An Overview of Drought Impacts on Whole Tree Physiology, Morbidity, and Death

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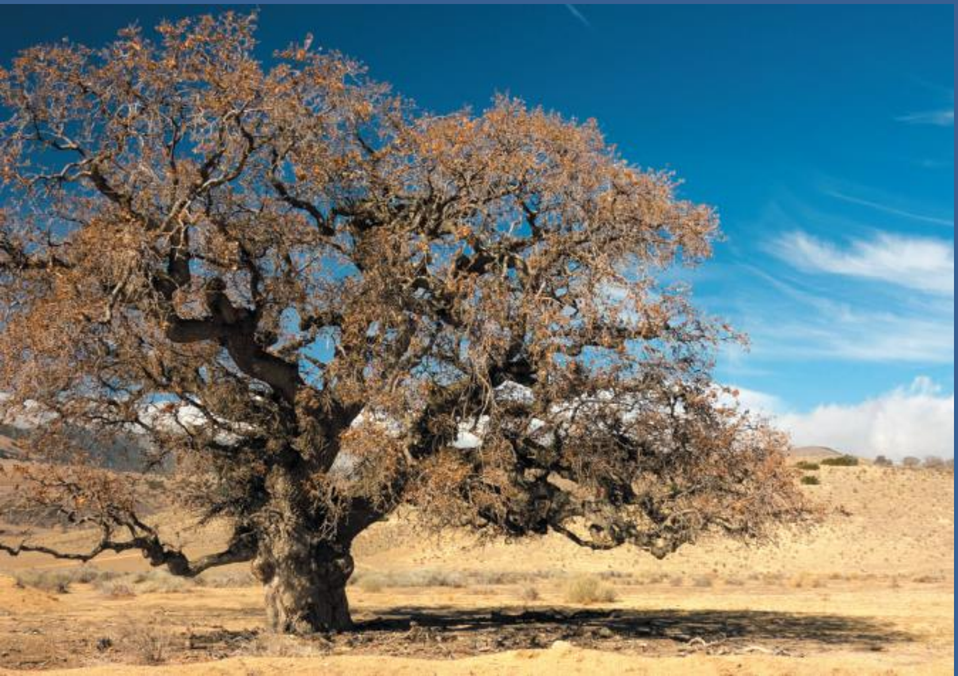
USDA PNW CAFER: **C**enter for **A**dvanced **F**orest **E**cosystem **R**esearch

DRIER-WF: **D**rought **I**ntensity & **E**cosystem **R**esilience in **W**estern **F**orests

Big picture of the CA drought severity:

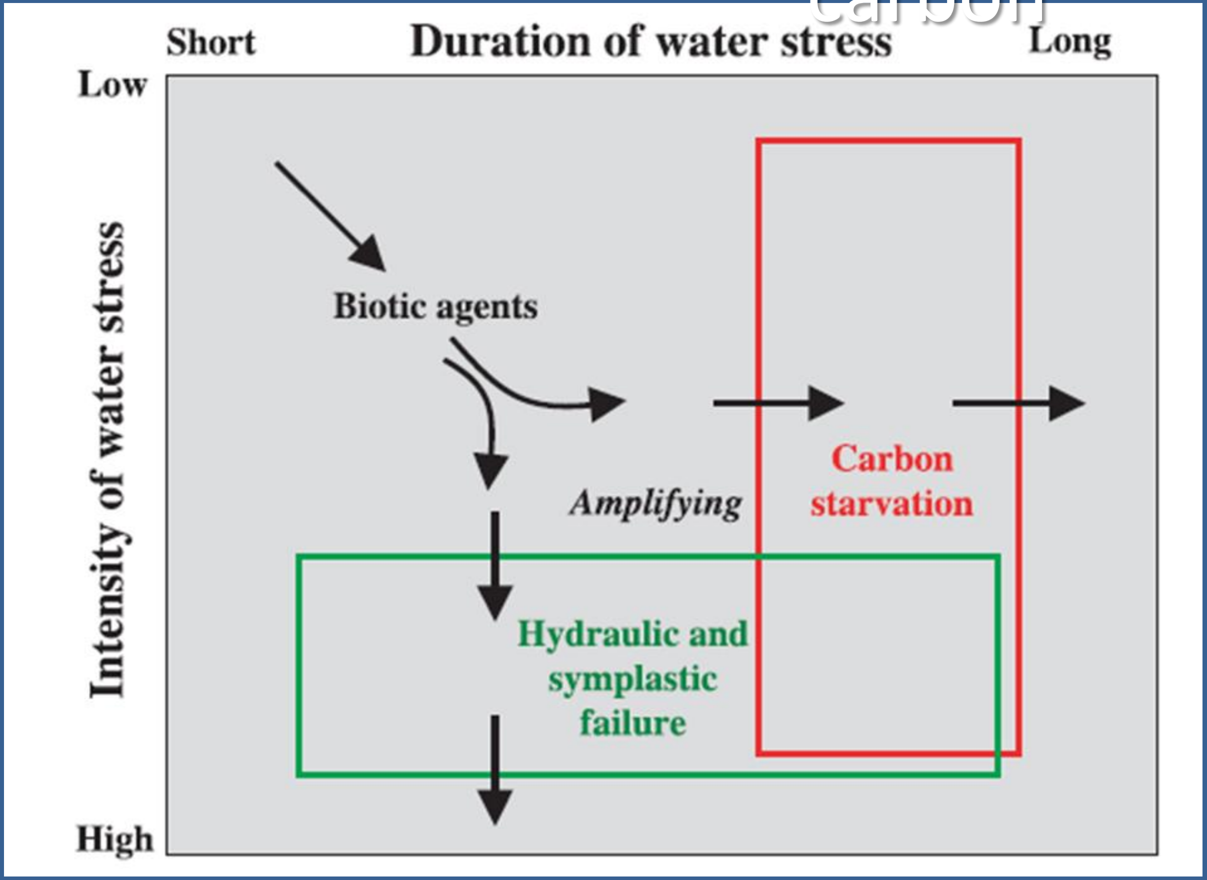
Return intervals:

- 2014 drought for southern CA is 800-900 yrs
- 2012-2015 drought unprecedented, >>1000 yrs
- Northern/coastal CA, return interval is 70-90 yrs



Robeson, Geophys Res Let 2015
Voelker et al., unpublished

Trees die through a lack of water and/or carbon

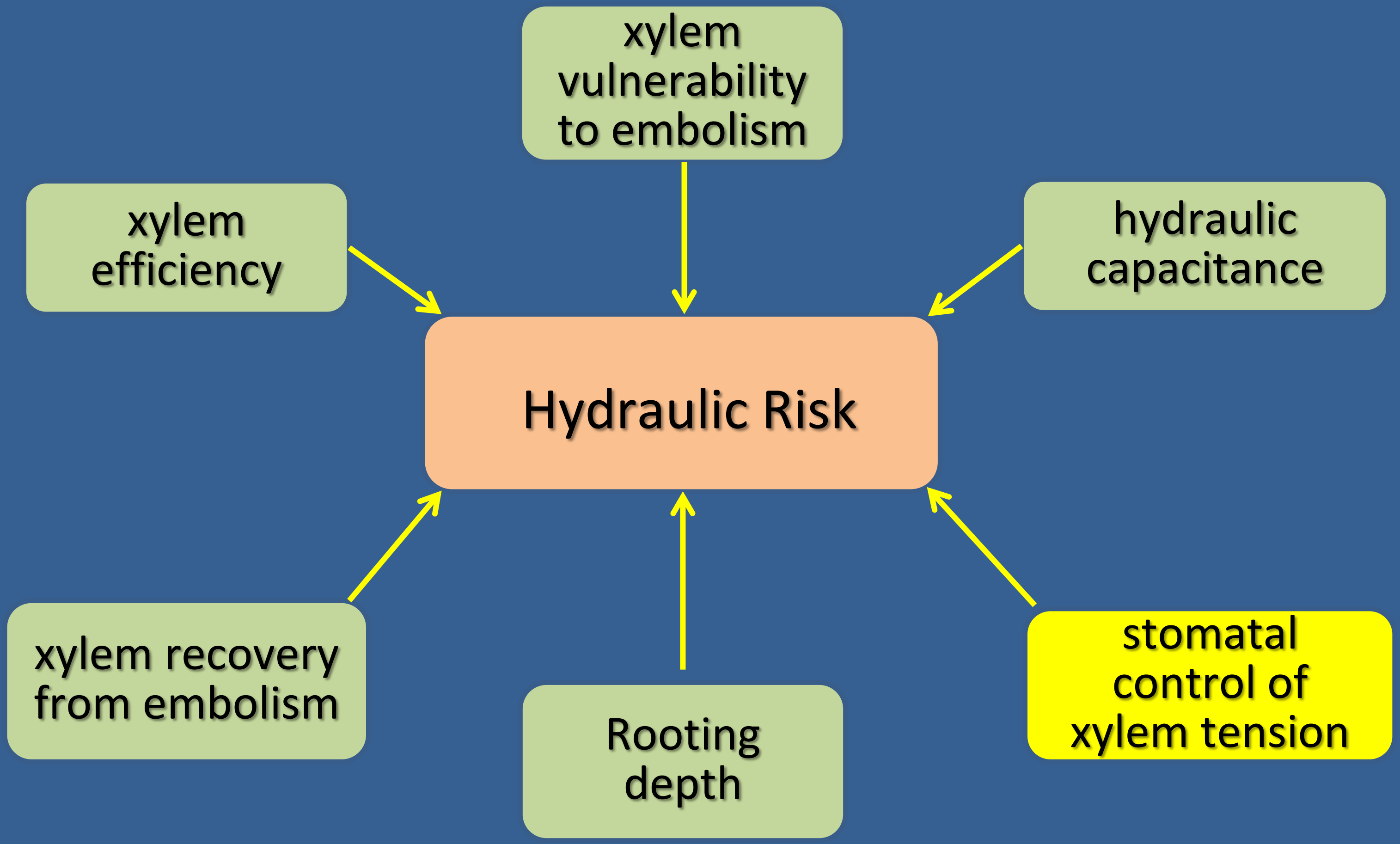


Isohydric species carbon starvation

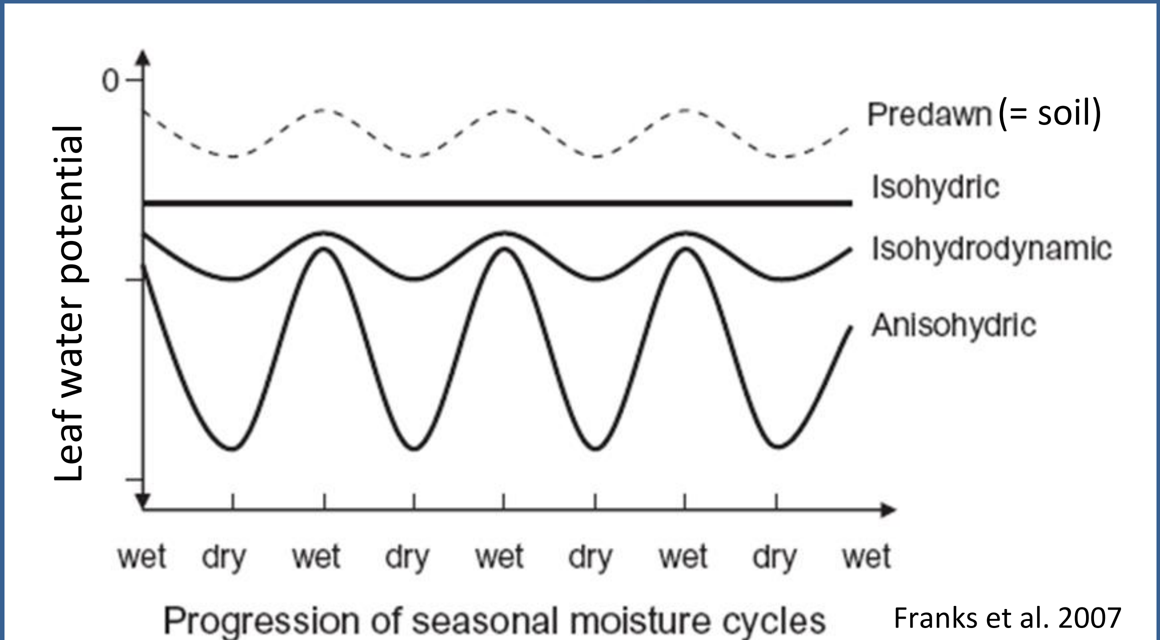
Anisohydric species: hydraulic/symplastic failure

McDowell et al. New Phytol. 2008

Determinants of Drought-related Hydraulic Vulnerability/Risk



Modes of stomatal regulation of leaf water potential



Franks et al. 2007

Isohydry and anisohydry are extremes along a continuum

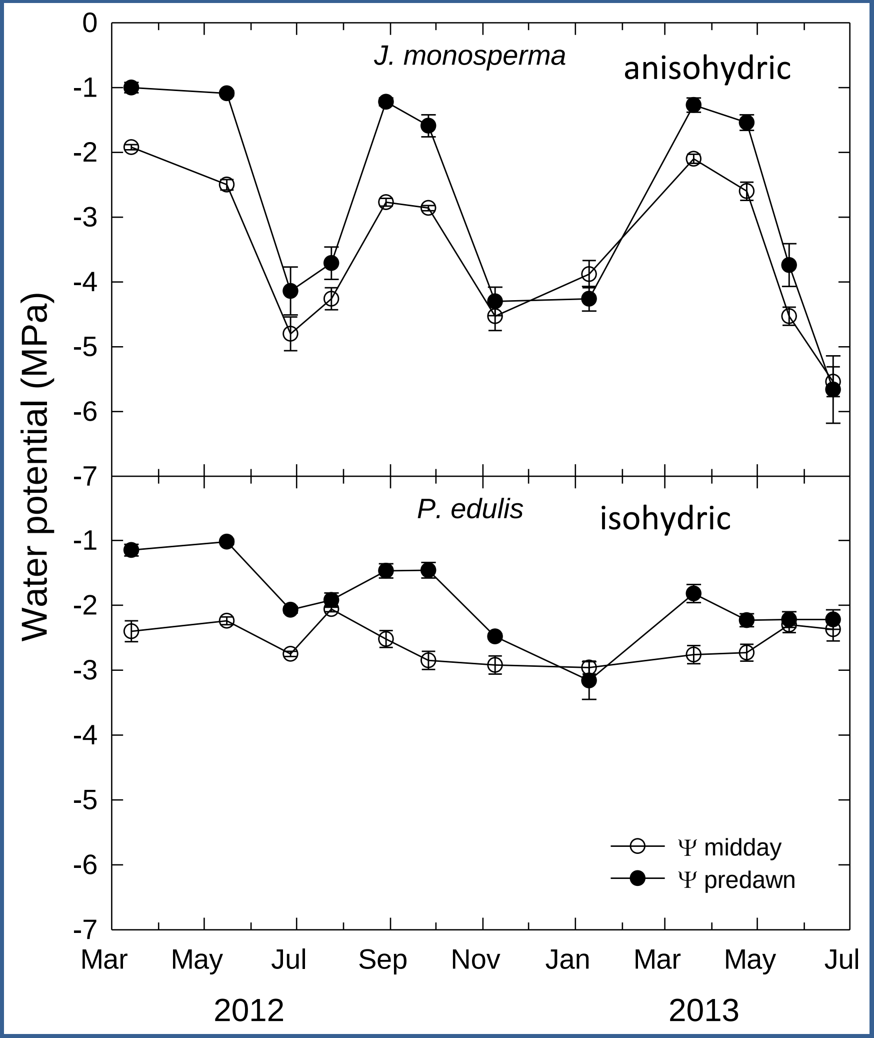
black cottonwood

ponderosa pine

blue oak

incense cedar

Species adapted to dry [or wet] environments can be far away on the Iso- to Anisohydric continuum



Plant Survival and Mortality (SUMO) Experiment, Los Alamos, NM

Elev: 2150 masl
Precip: 470 mm

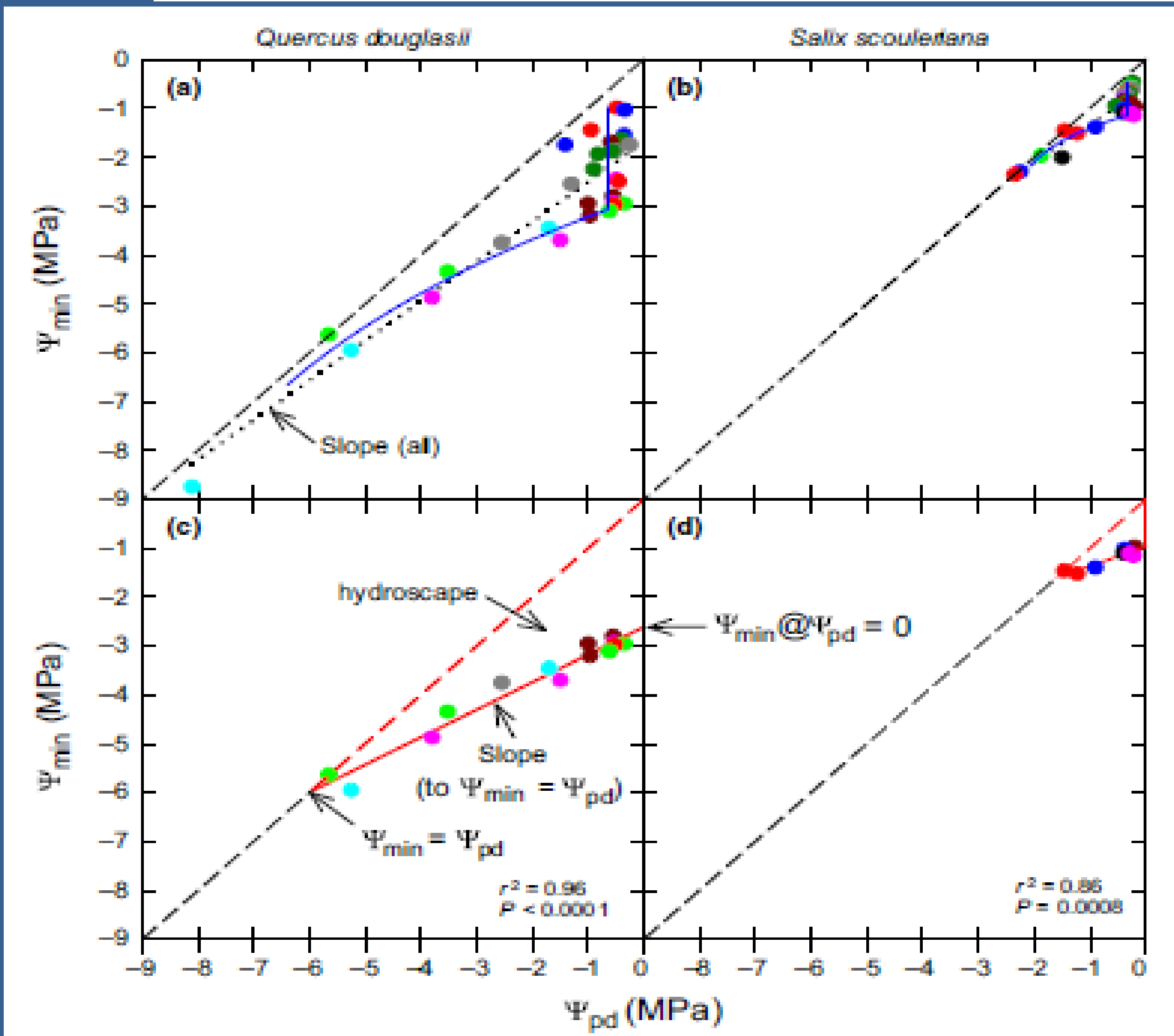
Meinzer et al.
Plant, Cell Environ 2014

ECOLOGY LETTERS

Ecology Letters, (2016) doi: 10.1111/ele.12670

LETTER

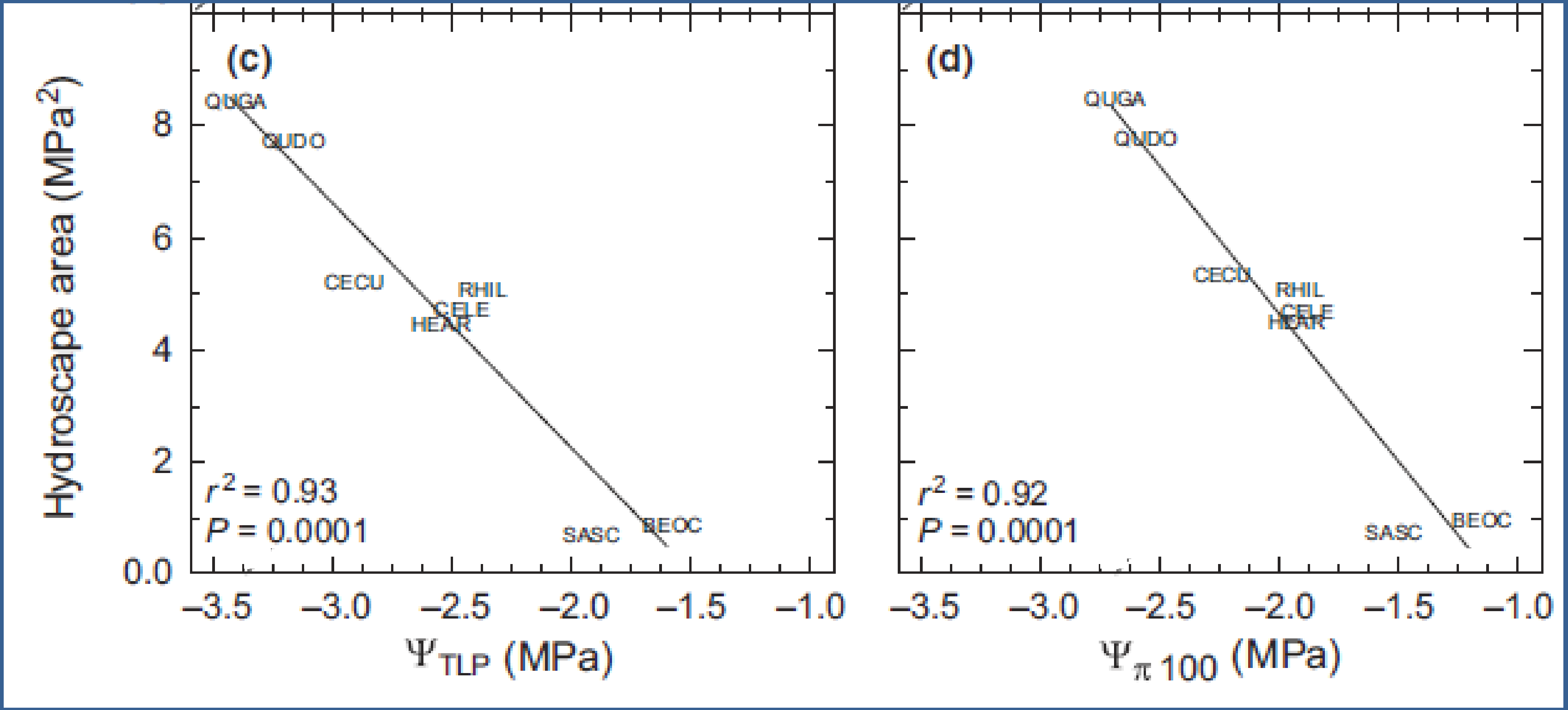
Mapping 'hydroscapes' along the iso- to anisohydric continuum of stomatal regulation of plant water status



Meinzer et al. (2016) introduced hydroscape area to quantify stomatal control on xylem tension

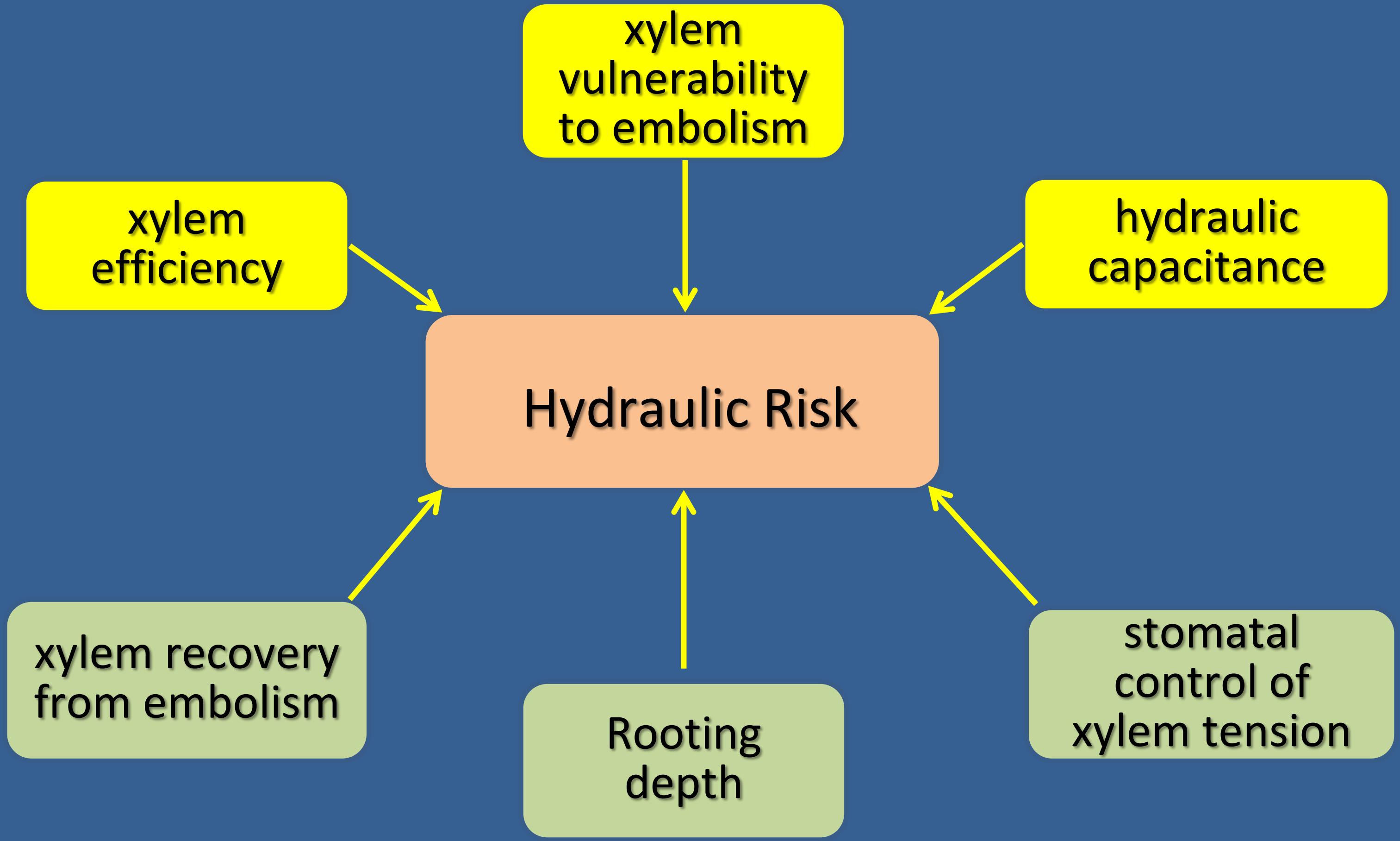
Traits and trade-offs along the iso- anisohydry continuum

Hydroscape area is closely tied to shoot osmoregulation:
- Water potential at turgor loss point
- Osmotic potential at full turgor



Meinzer et al.
Ecology Letters 2016

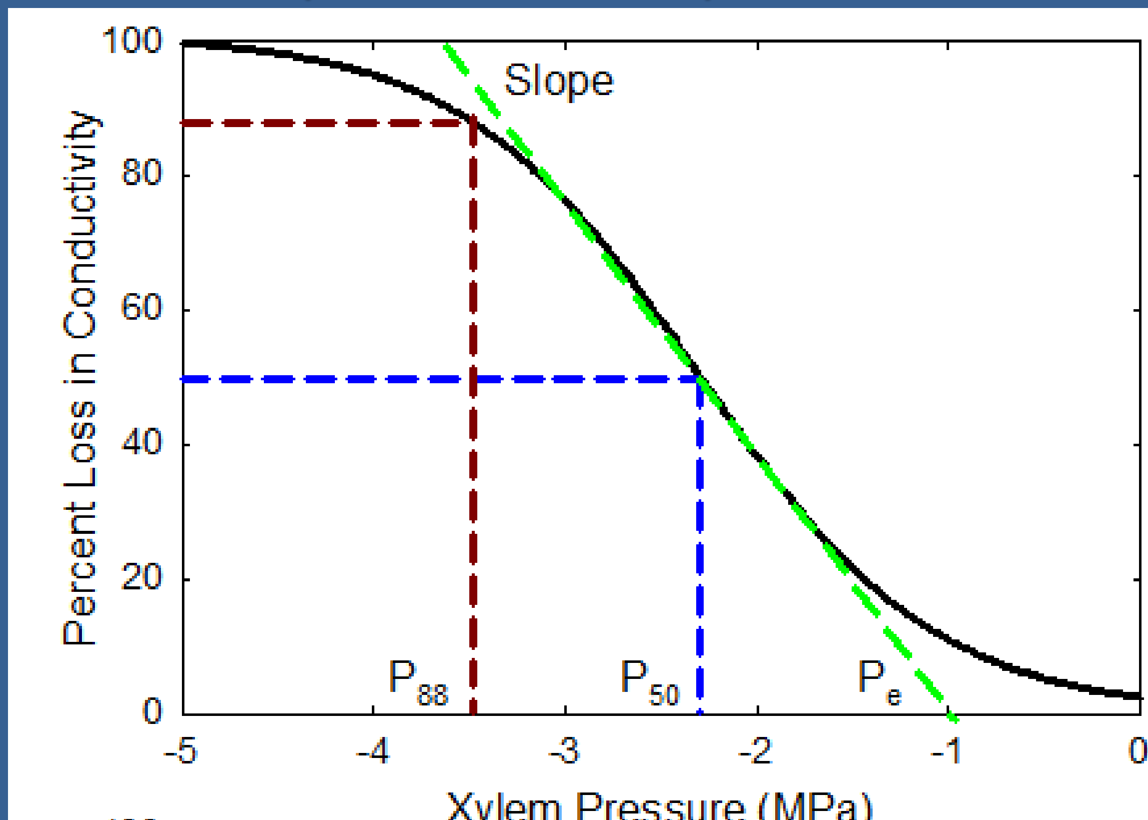
Determinants of Drought-related Hydraulic Vulnerability/Risk



Traits and trade-offs along the iso- anisohydry continuum

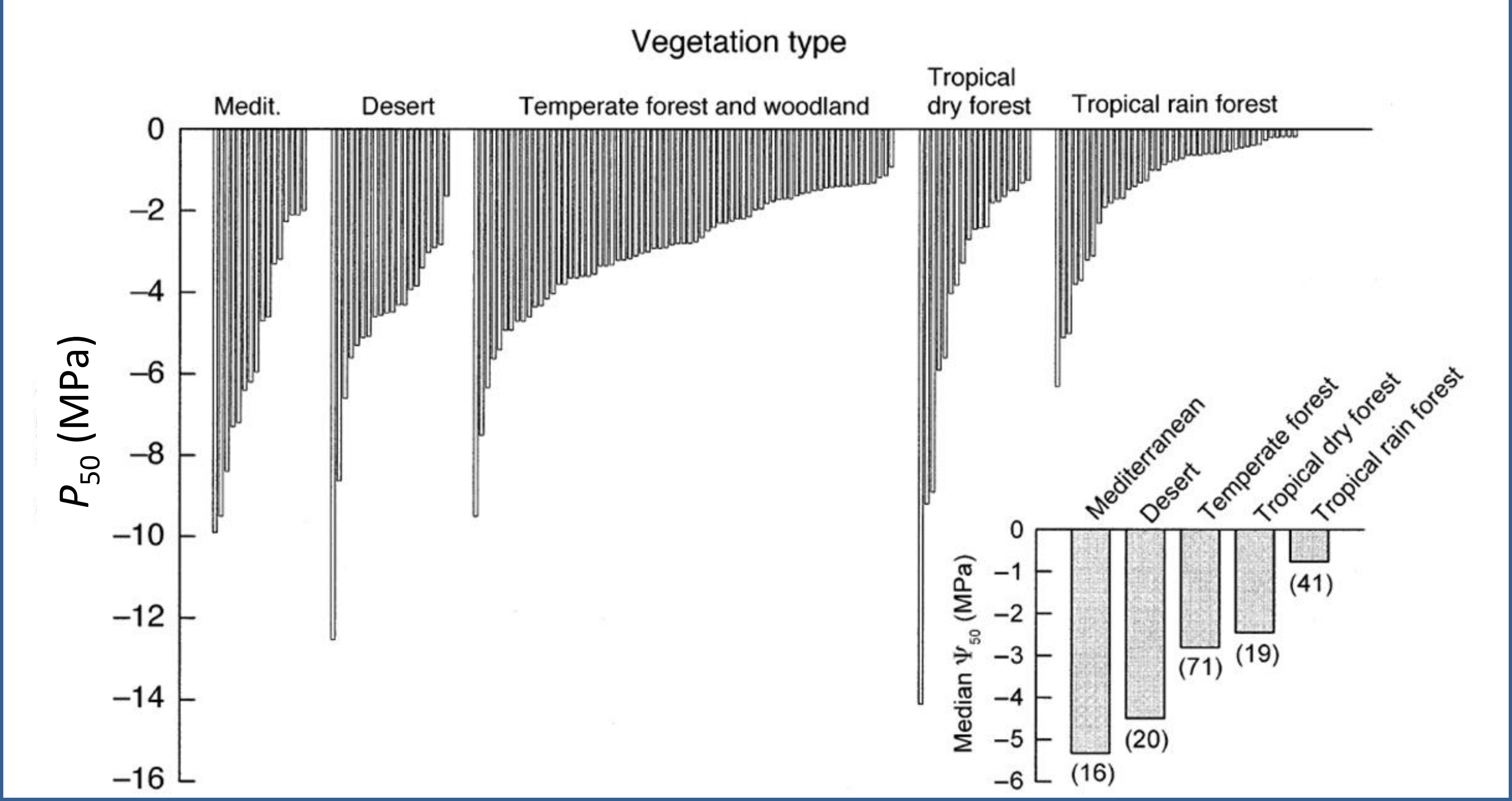
Determinants of Drought-related Hydraulic Vulnerability and Risk

Xylem vulnerability curve



Meinzer & McCulloh
Tree Physiol 2013

Determinants of Drought-related Hydraulic Vulnerability/Risk

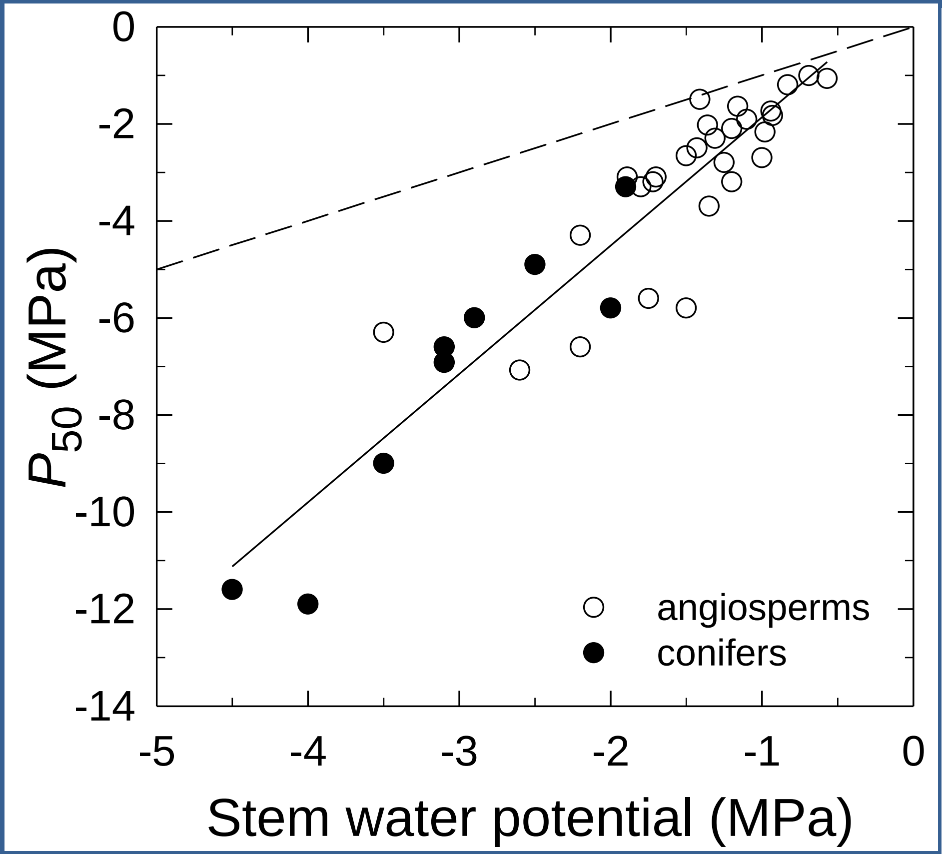


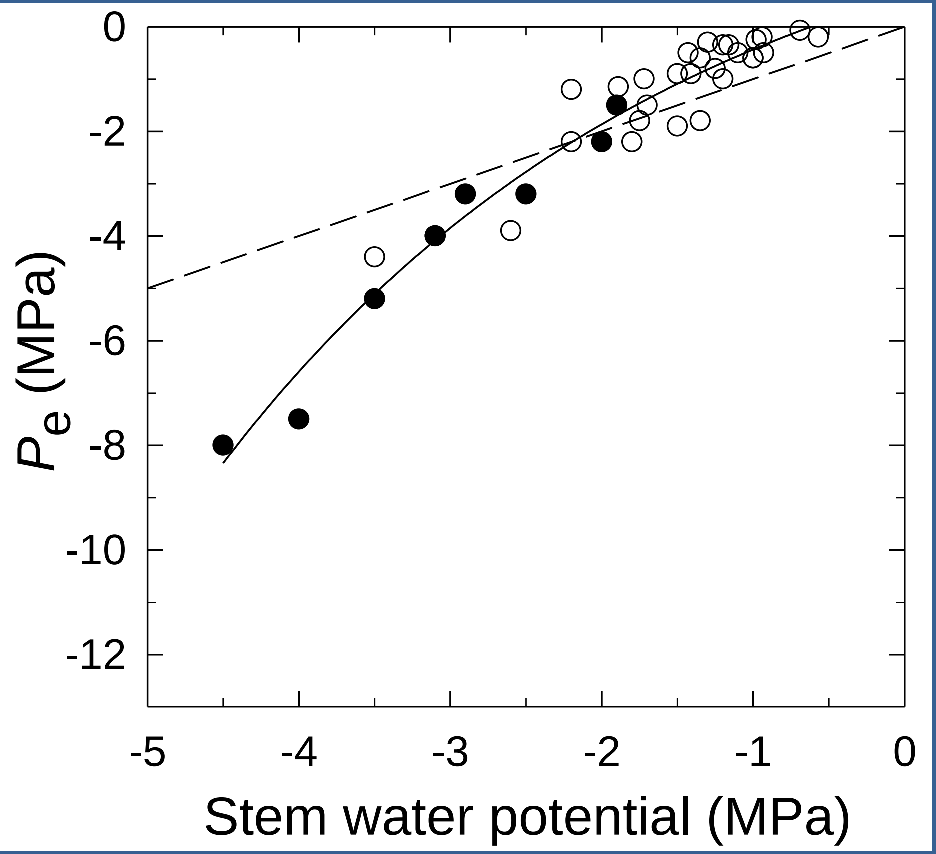
Range of P_{50} within vegetation types ≥ across vegetation types

Maherali et al.
Ecology 2004

Determinants of Drought-related Hydraulic Vulnerability/Risk

Hydraulic safety margin: stem Ψ - P_{50} or P_e

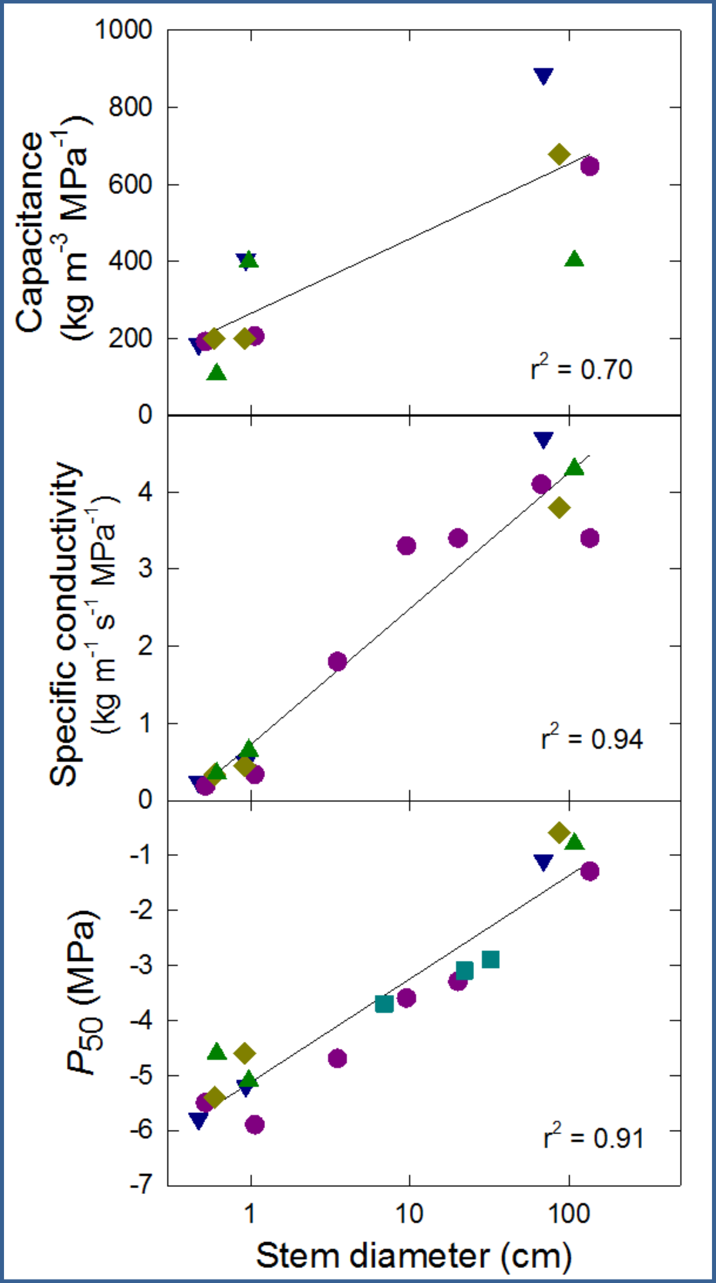




Conifers tend to have larger hydraulic safety margins

Meinzer et al.
Funct Ecology 2009

Determinants of Drought-related Hydraulic Vulnerability/Risk



Axial Gradients Within Trees

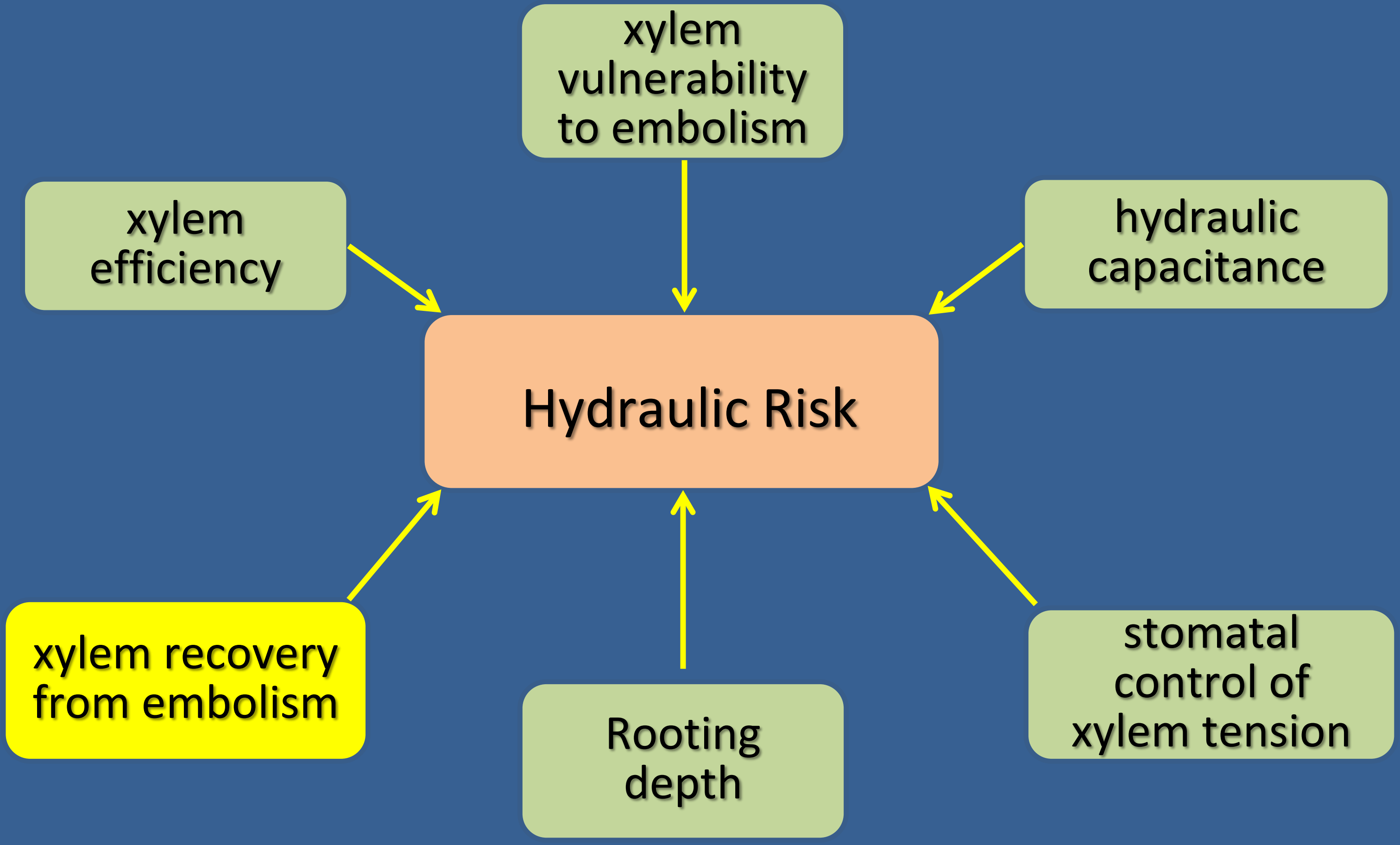
Path length ~60 m

Trunk:

- Smaller safety margin
- Greater capacitance

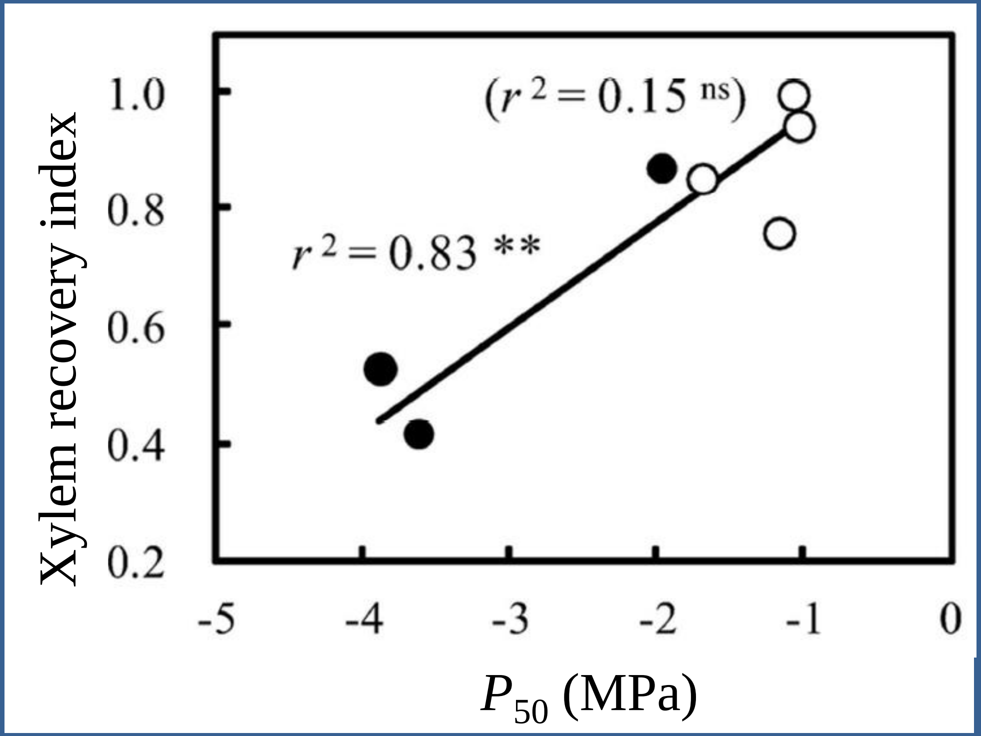
McCulloh et al.
Plant Cell Environ 2014

Determinants of Drought-related Hydraulic Vulnerability/Risk



Determinants of Drought-related Hydraulic Vulnerability/Risk

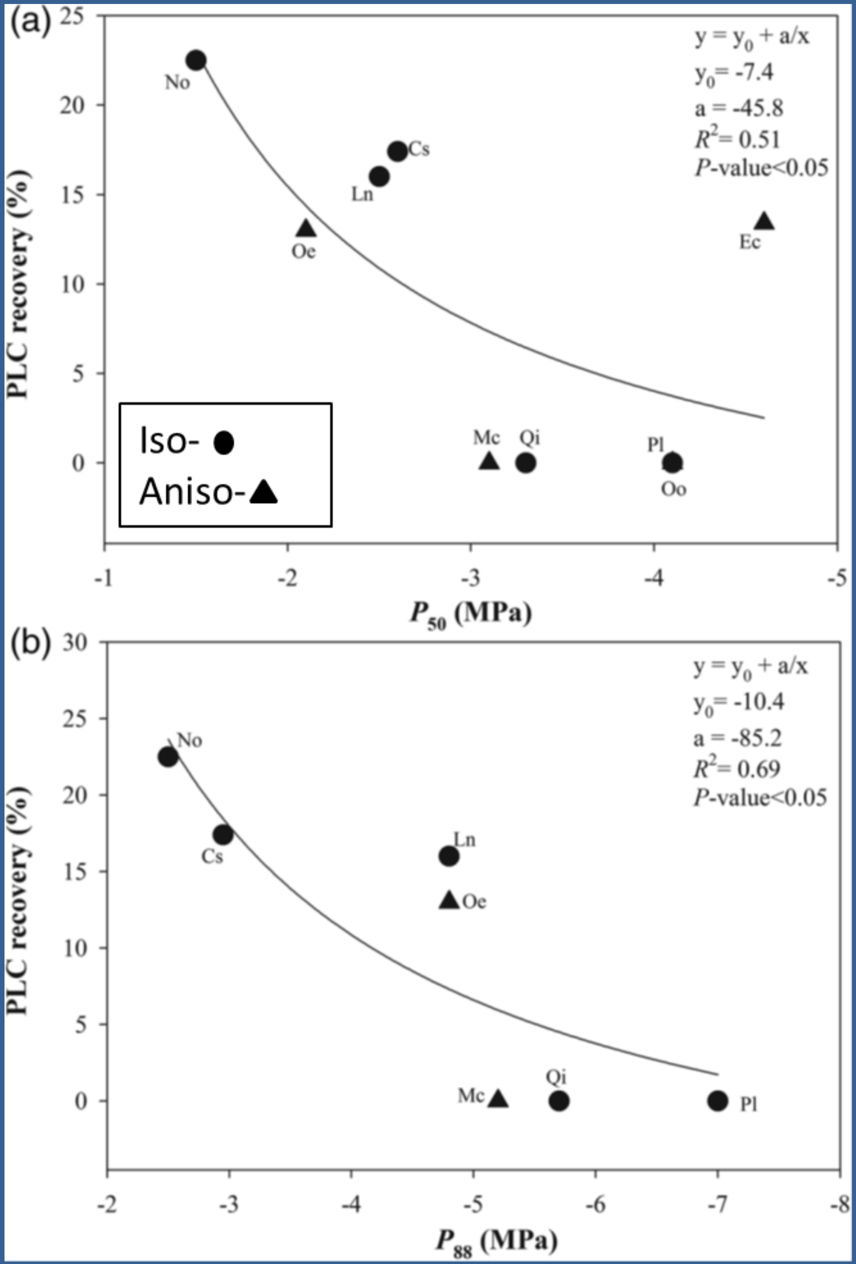
Ability to reverse drought-induced embolism varies among angiosperms



Trade-off of embolism resistance
against recovery capacity

Ogasa et al.
Tree Physiol 2013

Determinants of Drought-related Hydraulic Vulnerability/Risk

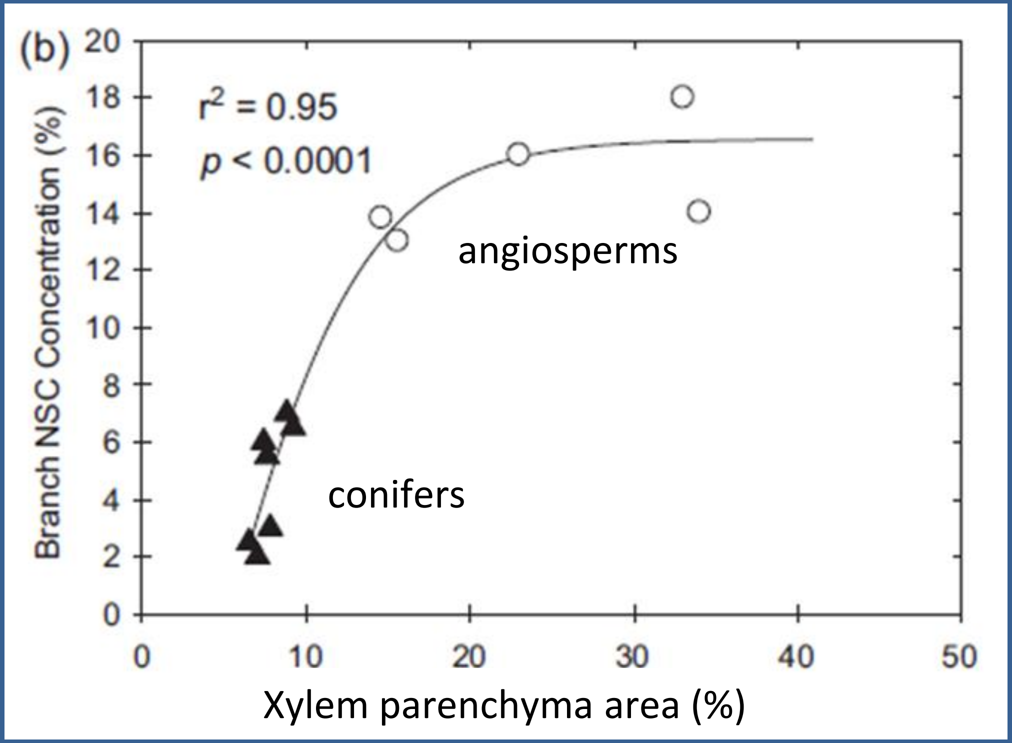


Trade-off of embolism resistance against recovery capacity

Trifilo et al.
Tree Physiol. 2015

Determinants of Drought-related Hydraulic Vulnerability/Risk

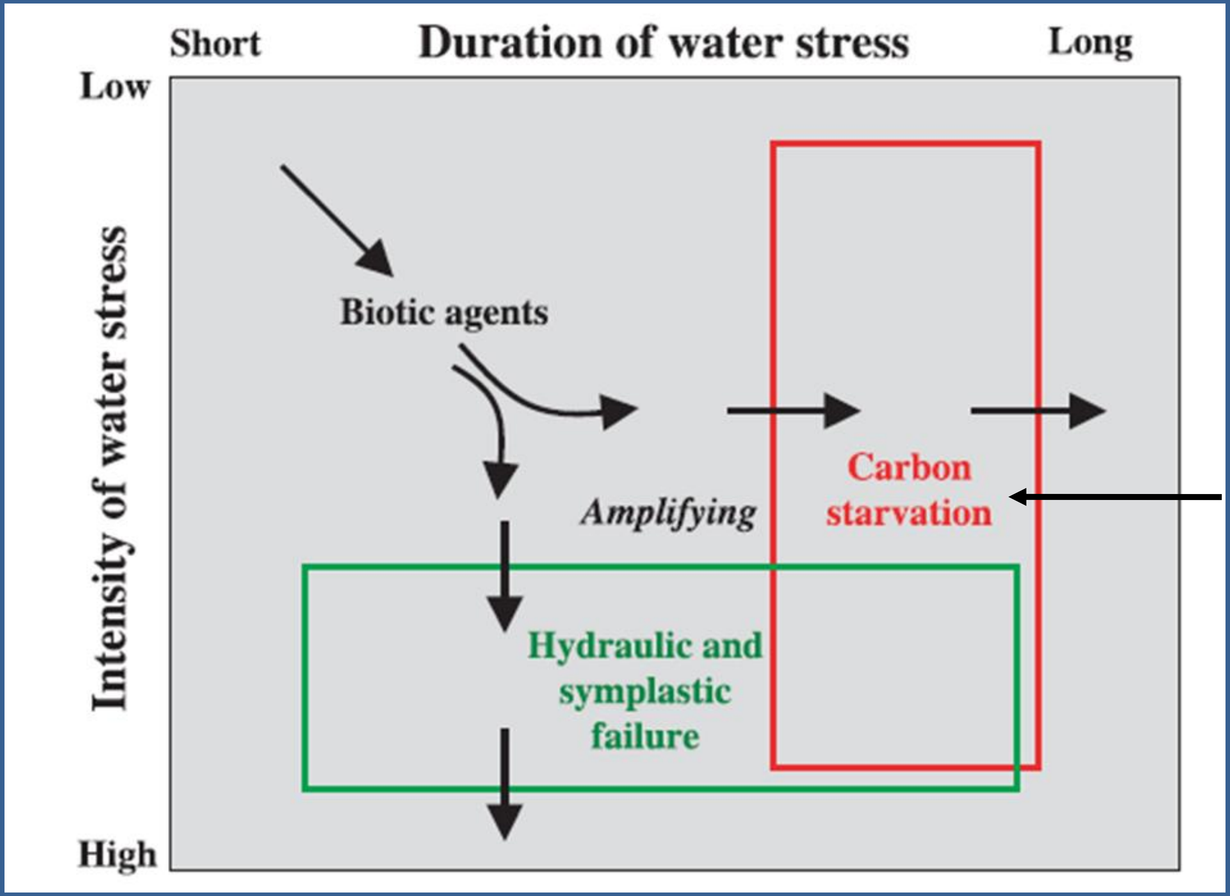
Potential role of non-structural carbohydrates in embolism reversal



Consistent with greater capacity for embolism reversal in angiosperms

Johnson et al.
Plant Science 2012

Drought and Non-structural Carbohydrates



Consumption of NSC

Failure of phloem transport

McDowell et al.
New Phytol. 2008

Drought-induced depletion of NSC greater in isohydric *P. edulis* than J. monosperma

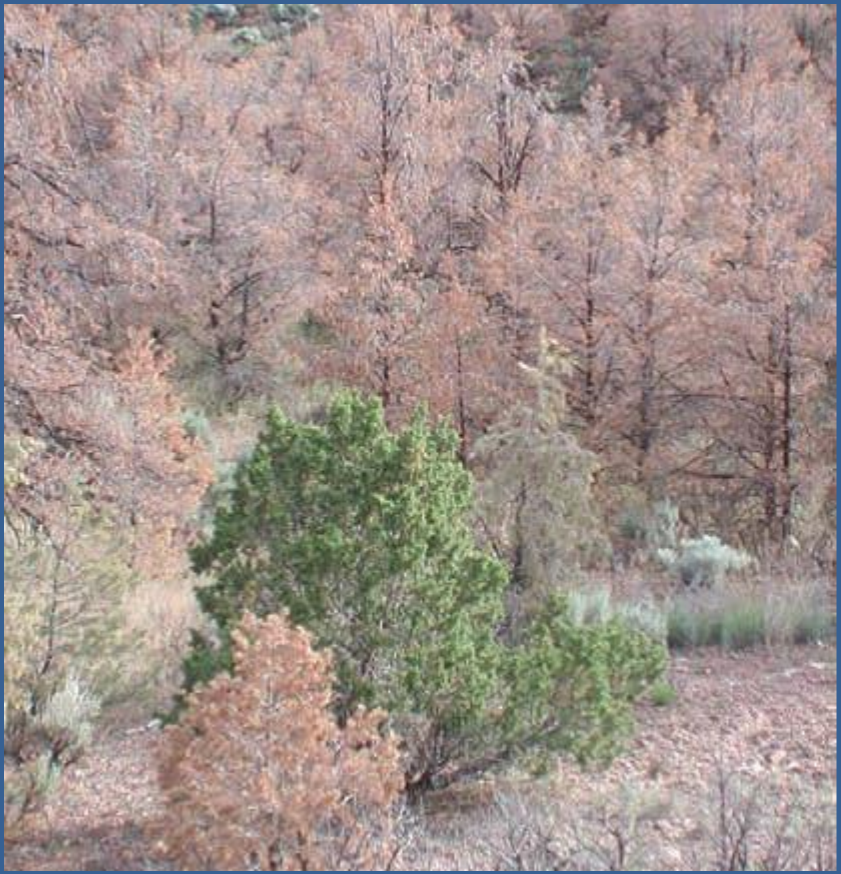
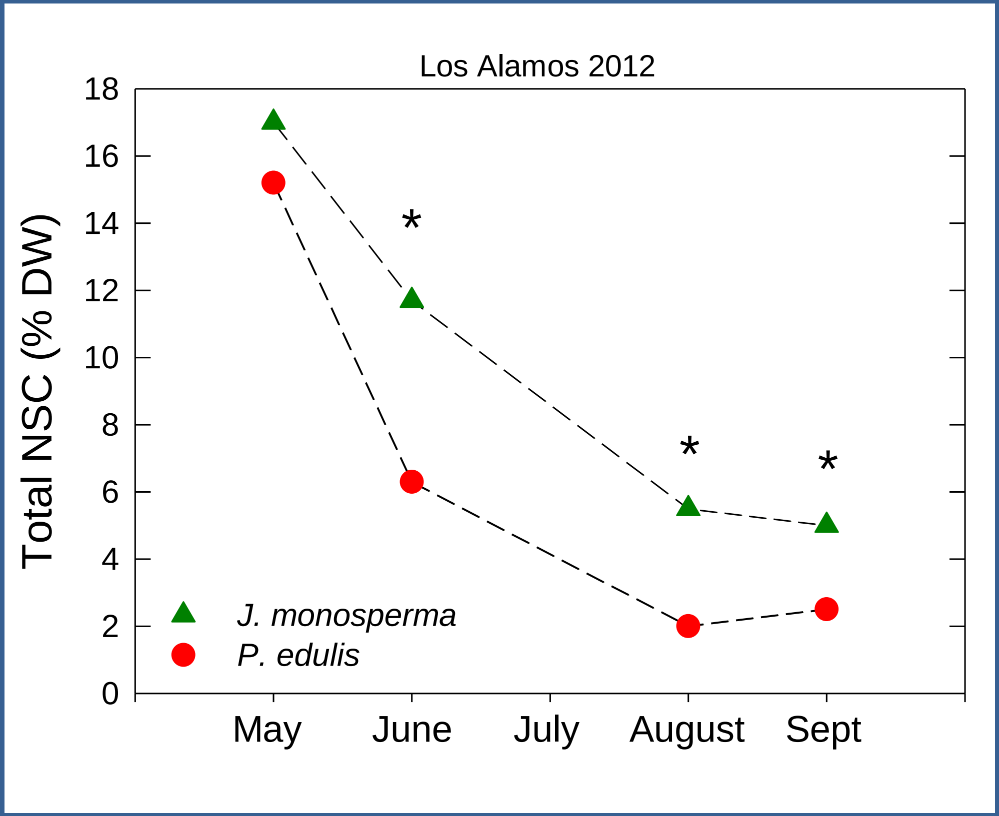
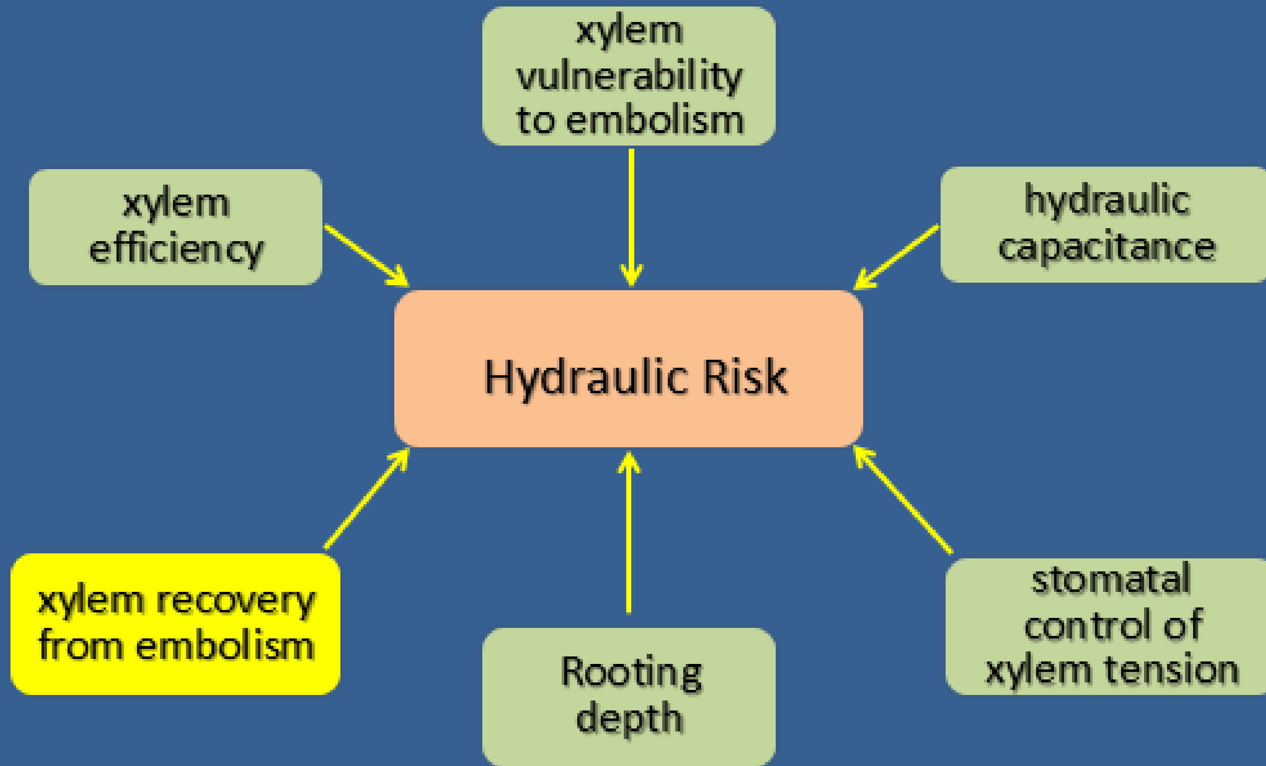


Photo: N.S. Cobb



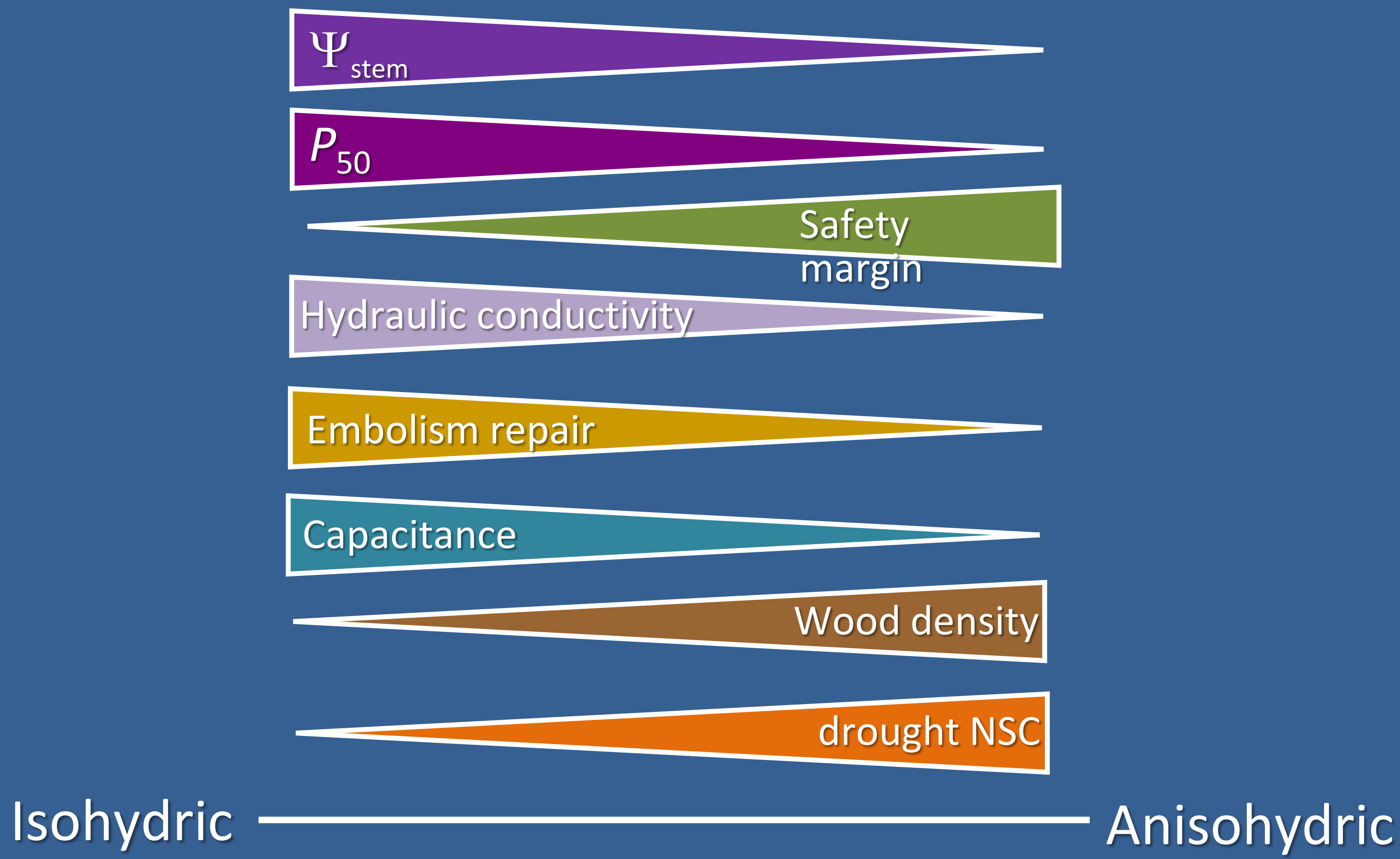
Woodruff et al.
New Phytol 2015

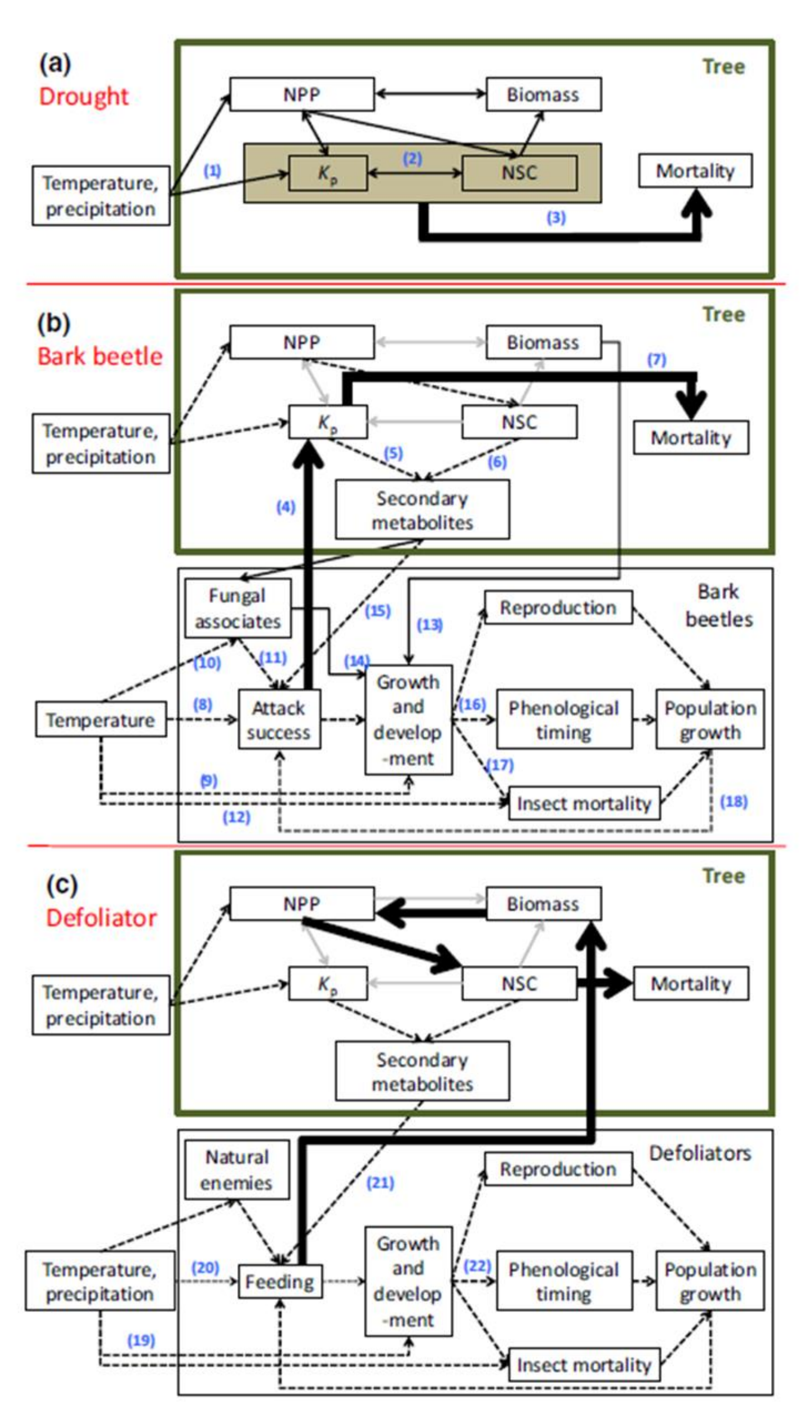


Xylem recovery requires NSC

NSC depleted by:
High temperatures
Increased defenses
Phloem disruption

Trends and trade-offs along iso- anisohydric continuum





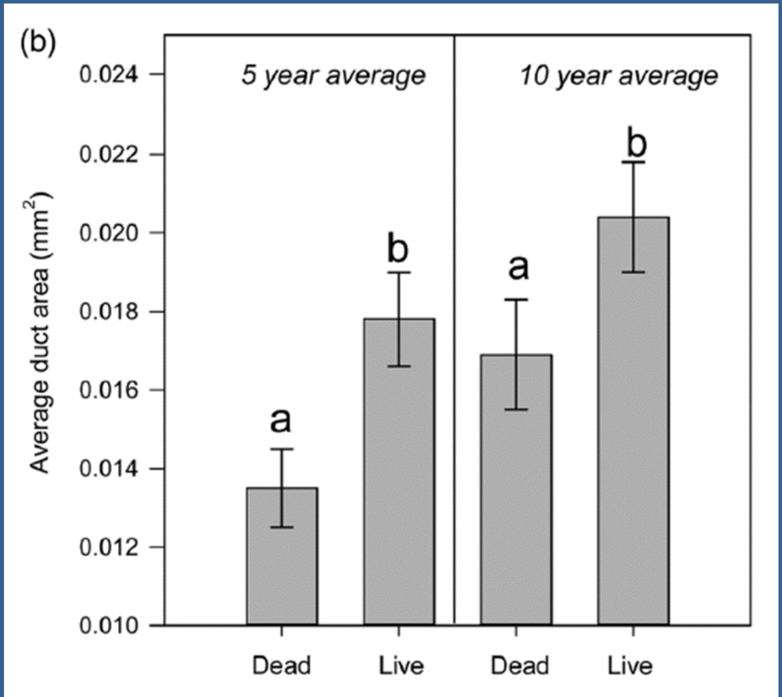
Anderegg et al. 2015 conceptual framework :

Relative impact of drought vs pests & pathogens during mortality events

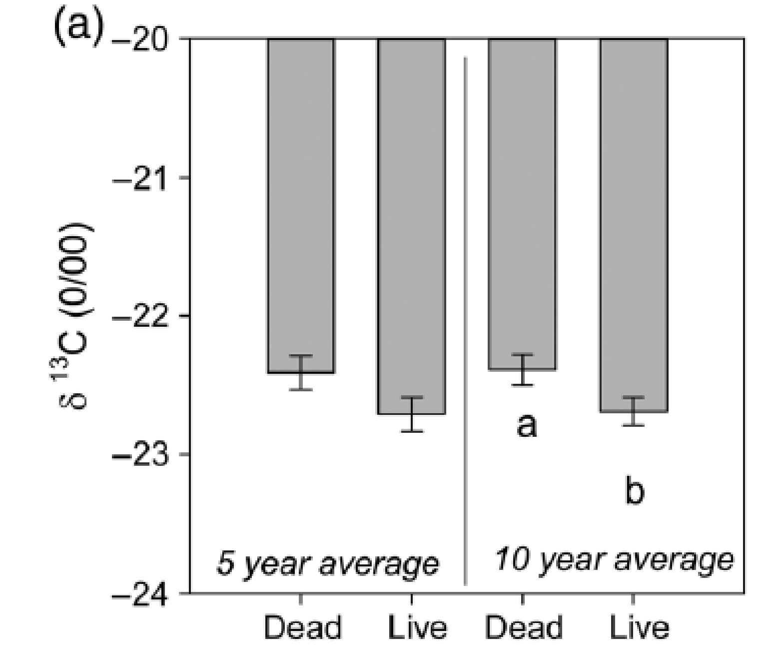
Anderegg et al.
New Phytol. 2015

Retrospective (post-mortem) approach

2002 piñon pine mortality Arizona, New Mexico



Dead trees had smaller
and fewer resin ducts

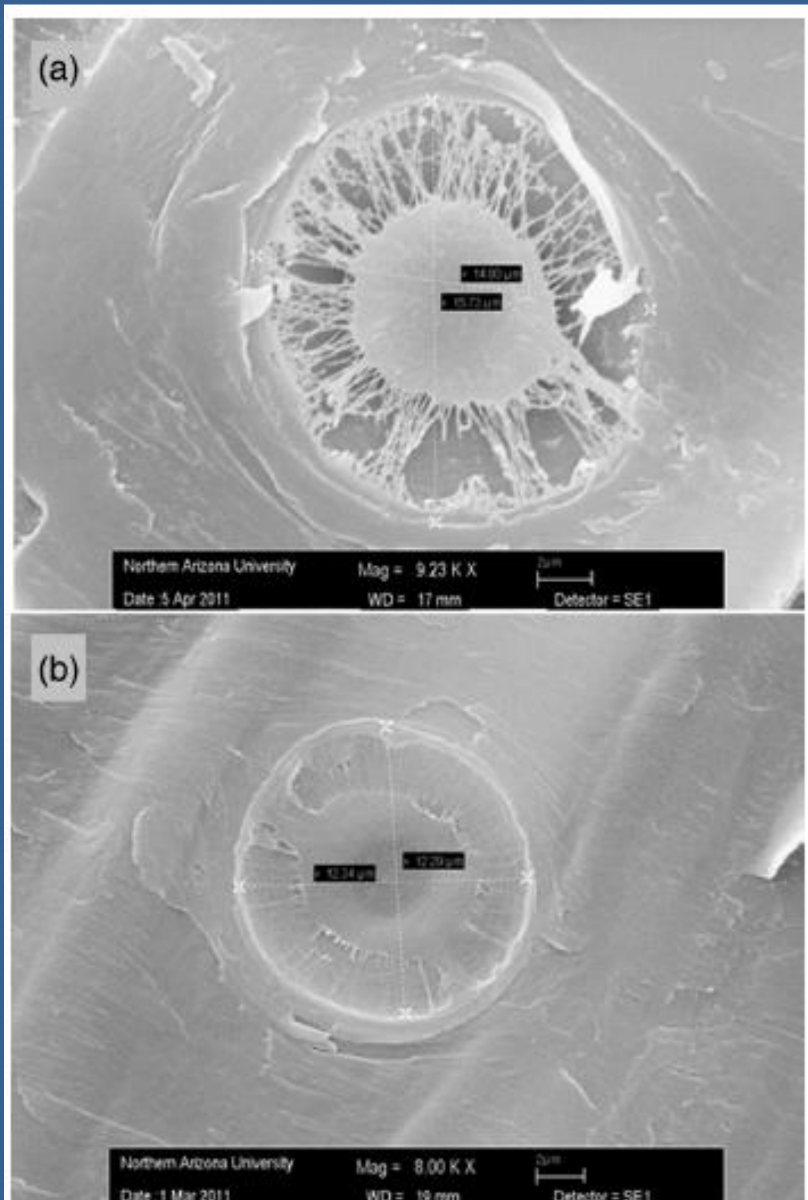


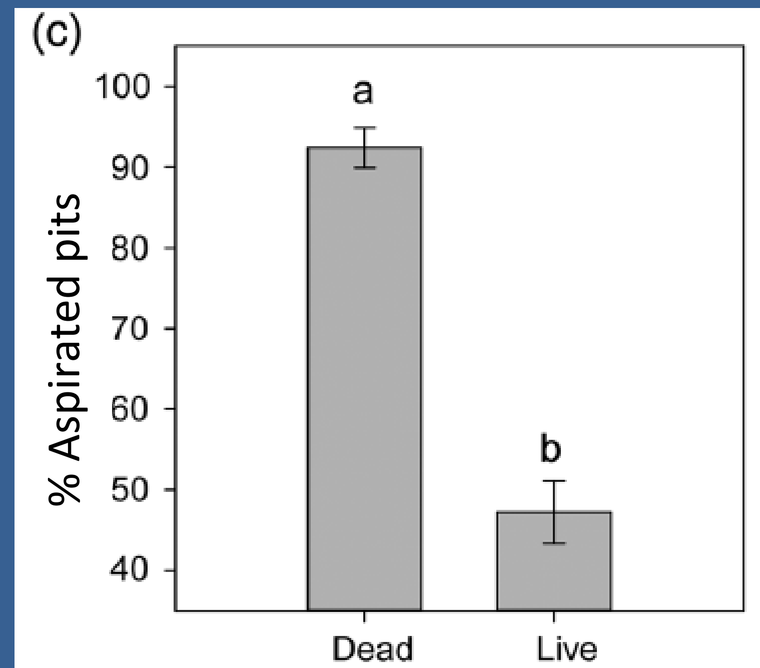
Dead trees had greater stomatal
limitation of photosynthesis

Gaylord et al.
Tree Physiol. 2015

Retrospective (post-mortem) approach

2002 piñon pine mortality Arizona, New Mexico





Dead trees had greater xylem embolism

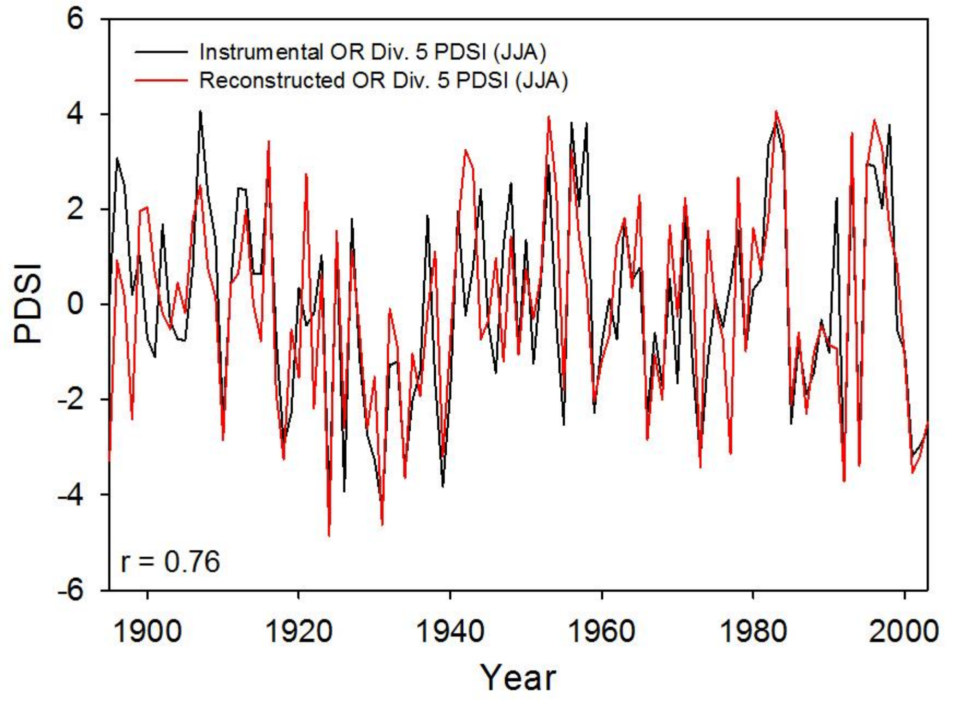
Gaylord et al.
Tree Physiol. 2015

Common knowledge?

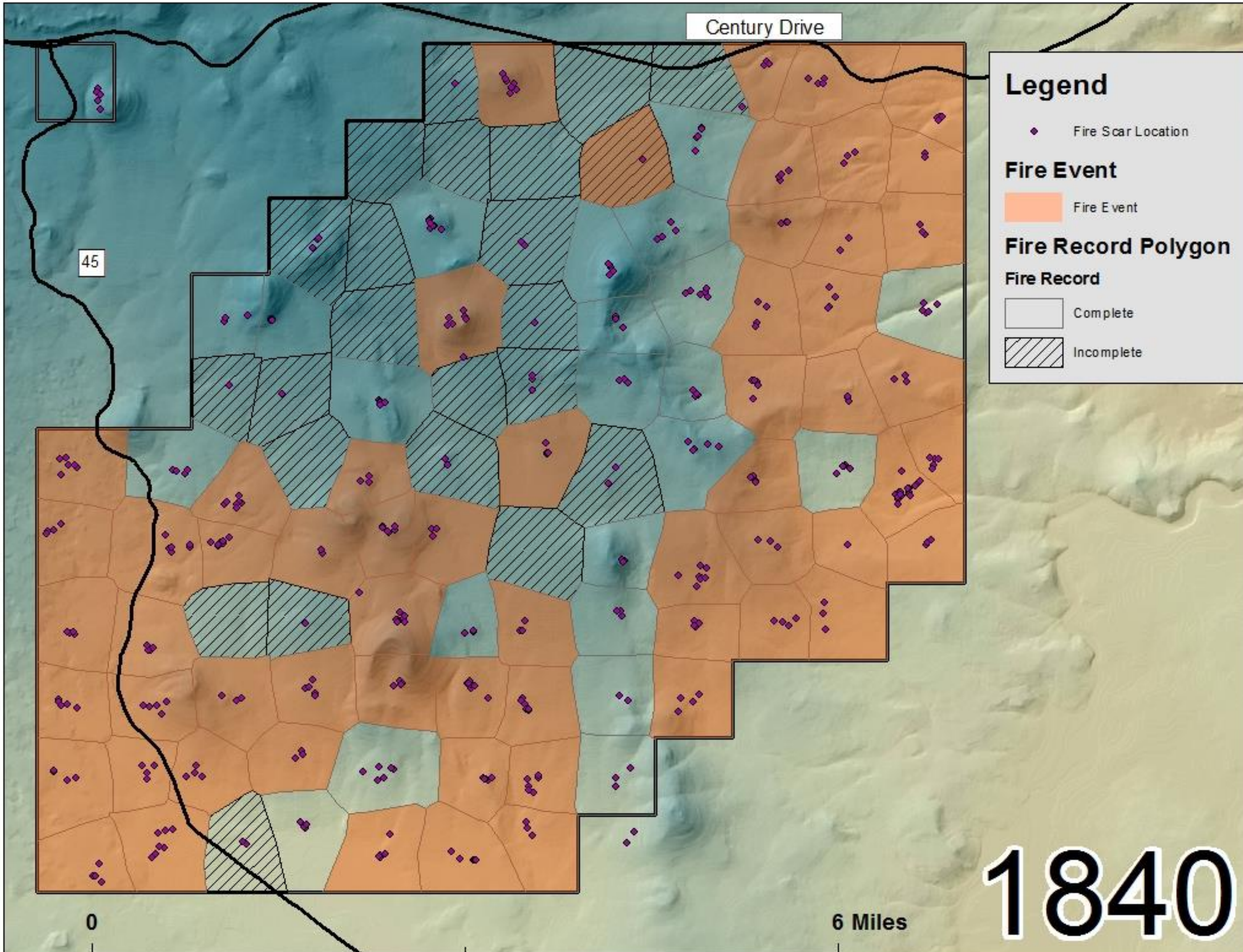
Lower fire frequencies have increased tree densities

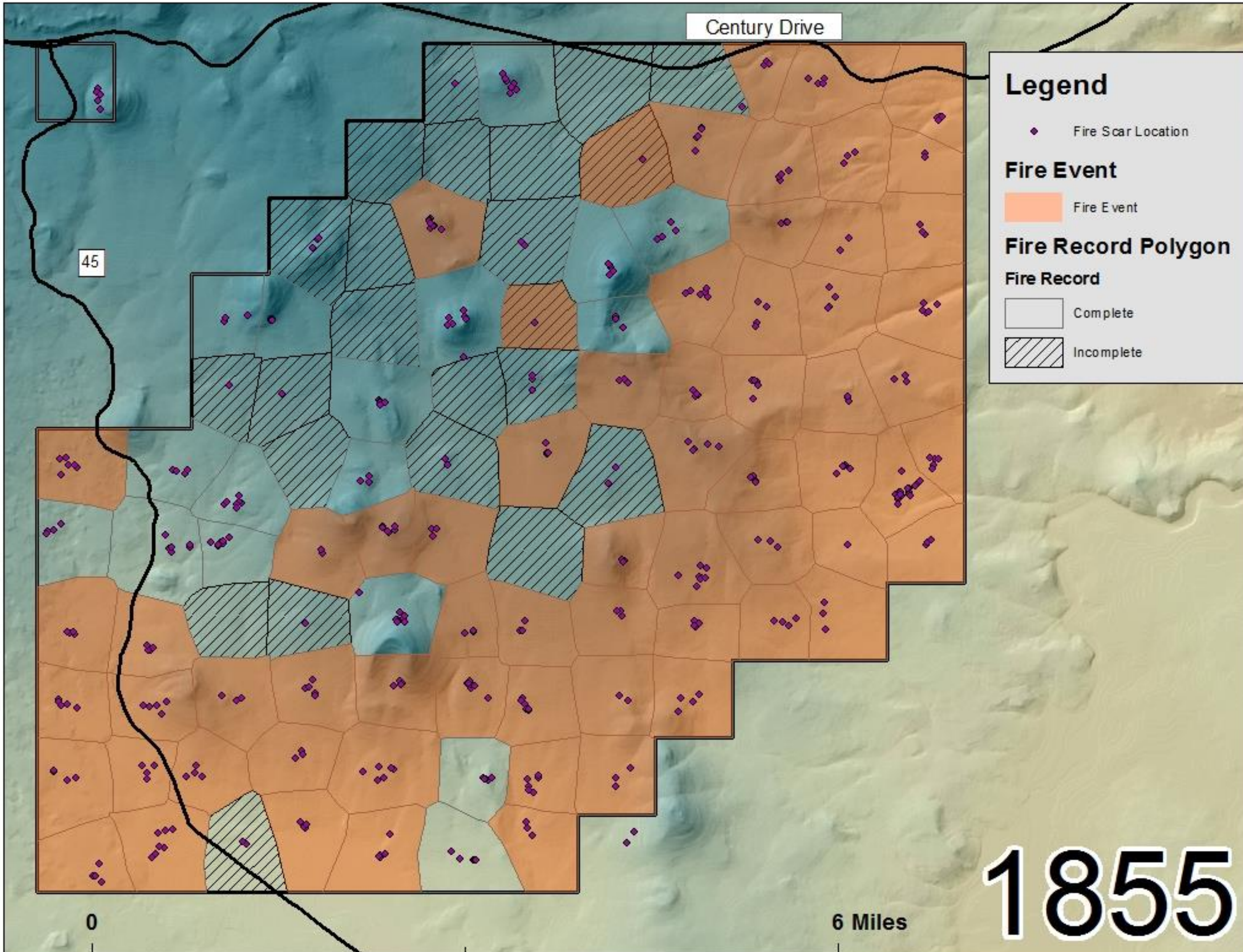
Increased tree densities lead to increased drought stress

Increased drought stress leads to greater pest/pathogen problems

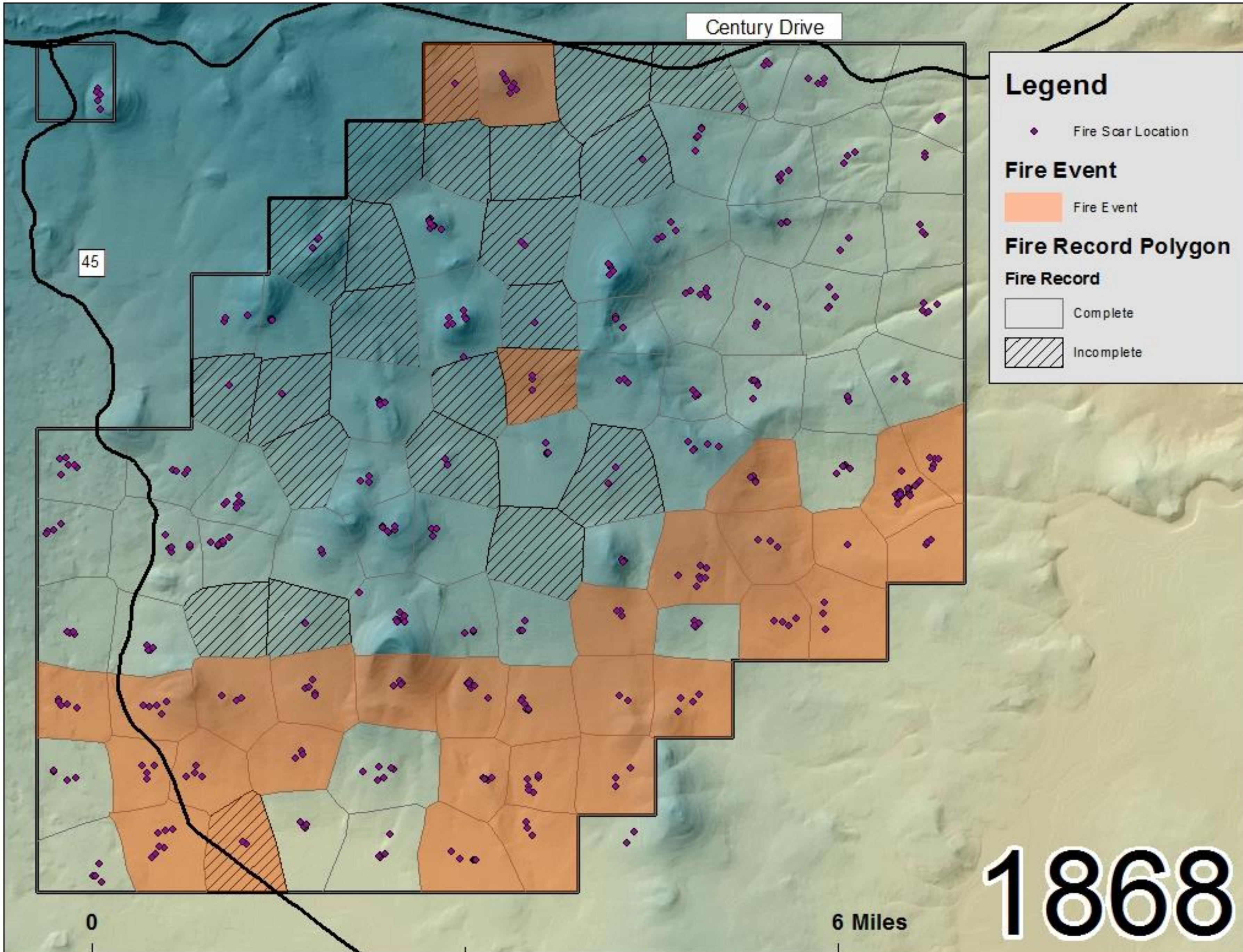



Bend
97
Deschutes
River Woods
Mt Bachelor
Kew fire
history site
97
Sunriver
97

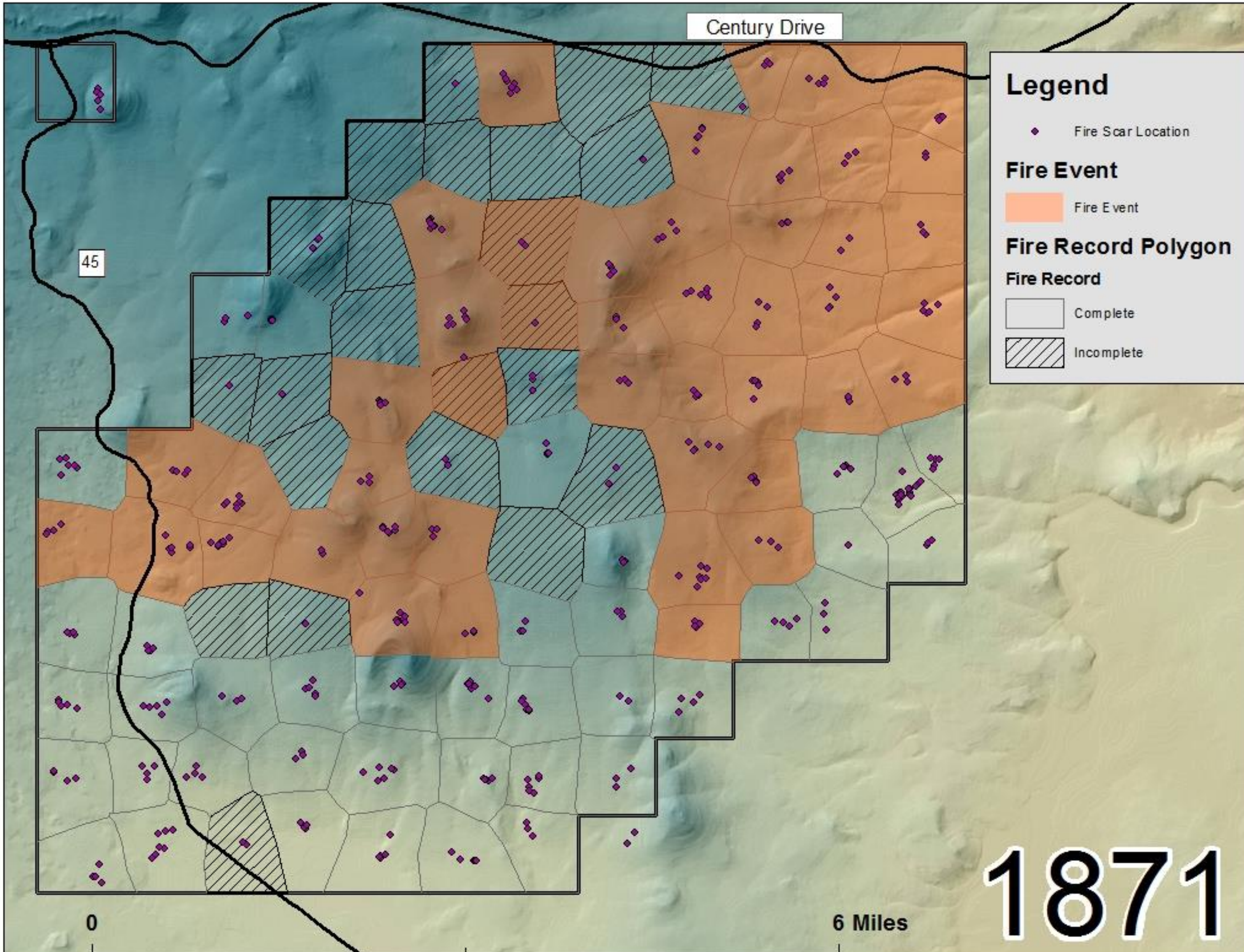

Century Drive
45
Legend
Fire Scar Location
Fire Event
Fire Event
Fire Record Polygon
Fire Record
Complete
Incomplete
0
6 Miles
1840

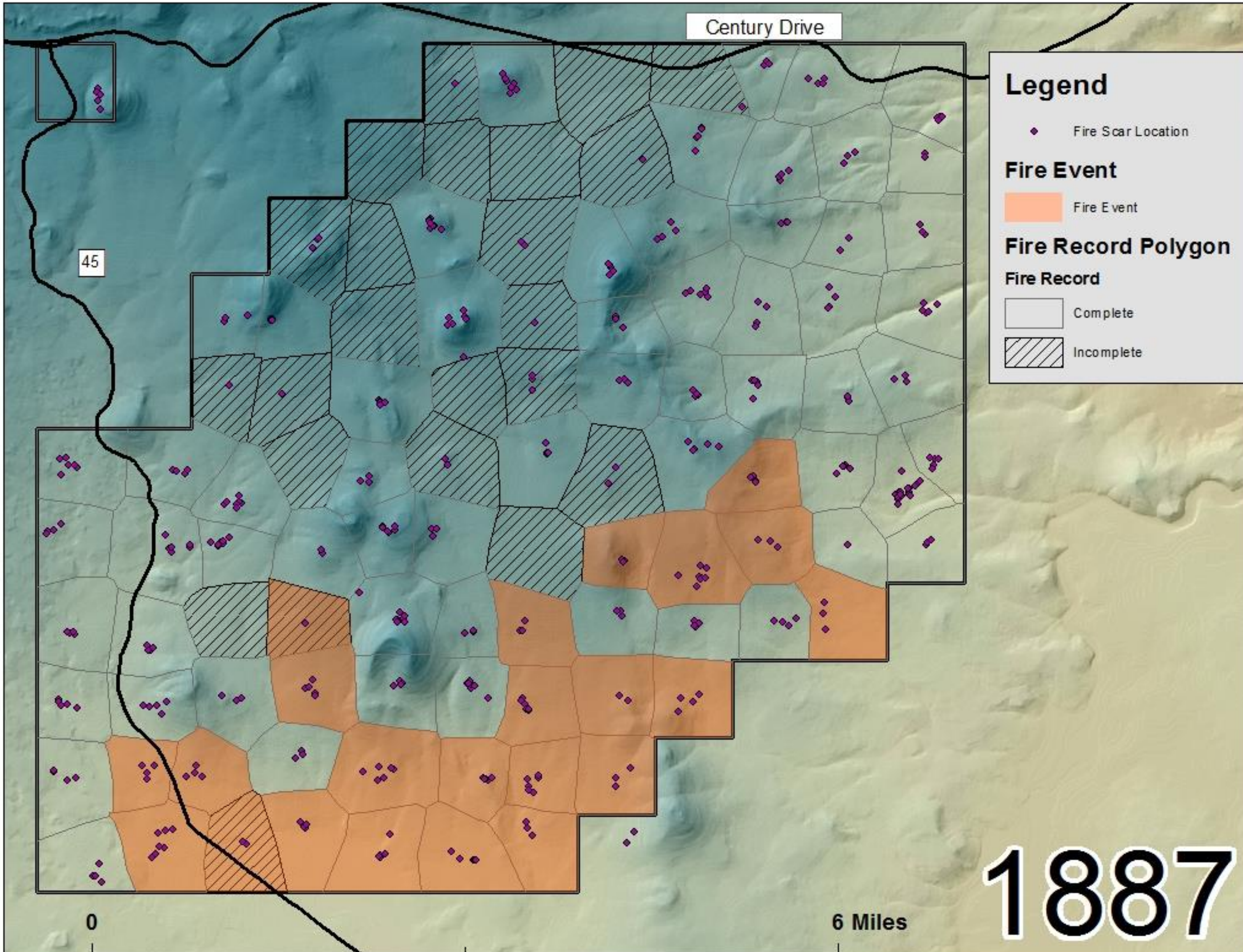


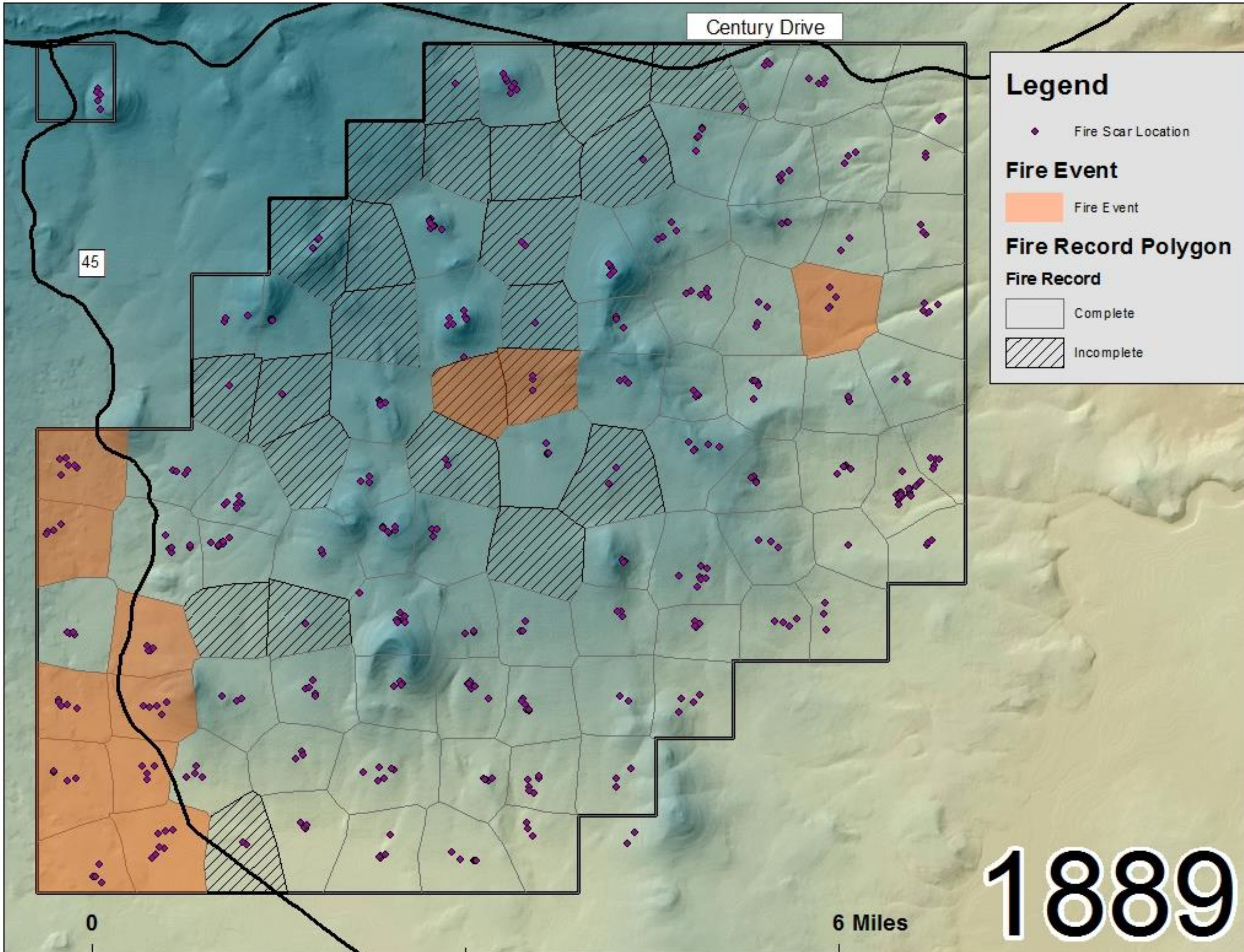
Century Drive
45
Legend
Fire Scar Location
Fire Event
Fire Event
Fire Record Polygon
Fire Record
Complete
Incomplete
0
6 Miles
1855



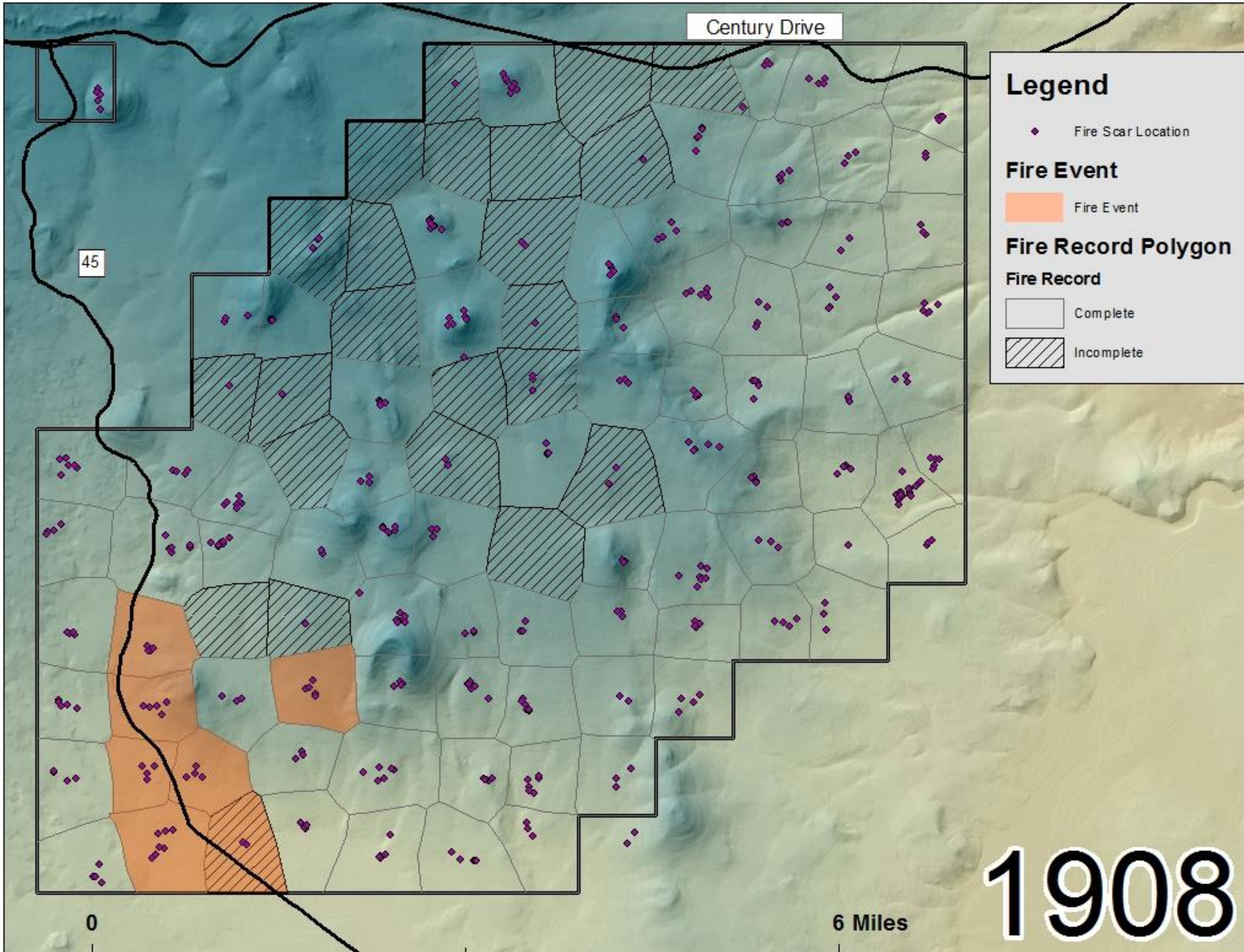
Century Drive
45
Legend
Fire Scar Location
Fire Event
Fire Event
Fire Record Polygon
Fire Record
Complete
Incomplete
0
6 Miles
1868

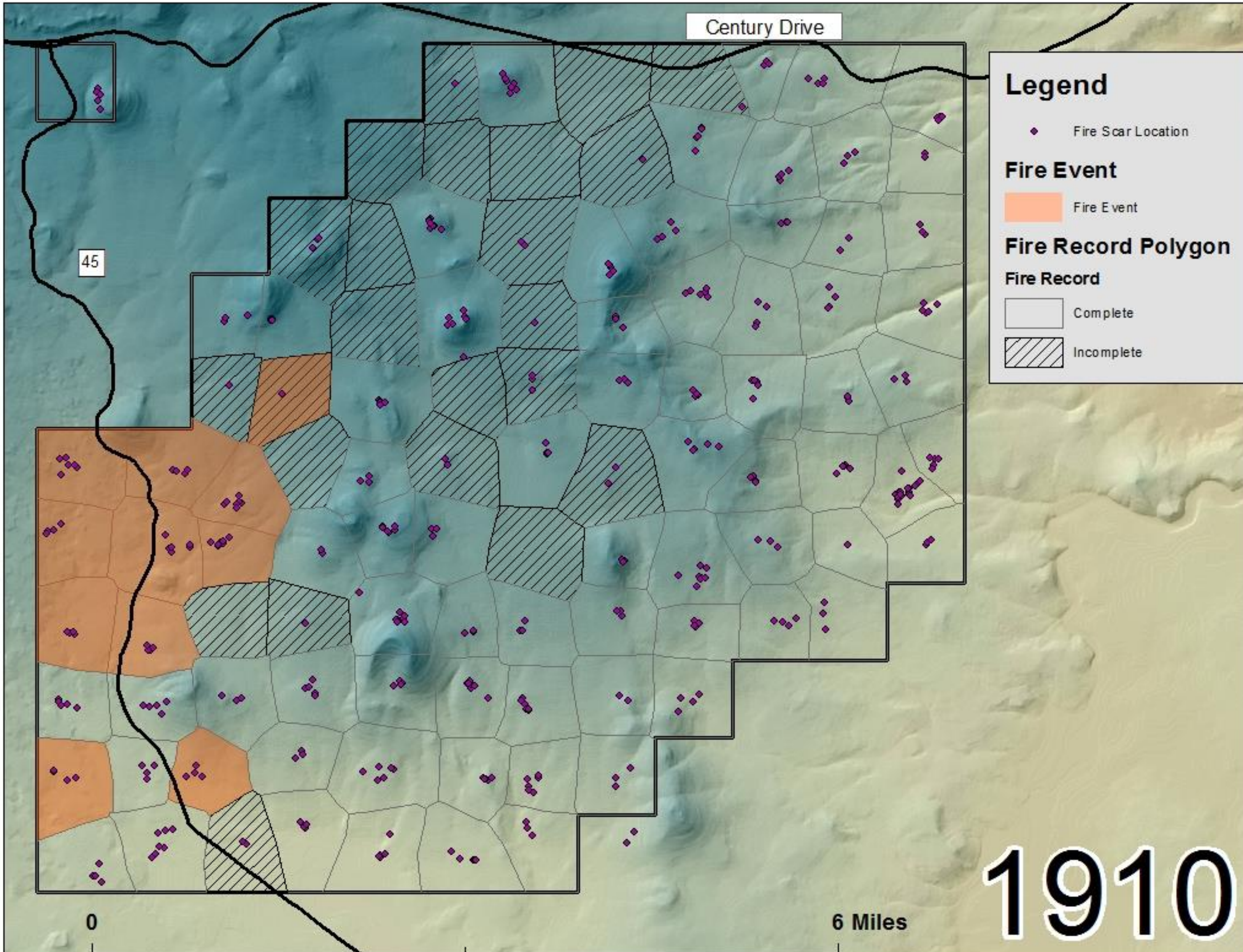

Century Drive
45
Legend
Fire Scar Location
Fire Event
Fire Event
Fire Record Polygon
Fire Record
Complete
Incomplete
0
6 Miles
1871


Century Drive
45
Legend
Fire Scar Location
Fire Event
Fire Event
Fire Record Polygon
Fire Record
Complete
Incomplete
0
6 Miles
1887

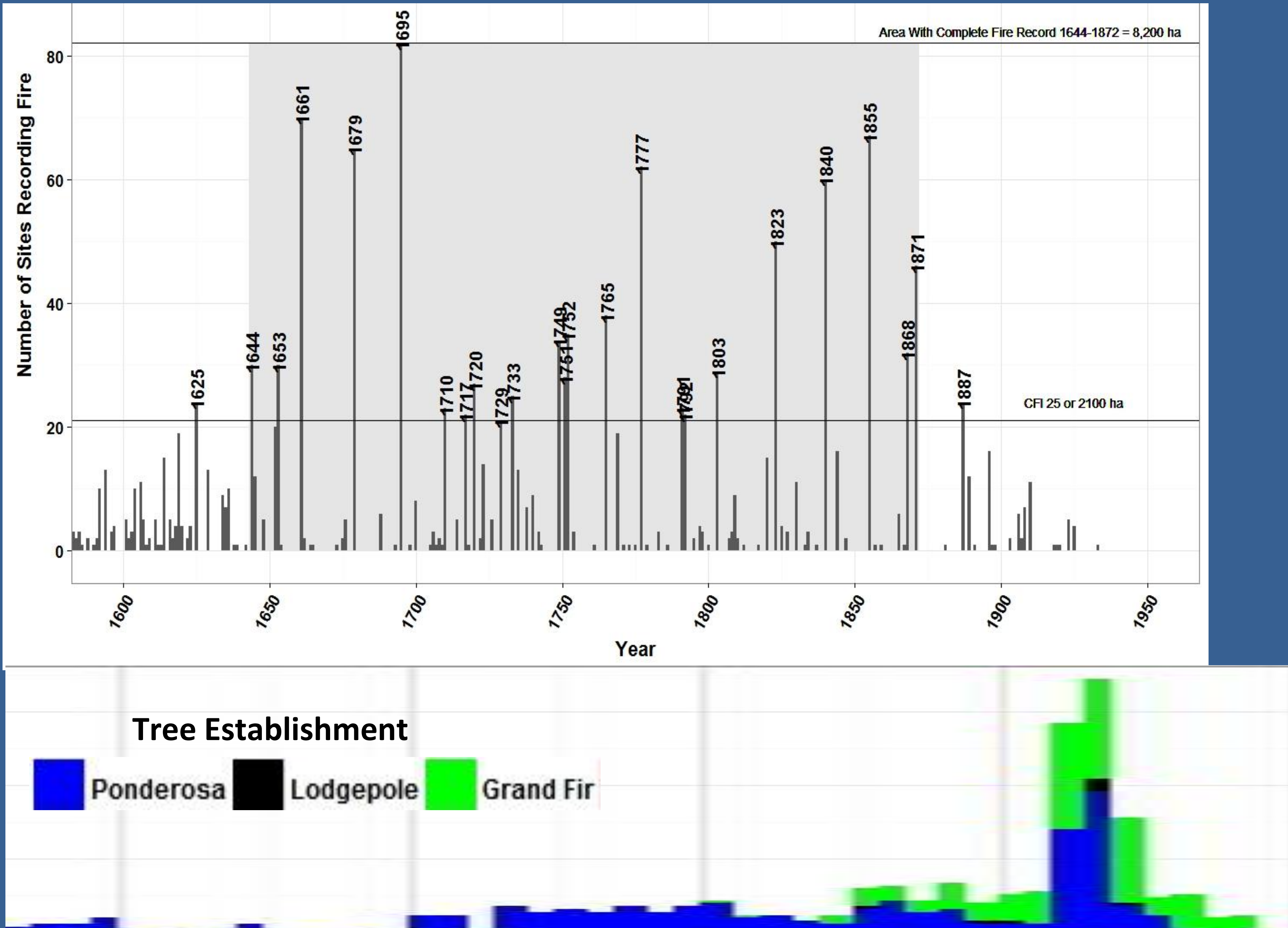


Century Drive
45
Legend
Fire Scar Location
Fire Event
Fire Event
Fire Record Polygon
Fire Record
Complete
Incomplete
0
6 Miles
1889

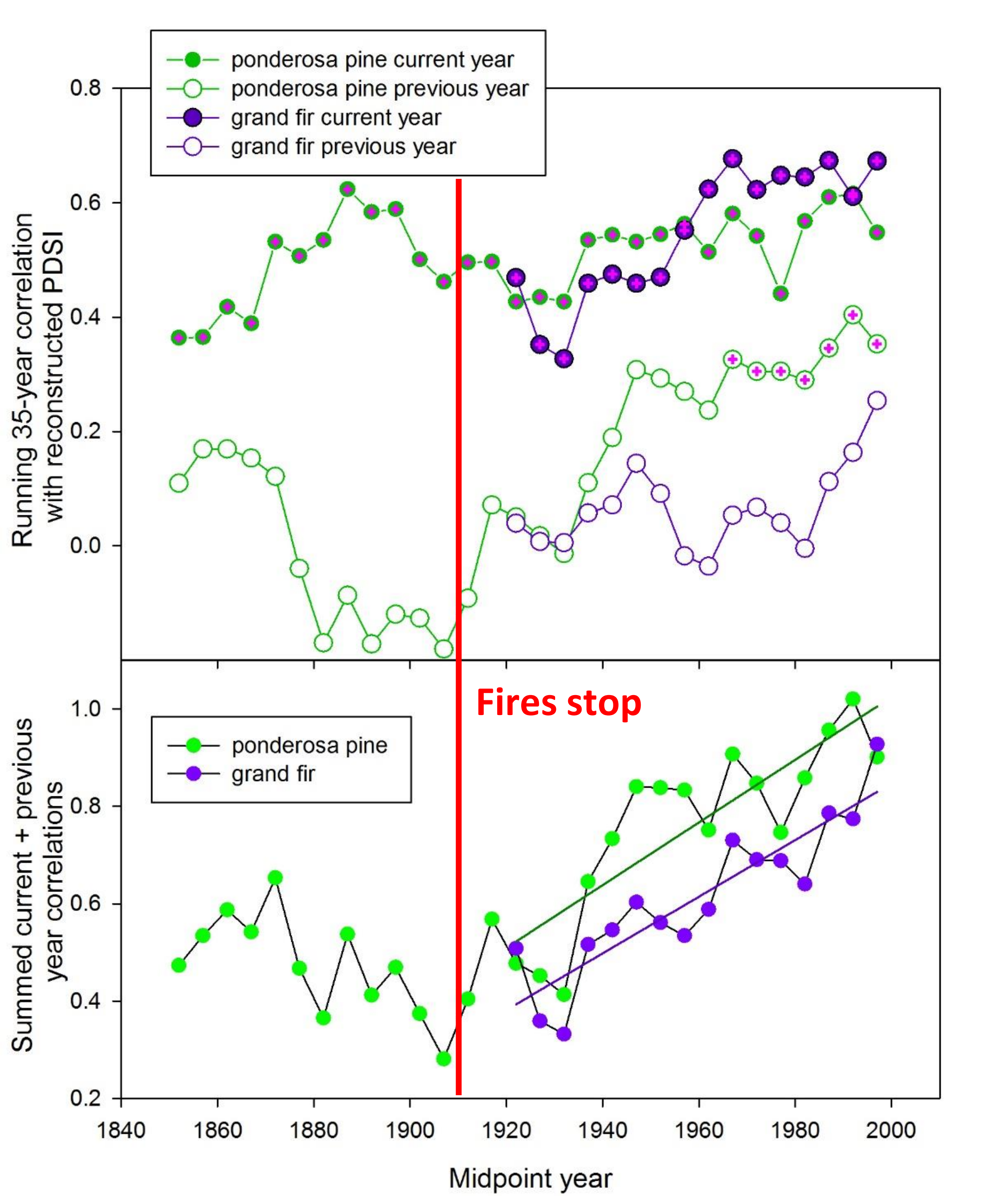

Century Drive
45
Legend
Fire Scar Location
Fire Event
Fire Event
Fire Record Polygon
Fire Record
Complete
Incomplete
0
6 Miles
1908



Century Drive
45
Legend
Fire Scar Location
Fire Event
Fire Event
Fire Record Polygon
Fire Record
Complete
Incomplete
0
6 Miles
1910



Area With Complete Fire Record 1644-1872 = 8,200 ha
CFI 25 or 2100 ha
Number of Sites Recording Fire
Year
0
20
40
60
80
1600
1650
1700
1750
1800
1850
1900
1950
1625
1644
1653
1661
1679
1695
1710
1717
1720
1729
1733
1749
1751
1752
1765
1777
1803
1823
1840
1855
1868
1871
1887
Tree Establishment
Ponderosa
Lodgepole
Grand Fir

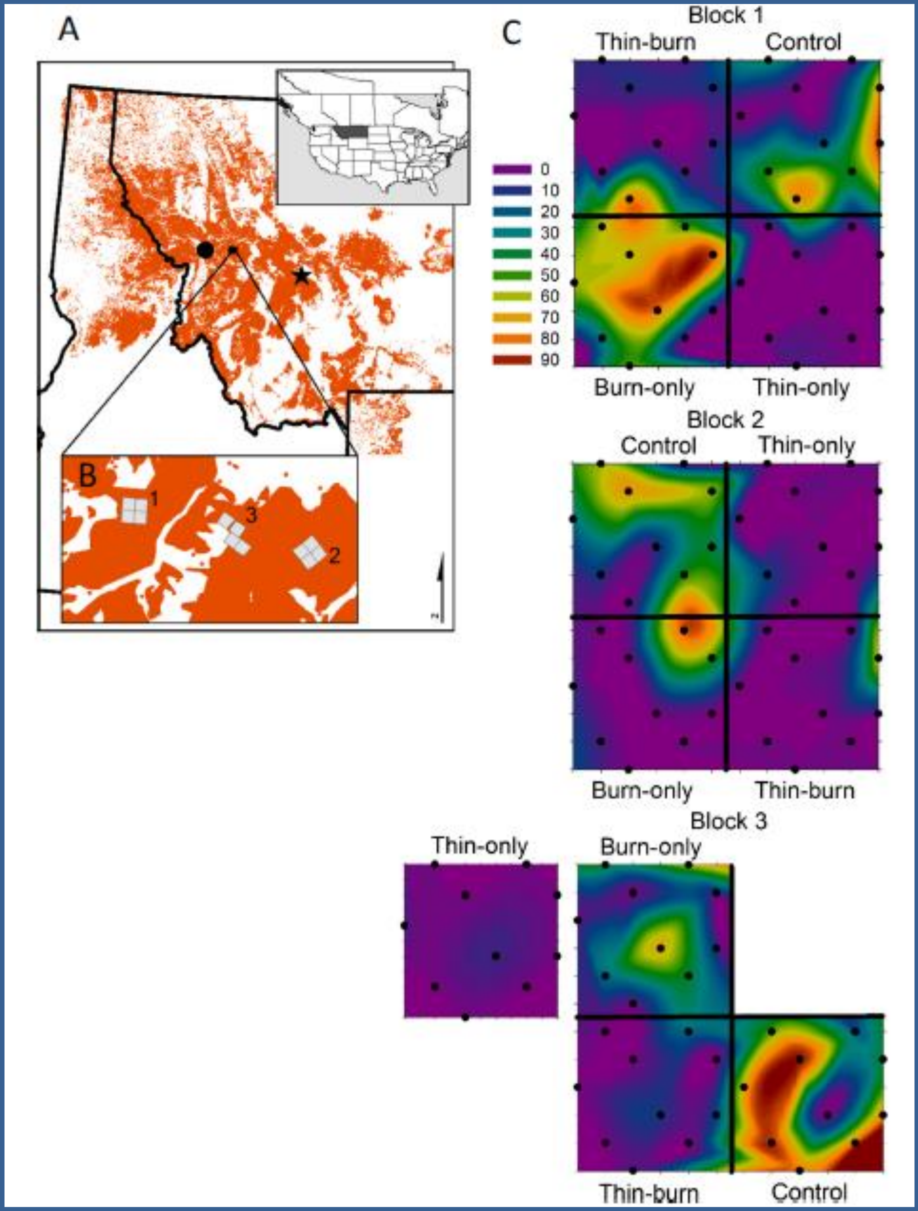


$\Delta^{13}C$ is lower for the same drought severity (PDSI)

Greater sensitivity of photosynthetic gas exchange to drought since 1920

Greater dependence on previous year growing conditions

Opposite of expected CO_2 response



Thinning and/or burning decreased susceptibility to mountain pine beetle mortality in montana

Hood et al.
Ecol. Appl. 2016

Concluding thoughts on forest drought responses:

Forest management practices should not be based on a 1000-year drought and outbreak beetle conditions

Forests need to be managed understanding that future droughts will occur

Investments in thinning and/or prescribed burning may not be cost-effective in the short-term but the only way to help prevent costly beetle outbreaks during future droughts