Past, Present, and Future Impacts of Drought on Forests in the Southwestern USA

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Photo: Craig D. Allen
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Goal: Figure out how much temperature matters (relative to precipitation) to regional forest productivity and mortality in the Southwestern USA.

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Photo: Craig D. Allen
Southwest United States
Last 117 Years of Climate in the Southwest

5-Year Running Average

Temperature

Precipitation

°C

mm

1900 1920 1940 1960 1980 2000
Goal: Figure out how much temperature vapor-pressure deficit matters (relative to precipitation) to regional forest productivity and mortality in the Southwestern USA.
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Regional Ring-Width Record

- No Drought
- Drought
Regional Ring-Width Record

3 Primary Tree Species

- piñon pine
- ponderosa pine
- Douglas-fir

No Drought

Drought
Regional Ring-Width Record

Southwest-wide record represents local region well

- **Southwest**
- **Santa Fe Region**

$r = 0.82$
During which seasons are precipitation and vapor-pressure deficit most influential on the regional ring-width record?
Ring-Widths Vs. Climate

During which seasons are precipitation and vapor-pressure deficit most influential on the regional ring-width record?

- Previous year
- Growth year

May-July
Nov.-Jan.
Feb.-April
May-July

No Drought
Drought

$\text{r} = 0.65$
During which seasons are precipitation and vapor-pressure deficit most influential on the regional ring-width record?

- Previous year: May-July, Aug.-Oct.
- Precip.: Nov.-Jan.

![Graph showing ring-width index with seasons labeled and correlation coefficient r = 0.78]
During which seasons are precipitation and vapor-pressure deficit most influential on the regional ring-width record?

![Graph showing ring-width index over time with seasons marked and correlation value r = 0.87]
During which seasons are precipitation and vapor-pressure deficit most influential on the regional ring-width record?

- Previous year
- VPD: May-July
- Growth year
  - Nov.-Jan.
  - Feb.-April
  - VPD: May-July

Graph shows:
- Ring-Width Index
- Correlation coefficient $r = 0.91$
- No Drought
- Drought
During which seasons are precipitation and vapor-pressure deficit most influential on the regional ring-width record?

- **Previous year**
  - May-July: VPD

- **Growth year**
  - Nov.-Jan.: Precip.
  - Feb.-April: VPD
  - May-July: VPD
  - Aug.-Oct.: VPD

- "cold-season" Precipitation
- "warm-season" vapor-pressure deficit
During which seasons are precipitation and vapor-pressure deficit most influential on the regional ring-width record?

[Graph showing the relationship between ring-width index and climate variables over time, with annotations for 'No Drought' and 'Drought', and a correlation coefficient of r = 0.91.]
Warm-season Vapor-Pressure Deficit is AT LEAST as important as cold-season precipitation.

- Warm-season VPD: 56%
- Cold-season precipitation: 44%
Forest Drought-Stress Index (FDSI)

\[ FDSI = 0.44[zscore(\text{cold-season Precip.})] - 0.56[zscore(\text{warm-season VPD})] \]
Average Summer Vegetation Greenness
Average Summer Vegetation Greenness

![Map of Average Summer Vegetation Greenness](image)
Summer Vegetation Greenness
1981–2008

NDVI data collected by the AVHRR satellite
Summer vegetation greenness agrees well with FDSI

NDVI data collected by the AVHRR satellite
Dying piñon pine, Jemez Mts.  October 2002

Photo:  Craig D Allen
Pine skeletons, conversion to juniper woodlands, Jemez Mts. May 2004

Photo: Craig D Allen
Number of dead piñon pines roughly doubled during 2001–2006

USFS Forest Inventory & Analysis (FIA) data
Same is true for ponderosa pine and Douglas-fir

USFS Forest Inventory & Analysis (FIA) data

- piñon pine
- ponderosa pine
- Douglas-fir
How did all those trees die?
One cause was bark beetles

Forest Health Technology Enterprise (FHTET) data
Bark beetle-induced forest mortality, 1997-2010

~ 8% of forest and woodland was affected.

(Williams et al., 2010 PNAS)
Bark-beetle outbreak corresponded with major forest drought stress

\[ r = -0.84 \]
How did all those trees die?
Another cause was wildfire

LANDSAT & MODIS satellite data

km²

Area of Moderate and Severe forest fires, 1984-2008

~ 3% of forest and woodland was affected.

(Williams et al., 2010 PNAS)
How did all those trees die?
Another cause was wildfire

LANDSAT & MODIS satellite data
Burned area correlates well with forest drought stress

$r = -0.8$
2011 Vapor-Pressure Deficit: 2 to 6 standard deviations above average from east AZ through west TX compared to top 20% of drought years since 1895.
Importantly, drought-induced forest mortality is normal in the Southwest.
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Importantly, drought-induced forest mortality is normal in the Southwest

The 1899–1904 and was also may have caused widespread tree mortality. From Plummer et al. 1904: “The scarcity of precipitation [that] has afflicted this region is shown by the condition of yellow pine, alligator juniper, and Arizona cypress, which, as a rule, stand an extreme drought... Yellow pine is rapidly being killed, as the whole of them are dead or so far diseased as to be beyond resuscitation.”
Drought variability over the past 1000 years

Drought intensity during the past century appears within the range of expected variability.
Drought variability over the past 1000 years

Historic droughts also caused widespread mortality

Late-1500s Megadrought
Drought variability over the past 1000 years

Tree Establishment Dates

- Douglas-fir
- ponderosa pine
- piñon pine

Swetnam & Brown 1992
Drought variability over the past 1000 years

Historic droughts also caused widespread mortality

Late-1200s Megadrought
Drought variability over the past 1000 years

Historic droughts also caused widespread mortality.
Climate Model Projections through 2100

**Cold-season precipitation**

- Standard deviation anomaly
- 5-15% decrease in cold-season precipitation by 2100

**Warm-season vapor-pressure deficit**

- Standard deviation anomaly
- 40% increase in warm-season VPD
Cold-season precipitation

5-15% decrease in cold-season precipitation by 2100

Warm-season vapor-pressure deficit

40% increase in warm-season VPD
Climate Model Projections of Forest Drought-Stress Index (FDSI) through 2100

Climate models project persistent “megadrought” conditions by the 2050s

Most severe 50% of years during 1200s and 1500s Megadroughts
Conclusions

• Southwestern tree-ring records indicate similar year-to-year growth response to drought stress regardless of species or location.

• Warm-season vapor-pressure deficit appears to at least as important as cold-season precipitation in dictating drought stress.

• Drought stress corresponds well with regional forest productivity, area killed by bark beetles, and area burned by wildfire.

• If climate models are correct, average drought stress by the 2050s will match that of the worst years during the largest megadroughts in at least 1000 years.