The *Office of Sustainability and Climate* welcomes you our webinar on

Drought and Invasive Species

AUDIO CONNECTION

1. **Phone:** mute your computer speakers and call 1-877-369-5243; access code: 0288882#

OR

2. Audio through the computer: Make sure your computer speakers are on and listen with speakers or headphones.

Note: Phone audio will allow you to both listen and speak up with questions. *If you listen through the computer, you will not be able to speak up with questions,* but will be able to type questions into the Q&A pod which will be answered by the appropriate speaker.

Cynthia West
Director, Office of Sustainability & Climate


Autumn olive *(© James R. Allison/Bugwood)*

USDA
United States Department of Agriculture

Office of Sustainability & Climate

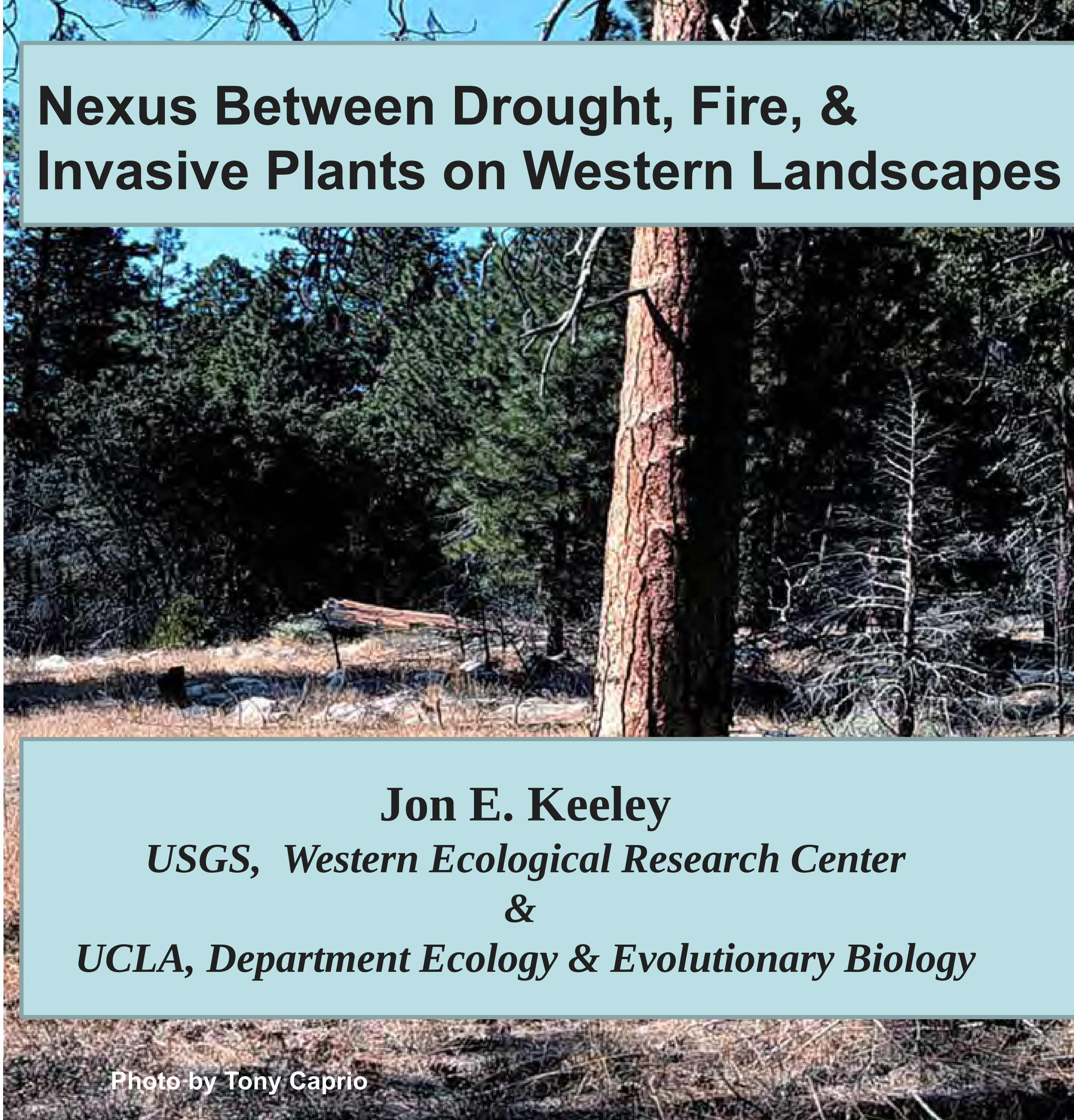
Japanese knotweed *(© Martin Fowler)*

Allen Rowley

Director, Forest Management, Rangeland Management & Vegetation Ecology

USGS
science for a changing world

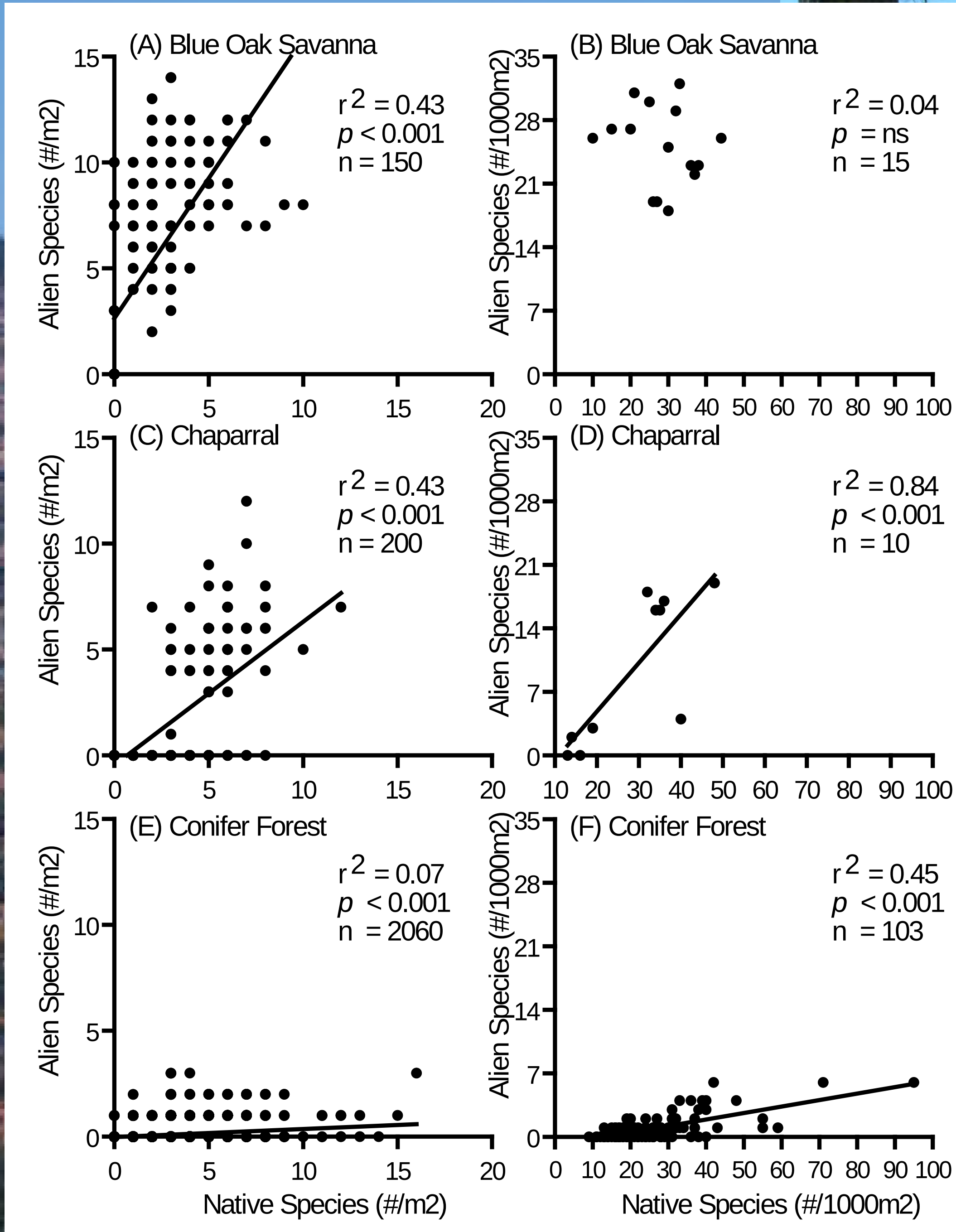
Sequoia
Field
Station



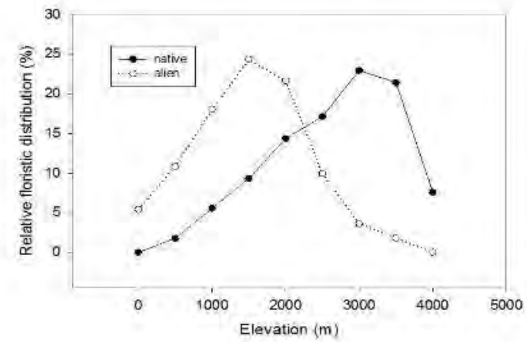
Nexus Between Drought, Fire, & Invasive Plants on Western Landscapes

Jon E. Keeley
USGS, Western Ecological Research Center
&
UCLA, Department Ecology & Evolutionary Biology

Photo by Tony Caprio



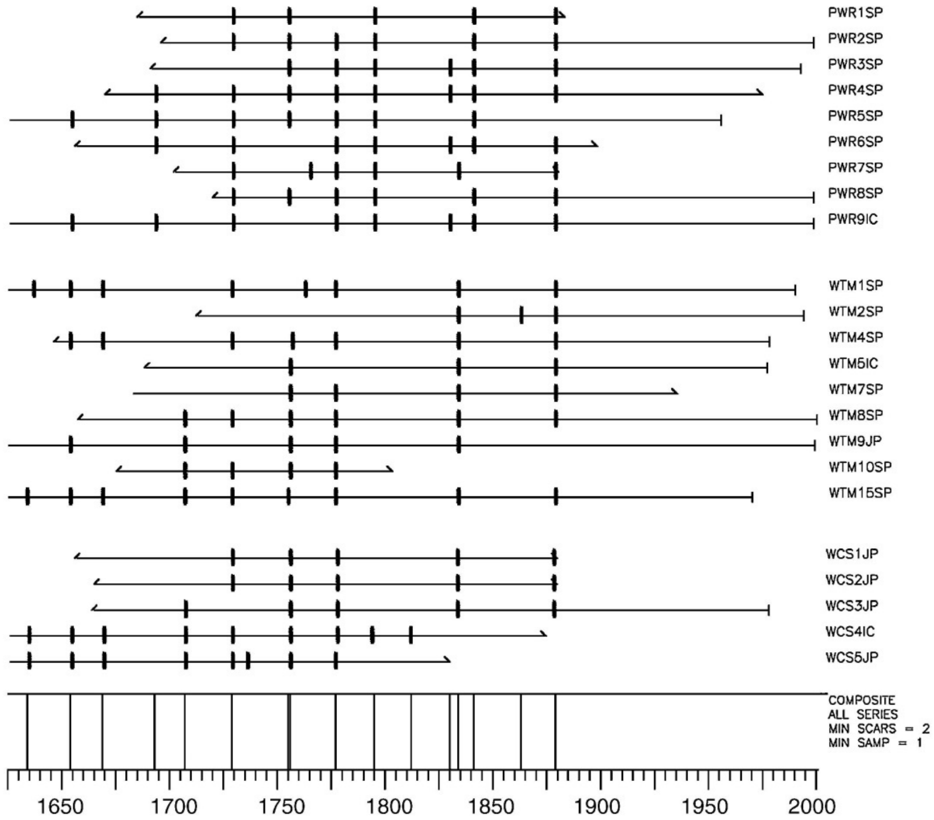
(Keeley et al 2003)



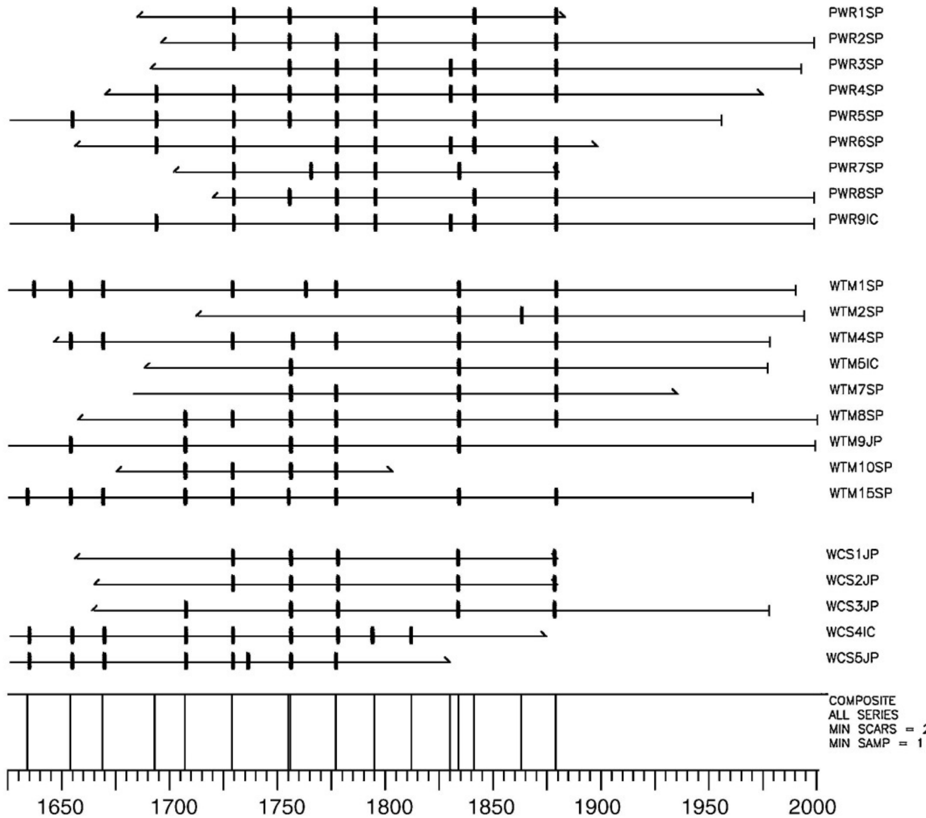
Rundel & Keeley 2016)

A Key Determinant of Alien Plant Invasions is Fire and Fire Management Practices

USGS



Proximal response:
fire suppression ≠
alien plant exclusion



Ultimate response:

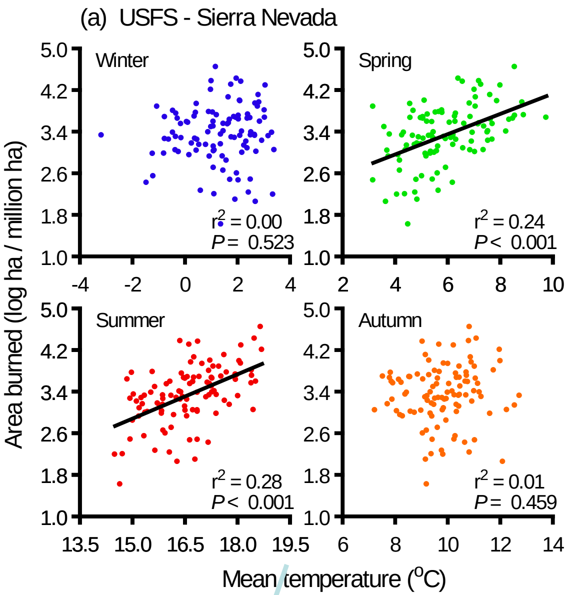
fire suppression = fire regime change

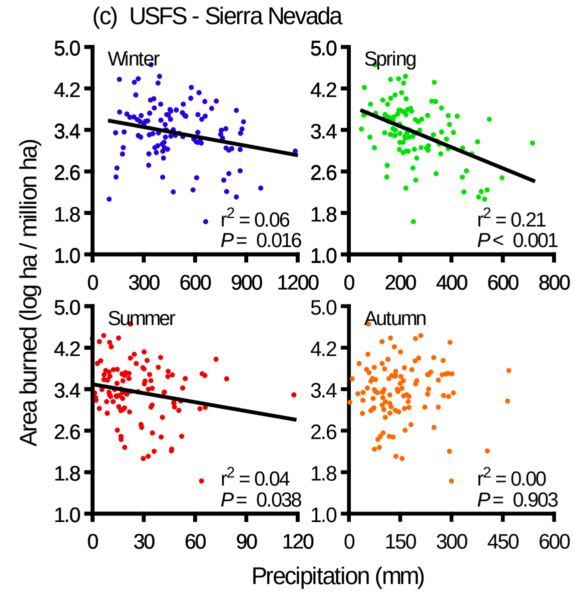
= alien plant invasion

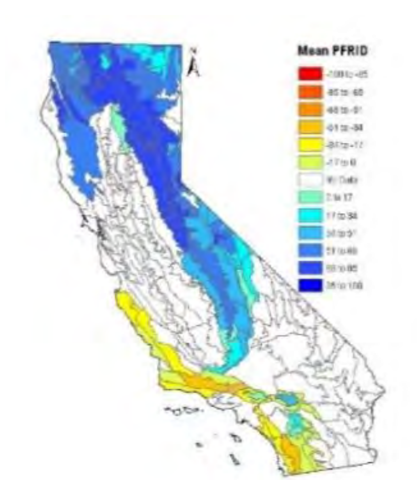

Photo: JE Keeley

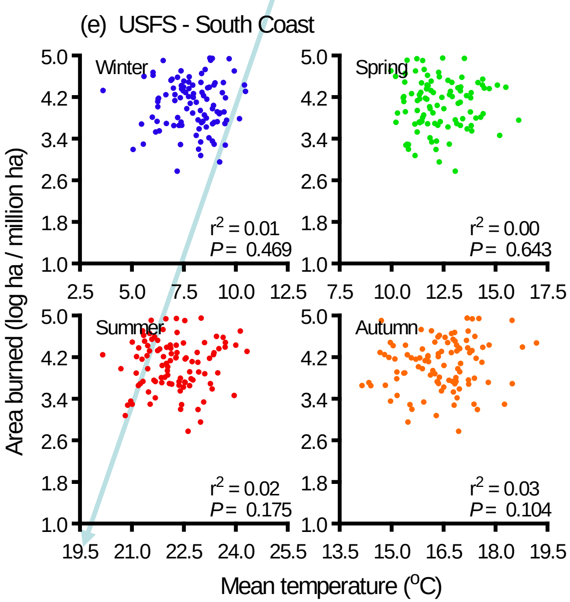

Photo: JE Keeley

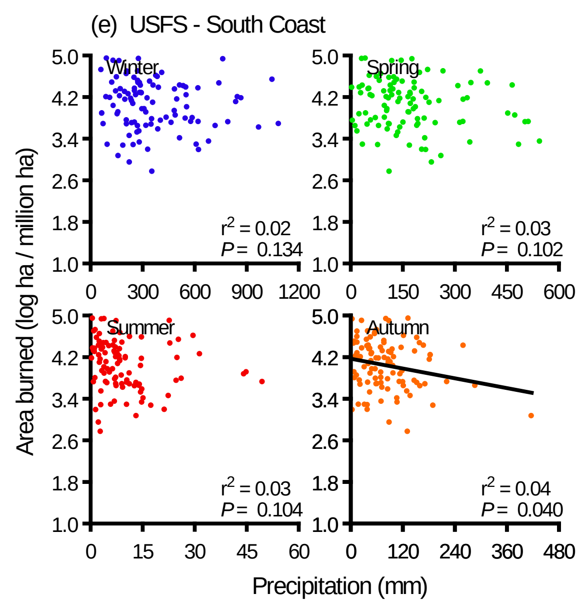
Fires most strongly controlled by climate in montane forests









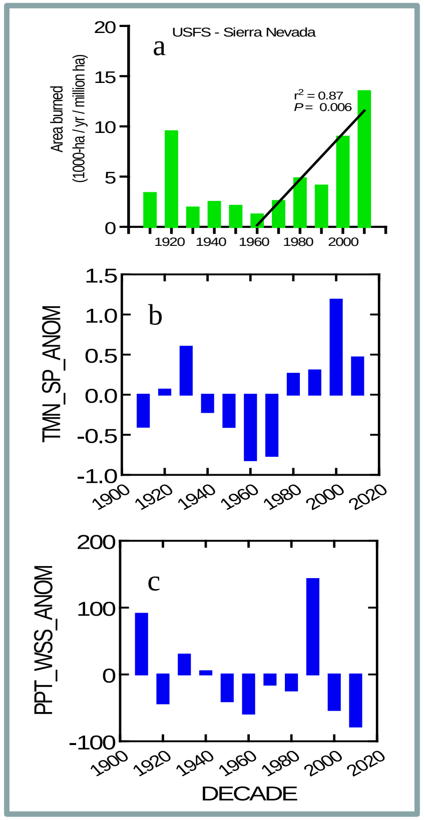


Fires most strongly controlled by climate in montane forests

Akaike IC regression models

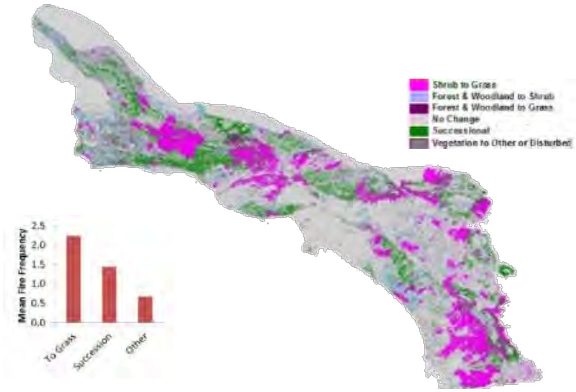
Sierra Nevada (USFS) r2

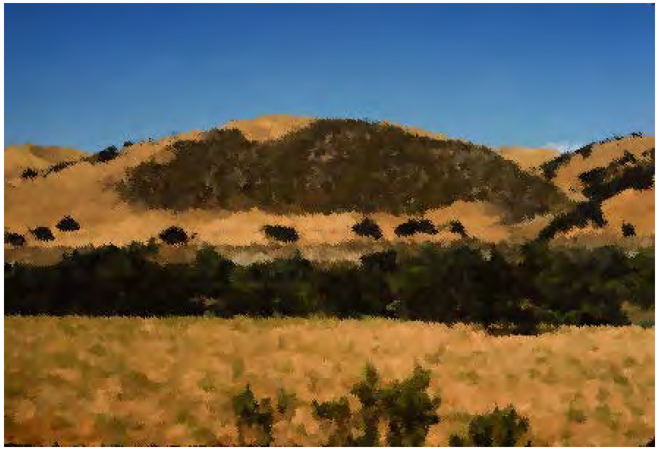
1910 - 2013	0.39	Temp spr+Temp sum-Ppt spr
1910 – 1959	0.42	- Ppt spr - Ppt win
1960 - 2013	0.52	Temp spr + Temp sum



South coast (Cal Fire) r2

1919 - 2013	0.00	
1919 - 1959	0.00	
1960 - 2013	0.25	Prior year ppt





Fire Regimes

Flammability-limited

Fire controlled by current yr climate

Fuel-limited

Fire controlled by prior yr high ppt

Ignition-limited

Fire controlled by human ignitions


1899
1879
1874
1861
1847


Google earth

Photo: K Merriam

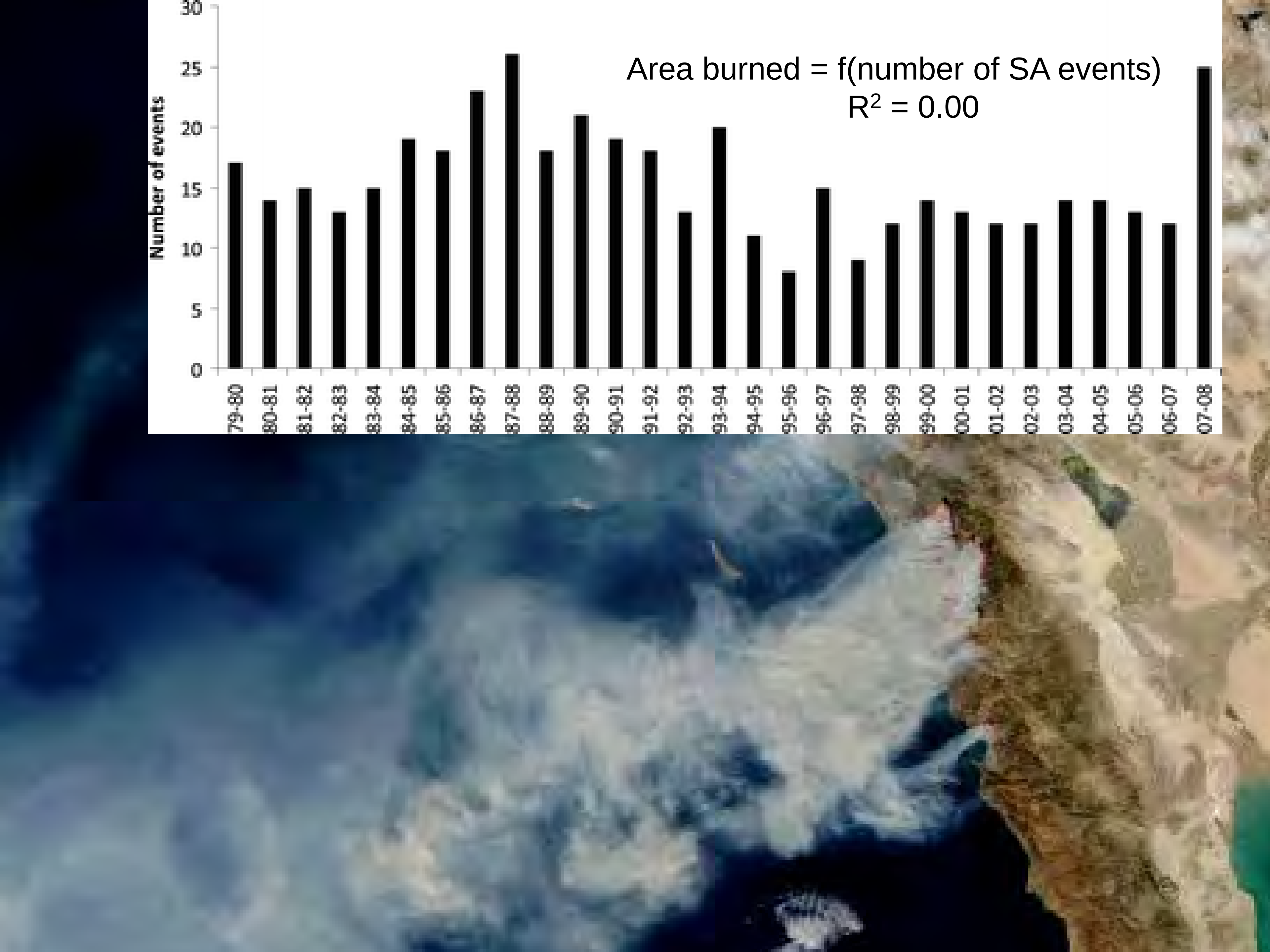
Grasslands and savannas

Elevated **ppt** increases herbaceous fuels that contribute to enhanced fire activity in the following year

Drought may decimate fuels and lead to decreased fire probability

Southern California shrublands major fires occur in autumn following 6 month annual drought

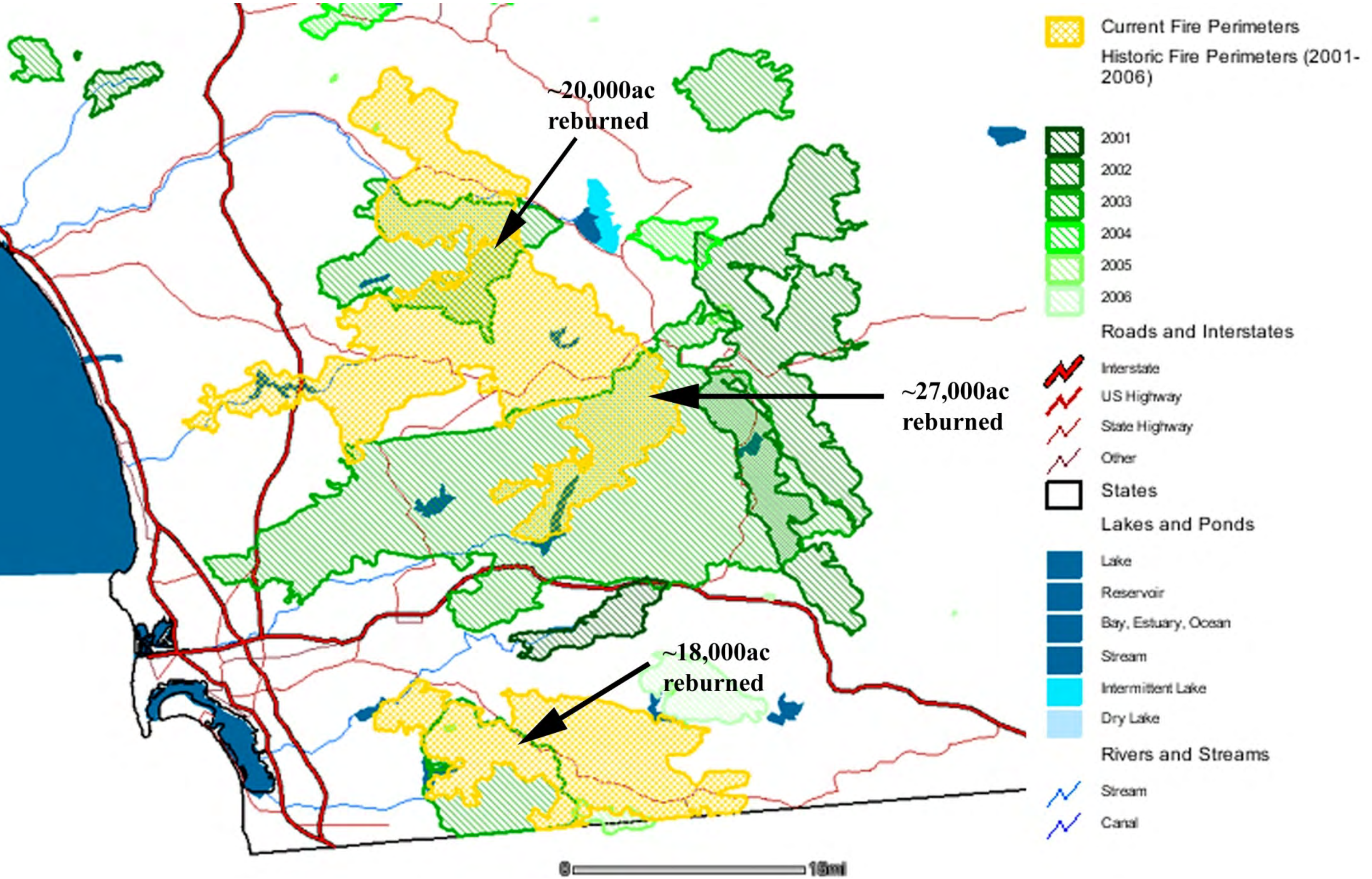
Extreme events due to Santa Ana winds



Area burned = f(number of SA events)
$R^2 = 0.00$
Number of events
0
5
10
15
20
25
30
79-80
80-81
81-82
82-83
83-84
84-85
85-86
86-87
87-88
88-89
89-90
90-91
91-92
92-93
93-94
94-95
95-96
96-97
97-98
98-99
99-00
00-01
01-02
02-03
03-04
04-05
05-06
06-07
07-08

Year	Fire	County	Month	Acres	Drought
1889	Santiago Cyn	Orange	Sept	308,900	12 ?
1932	Matilija	Sta Barbara	Sept	219,900	23
1970	Laguna	San Diego	Sept	174,200	14
1985	Wheeler #2	Ventura	July	122,800	7
2003	Cedar	San Diego	Oct	270,575	54*
2006	Day	Ventura	Sept	161,850	12
2007	Zaca	Sta Barbara	July	240,425	20
2007	Witch	San Diego	Oct	198,175	17
2009	Station	Los Angeles	August	166,600	32

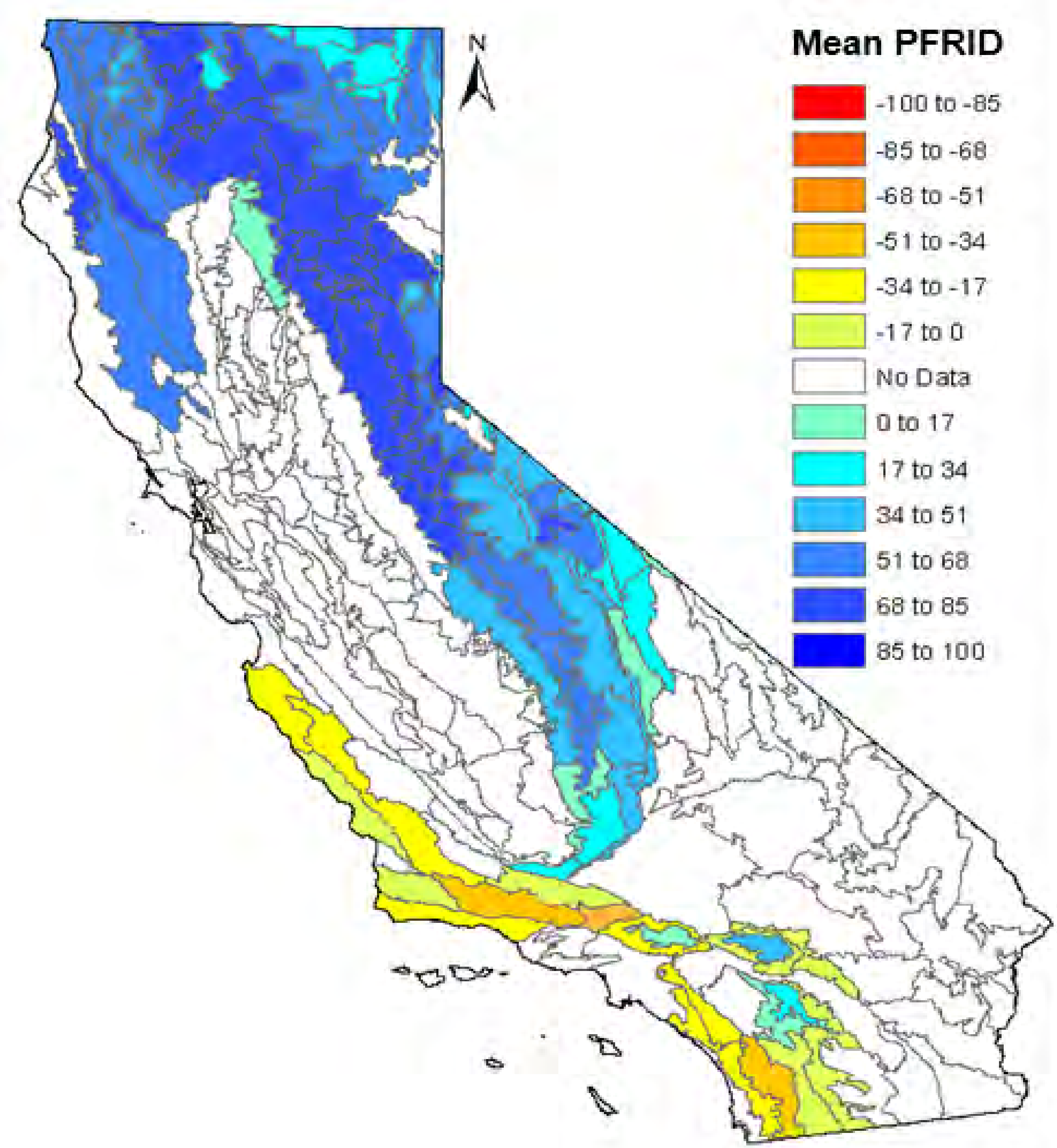
San Diego County --- 2003 & 2007 fires




Laguna Fire 1970
Viejas Fire 2001
Cedar Fire 2003
(photo by R. Halsey)

Fires occurring less than 15 - 20 years apart can convert chaparral to alien annual grasslands

Droughts will exacerbate this process



(Safford & van de Water 2014)

Future Drought Impacts

Flammability-limited ***Fuel-limited*** ***Ignition-limited***

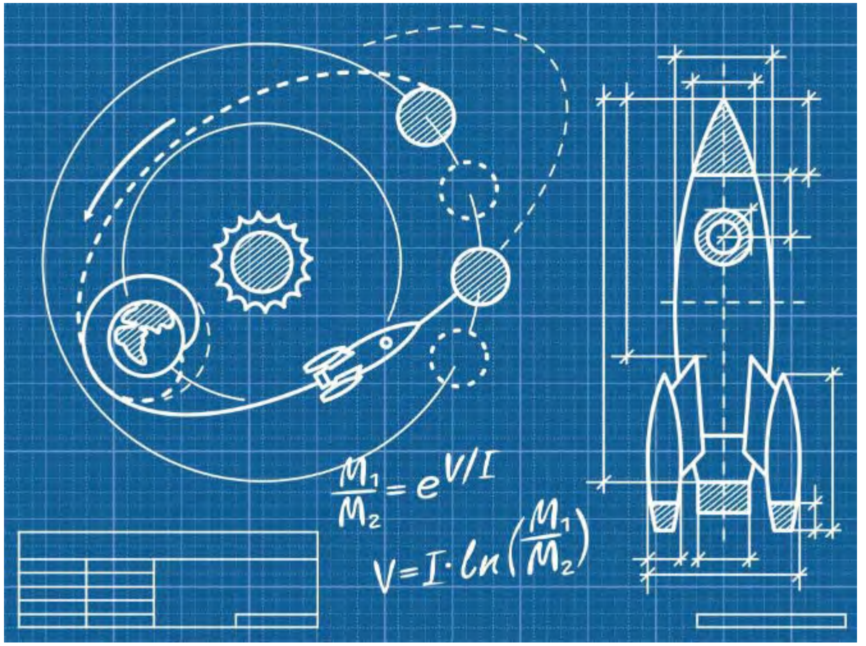
Future Drought Impacts

Flammability-limited *Fuel-limited* *Ignition-limited*

→ **Type conversions put systems on very different trajectories**
→ **New invasives may product novel ecosystems**
→ **Fire-climate models have changed in the past and may in the future**
→ **Precipitation may increase, or decrease, or occur with greater variability**
→ **Increased CO_2 increases WUE, potentially offsetting drought impacts**
→ **As climates change, new combinations of temperature and ppt w no analogue**
→ **Impact will depend on order, timing and magnitude of many contingencies**

Predicting Future Drought / Fire /Invasive Outcomes

It's Not Rocket Science



… It's Far More Complicated

This is not hyperbole, e.g. Apollo can predict to the minute the arrival of a space craft 400,000 km away

Anyone who says they have a grasp on how climate and other global changes will impact future conditions possesses an impressive level of optimism

and

Questions & Answers

- **By phone:** Dial #2 to enter the queue.
- **On your computer:** Type your question into the Q & A pod on the left side of your screen.

Drought and Invasive Plants in Eastern Forests

Cynthia D. Huebner, PhD
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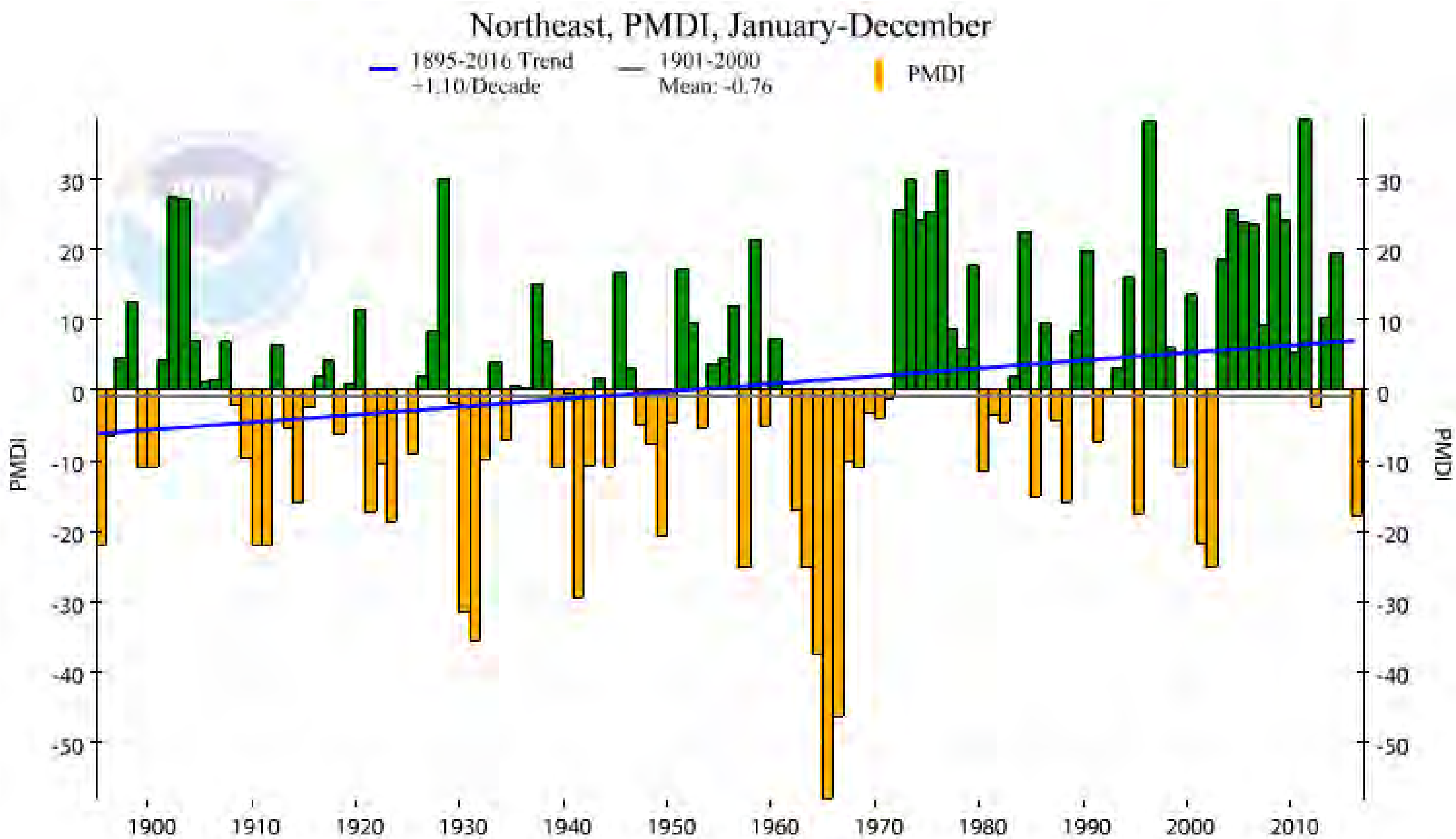
Northern Research Station, USDA Forest Service
Morgantown, WV

Likelihood of Drought in Eastern United States

https://www.ncdc.noaa.gov/cag/time-series/us

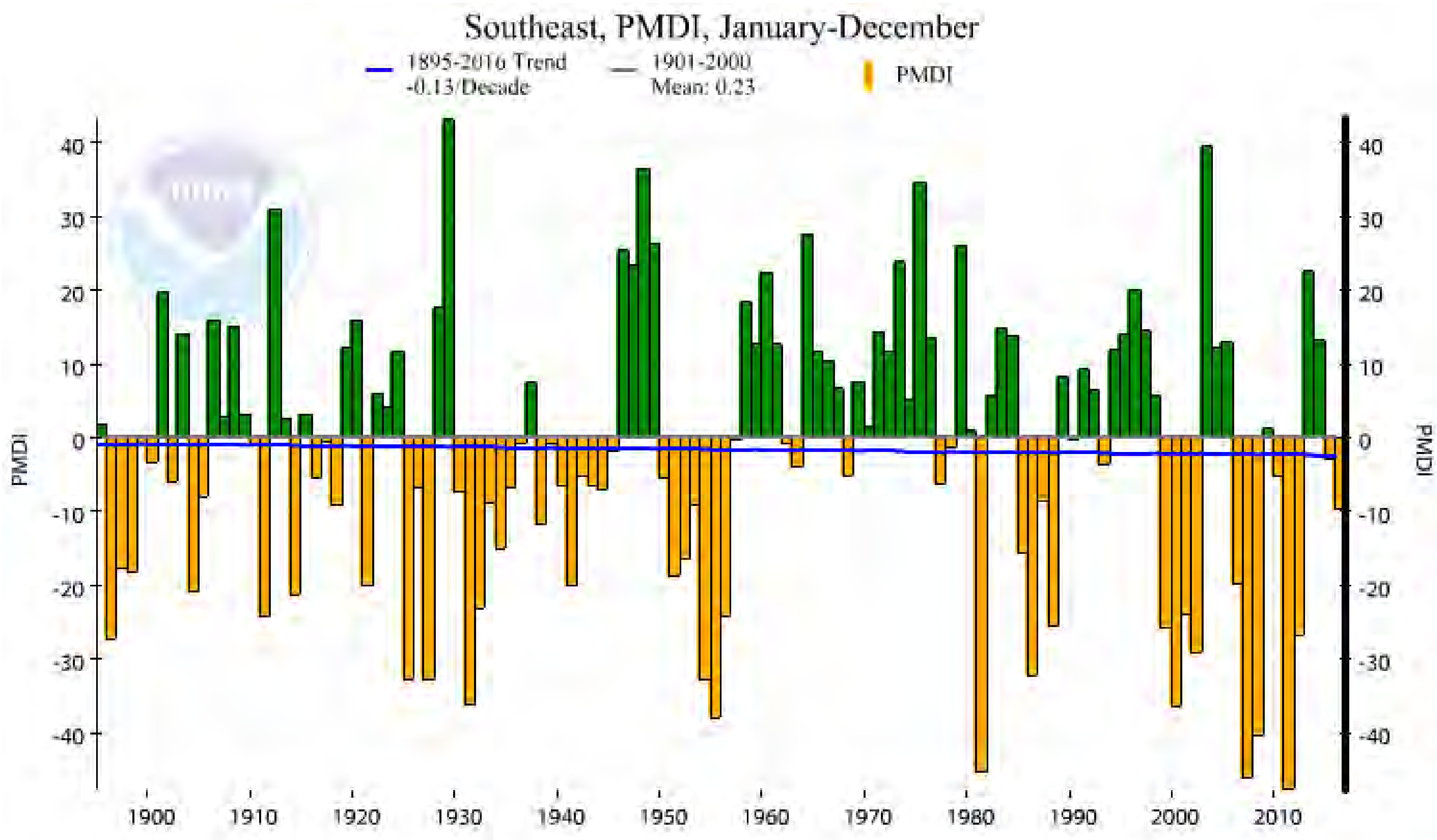
NOAA – National Center for Environmental Information



PMDI = Palmer-Modified Drought Index

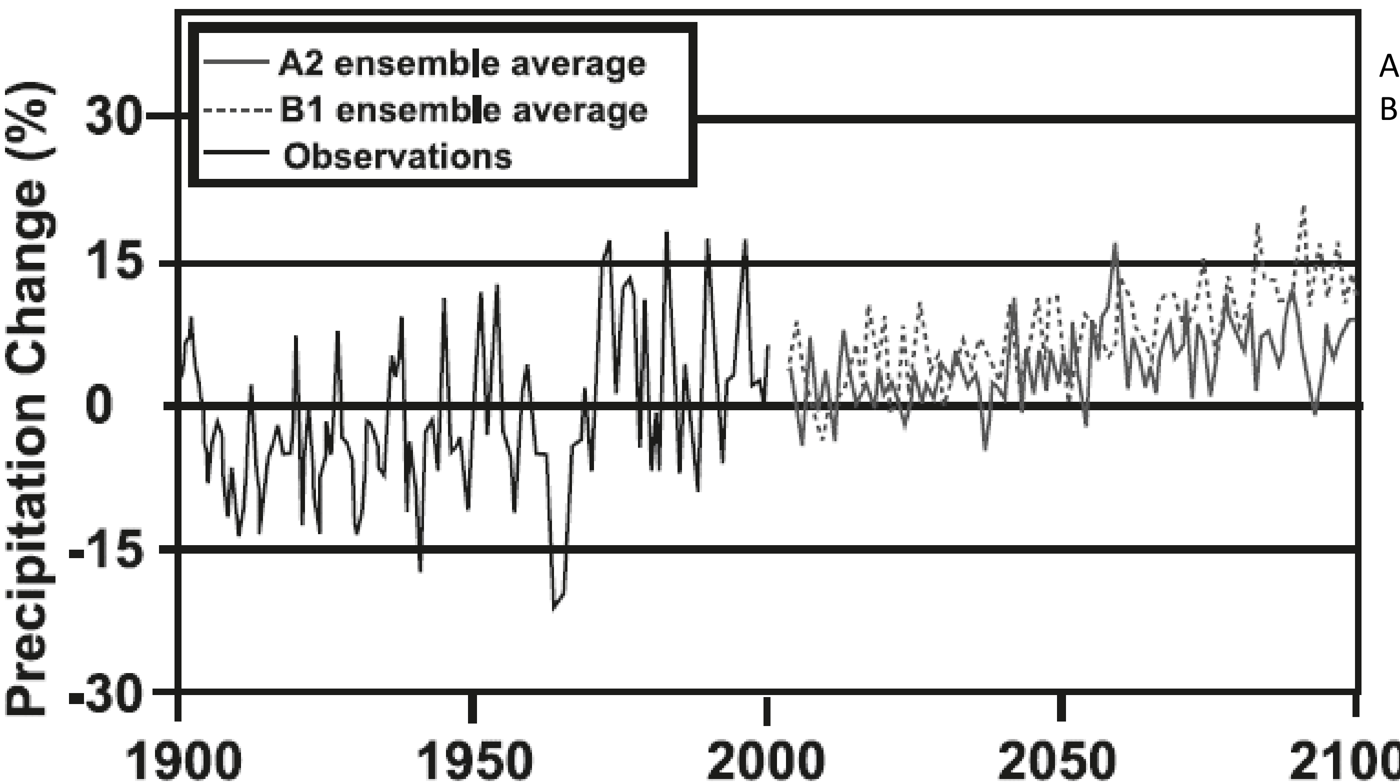
https://www.ncdc.noaa.gov/cag/time-series/us

NOAA – National Center for Environmental Information



PMDI = Palmer-Modified Drought Index

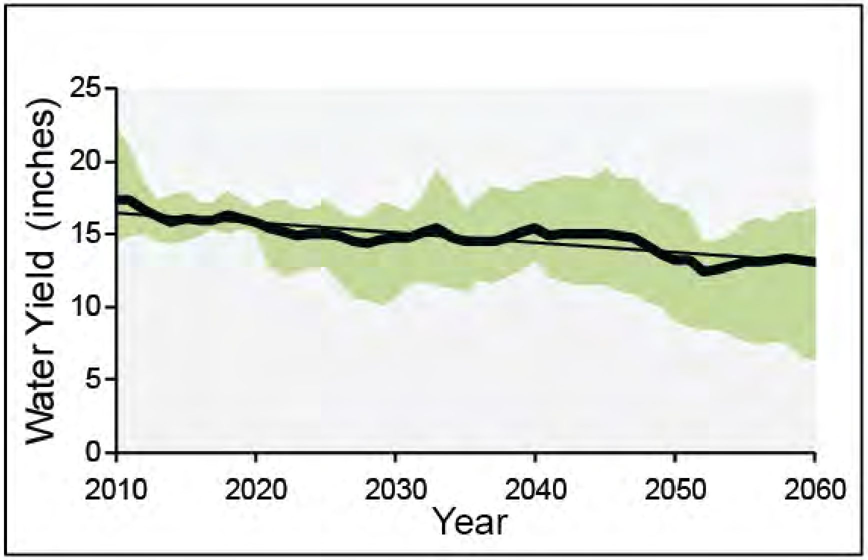
Simulated Trends in Precipitation Change for Northeastern US Using Two Scenarios of GCMs

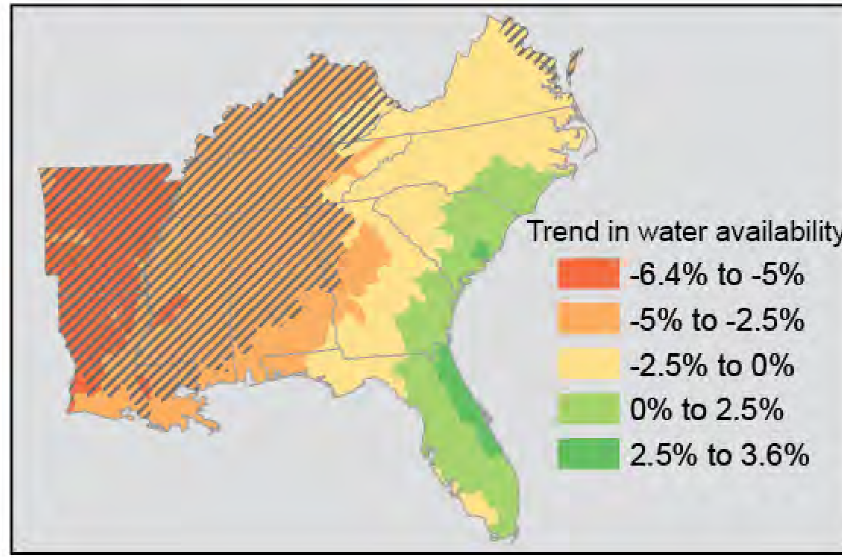


A2 = Mid-high CO_2 emissions
B1 = Low CO_2 emissions

Huntington et al. 2009

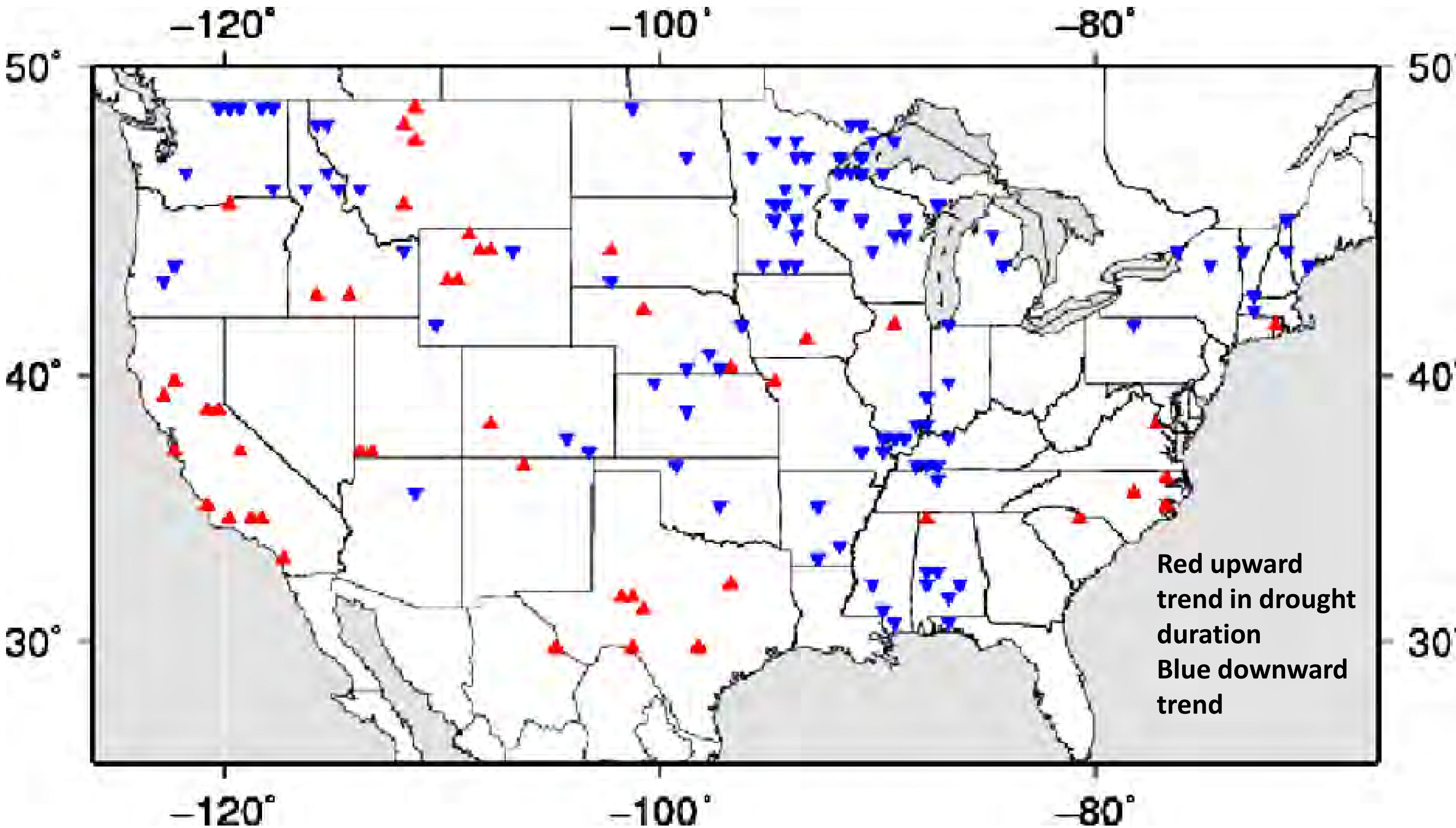
Trends in Water Availability



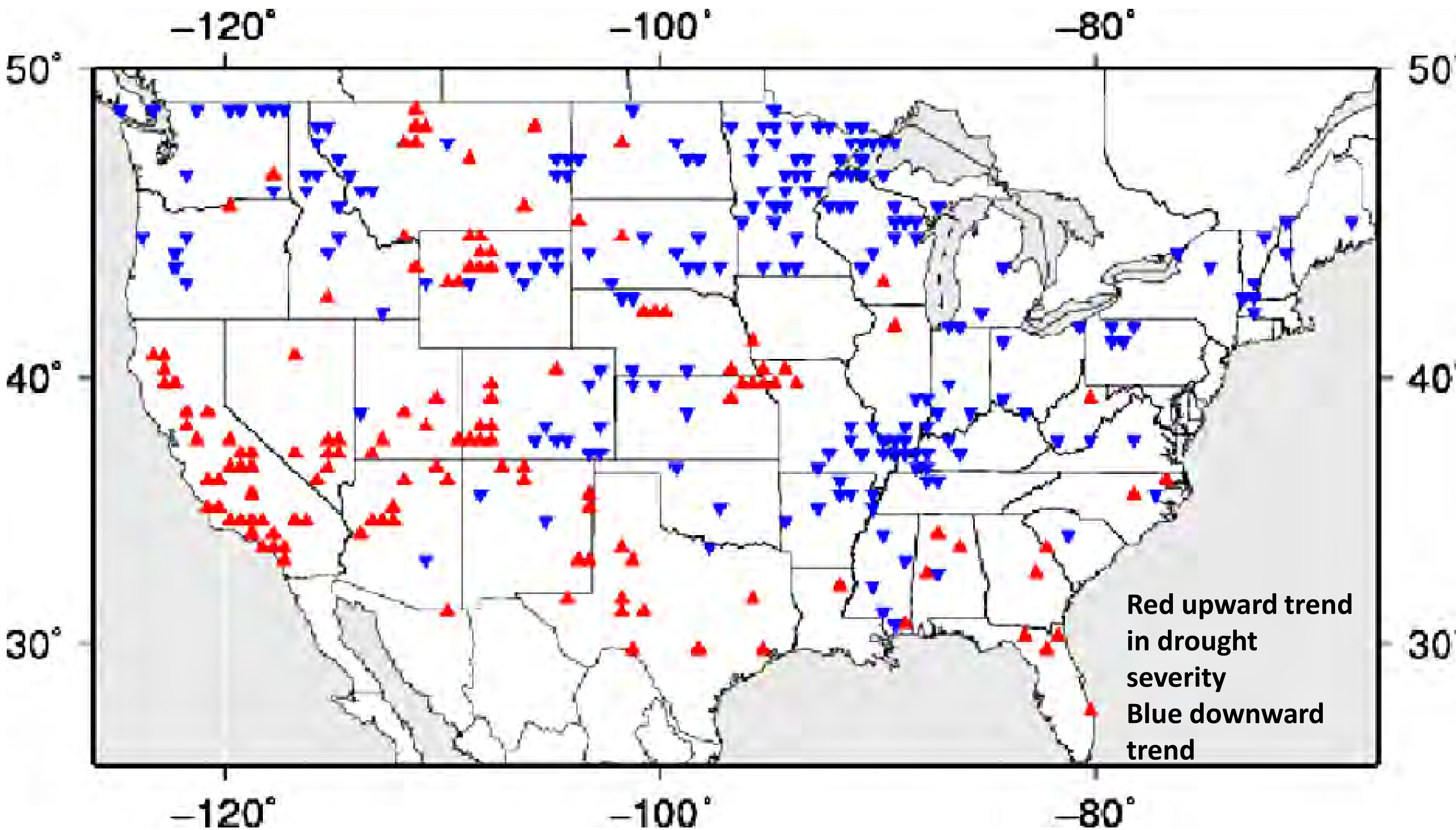


Carter et al. 2014. Climate Change Impacts in the United States: The Third National Climate Assessment. Adapted from: Sun et al. 2013.

Hatched area where water availability will decrease relative to 2010.



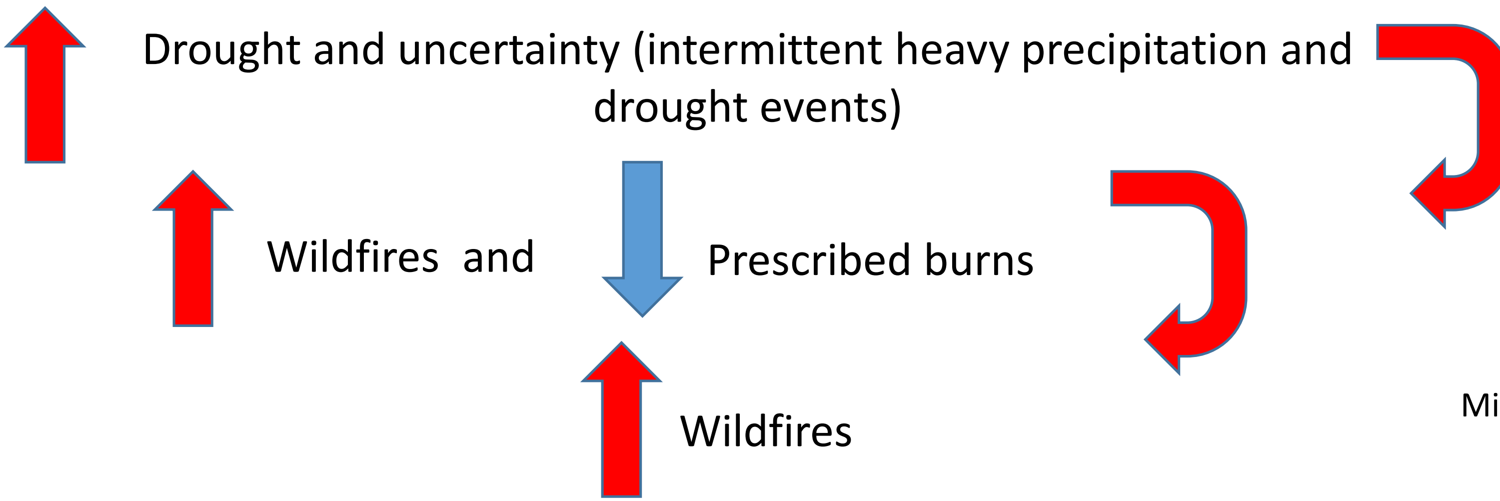
Andreadis and Lettenmaier 2006



Andreadis and Lettenmaier 2006

Pigeon Forge Fire – Smokey Mountains -- 2016

Drought and Fire Effects



Mitchell et al. 2014

Some invasive plant species <u>promote</u> fire (*Imperata cylindrica* – Cogon grass, *Microstegium vimineum* – Japanese stiltgrass, and *Lygopodium japonicum* – climbing fern); others <u>decrease</u> it (*Schinus terebinthifolius* – Brazilian pepper tree, *Ligustrum sinense* – Chinese privet) (Mitchell et al. 2014).

Contradictions – Average effective heat of combustion and time of sustained ignition actually low for Japanese stilt grass (and *Frangula alnus* -- glossy buckthorn and *Rumex acetosella* -- sheep sorrel) but high for *Ailanthus altissima* -- tree of heaven, *Lonicera japonica* -- Japanese honeysuckle, *Berberis thunbergii* -- Japanese barberry, and *Alliaria petiolata* -- garlic mustard (Dibble et al. 2007).

Drought and increased tree mortality -- four documented cases NE and SE (Allen et al. 2010).

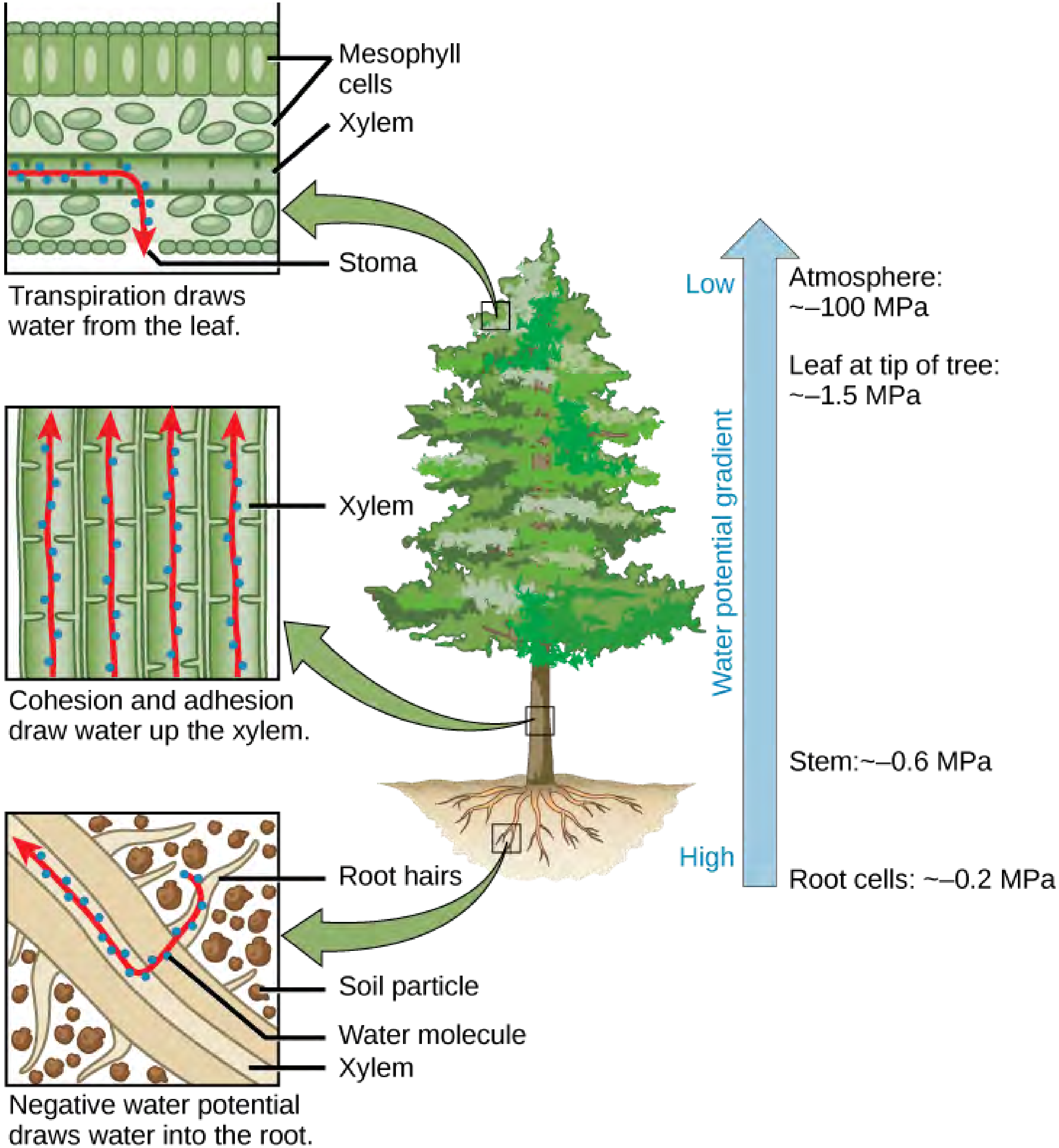
1. Multiyear drought and high temps preceded by severe winters in 1970-1980s in the SE, NE and MW. Species effected: *Quercus* and *Carya* spp.; wood borers, fungus, and insect defoliators also present.

2. Multiyear drought between 1984 and 1989 in North Carolina. Species affected: *Acer saccharum*, *Fagus grandifolia* , *Tilia americana*, *Aesculus, flava*; no insects or pathogens noted.

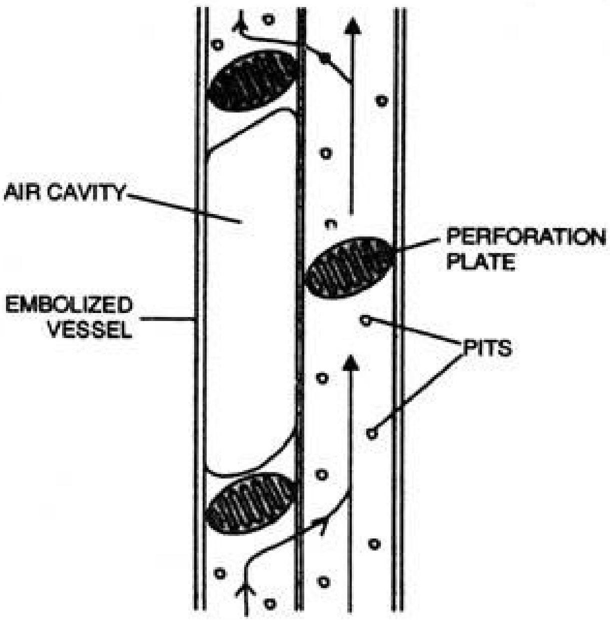
3. Drought, high temps preceded by winter thaw in the 1980s in eastern U.S. Species affected: *Acer saccharum*; insect defoliator also present.

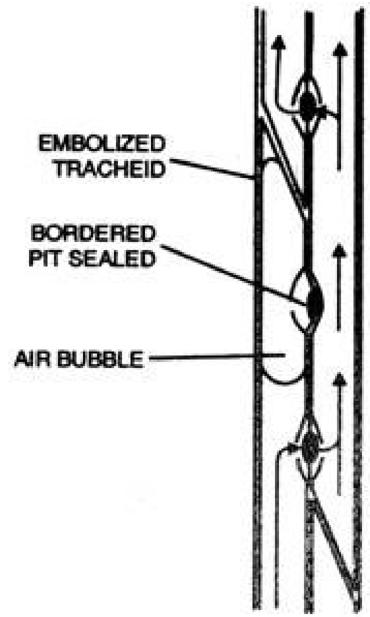
4. Multi-year drought between 1990 and 2001 in the MW and SE. Species affected: *Quercus* spp.; wood borers and fungi also present.

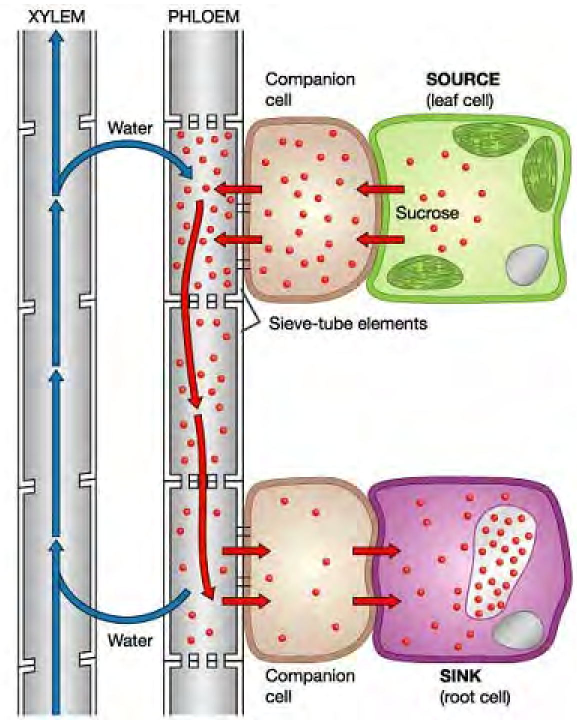
How Plants Cope with a Lack of Water



Mesophyll cells
Xylem
Stoma
Transpiration draws water from the leaf.
Xylem
Cohesion and adhesion draw water up the xylem.
Root hairs
Soil particle
Water molecule
Xylem
Negative water potential draws water into the root.
Low
High
Water potential gradient
Atmosphere: ~–100 MPa
Leaf at tip of tree: ~–1.5 MPa
Stem:~–0.6 MPa
Root cells: ~–0.2 MPa


AIR CAVITY
PERFORATION PLATE
EMBOLIZED VESSEL
PITS


EMBOLIZED TRACHEID
BORDERED PIT SEALED
AIR BUBBLE


XYLEM
PHLOEM
Companion cell
SOURCE
(leaf cell)
Water
Sucrose
Sieve-tube elements
Water
Companion cell
SINK
(root cell)

Plant Physiological Responses to Drought

1. Embolism – air seeding or breaks in water column in xylem. Woody plants especially operate at xylem pressures close to the critical threshold for hydraulic failure. Even if not lethal can lead to stomatal closure.

2. Carbon starvation – occurs with stomatal closure and when a reduction in CO_2 uptake through the stomates causes the carbon balance to drop to negative values; occurs when non-structural carbohydrates consumption by respiration surpasses carbon fixation by photosynthesis.

Plant Mechanisms of Drought Tolerance

1. Stomatal closure: Isohydric – conservative use of water; close stomates even with mild water stress; possible experience carbon starvation. Anisohydric – more exposed to embolism than carbon starvation; stomatal closure delayed for more severe water stress levels; risk taking behavior (Attia et al. 2015; Savi et al. 2016).

2. Plant biochemistry: biochemical indicators of stress --osmolytes, osmoprotectants (osmotic balancing agents, proline, soluble sugars), reactive oxygen species (ROS; free radicals), and antioxidants (tocopherols, carotenoids, phenolic compounds) that scavenge and remove ROS (Pinto-Marijuan and Munne-Bosch 2013; Savi et al. 2016).

3. Plant structural differences – shrunken cortical cells (Trifilo 2004); decreased hydraulic diameter (xylem cells) (Beikercher and Mayr2009); increased root to shoot ratios (Niu and Rodrigues 2009).

Patterns of Water Use and Drought Resilience between Invasive and Native Plants

1. Invasive plants and communities dominated by invasives have a strong tendency for higher water use than paired native species (greater stomatal conductance and carbon assimilation) (Cavaleri and Sack 2010)

2. Invasives (woody) more water efficient with limited resources (Heberling and Fridley 2013); but several examples show limited resources limit invasions (Alpert et al. 2000)

3. Invasive species more plastic compared to paired native species, but native species higher fitness than nonnative invasive when resources limited (Davidson et al. 2011); invasive species are not more plastic than paired native species (Palacio-Lopez and Gianoli 2011)

4. Leaf mass per unit area lower in nonnatives than natives in arid environments (Griffen 1994; Funk2013); invasive species put more resources into root biomass than shoot biomass (Grotkopp and Rejmanek 2007)

5. Low construction cost for nonnative annuals – produce large photosynthetic leaves fast -- take advantage of short rain periods and seed bank during dry years (Cordell et al. 2002; Funk 2013)

Drought Tolerance Rankings – Niinemets and Valladares 2006 (ranked 806 species)

Information from research in native regions

Rankings: 1 = very intolerant, 2 = intolerant, 3 = moderately tolerant, 4 = tolerant, 5 = very tolerant

Nonnative:

Acer platanoides 2.73
Ailanthus altissima – 2.96
Albizia julibrissin – 4.47
Aralia elata – 3.00
Berberis thunbergii – 3.50
Buddleja davidii – 3.46
Catalpa speciosa – 4.22
Euonymus alatus – 2.00
Frangula alnus – 1.37
Gingko biloba – 3.99
Ligustrum vulgare – 3.46
Phellodendron amurense – 4.10
Pyrus calleryana – 4.47
Rhamnus cathartica – 3.46
Rubus phoenicolasius – 2.50

Native:

Acer saccharum – 2.25
Aralia spinosa – 4.00
Cercis canadensis – 4.05
Fraxinus americana – 2.38
Hammamelis virginiana – 2.00
Liriodendron tulipifera -- 2.60
Lindera benzoin – 2.00
Nyssa sylvatica 2.00
Ostrya virginiana – 3.25
Prunus serontina – 3.02
Quercus rubra – 2.88
Rhus typhina – 4.00
Robinia pseudoacacia – 4.11
Rubus allegheniensis – 4.00
Sassafras albidum -- 5.00

Ailanthus altissima
Tree of heaven

Photo credit: Invasivespecies.gov

Lower mortality compared with native and nonnative species in areas with drought (Savi et al. 2016); little effect on growth (tree rings) during drought years (Knusel et al. 2015) – in its invaded regions.

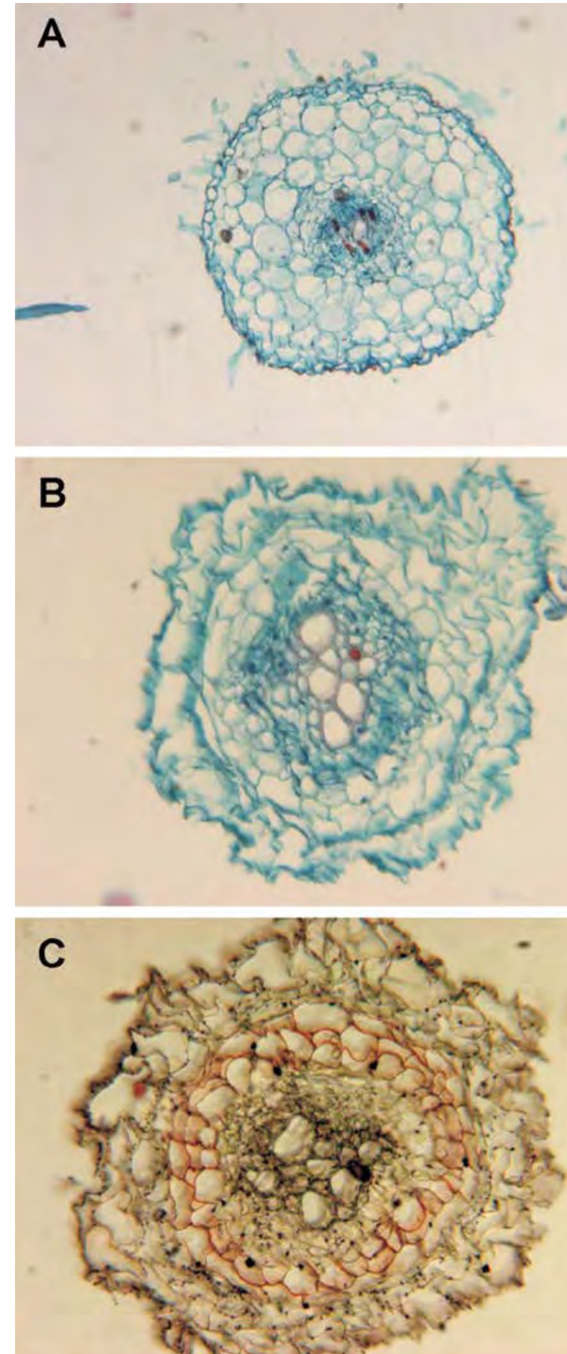
Support for *Ailanthus altissima*’s drought tolerance in its invasive range:

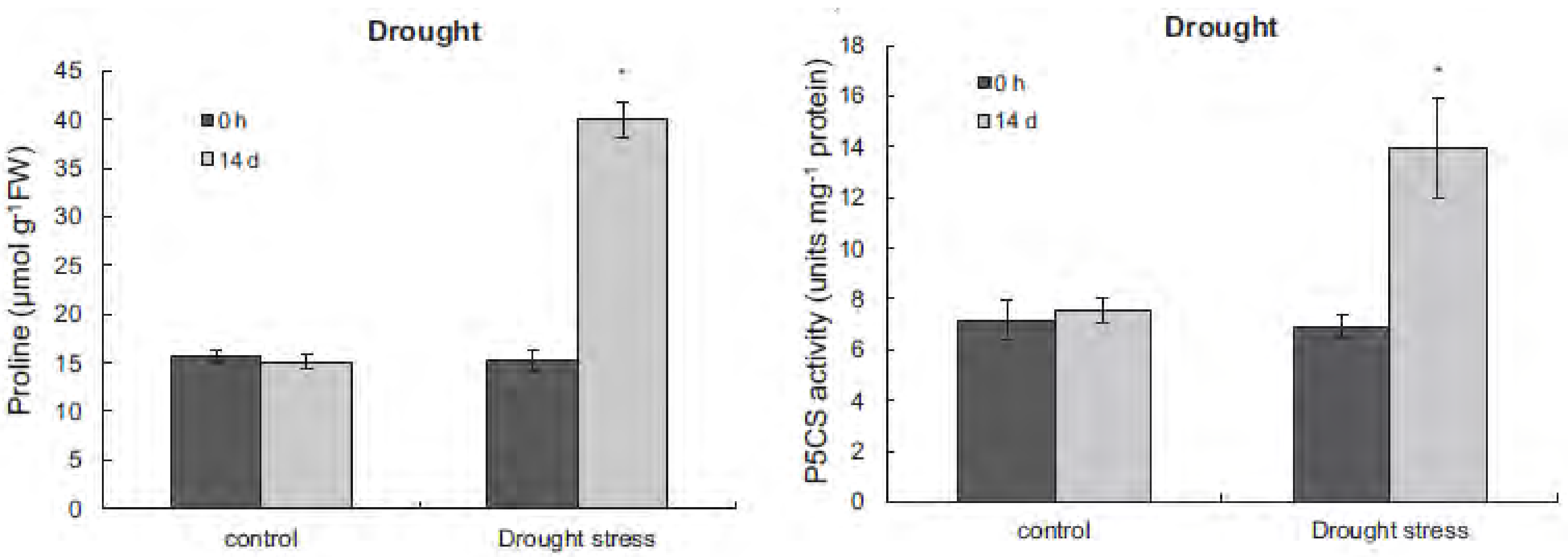
1. Effective stomatal closure (Trifilo et al. 2004) – Isohydric

2. Roots become less permeable to water – shrunken cortical cells and multilayer endodermal–like tissue impairs water transport –reducing root hydraulic conductance (Trifilo et al. 2004)

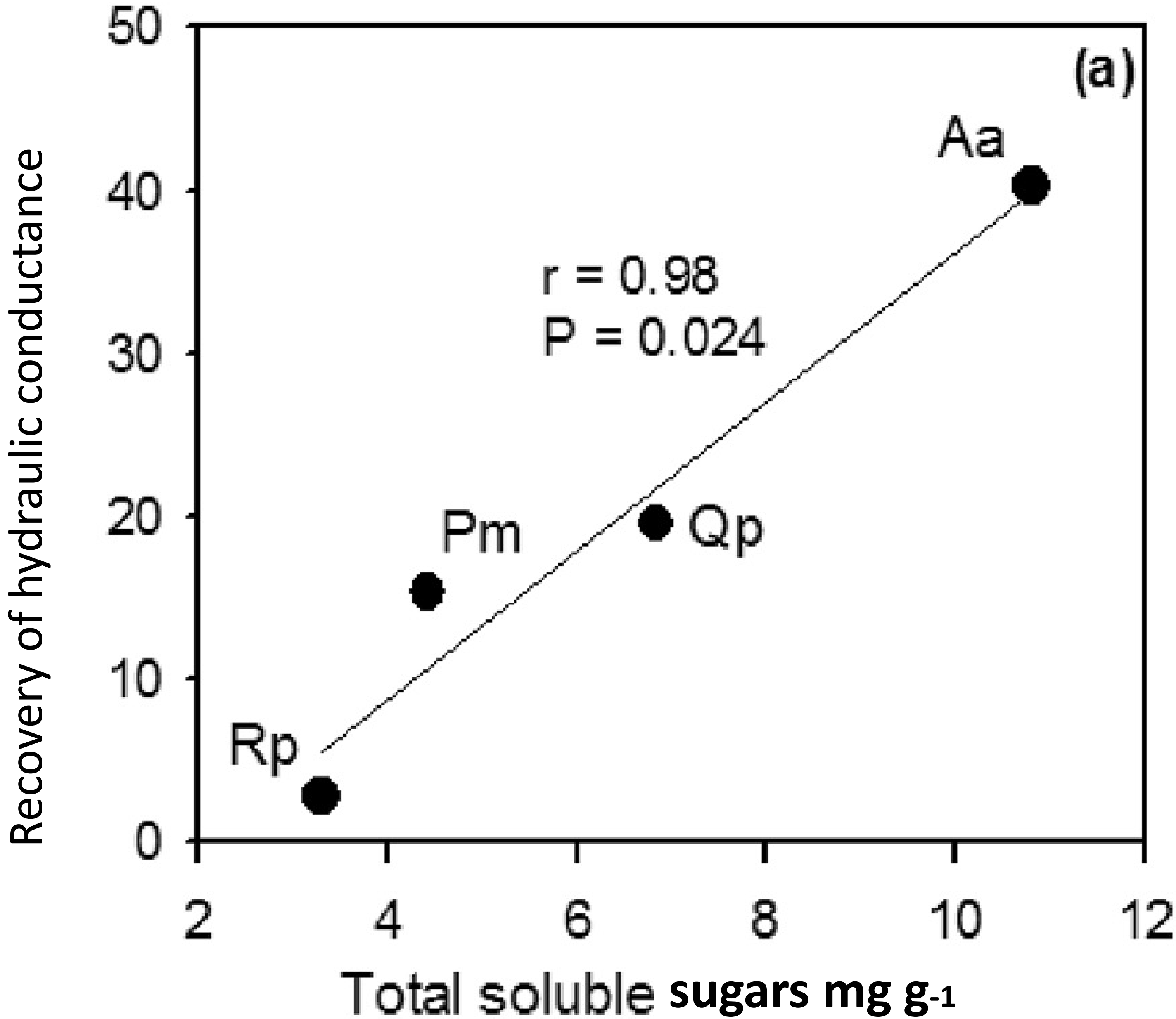
3. Proline – osmoprotective protein and hydrogen peroxide scavenging enzymes (dismutase and catalase) both increased in response to drought (Filippou et al. 2014)

4. Lower embolism rates than *Robinia pseudoacacia* – can reverse embolism and restore hydraulic function; possible via transport of concentrated levels of soluble carbohydrates from the phloem (Savi et al. 2016)

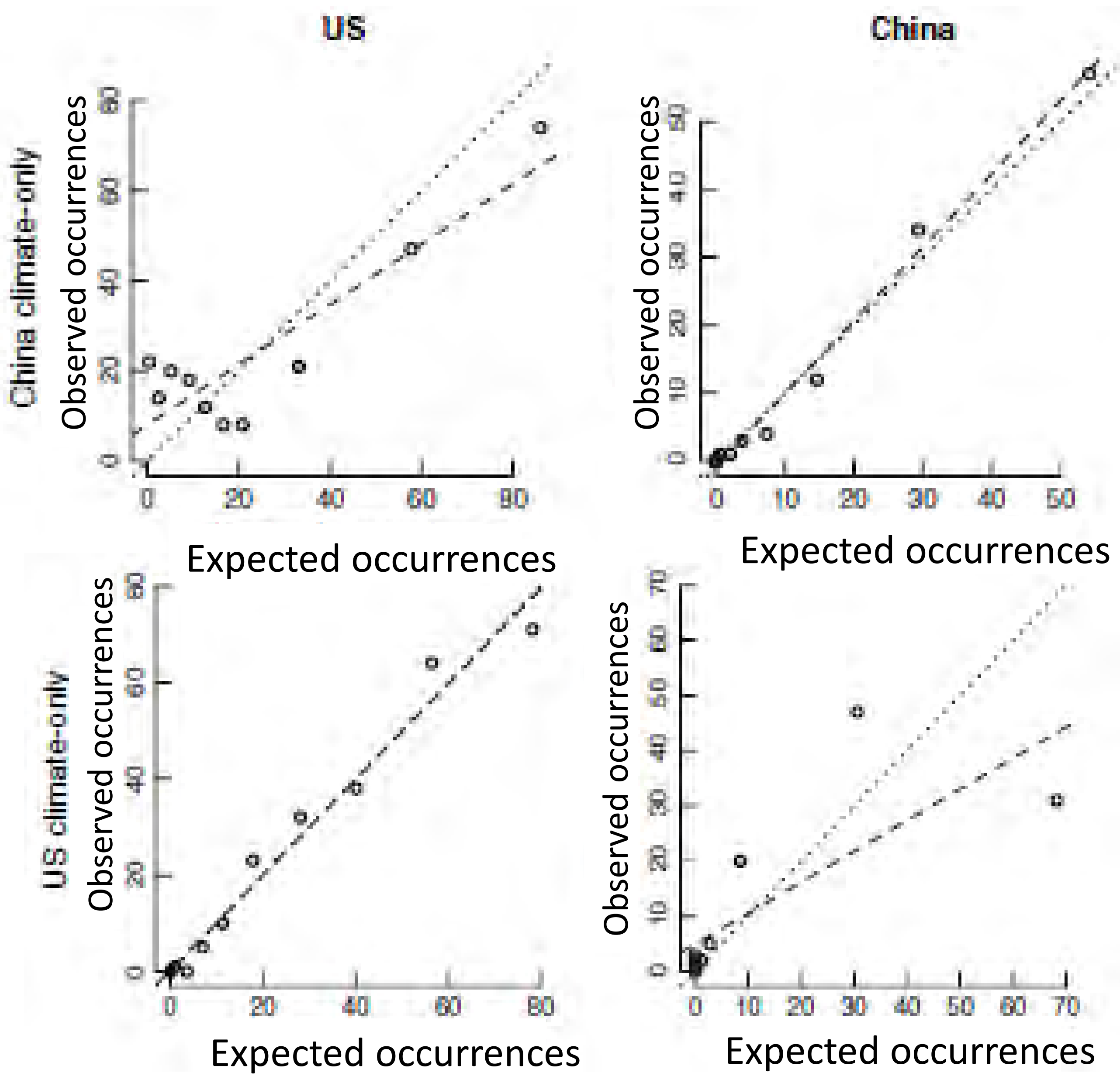




(Filippou et al. 2014)



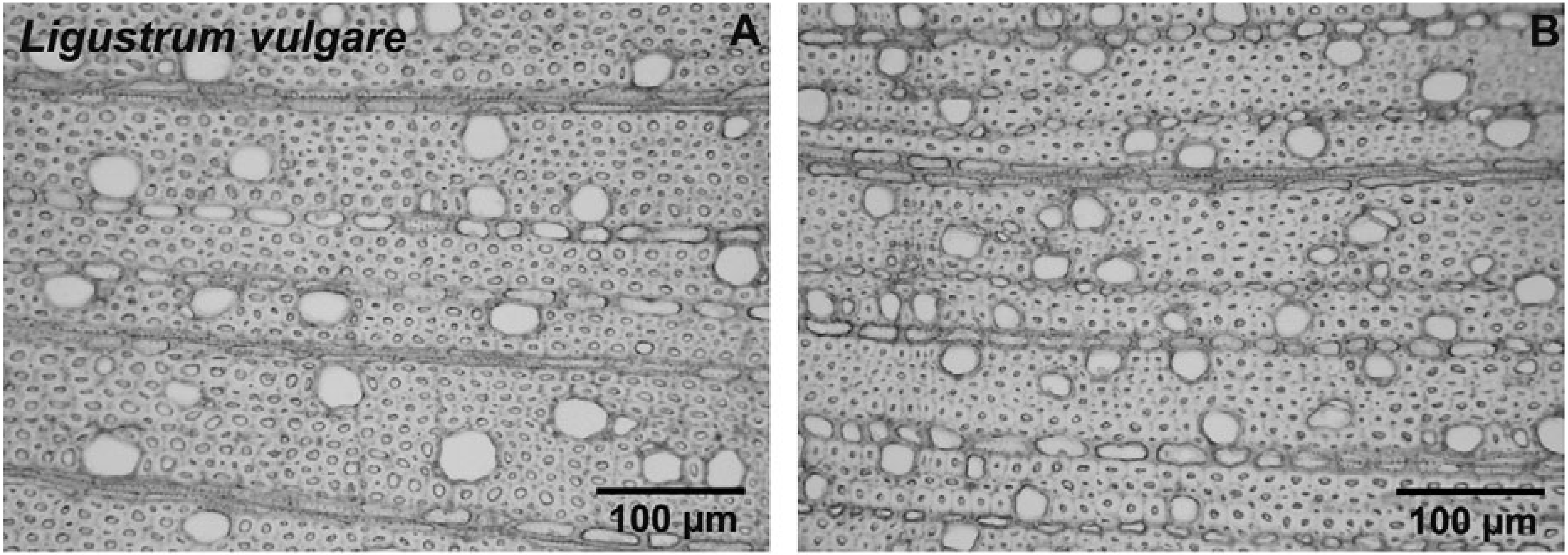
Savi et al. 2016)



Example of niche shift (Albright et al. 2010)

A pattern that is emerging for several invasive plants (Broennimann et al. 2007).

Ligustrum vulgare -
- **privet**

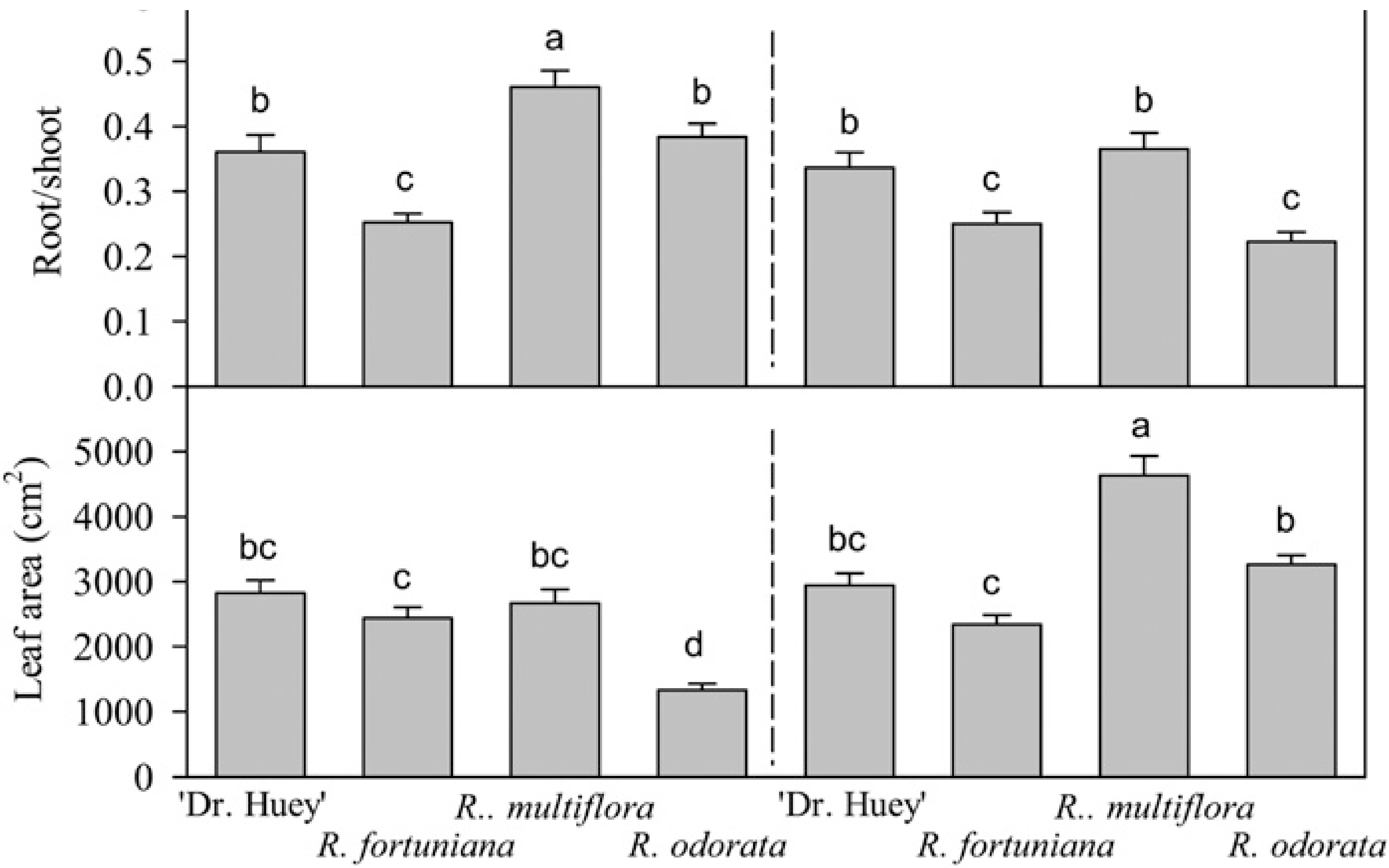


Beikercher and Mayr 2009

Rosa multiflora -- Multiflora Rose

Drought

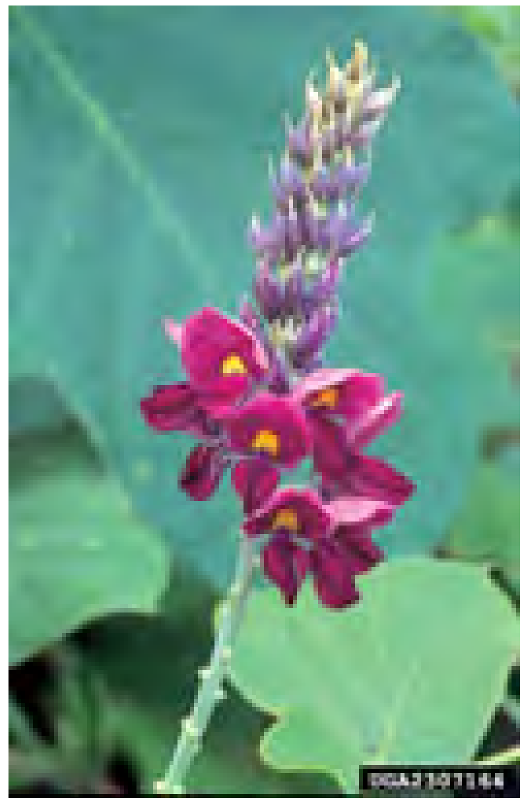
Well-watered

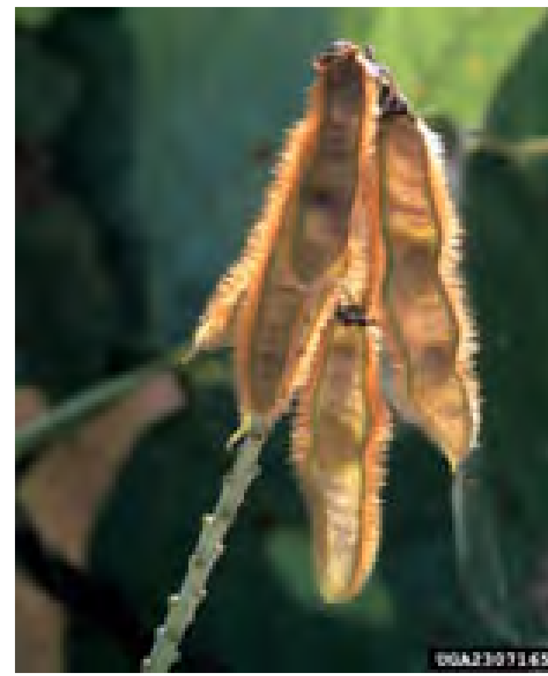


Niu and Rodriguez 2009

Pueraria lobata – **kudzu**

Has been labeled as drought tolerant (Lynd and Ansman 1990)





Center of origin is temperate to sub-tropical Asia – Evidence of traits that now occur on kudzu that has invaded a drier climate (Bellarmino de Pereira-Netto et al. 1999):

1. Low stomata frequency on upper side of leaves – reduce loss to transpiration

2. Abundant and large trichomes on both sides of the leaves -- increase boundary layer resistance and reduce water loss

Microstegium vimineum
Japanese stiltgrass

Evident preference towards wet/moist habitats

Characteristics that may improve *Microstegium vimineum*'s ability to withstand droughts:

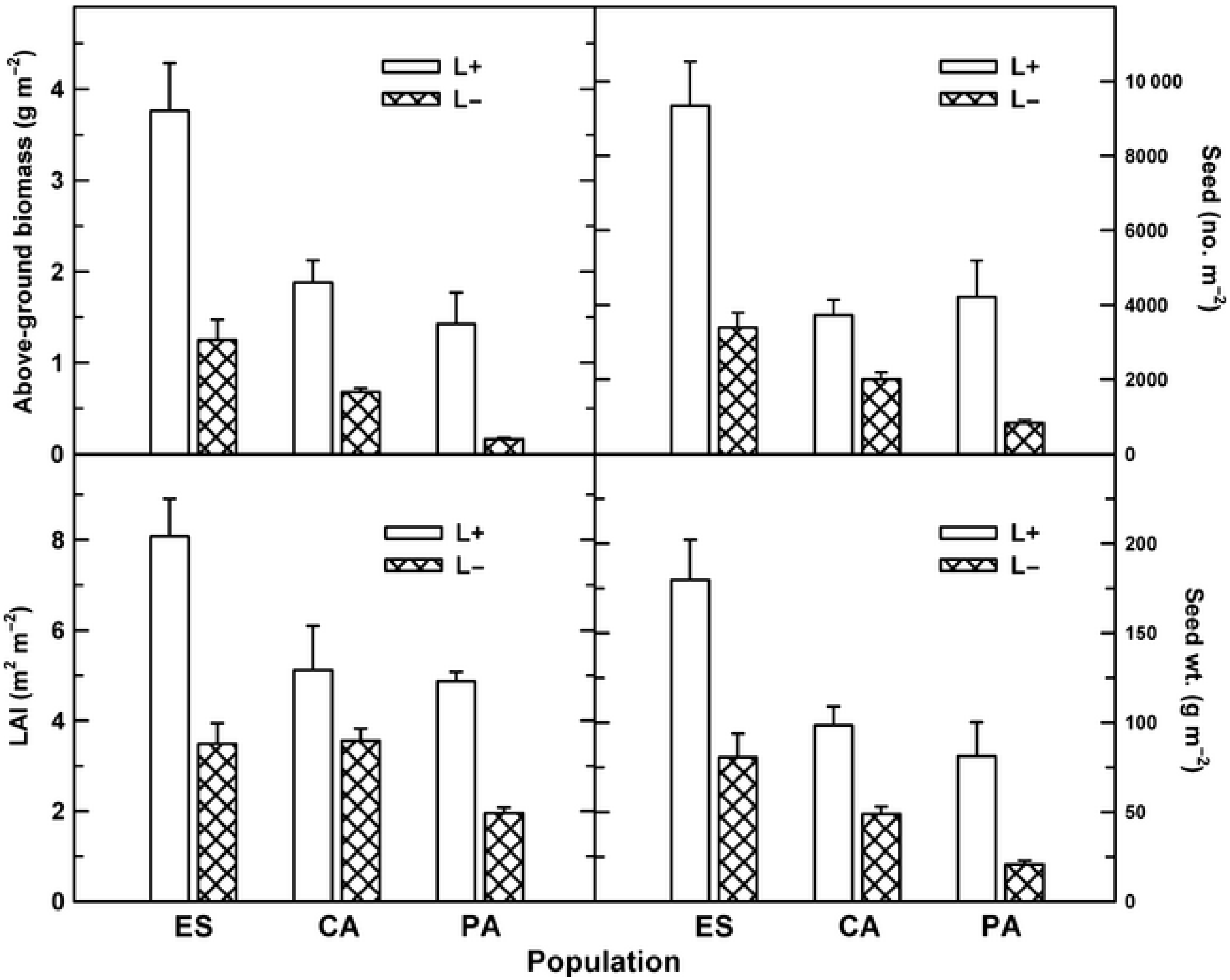
1. C_4 photosynthesis -- requires more energy but able to fix carbon even during drought and high temperatures by concentrating/storing CO_2 in bundle-sheath cells, so that opening stomates becomes less critical.

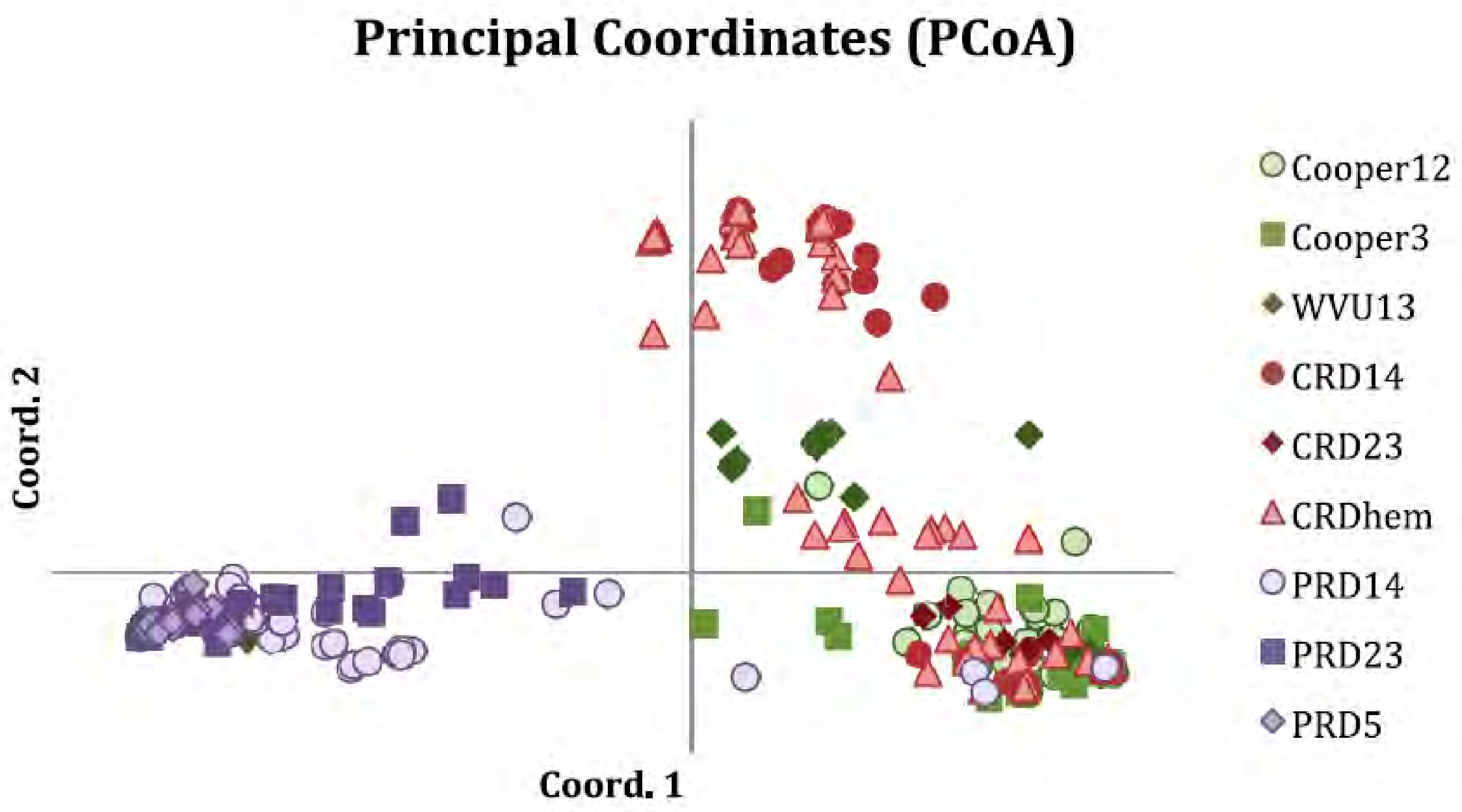
2. Phenotypically plastic (Droste et al. 2010; Ziska et al. 2015)

3. Possible selection toward varied environmental conditions (Novy et al. 2013; Ziska et al. 2015; Cully et al. 2016).

Recent evolution
in *Microstegium vimineum*

Ziska et al. 2015





Culley et al. 2016

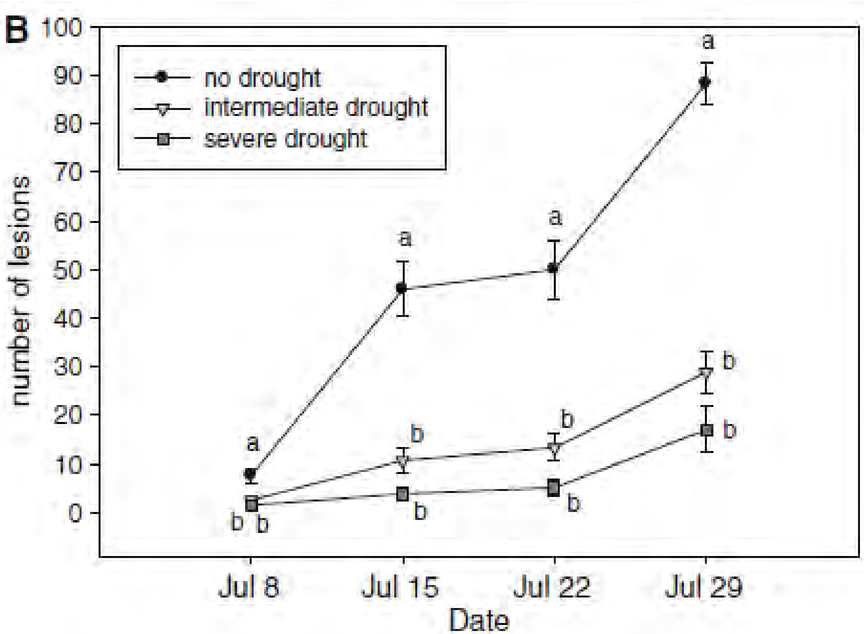
Bromus tectorum – more drought avoidance by phenological differences in timing of flowering – earlier in drier habitats (but no comparison of eastern populations).

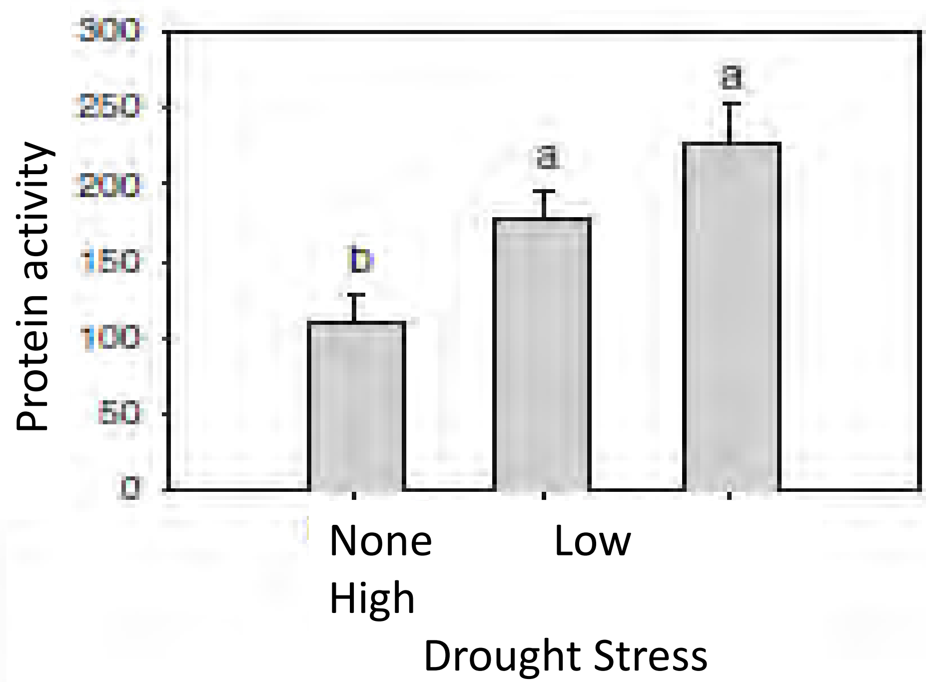
No real evident physiological drought tolerance (Rice et al. 1992).

Alliaria petiolata – garlic mustard

Potential positive and negative impacts related to defensive compounds

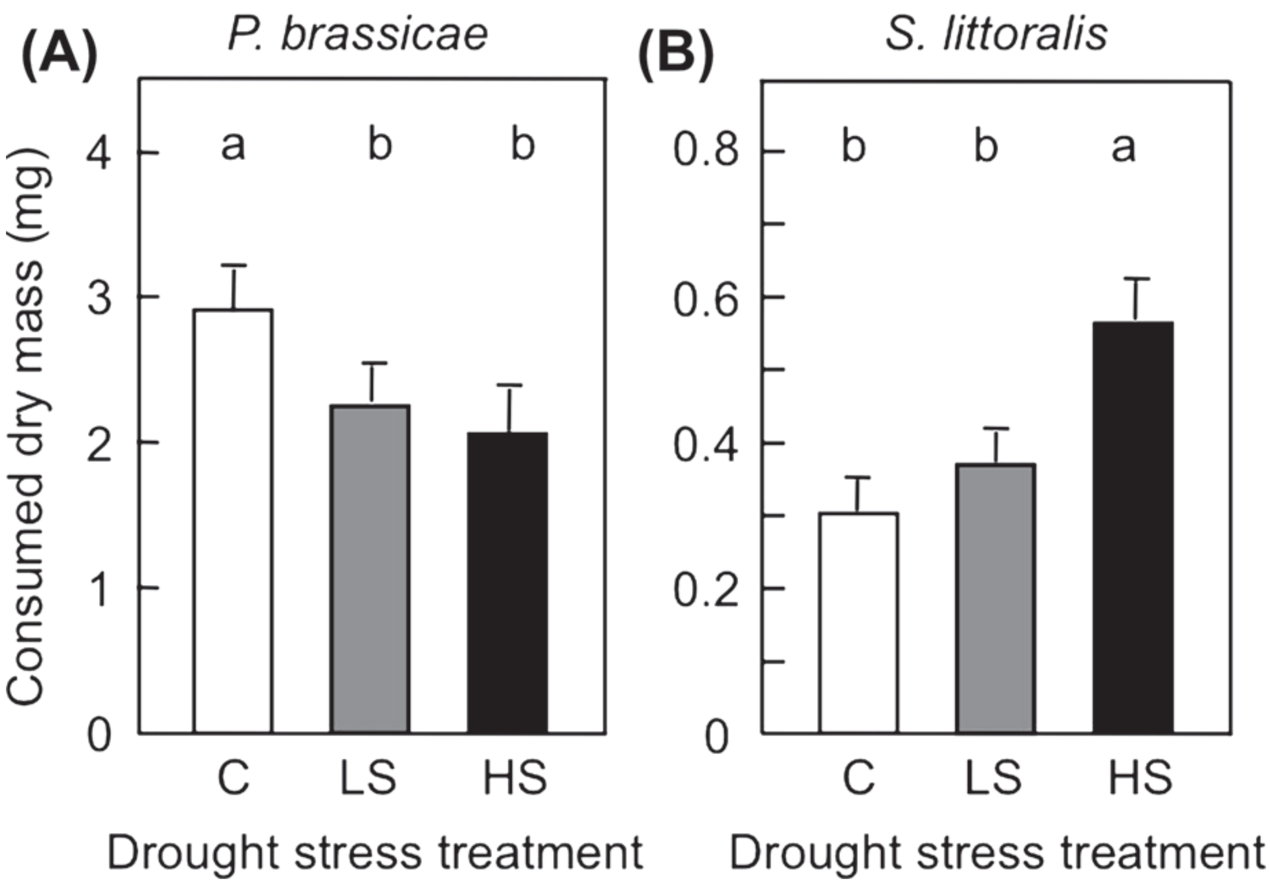
Activities of pathogenesis-related proteins increase with increasing drought stress (Enright and Cipollini 2011).





In turn, there is an increase in resistance to powdery mildew (Enright and Cipollini 2011).

But ….

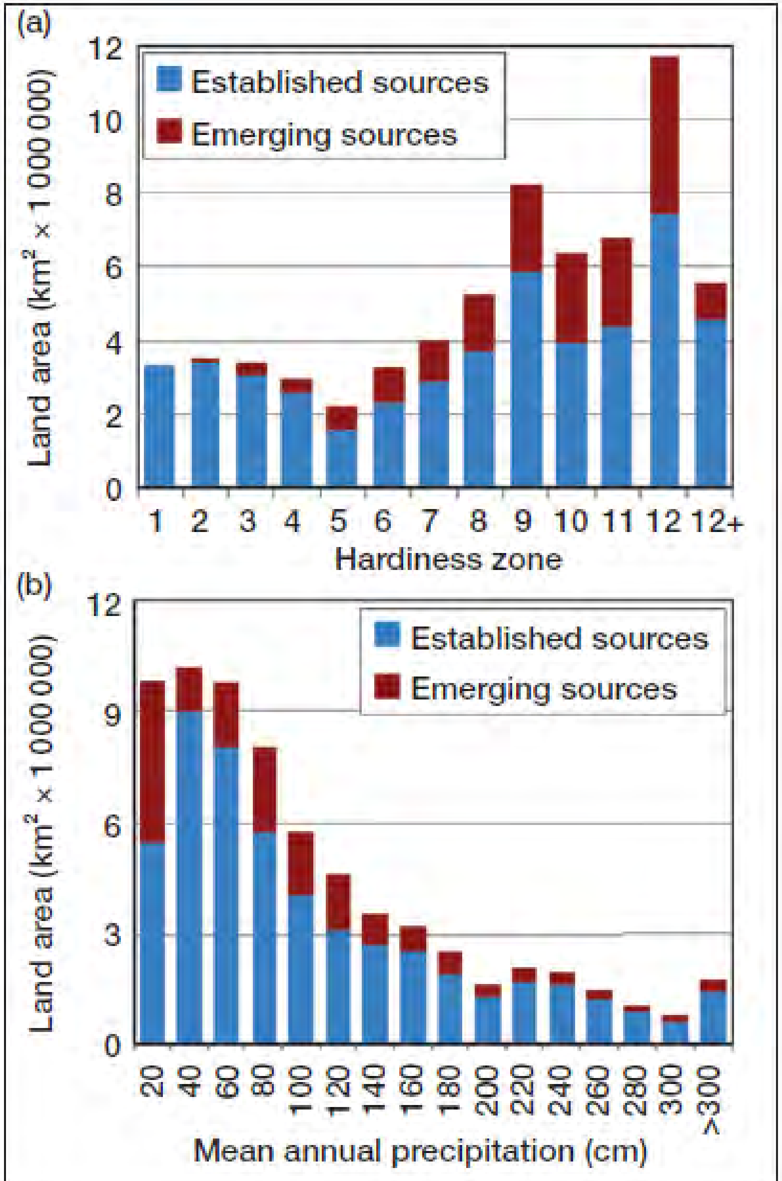


Pieris brassicae feeds exclusively on glucosinolate-containing plants

Spodoptera littoralis feeds on a broad range of host plants

Gutbrodt et al. 2011

People's Behavior: Gardening Response to Droughts:



(a) Current hardiness of emerging source countries are skewed toward warmer climates
(b) Current mean annual precipitation of emerging source countries includes many arid areas

Thus, concerted planting efforts to mitigate a drier climate may occur more rapidly for garden/horticultural plants (which may also supply a new suite of invaders), putting natives at even more of a disadvantage.

Bradley et al. 2012

Summary Statements:

1. The eastern U.S. will likely experience more less-predictable and severe droughts, especially the southeastern states.

2. Some eastern invasive plants (that invade our forests) currently appear likely to handle such droughts well – e.g., *Ailanthus altissima.*

3. Others may survive due to phenotypic plasticity or rapid evolution – e.g., *Microstegium vimineum* and/or phenological timing e.g., *Bromus tectorum*.

4. Some invasive plants may also have a negative response with lowered defenses – e.g., *Alliaria petiolata*.

5. Because of the potential for niche shifting and rapid evolution, our ability to predict new plant species compositions in response to a changing environment is much more challenging.

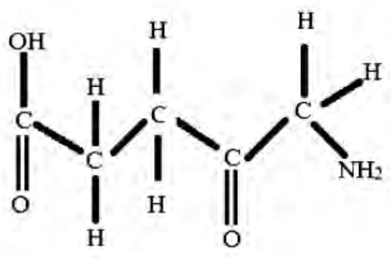
6. An increase in demand of more drought-tolerant species could affect horticultural trade – inundating the market with <u>new,</u> drought-tolerant, but potentially invasive, nonnative plants.

Solutions?

1. Preconditioning of native plants may be possible – (Beikircher et al. 2010).

2. Promote use of native drought-tolerant plants that could naturally shift their range in response to a drier environment – instead of nonnative species outside of the range potential for a natural niche shift (Bradley et al. 2012).

3. Potential plant growth regulators – 5-Aminolevulinic Acid (Akram and Ashraf 2013).



5-Aminolevulinic acid ALA

Structural formula for 5-aminolevulinic acid

Foliar spraying or presoaking seed has increased yield, net photosynthesis, stomatal conductance, and water use efficiency for several crop species (barley, wheat, and oilseed rape).

Genetically manipulating increases in synthesis of ALA to improve stress tolerance is being researched.

Questions & Answers

- **By phone:** Dial #2 to enter the queue.
- **On your computer:** Type your question into the Q & A pod on the left side of your screen.

Wicked Problems: Drought and Invasive Annual Grasses

Louisa Evers
Science Coordinator
Oregon/Washington BLM

Wicked Problems

- Difficult or impossible to solve because of incomplete, contradictory, and changing requirements that are often difficult to recognize
- Often have components or aspects over which we have no influence or control
- Efforts to solve one aspect may reveal or create additional problems
- Never solved definitively or completely
- No “right” or optimal solution

Source: Wikipedia

Drought Defined

- Insufficient water to meet needs

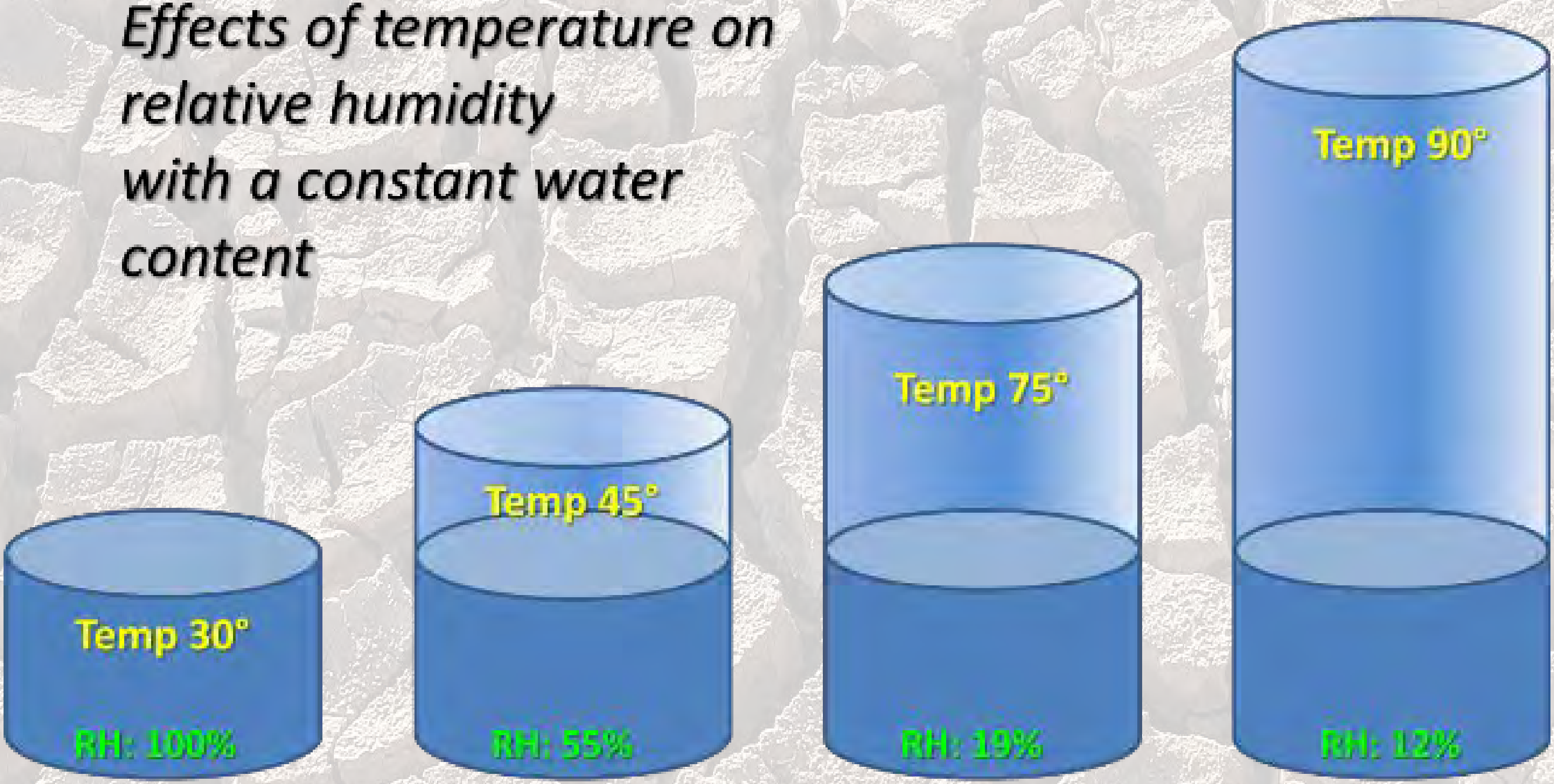
- Traditional types of drought
  - ***Meteorological drought*** – shortage of precipitation
  - ***Hydrological drought*** – reduced streamflow and/or water storage
  - ***Agricultural drought*** – reduced crop yields

- "New" types of drought
  - ***Ecological drought*** – significant changes in ecosystems
  - ***Flash Drought*** - very rapidly developing drought in spring or summer, often after abundant winter precipitation
  - ***Snow Drought*** – warm winter producing unusually low snowpacks

- Temperature as important as precipitation

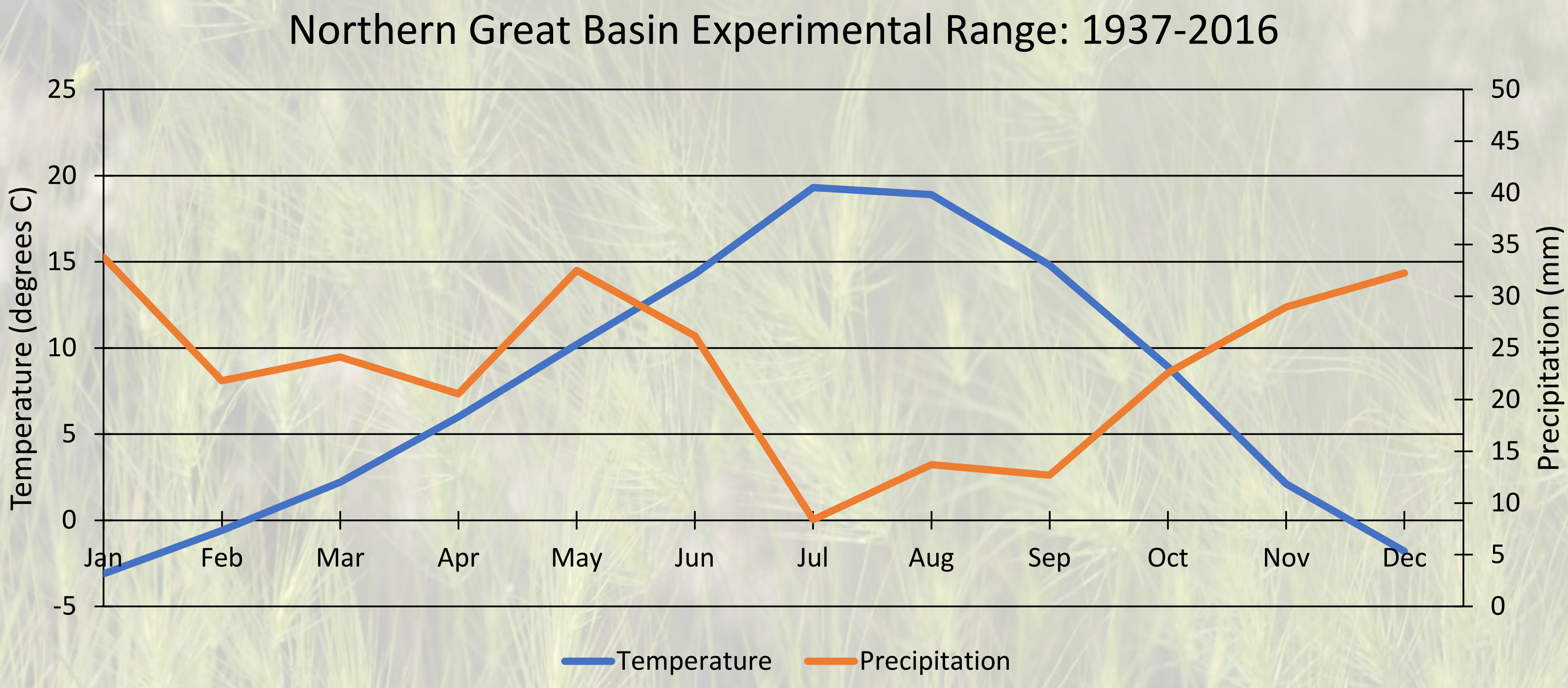
Temperature and Drought

Effects of temperature on relative humidity with a constant water content



How Does Drought Favor Annual Grasses?

Climate Diagram



Source: Western Regional Climate Center


CONSERVE OUR WESTERN ROOTS
feet
3
2
1
1
2
3
4
Invasive Weed

Annual Grasses of Concern

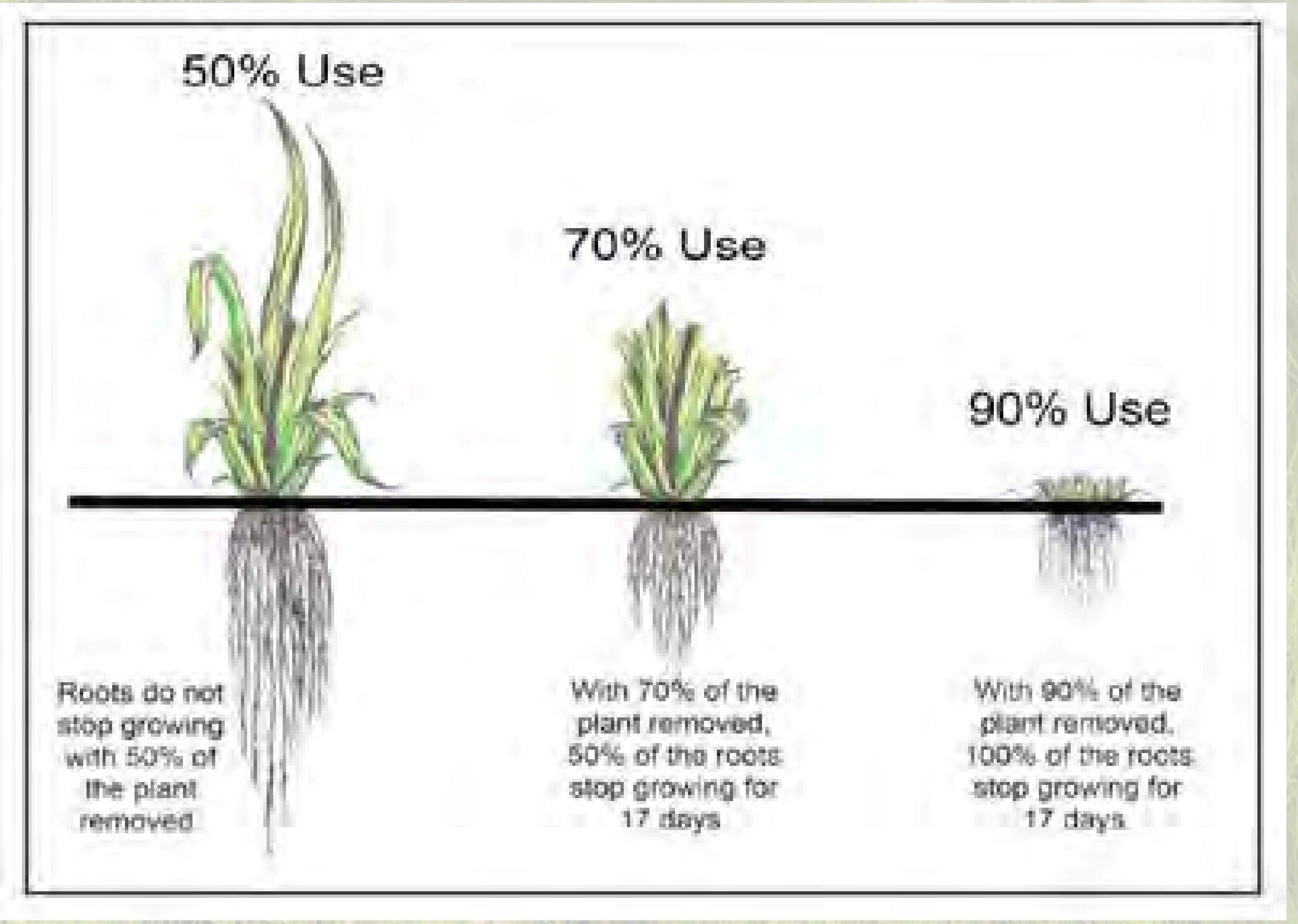
Cheatgrass Phenology

- Germinates in fall
- Produces basal rosette
- Roots grow all winter
- Growth resumes when soil temperature >0ºC

Bluebunch Wheatgrass Phenology

- Germinates in fall
- Produces basal rosette
- Goes dormant
- Growth resumes when soil temperature reaches 4ºC

Bunchgrasses and Drought



Annual Grasses and Drought

- Annuals MUST reproduce every year
- Seeds typically have high viability
- During drought more energy goes to seed production
- Height may be less than one inch
- May produce only one flower head
- May produce only one seed
- Nearly all seeds germinate by spring the following year

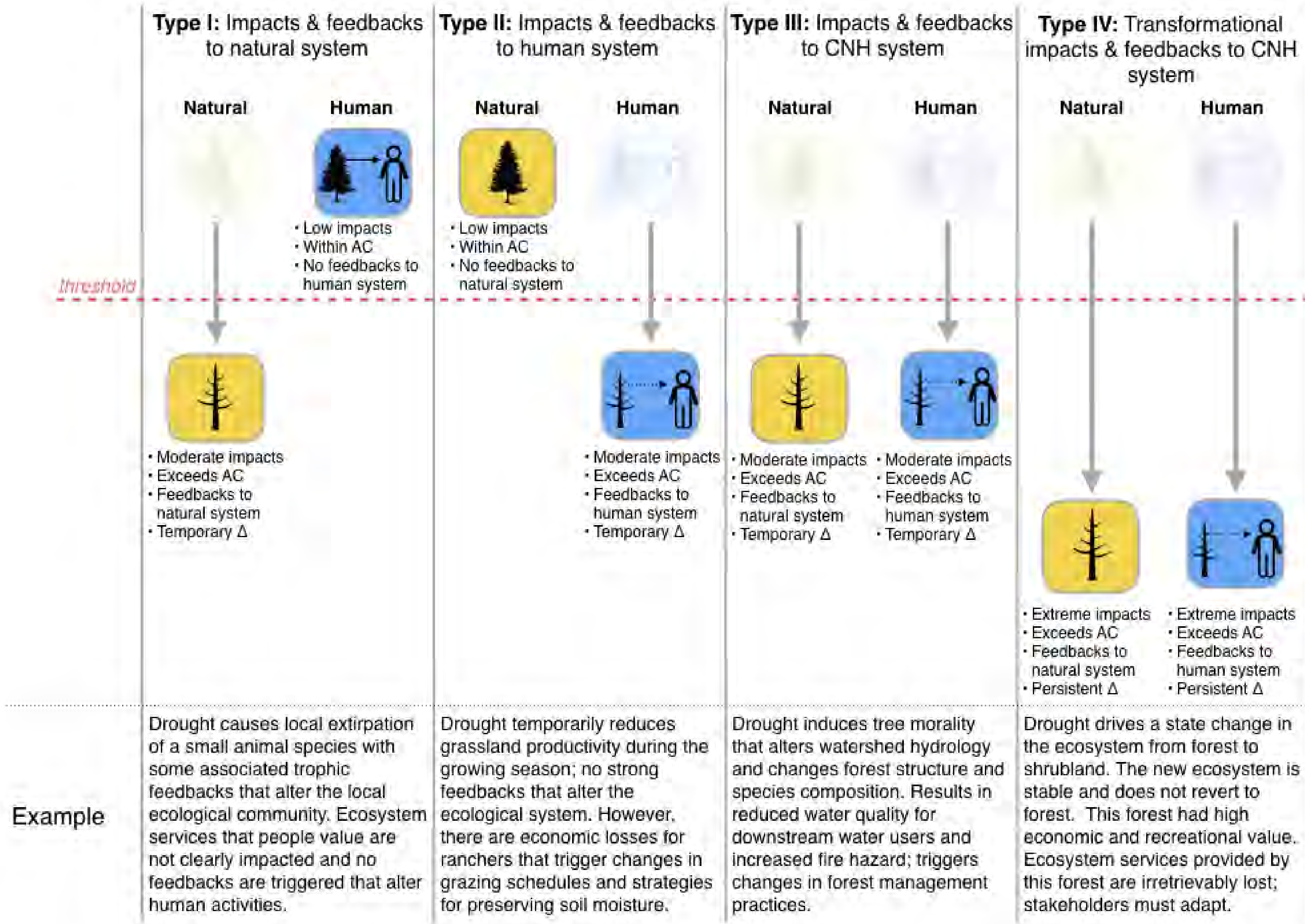
Precipitation Timing

- Fall/Winter precipitation key to soil water recharge
  - Fall/winter drought reduces deep soil water recharge
  - Snow drought tends to reduce deep soil water recharge
- Spring precipitation timing
  - Primarily in early spring – favors annual grasses
  - Primarily in late spring – favors native perennial grasses
- Growing season moisture favors native perennial grasses
- Winter moisture favors woody plants
- Summer moisture favors grasses

Evidence for Drought-Facilitated Spread of Annual Grasses

- Several studies have implicated drought in the spread of annual grasses even in the absence of grazing
  - Tisdale et al. 1965 – cheatgrass displaced Idaho fescue on ungrazed kipukas in Craters of the Moon National Monument following drought in 1959-1961
  - Kindschy 1994 – cheatgrass documented invading ungrazed kipukas at Jordan Craters in Oregon, believed to be due to drought stress reducing perennial grasses
  - Tausch et al. 1994 – annual grasses taking over Anaho Island National Wildlife Refuge in Pyramid Lake in Nevada; area grazed for only a few years in the late 1800s well before annual grasses identified on the island

Ecological Drought Types



Source: Crausbay et al. In Press

Sagebrush over Annual Grass

What to do about Drought?

- Can't do anything about drought timing, intensity, or frequency
- Can we alter severity through management?
  - Reduce livestock grazing – but what about wild horses and burros?
  - Reduce sagebrush density – but what about sage-grouse habitat needs?
  - Reduce pinyon-juniper – possible, but not that big an issue where annual grasses are the highest concern

What to do about Annual Grasses?

- No effective treatments
  - Current herbicides – imazapic
  - Current competitors – non-native perennial grasses
- Learn to live with them

Pseudomonas fluorescens (aka D7)

Cheatgrass Die-Off and Black Fingers of Death

Seeds of Success Program

- National seed collection program
- Collect and store by climate and ecoregion
  - Colorado Plateau
  - Great Basin
  - Mojave Desert
  - Pacific Northwest
- Support commercial seed production
- Provide climatically appropriate seed

Questions & Answers

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Thank you for attending today's webinar!

A recording of this session will be available shortly at the Climate Science Webinar Portal:
http://climatewebinars.net/webinars/drought-invasives