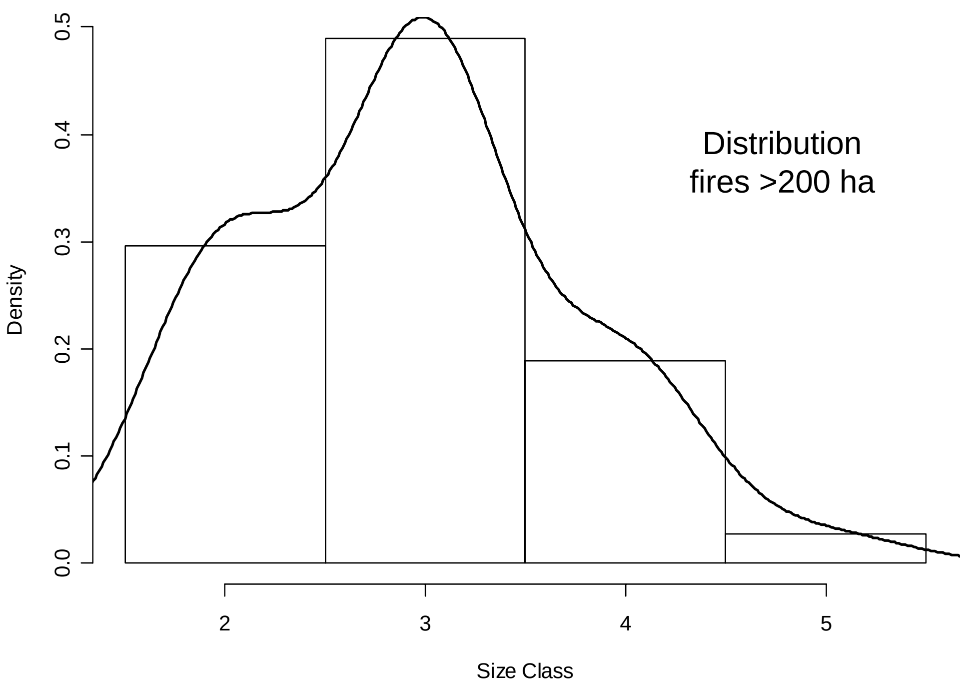

Data are yearly values on 1/8º grid cells

Response variable was grouped into 5 size classes

## Area burned - size classes

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Hectares | [0-200] | (200-400] | (400-3000] | (3000-22,000] | >22,000 |
| #fires | 129221 | 209 | 479 | 184 | 26 |

Data
Forest Service lands
1972 - 1999



## Statistical Model

$Y_{ij} = k$ if fire of size class $k$ at location $i$ year $j$ $k$=1, 2, 3, 4, 5

$Y_{ij} \sim$ Multinomial $\{ 1, \pi_k(\theta_{ij})\}$ with $\pi_1 + \ldots + \pi_5 = 1$

$$\theta_{ijk} = \text{linear predictor}$$
$$= \alpha_k + \sum_m g_m(X_{mij}) + g(year_j) : \mathrm{h}(lon_{ij}, lat_{ij})$$

$X_{mij}$ = value of $m^{th}$ explanatory variable at location $i$ year $j$

$g(\ )$ and h( ) ~ smoothing functions
e.g. basis splines and thin plate splines

## Multinomial probabilities

$$\pi_k = \exp(\theta_k)/\sum_k \exp(\theta_k)$$

## Ordinal responses

$$\begin{aligned} p_k &= \Pr[Y = k \mid Y > k-1] \\ &= 1 - \exp(-\exp(\gamma_k)) \end{aligned}$$

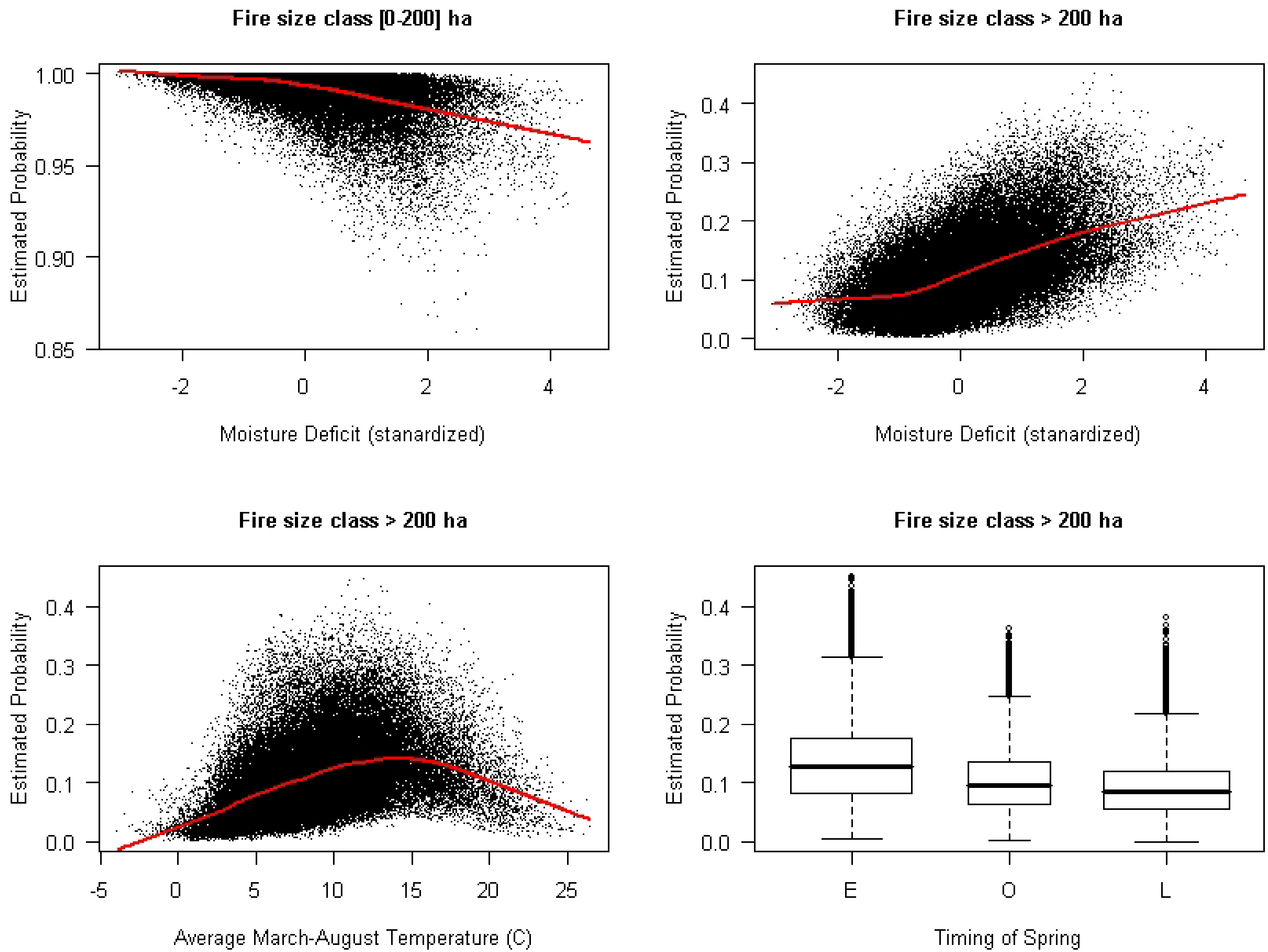
$$\pi_k = p_k[1 - p_1 - \cdots - p_{k-1}]$$

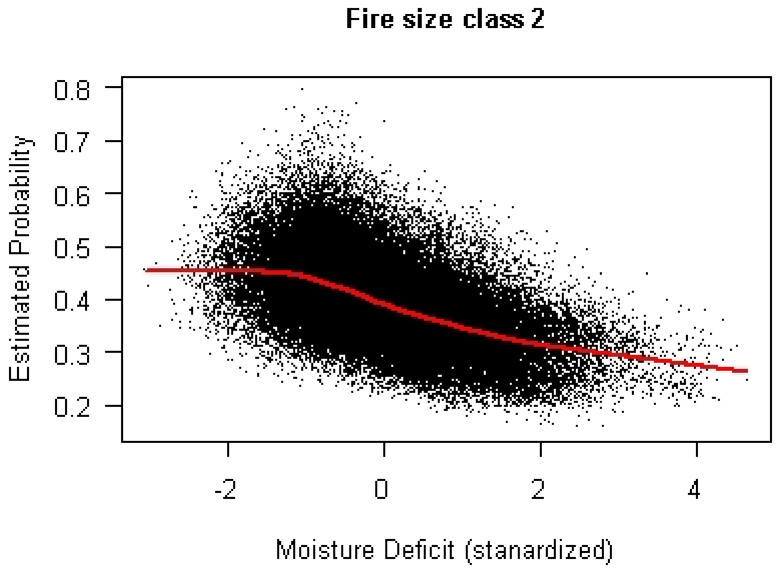
## RESULTS

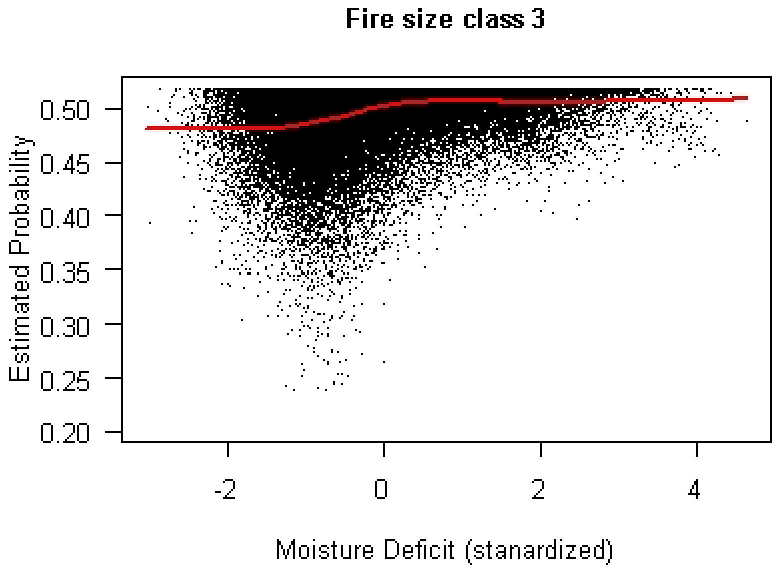
Analysis of Deviance Table: Percent explained

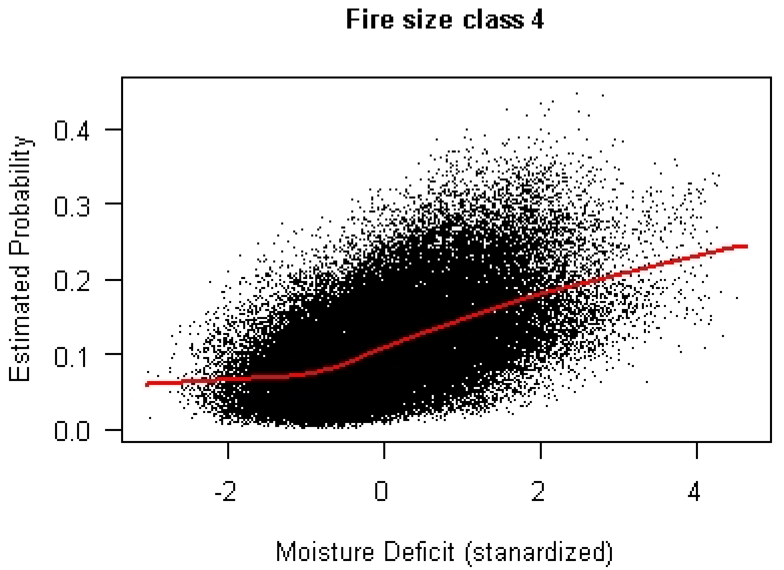
| X | Deviance | AIC | MI |
|---|---|---|---|
| 1. Spring | 0.9 | 0.7 | 0.6 |
| 2. Moisture | 21.1 | 22.9 | 25.5 |
| 3. Temp. | 6.3 | 6.4 | 6.4 |
| 4. %forest | 4.3 | 4.3 | 3.1 |
| 5. Elev. | 6.3 | 6.4 | 3.1 |
| 6. Year:loc | 38.3 | 34.3 | 40.1 |

AIC ~ Akaike Information Criteria
MI ~ Mutual Information statistic


Fire size class [0-200] ha
Estimated Probability
1.00
0.95
0.90
0.85
-2
0
2
4
Moisture Deficit (stanardized)
Fire size class > 200 ha
Estimated Probability
0.4
0.3
0.2
0.1
0.0
-2
0
2
4
Moisture Deficit (stanardized)
Fire size class > 200 ha
Estimated Probability
0.4
0.3
0.2
0.1
0.0
-5
0
5
10
15
20
25
Average March-August Temperature (C)
Fire size class > 200 ha
Estimated Probability
0.4
0.3
0.2
0.1
0.0
E
O
L
Timing of Spring

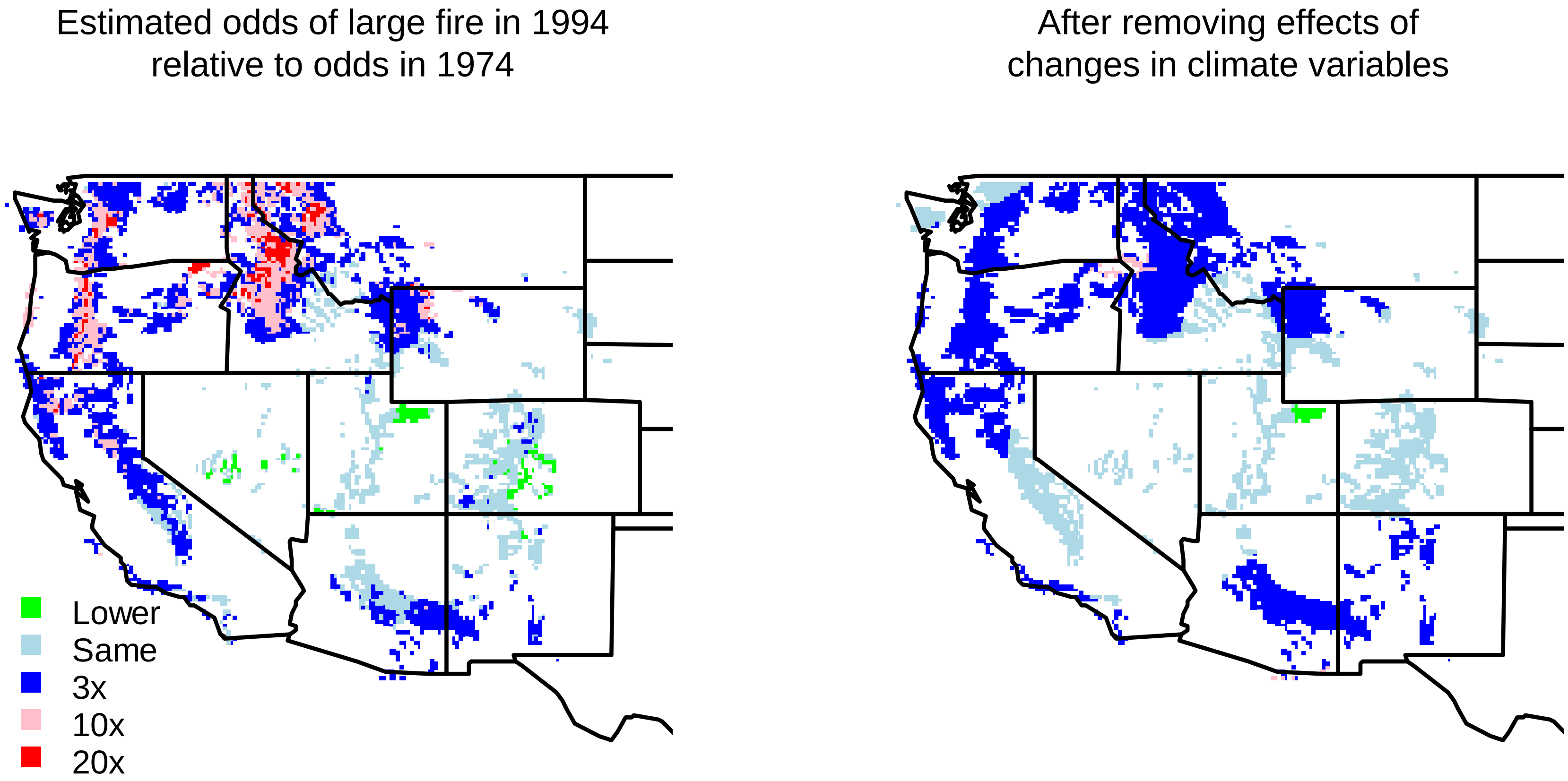



Conditional probability of size class Y= k given Y>1

size class 1 => [0-200] ha
2 => (200-400] ha
3 => (400-3000] ha
4 => >3000 ha


Estimated odds of large fire in 1994
relative to odds in 1974
After removing effects of
changes in climate variables
Lower
Same
3x
10x
20x

## Summary

- Apparent shift in distribution of wildfires (towards larger fires) in recent decades in Western US Forest Service lands.

- No apparent increase in number of wildfire starts.

- Apparent increase in estimated probabilities of fires in the largest size classes with warming and early spring through moisture deficit.

- Effect of moisture deficit seems to be mostly in the North Western regions (Northern Rockies, Northern California, Oregon and Washington).

# References


1. Westerling, A. L., Hidalgo, H.G., Cayan, D.R. and Swetnam, T.W. (2006). ‘Warming and earlier spring increase western US forest wildfire activity’. Science, Vol. 313, 940-943.
2. Preisler, H.K. and Westerling, A.L. (In press). ‘Statistical model for forecasting monthly large wildfire events in Western US’. Journal of Applied Meteorology and Climatology.
3. Preisler, H.K., Ager, A.A. and Hayes, J.L. (In press). ‘Probabilistic risk models for multiple disturbances: An example of forest insects and wildfires’. Encyclopedia of Forest Environmental Threats.