Growth and Tree Rings: Responses of Northern Forests to Drought (emphasis on Sugar Maple)

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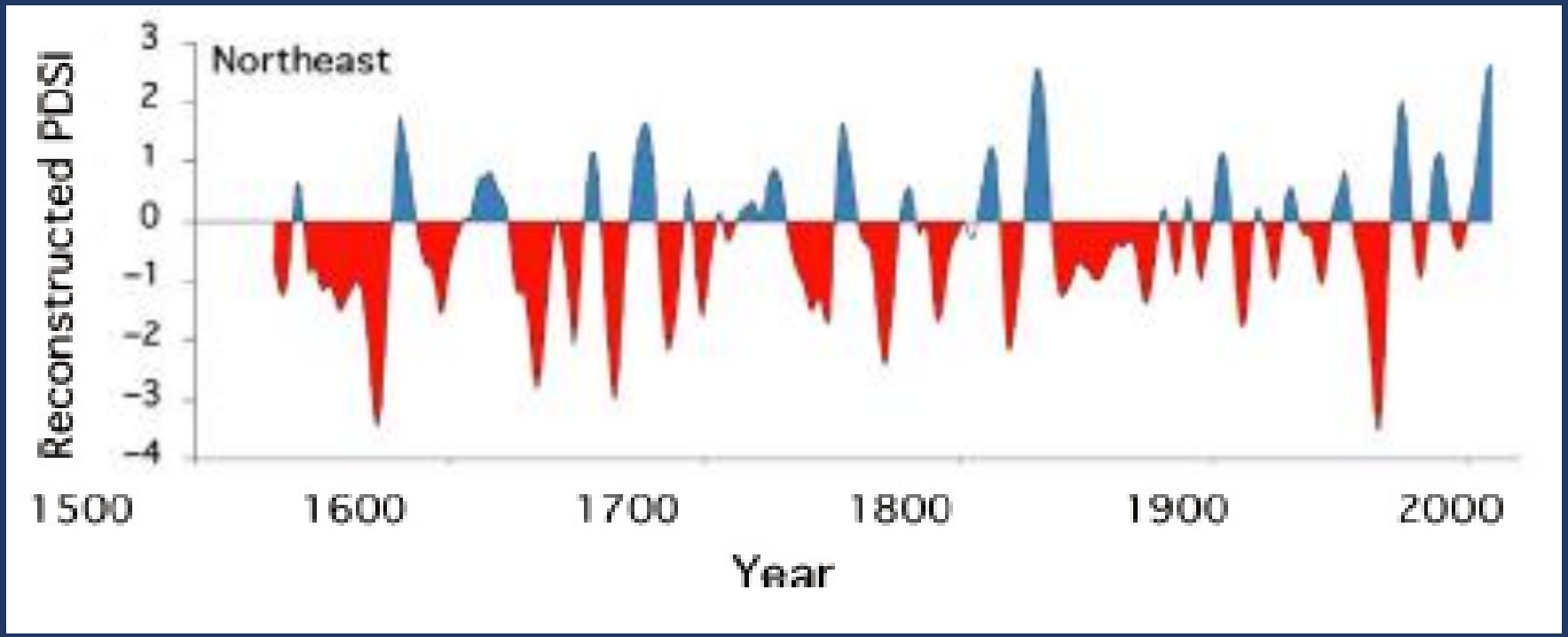
Matt Vadeboncoeur

Historic Climate Variability: Northeast

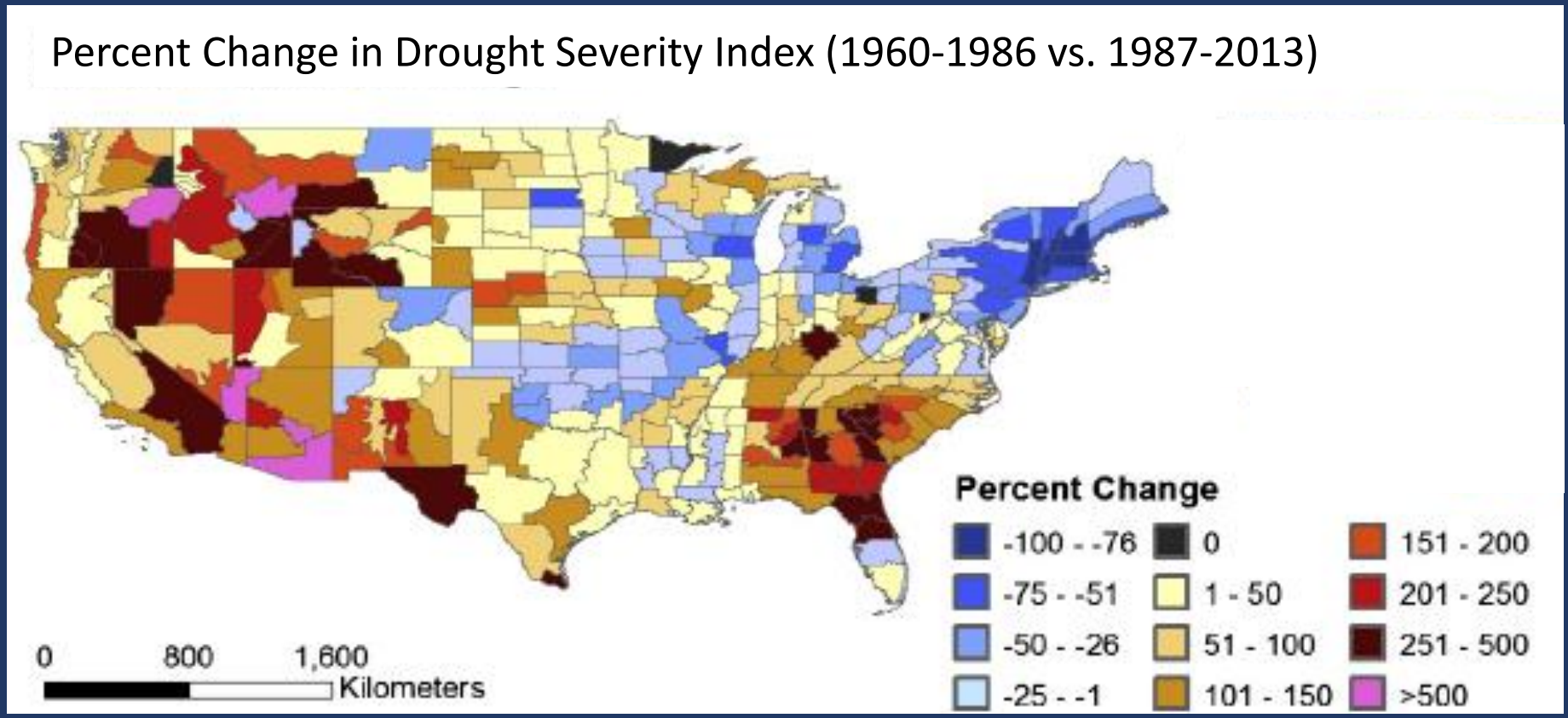
- 1930-2005: one of the wettest periods since 1500 CE
- Few drought periods: 1930s, 1960s



Pederson et al. 2015

Recent Climate Variability: Northeast

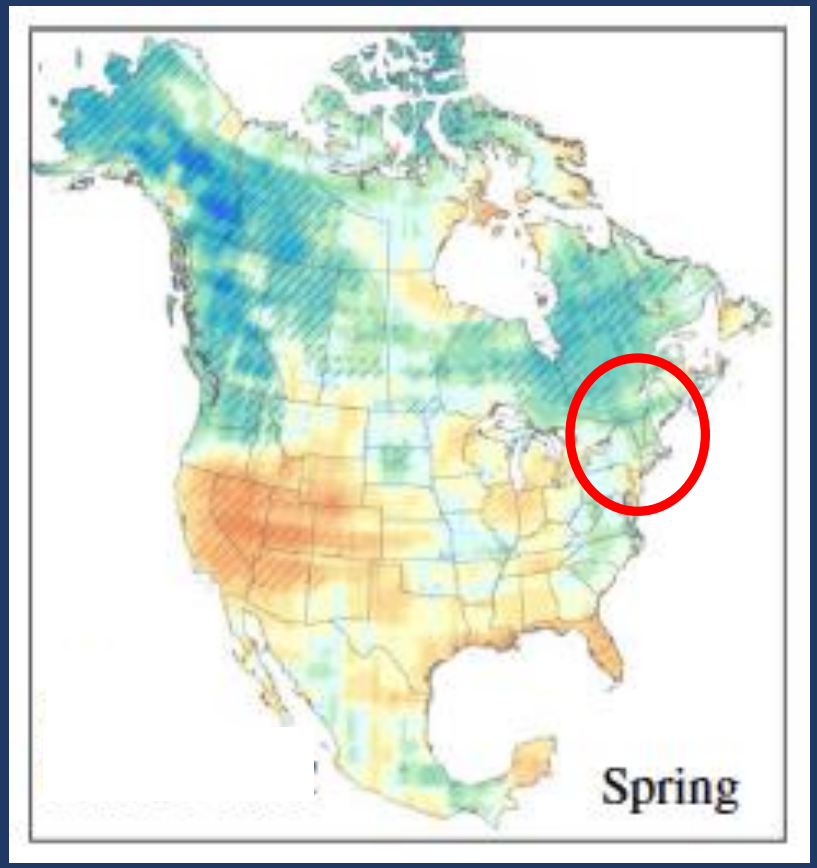
- Last ~ 25 years: Wetter than the previous 25 years (1960-1986)

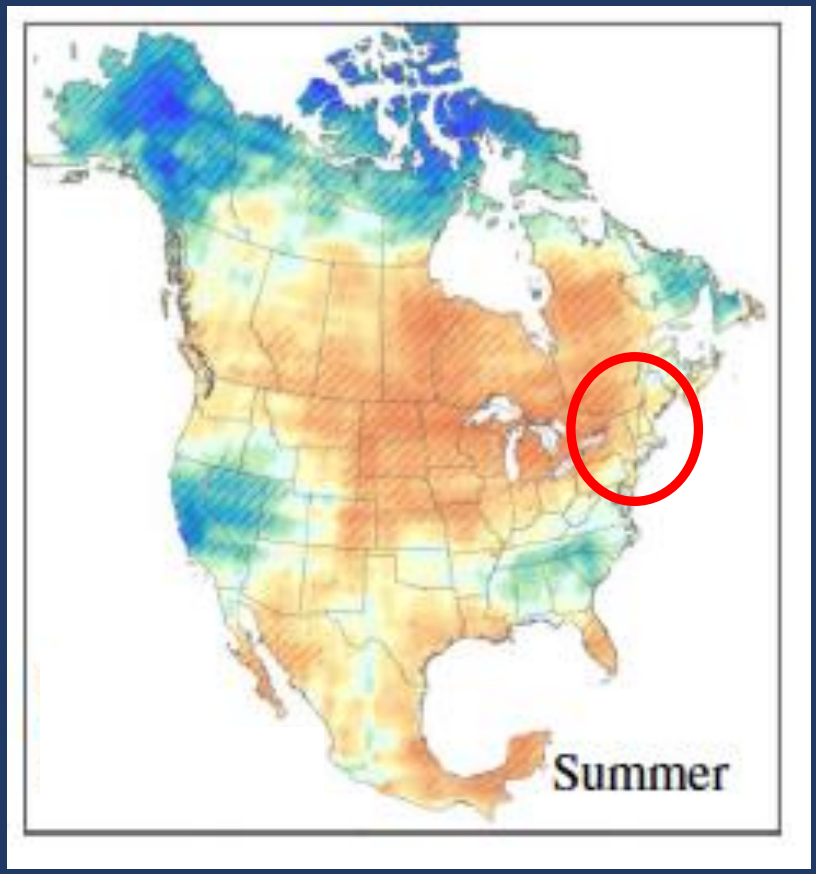


Peters et al. 2015

Predicted Future Precipitation: Northeast

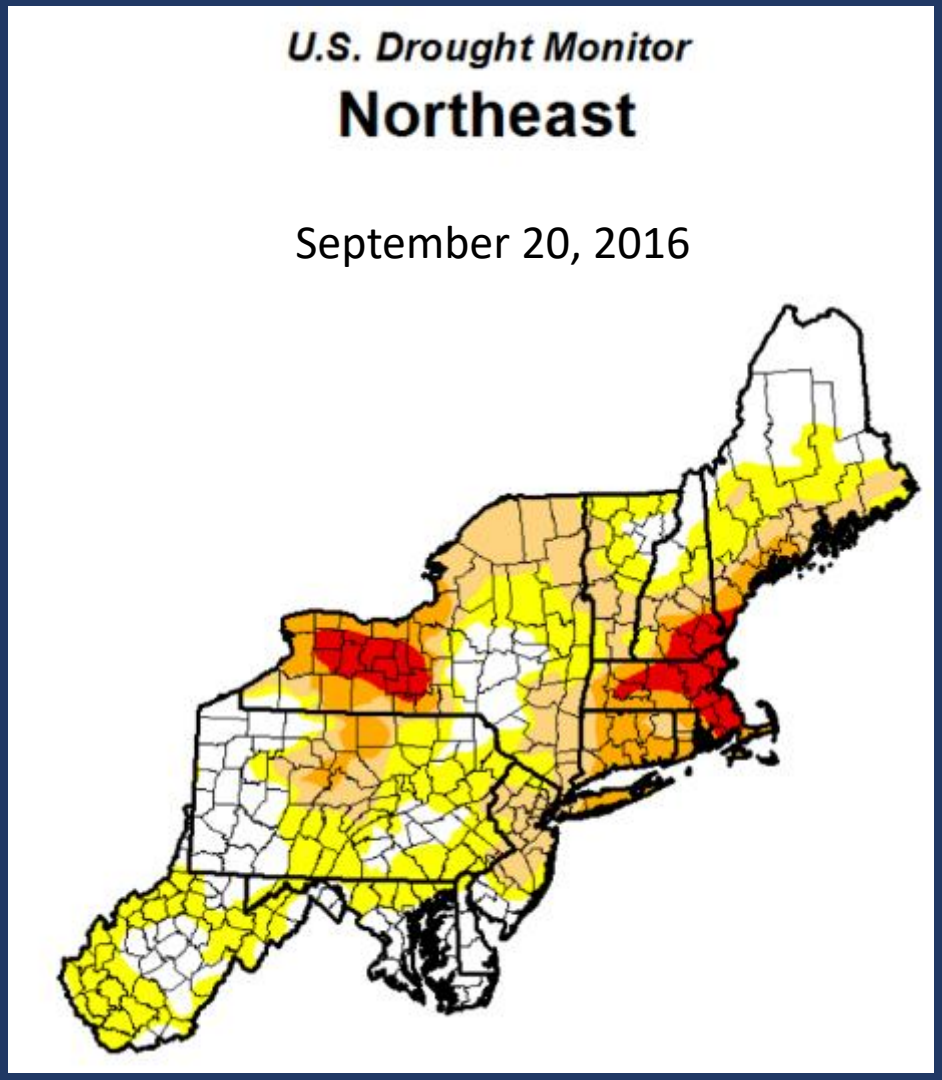
- Increasing total annual precipitation
- More frequent extreme precipitation events
- Spring wet spells; Summer droughts

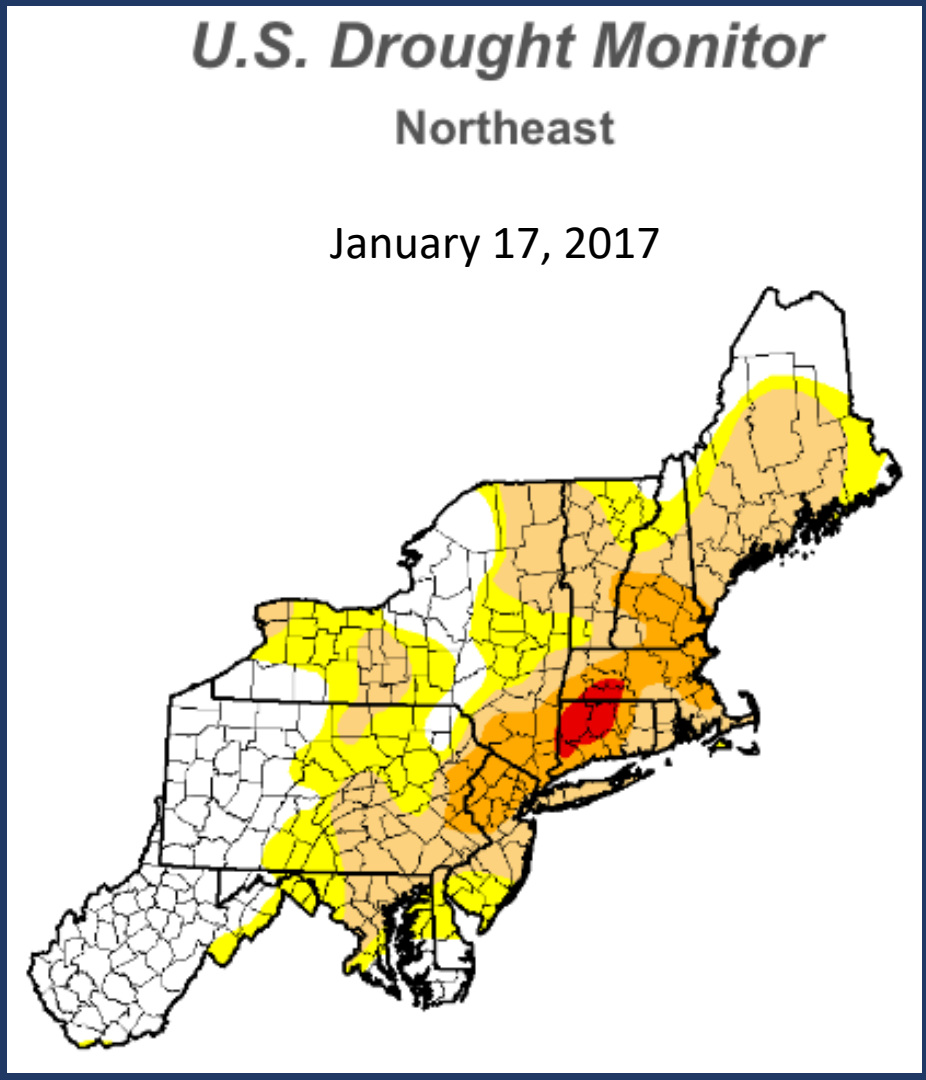




2014 U.S. National Climate Assessment; Swain & Hayhoe 2015

2016 Extreme/Severe Drought in the NE





Sensitivity and resilience of northern forests and tree species to drought?

- Future droughts (and wet spells) will likely fall outside the climate space to which NE tree species are adapted

- Many northern hardwood forest species (e.g., Sugar Maple) may be especially vulnerable to drought:
  - Past drought events rare
  - Limiting resources: light and nutrients
  - Mesophytic northern hardwood species = “drought intolerant” – but lack of research

Outline of Talk

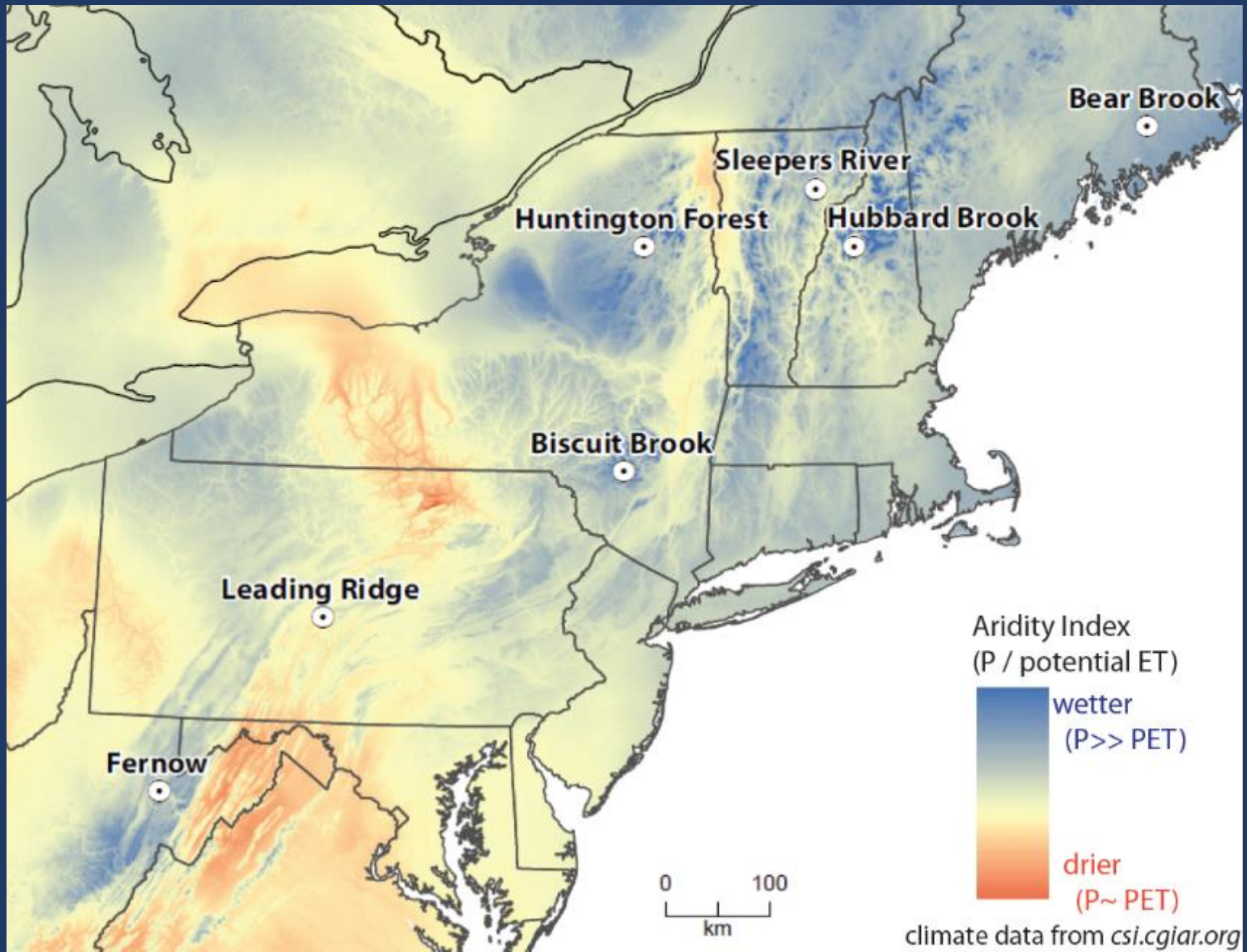
- Sugar maple response to past climate (tree rings)
- 2016 drought and drought experiments in NH
- Sensitivity of sugar maple to drought: what do (don't) we know?
- Implications for syrup production
- Summary and future research directions

Sugar Maple Response to Past Climate: Research Questions

- What climate variables affect sugar maple growth, and do they differ across the northeast?

- How does its sensitivity of sugar maple compare with other species? (**beech**, white ash, **red spruce**, hemlock, **red oak**, yellow birch, yellow poplar)

Study sites


Bear Brook
Sleepers River
Huntington Forest
Hubbard Brook
Biscuit Brook
Leading Ridge
Fernow
0
100
km
Aridity Index
(P / potential ET)
wetter
(P>> PET)
drier
(P~ PET)
climate data from csi.cgiar.org

Growth correlations with precipitation

	SUGAR MAPLE					
	WV	PA	NY	VT	NH	ME
Precip						
prev may			~-		~+	
prev jun				~+		
prev jul			~-			
prev aug						
prev sep						
prev oct	~+					
prev nov						
prev dec				~+		
jan						+
feb						
mar						
apr						
may					~-	
jun		~+				
jul		+	~+			
aug						~-
sep				~+		

- South (PA): SM likes wet summers
- North (ME, VT): A snowy winter good for maple in climates with reliable snowpack (frost damage).
- North previous year: mixed, but not very water sensitive

Growth correlations with temperature

	SUGAR MAPLE					
	WV	PA	NY	VT	NH	ME
Temperature						
prev may						
prev jun						
prev jul						
prev aug						
prev sep						
prev oct			~+			
prev nov						~+
prev dec						
jan			~-			
feb					-	
mar						
apr						
may						
jun		-				
jul		-				
aug						
sep					~-	

- South (PA): hot summers are bad for SM
- North (NH, NY): warm winter is bad for SM (snowpack freeze-thaw?)

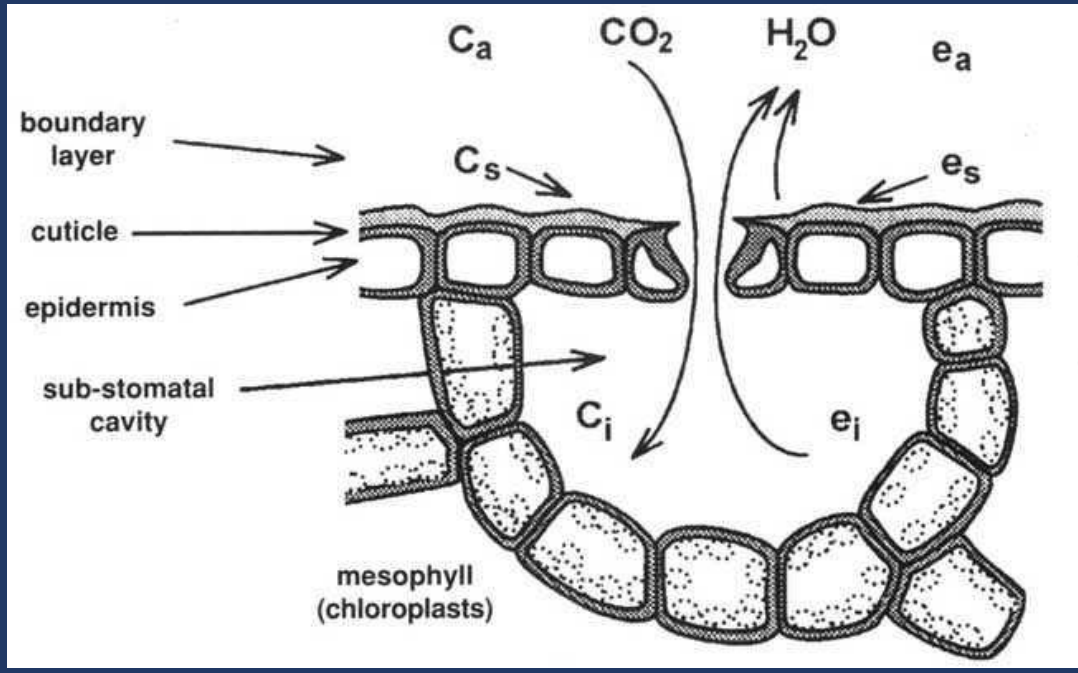
What else can we learn from tree cores?: WUE

- **Water use efficiency** (WUE): How much water is lost relative to the amount of carbon taken up by photosynthesis

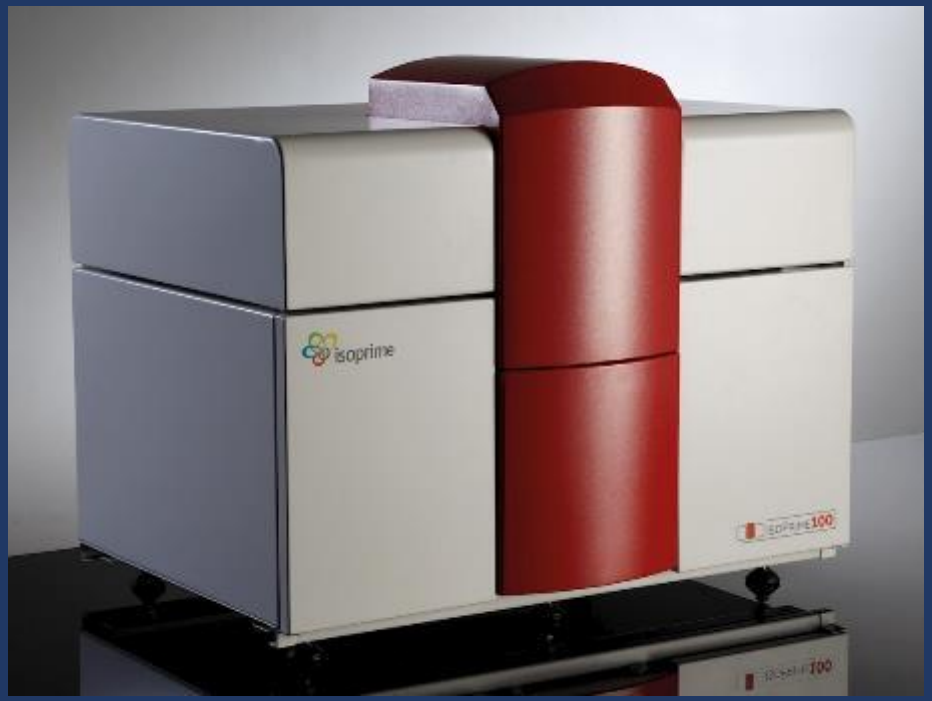
- **Tradeoff between photosynthesis and water loss**:
  - To photosynthesize, a leaf must lose water.
  - To conserve water, a leaf must reduce photosynthesis.

- **High WUE indicates water stress** (reduced photosynthesis to conserve water)

- Carbon isotopes in tree rings reflect the WUE during each growing season

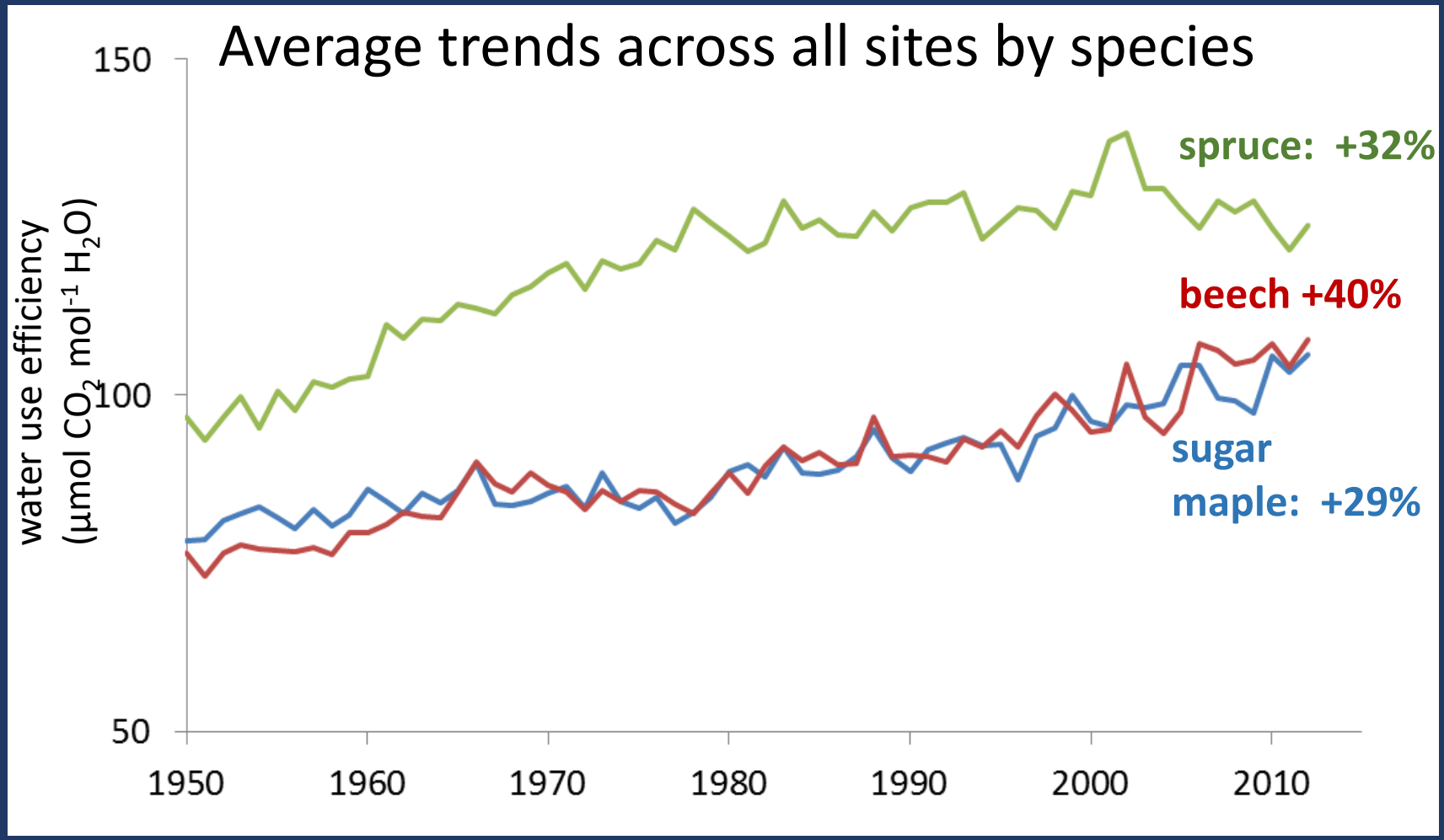



LR QURU
1964 LW


isoprime

WUE increased since 1950, driven by the increase in atmospheric CO2 concentrations (30%)

Enhanced drought resistance?



WUE correlations with precipitation: Sugar Maple

	SUGAR MAPLE					
	WV	**PA**	**NY**	**VT**	**NH**	**ME**
Precip (hypothesized relationship is negative)						
prev may						
prev jun						
prev jul			~+			
prev aug					~-	
prev sep						~-
prev oct			~+	~-		~-
prev nov						~-
prev dec						
jan						
feb						
mar						
apr						
may						
jun	-	-				
jul		~-				-
aug						
sep						

- High WUE = high stress (red)
- South: Dry June is bad for SM
- North: More correlation with previous growing season precip
- VT, NH, ME: negative response due to lower carbohydrate stores (NSCs) mobilized for wood growth and metabolism?
- More on NSCs later…

WUE correlations with temperature

	SUGAR MAPLE					
	WV	**PA**	**NY**	**VT**	**NH**	**ME**
Temperature (hypothesized relationship is positive)						
prev may						
prev jun				~-		-
prev jul						
prev aug		-	~+	~-		
prev sep			~+		~+	
prev oct						
prev nov						
prev dec	+					
jan		~-				
feb						
mar						~+
apr			~-			
may		-				
jun						
jul			+			
aug						
sep			+		~+	

- PA: Hot growing seasons are especially bad for SM (more important than moisture)
- NY: warm growing season less stressful
- VT: Sensitive to previous growing season temperature

Drought Experiments in New Hampshire

Research Questions:

- How do different northern forest types and species respond to extreme drought?
- What are the underlying physiological mechanisms that determine processes of dieback and mortality?

Thompson Farm

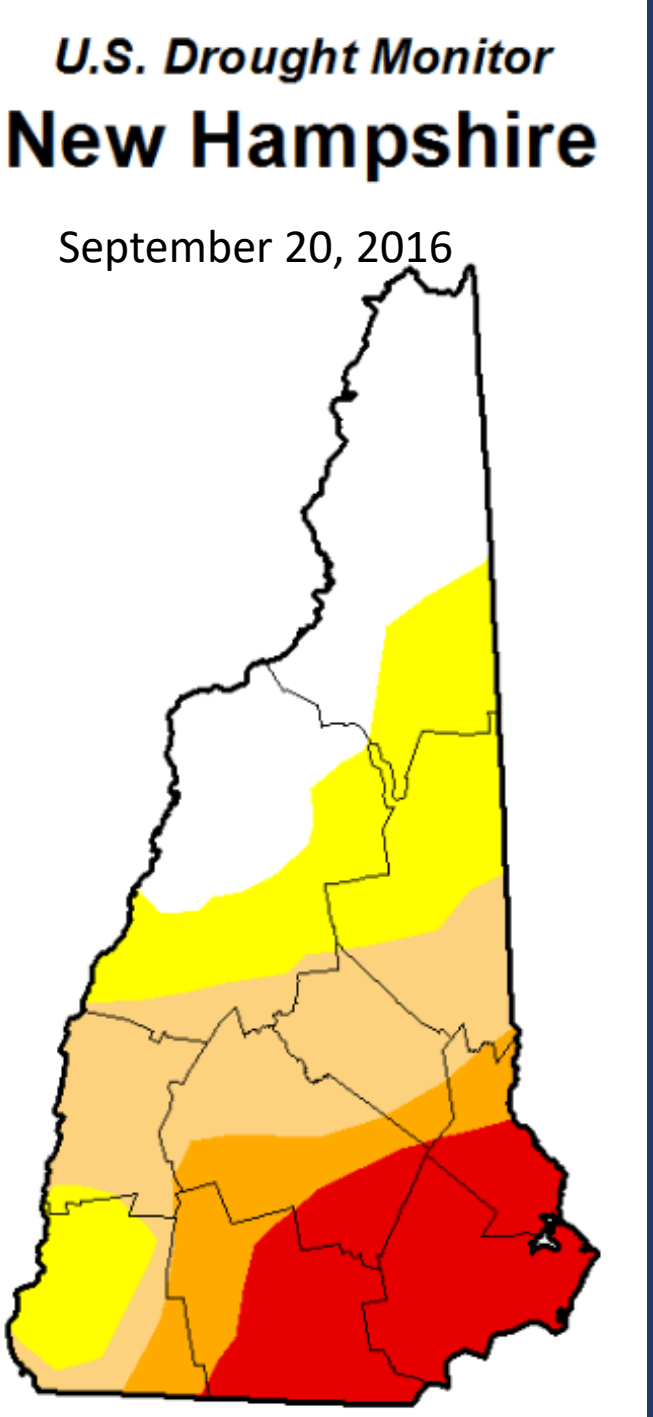
- Mature white pine and red oak forest
- Two replicated 30 x 30 m plots
- Pre-treatment data: 2014
- First treatment year: 2015

Hubbard Brook

- Young red maple- dominated forest
- Two replicated 15 x 15 m plots
- Pre-treatment data: 2013
- First treatment year: 2014

- ~ 50% removal of throughfall (June – September): 1-in-100-year drought

- 2016 drought less severe in the White Mountains compared to SE New Hampshire



Measurements in drought plots

Tree sapflow

Foliar gas exchange

Soil moisture

Soil Respiration

Tree diameter increment

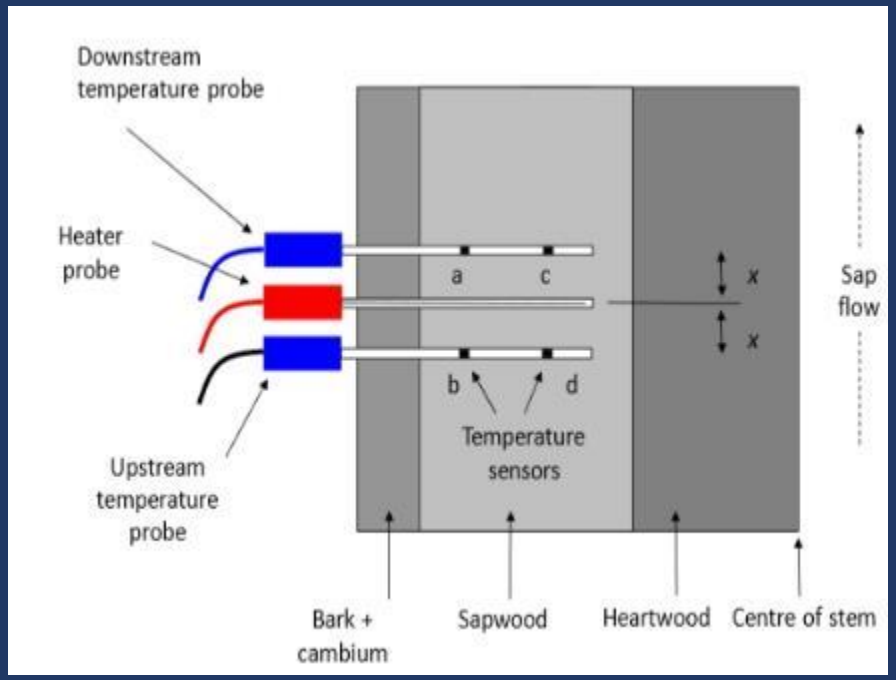
Litterfall

Fine root biomass

Decomposition

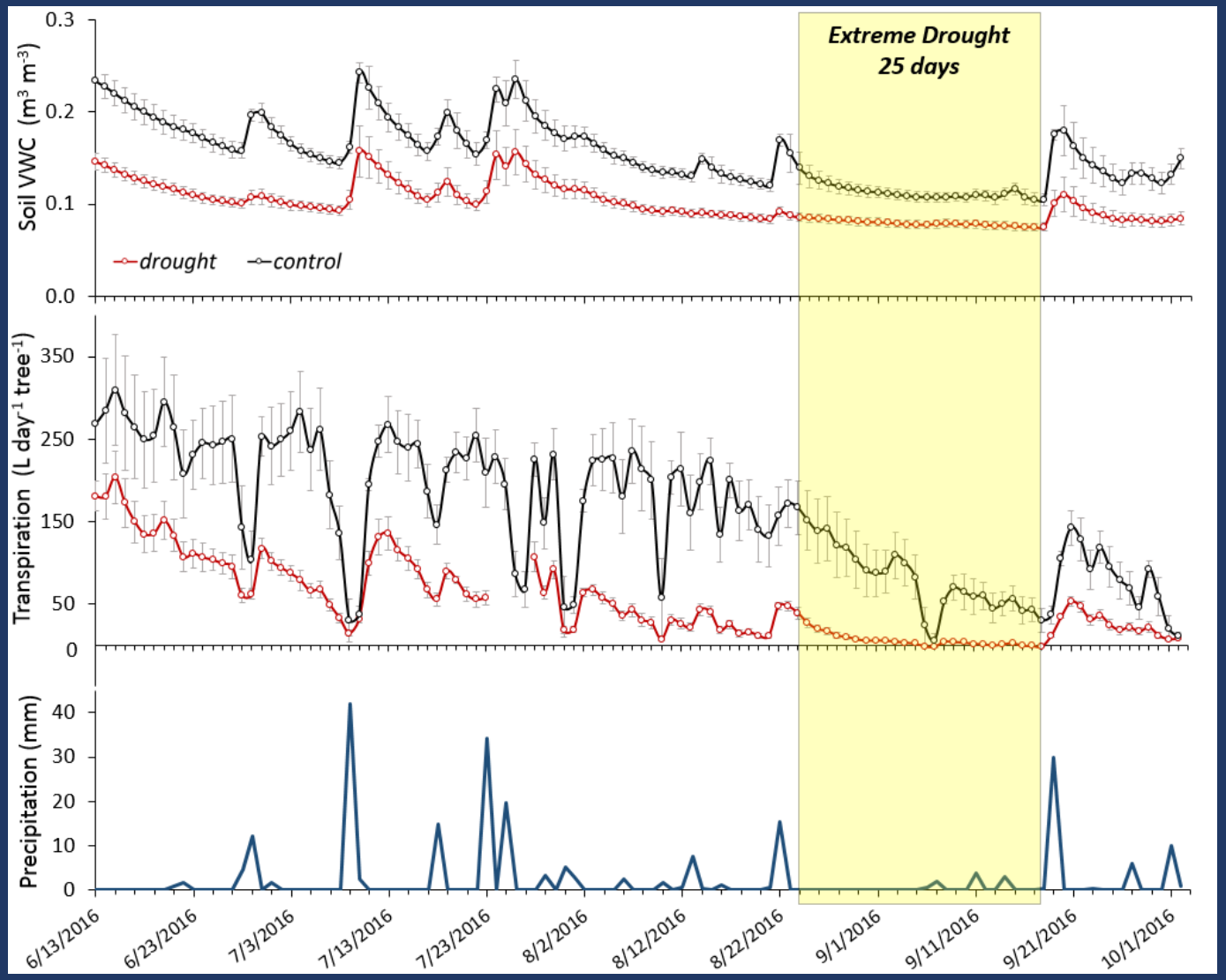
Tree water use: Sapflow measurements

Heat ratio method

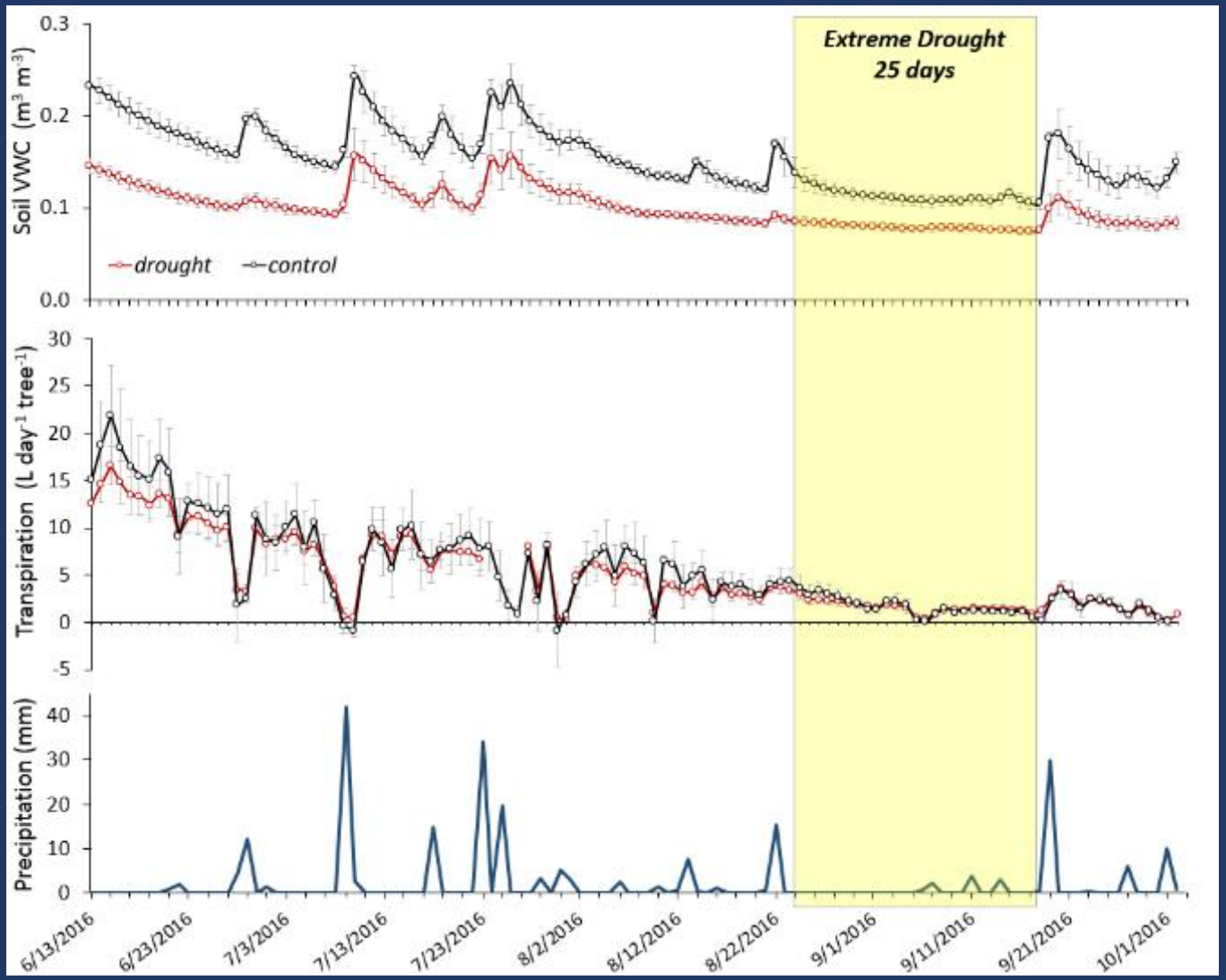


Thompson Farm: White Pine Sap Flow

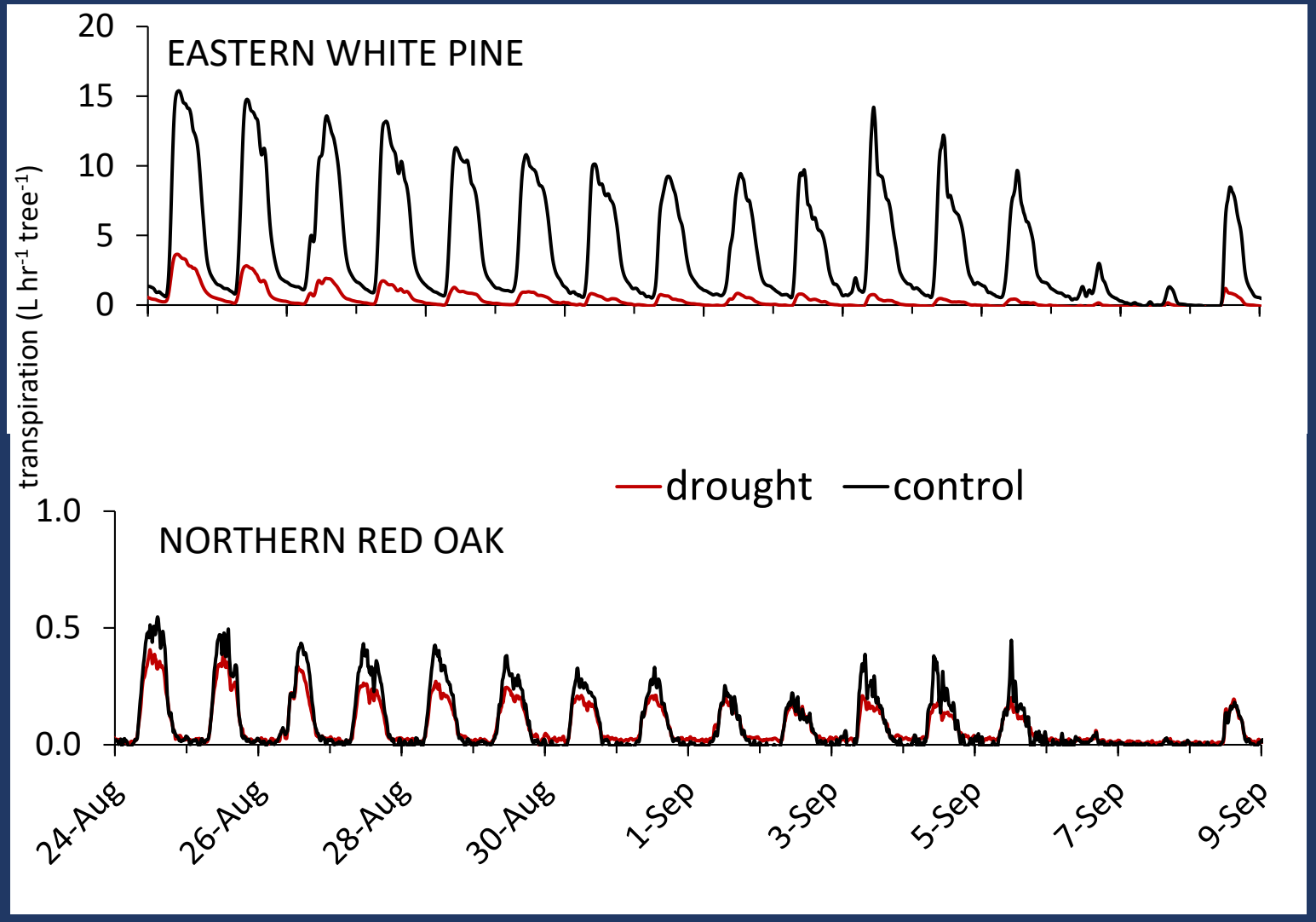
100 Litres
≈ 2 kegs
of beer
100 Litres
≈ 1 small
bathtub



Thompson Farm: Red Oak Sap Flow

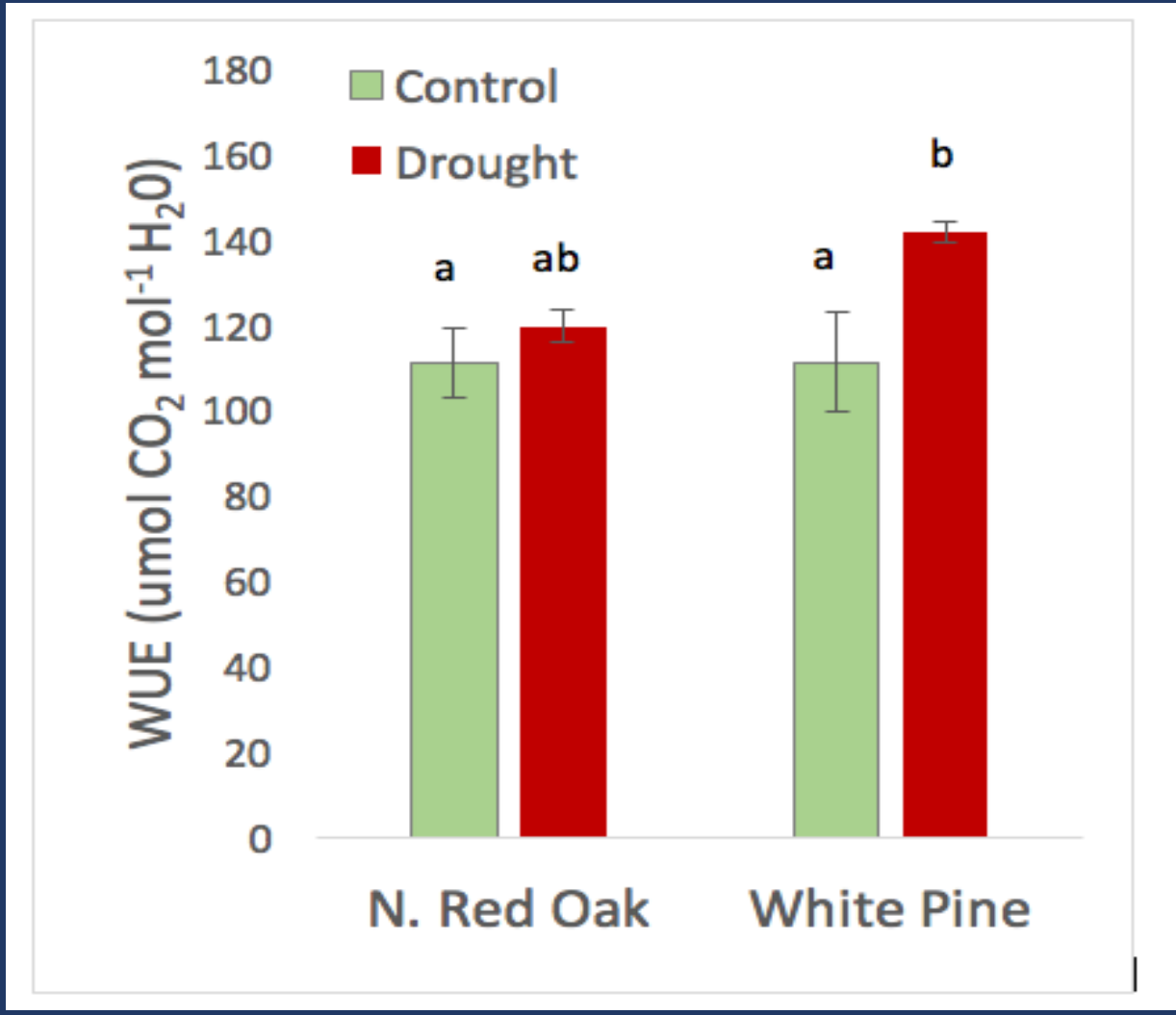


Sapflow during the extreme drought event Aug. 24 – Sept. 10, 2016



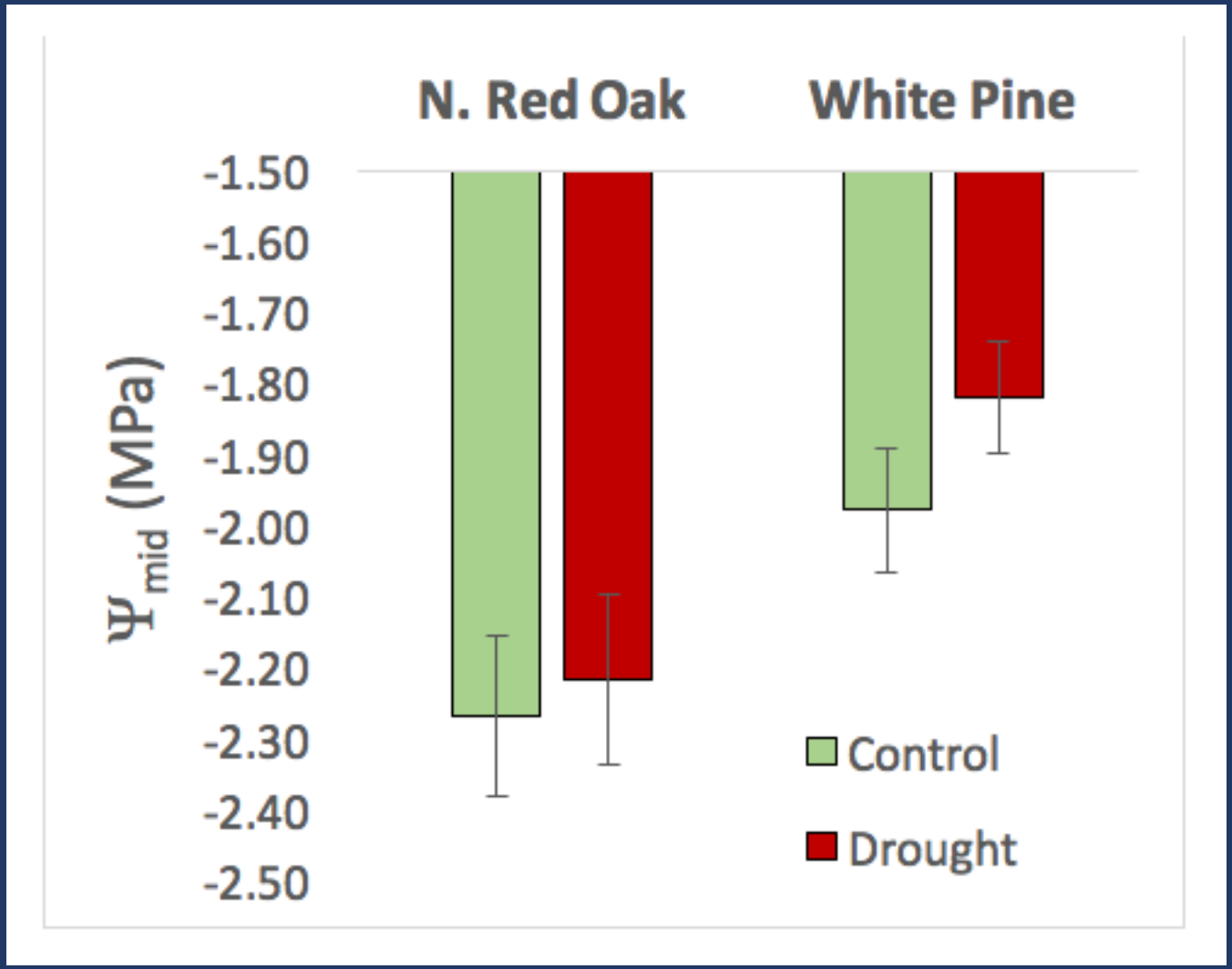
Leaf Water Use Efficiency (WUE) August 2016

- **High WUE = greater stress**
- **<u>Red Oak</u>**
  - Lower WUE
  - Keeps stomata open despite low soil moisture
  - More drought tolerant
- **<u>White Pine</u>**
  - Higher WUE
  - Closes stomata to conserve water



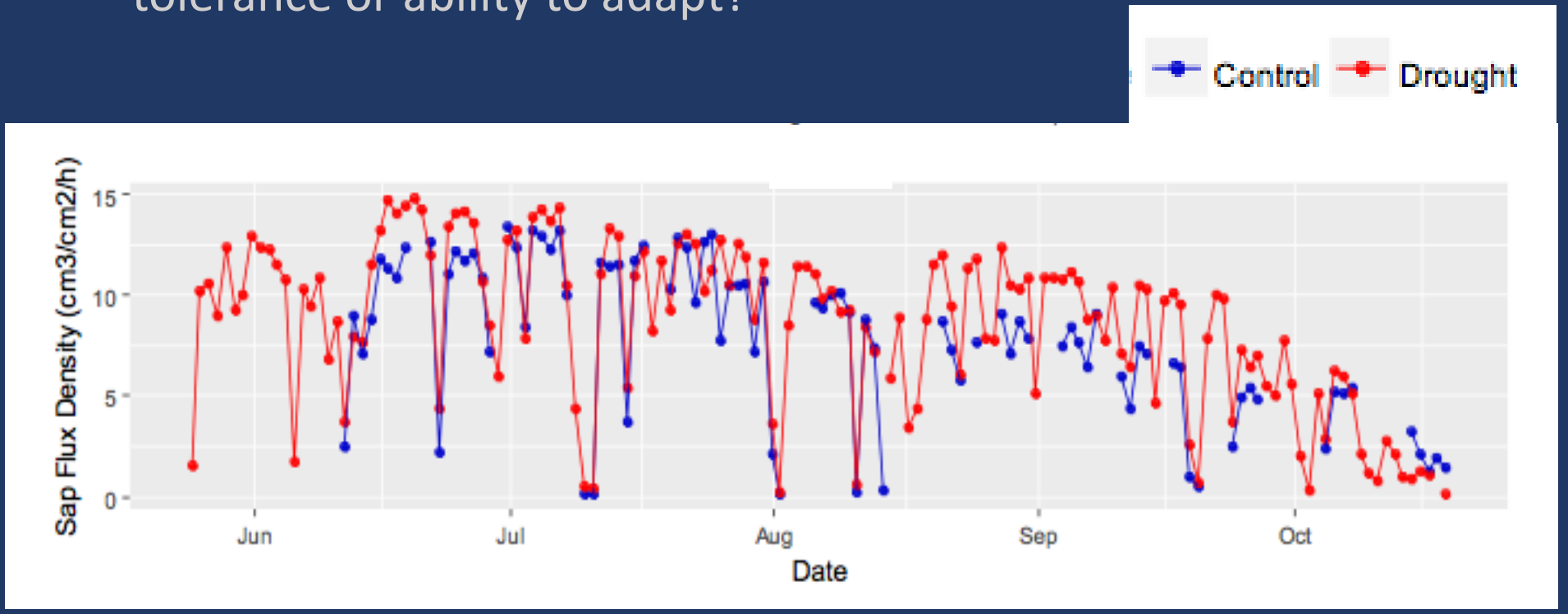
Leaf water potential – August (midday)

- Red oak reaches more negative leaf water potentials than white pine; more drought tolerant strategy.
- Sugar maple: more similar strategy to white pine.



Hubbard Brook: Red Maple Sap Flow

- No Significant difference between control and drought plots
- 2016 drought less severe?
- Throughfall removal not effective?
- Red maple known to be highly plastic : greater drought tolerance or ability to adapt?



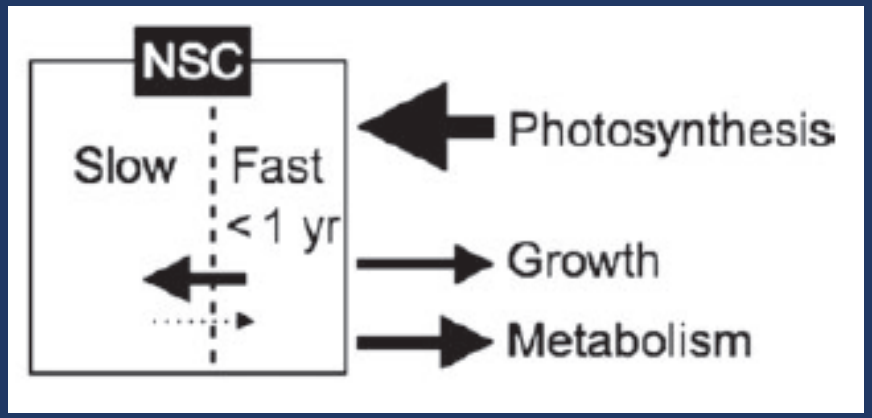
Sensitivity and resilience of Sugar Maple to Climate Change: *What do (don't) we know?*

- Vernal window for sap production earlier and more variable
- Sensitive to root damage: thin snow layers; soil freeze-thaw cycles (Bertrand et al. 1994)
- Soil freezing = lower sap volumes and sugar released during the season (Robitaille et al. 1995).
- Warm winter temperatures = lower soluble sugar concentration in sap (Bertrand et al. 1999).
- Increasing WUE may reduce drought stress (CO_2 response)
- Non-structure carbohydrate (NSC) storage and mobilization…
  - Sugars and starches stored by trees as reserves to support metabolic functions, growth, and repair during stressful times
  - "Buffering capacity" to survive drought?

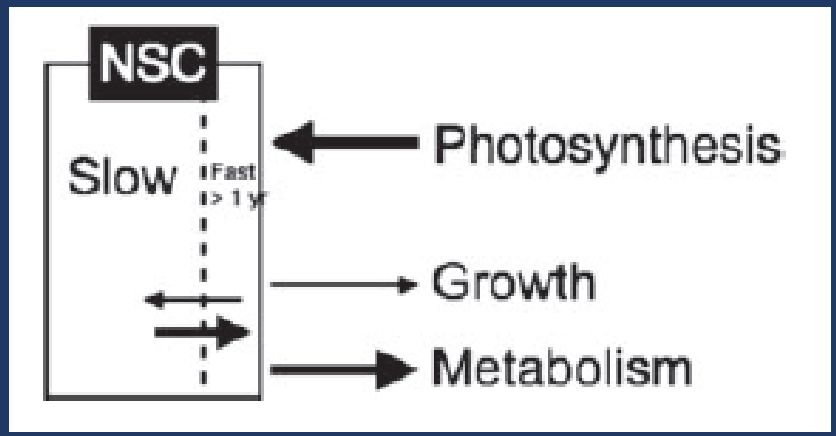
NSC Dynamics in Red Maple: Conceptual Model

- **Mean age** of NSCs: 10 y
- **Vigorous trees:**
  - Larger and younger NSC pools
  - Used younger NSCs (< 1 yr)
  - Fast pool
- **Low vigor trees:**
  - Smaller and older NSC pools
  - Relied on older NSCs (> 1 yr)
  - Slow pool
- **Stump sprouts** – remobilized older NSCs for growth (17 yrs)
- **Buffering capacity**!

High Vigor Trees



Low Vigor Trees

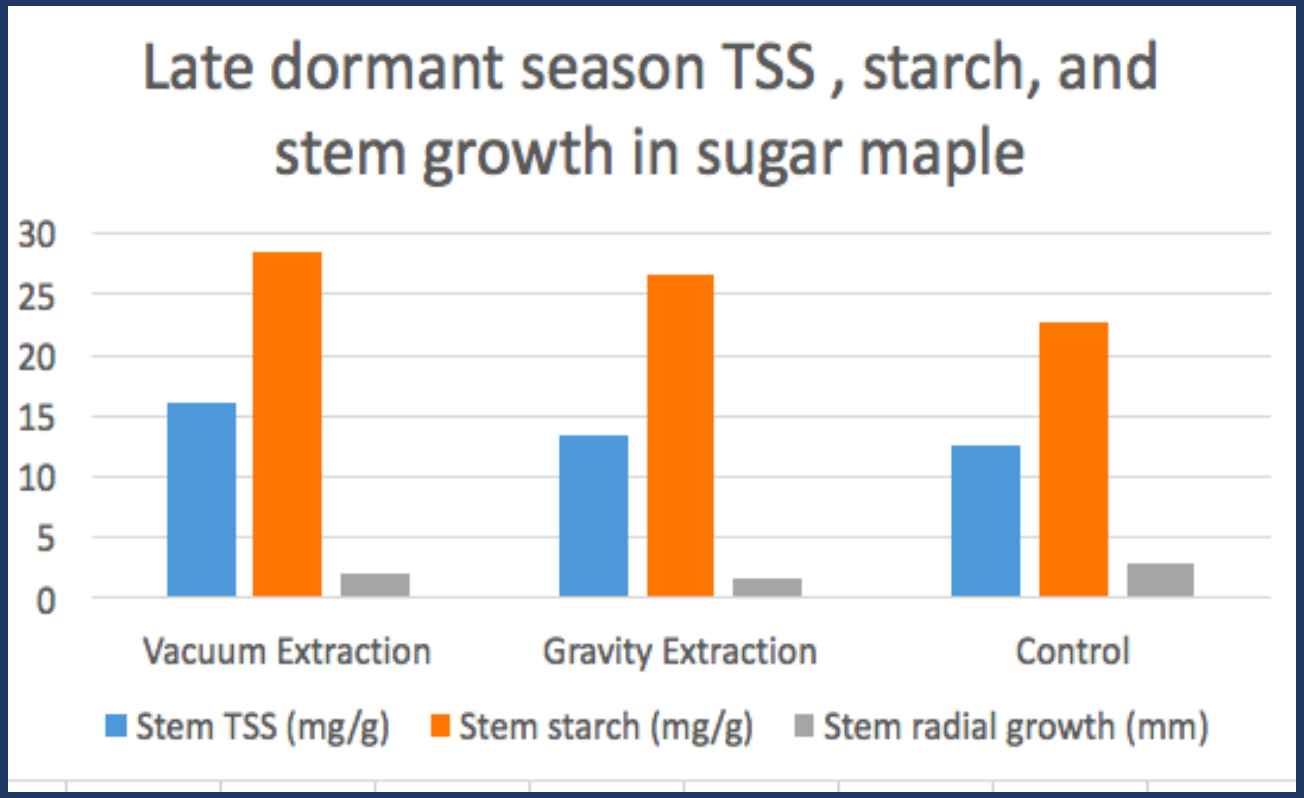


Carbone et al. 2013

NSC Dynamics: How buffered are sugar maple trees?

- European deciduous trees: NSC can re-foliate canopy 4X (Hoch et al. 2003)
- Spring heat wave (Ontario, 2010): SM shed 25% leaves, 2nd flush of neoformed leaves; LAI 64% lower (Filewod & Thomas 2013)
- Unknown: Capacity of trees to mobilize old NSC under stress (drought)?

Effect of Tapping Syrup on Non-Structural Carbohydrates (NSCs)



Isselhardt et al. 2016

- Tapped trees stored more NSCs in stemwood and showed reduced stem radial growth vs. untapped trees
- Vacuum sap extraction (VSE) showed more pronounced effects on NSC storage than Gravity sap extraction (GSE).

Alternative Syrup-Producing Species?

Drought tolerance class

	Species' range	Models (-3 - +3)
Sugar maple	Intolerant	-1
Red maple	Moderate	1
Birch species	Moderate	-1 to -2
Sycamore		1
Hickory species	Tolerant	2 to -2
Red oak	Tolerant	1

Nowacki & Abrams 2015 Peters et al. 2015
Abrams & Nowacki 2015

Summary and Future Research Directions

- Sugar maple does not appear to be very sensitive to historical variability in moisture availability
- Sugar maple may be more sensitive to previous season temperature (affect on NSC?s?)
- Red maple may have greater capacity to tolerate or adapt to moisture stress
- More work is needed to understand drought sensitivity and resilience of sugar maple, and implications for syrup production.
- Experimental drought manipulations provide a useful approach for pushing ecosystems beyond ecological thresholds that they may experience under future climates.

Acknowledgements: Collaborators

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Thank you! Questions?