Extreme Heat Impacts on Forest Ecosystems

Chris Still (Oregon State University)

Linnia Hawkins (NCAR/Columbia)

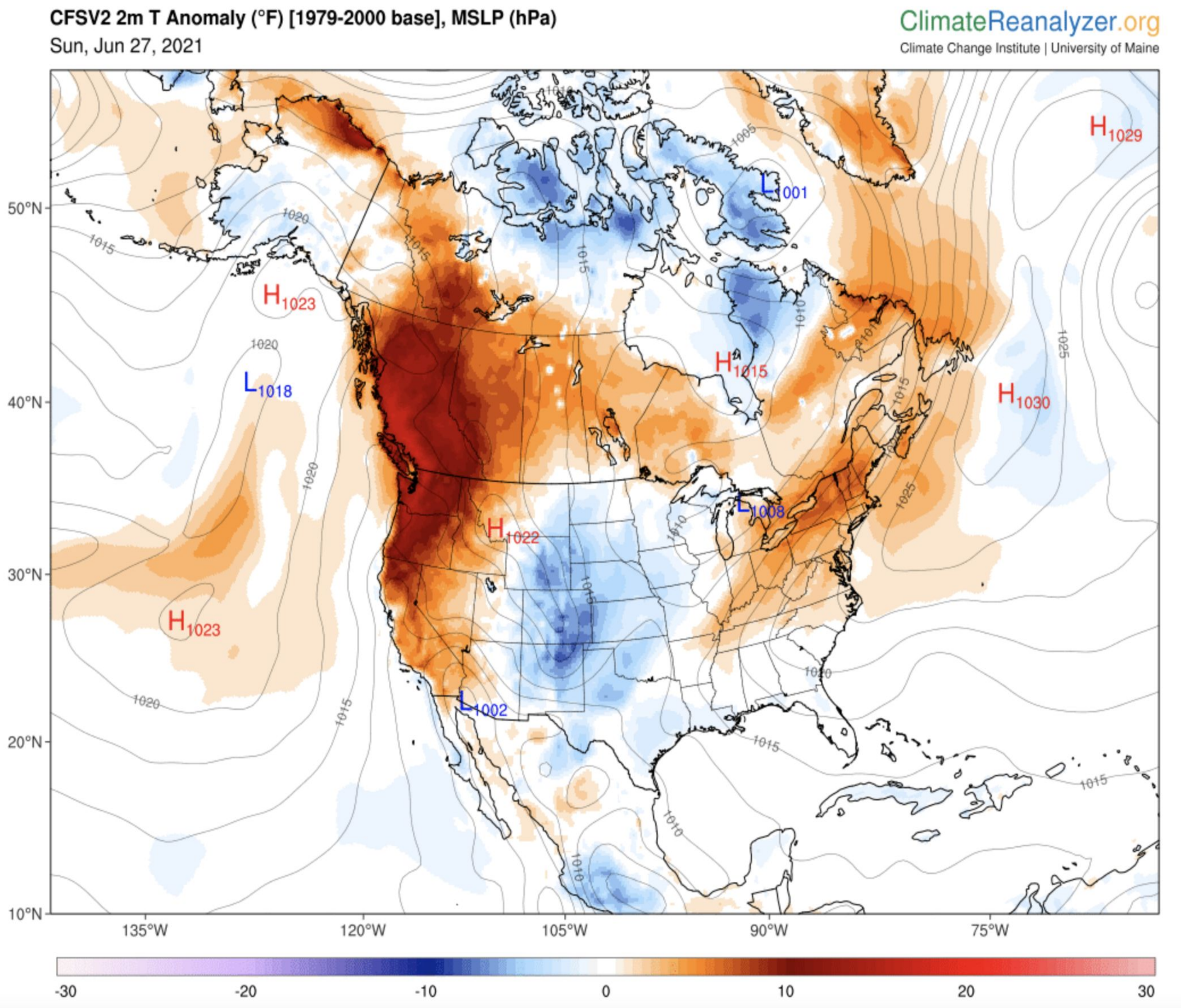
Contributors:

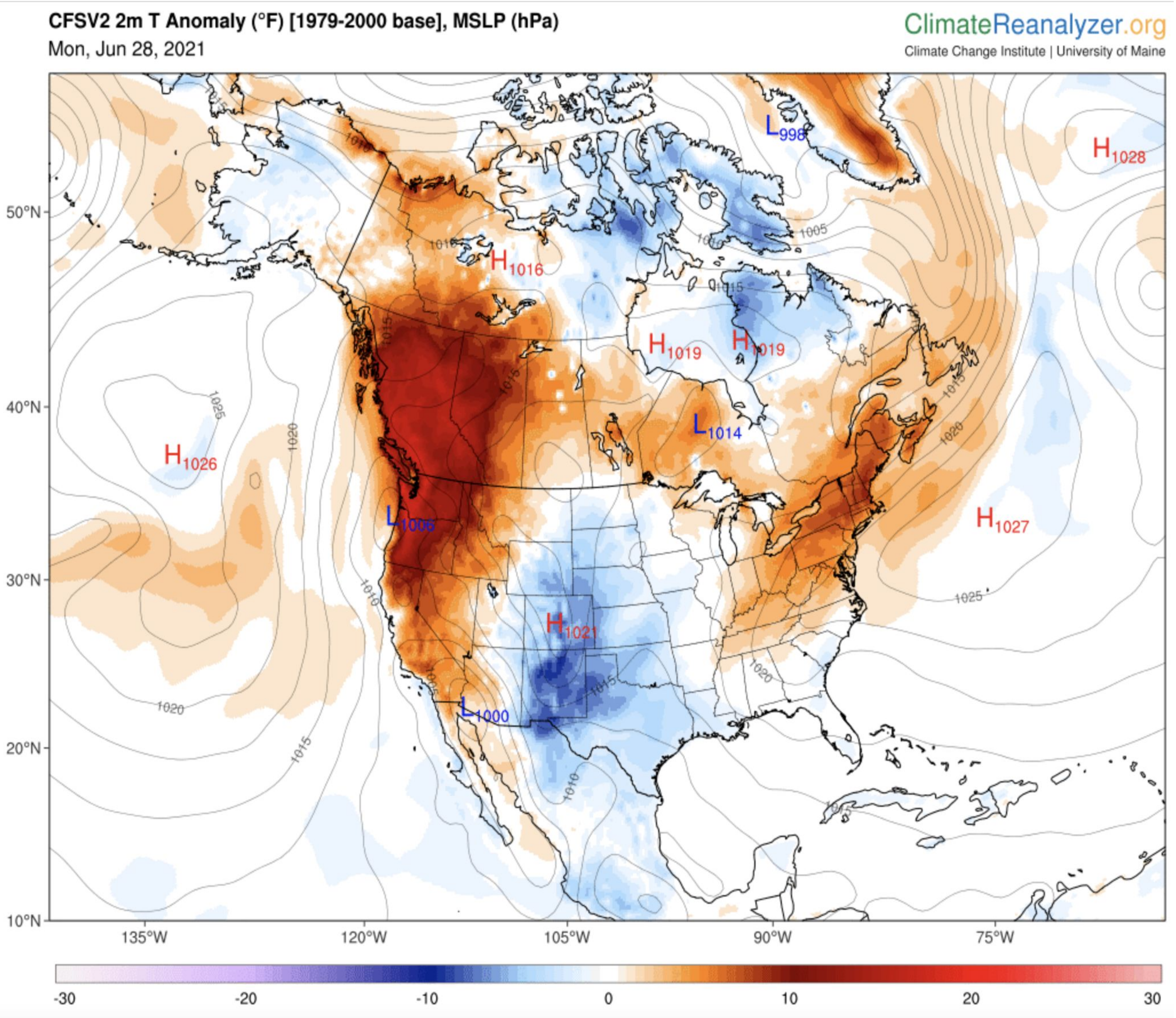
Adam Sibley, Mark Schulze (OSU)

Connie Harrington, David Woodruff (USFS)

Bill Hammond (UF)

2m air temperature anomaly (difference from the mean, in ºF) for Heat Dome event of June 27 and 28, 2021





CLIMATOLOGY

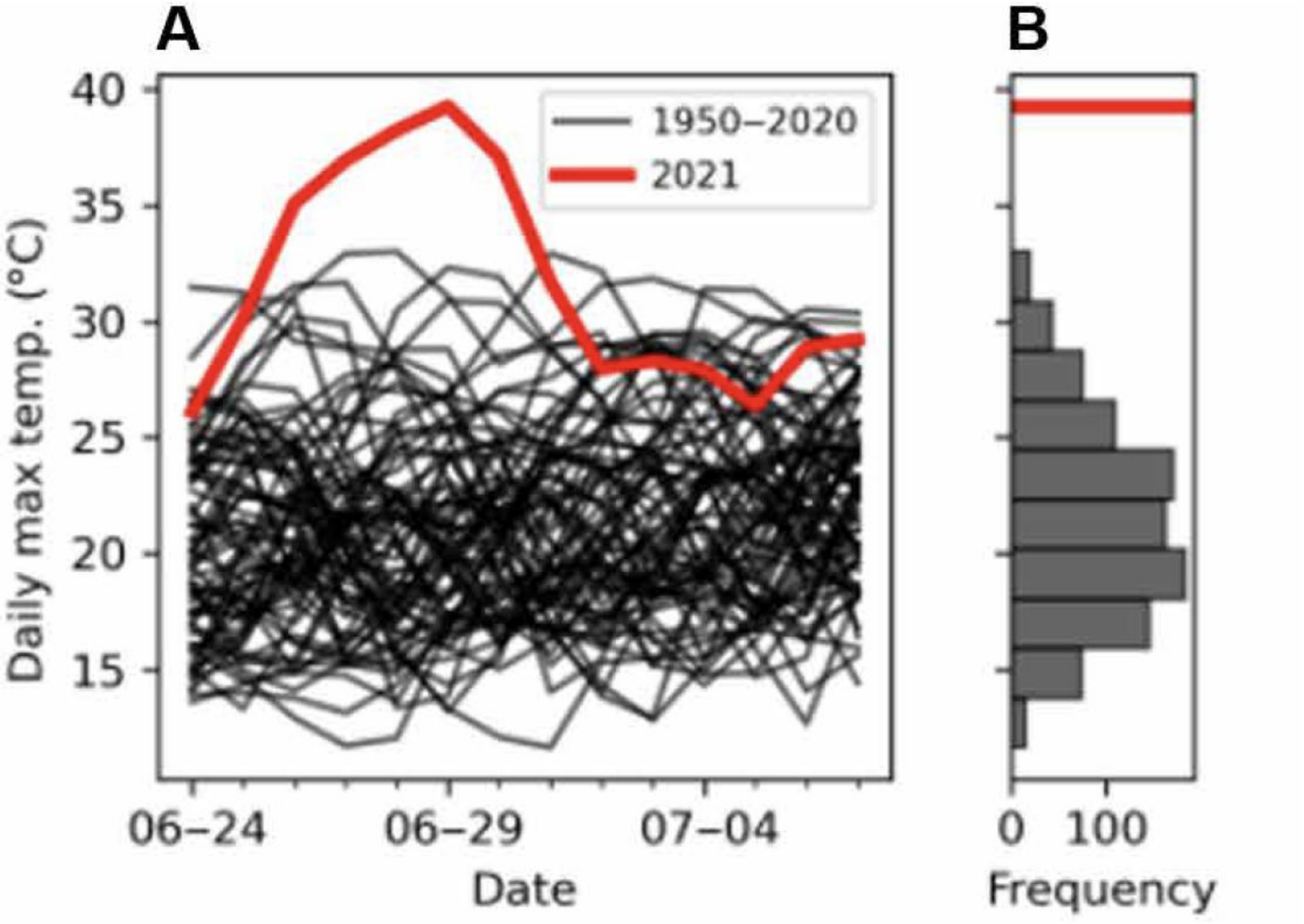
The 2021 western North America heat wave among the most extreme events ever recorded globally

Vikki Thompson[1]*, Alan T. Kennedy-Asser[1], Emily Vosper[1], Y. T. Eunice Lo[1], Chris Huntingford[2], Oliver Andrews[1], Matthew Collins[3], Gabrielle C. Hegerl[4], Dann Mitchell[1]

In June 2021, western North America experienced a record-breaking heat wave outside the distribution of previously observed temperatures. While it is clear that the event was extreme, it is not obvious whether other areas in the world have also experienced events so far outside their natural variability. Using a novel assessment of heat extremes, we investigate how extreme this event was in the global context. Characterizing the relative intensity of an event as the number of standard deviations from the mean, the western North America heat wave is remarkable, coming in at over four standard deviations. Throughout the globe, where we have reliable data, only five other heat waves were found to be more extreme since 1960. We find that in both reanalyses and climate projections, the statistical distribution of extremes increases through time, in line with the distribution mean shift due to climate change. Regions that, by chance, have not had a recent extreme heat wave may be less prepared for potentially imminent events.

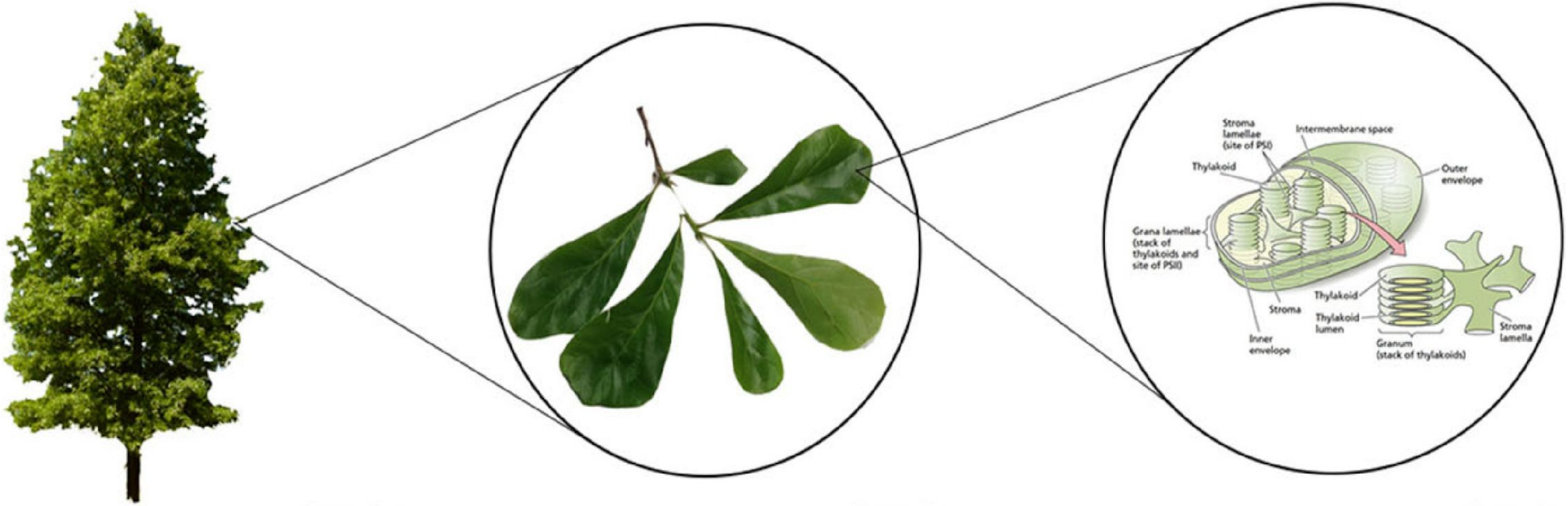
"Characterizing the relative intensity of an event as the number of standard deviations from the mean, the western North America heat wave is remarkable, coming in at over four standard deviations. Throughout the globe, where we have reliable data, only five other heat waves were found to be more extreme since 1960."

"…the western North America heat wave of June 2021 was an exceptional event. For that region, the extreme event was unprecedented in the observational record in terms of absolute magnitude and heat stress level."



What did the extreme heat do to trees and forests?

Responses of trees to heat waves and extreme heat events



Process	Extreme heat	Acclimation	Target for genetic selection
Leaf area development	–	N	x
Leaf shedding	+	?	
Early budburst	0/+	N	x
Growth	–	Y	x
Mortality	+	Y	
Fecundity	–	Y	

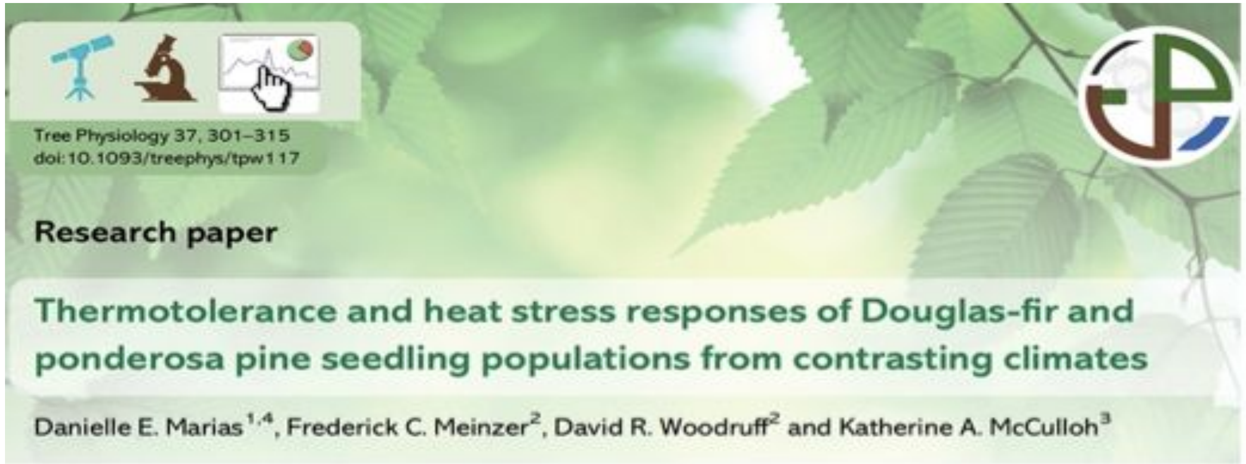
Process	Extreme heat	Acclimation	Target for genetic selection
Photosynthesis	–	Y	x
Dark respiration	+	Y	
Photorespiration	+	Y	x
VOC emission	+/0	?	
Stomatal conductance	+/–	Y	x
Transpiration	+/–	N	

Process	Extreme heat	Acclimation	Target for genetic selection
PSII functioning	–	Y	
Thylakoid membrane fluidity	+	Y	
Rubisco activity	–	Y	x
HSP expression	+	Y	x

Responses to extreme heat occur from molecular to whole tree to ecosystem levels and there is wide variation in thermal tolerance within and among species and ecotypes

Plant, Cell & Environment Volume 38, Issue 9, pages 1699-1712, 1 SEP 2014
DOI: 10.1111/pce.12417

Thermal tolerance studies in trees suggest many negative impacts occur between 40-50 ºC


Tree Physiology 37, 301–315
doi:10.1093/treephys/tpw117

Research paper

Thermotolerance and heat stress responses of Douglas-fir and ponderosa pine seedling populations from contrasting climates

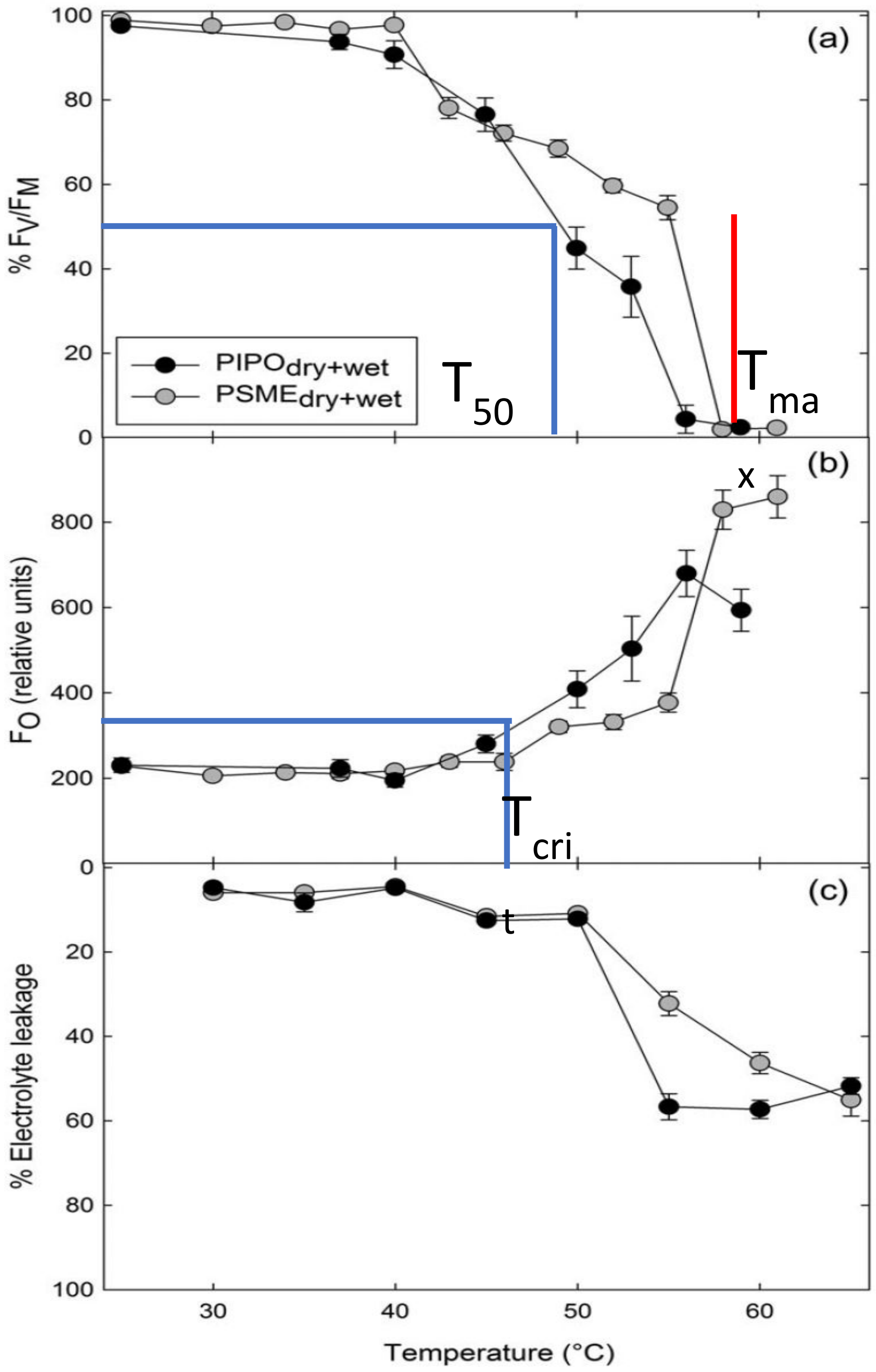
Danielle E. Marias[1,4], Frederick C. Meinzer[2], David R. Woodruff[2] and Katherine A. McCulloh[3]

Table 2. Thermotolerance parameters (°C) derived from curves of F_V/F_M, electrolyte leakage and F_o as a function of treatment temperature for dry, wet and dry + wet populations of PIPO and PSME. Uppercase letters indicate significant differences between species. There were no significant differences between populations. Asterisks indicate significant differences in T_{50} between F_V/F_M and electrolyte leakage methods.

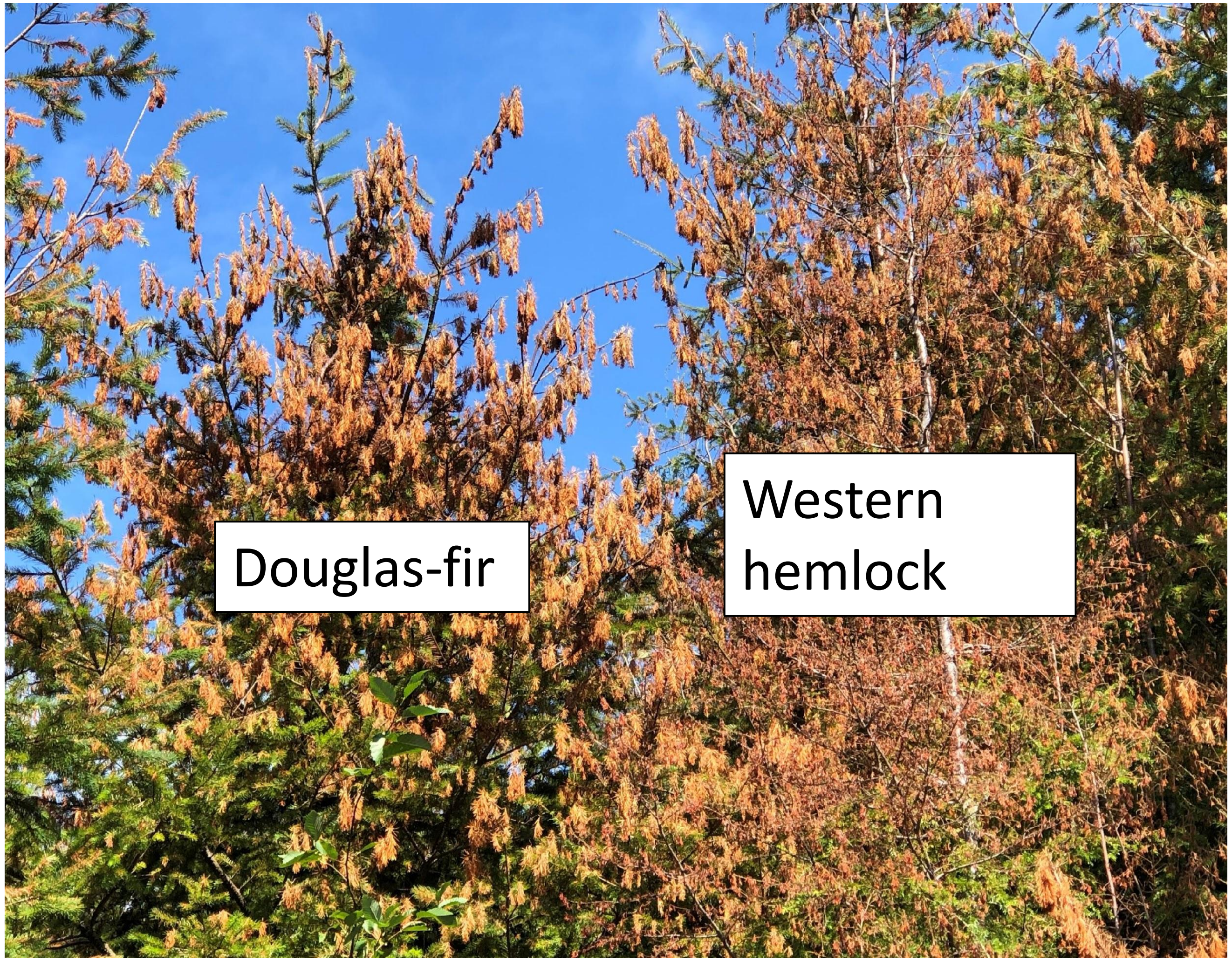
	$PIPO_{dry}$	$PIPO_{wet}$	$PIPO_{dry+wet}$	$PSME_{dry}$	$PSME_{wet}$	$PSME_{dry+wet}$
T_{50} (F_V/F_M)	48.8 ± 1.4*	50.5 ± 0.41*	49.6 ± 0.76 B*	52.8 ± 1.2*	52.0 ± 0.22*	52.4 ± 0.29 A*
T_{50} (electrolyte leakage)	61.8 ± 1.8*	61.6 ± 1.7*	61.7 ± 1.6 B*	63.6 ± 1.5*	66.0 ± 2.4*	64.8 ± 2.3 A*
T_{crit} (F_o)	45.1 ± 0.33	42.3 ± 1.1	44.3 ± 1.0 B	48.1 ± 0.88	48.3 ± 0.30	48.2 ± 0.45 A

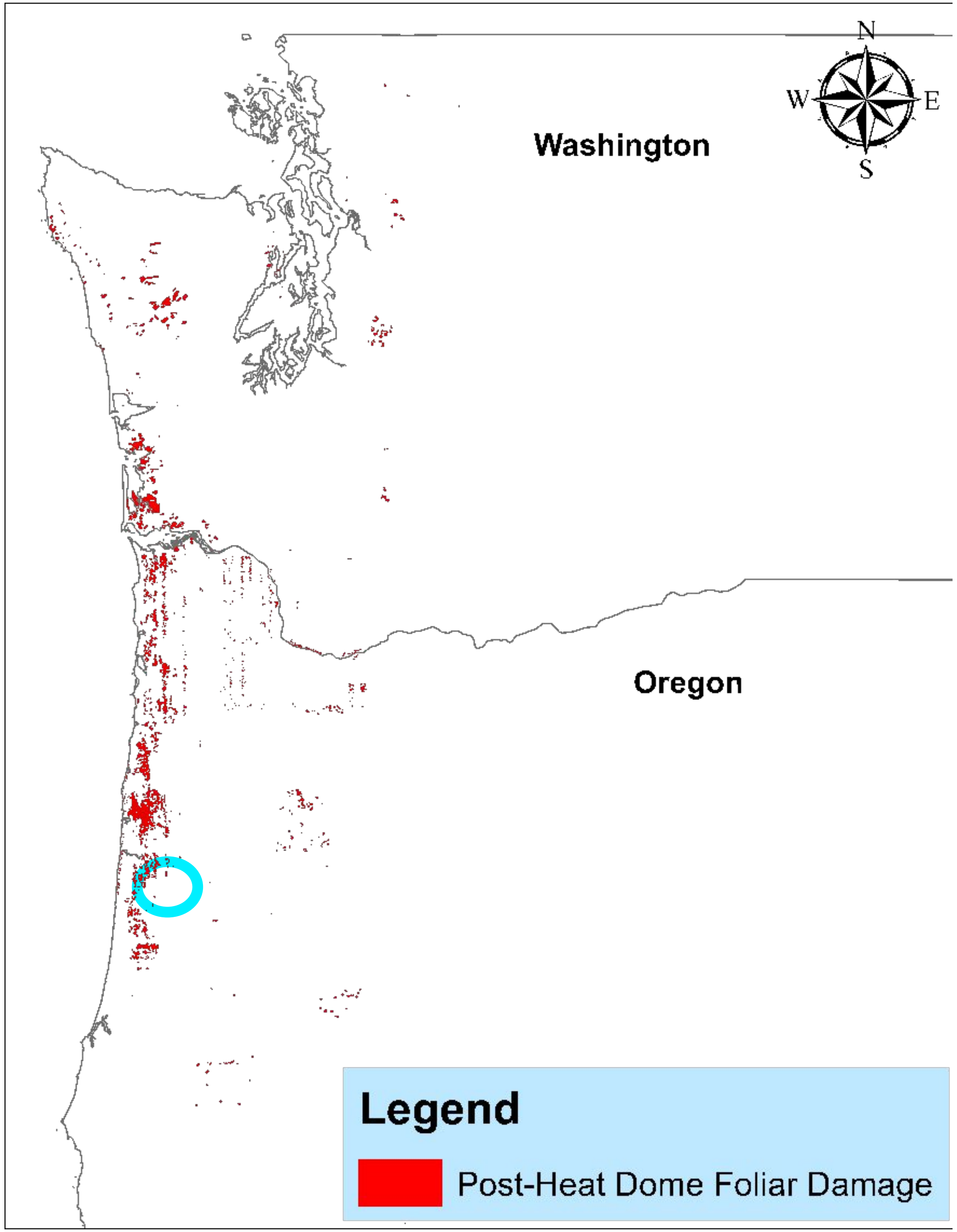
$N = 5$. Significance level is at $P < 0.05$. Means ± SE.

40 ºC = 104 ºF; 45 ºC = 113 ºF; 50 ºC = 122 ºF



Foliage scorch: the most obvious symptom of the heat dome impact on trees

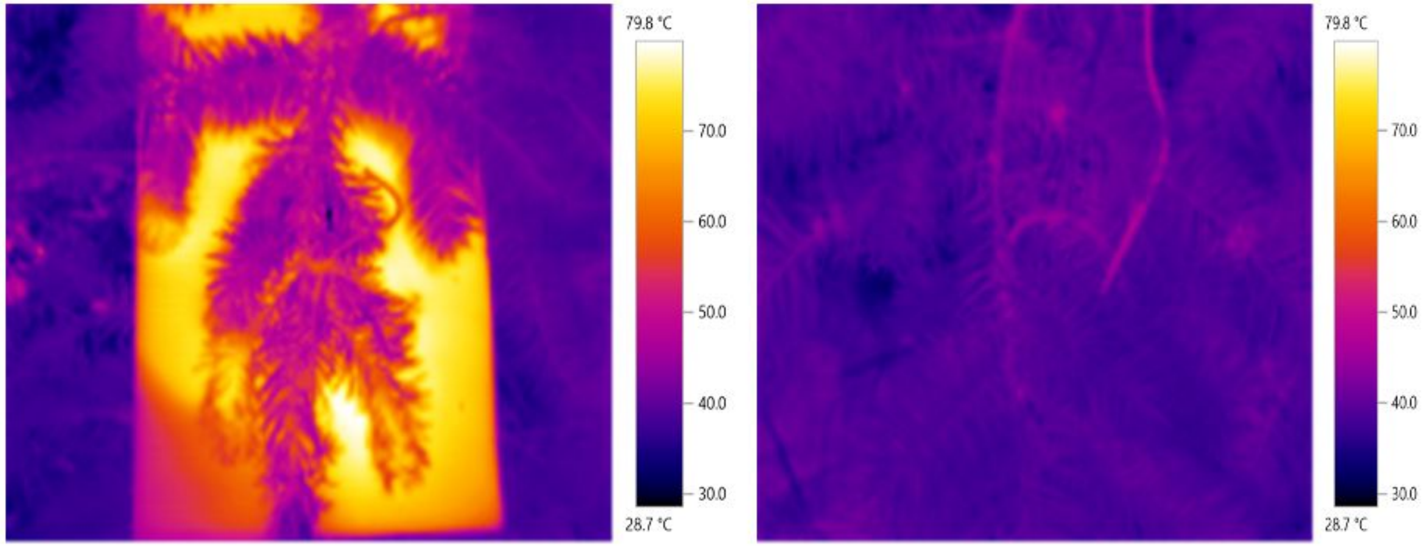


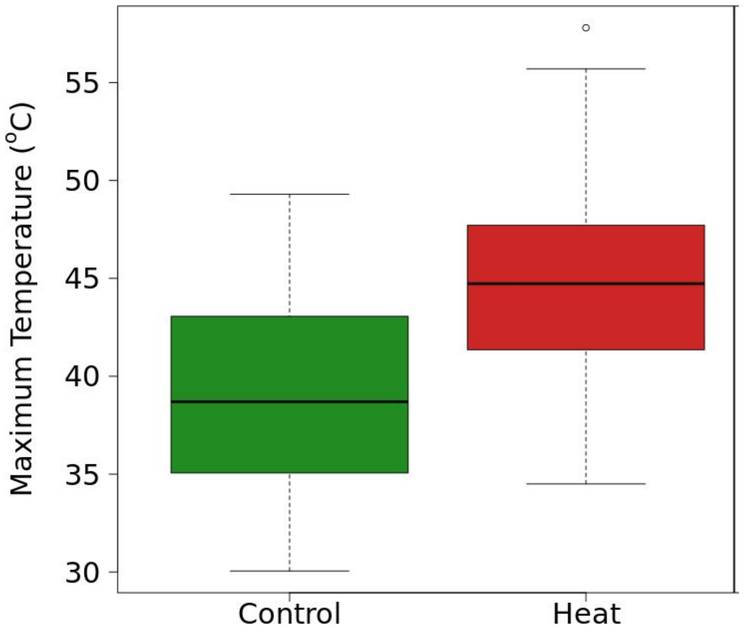


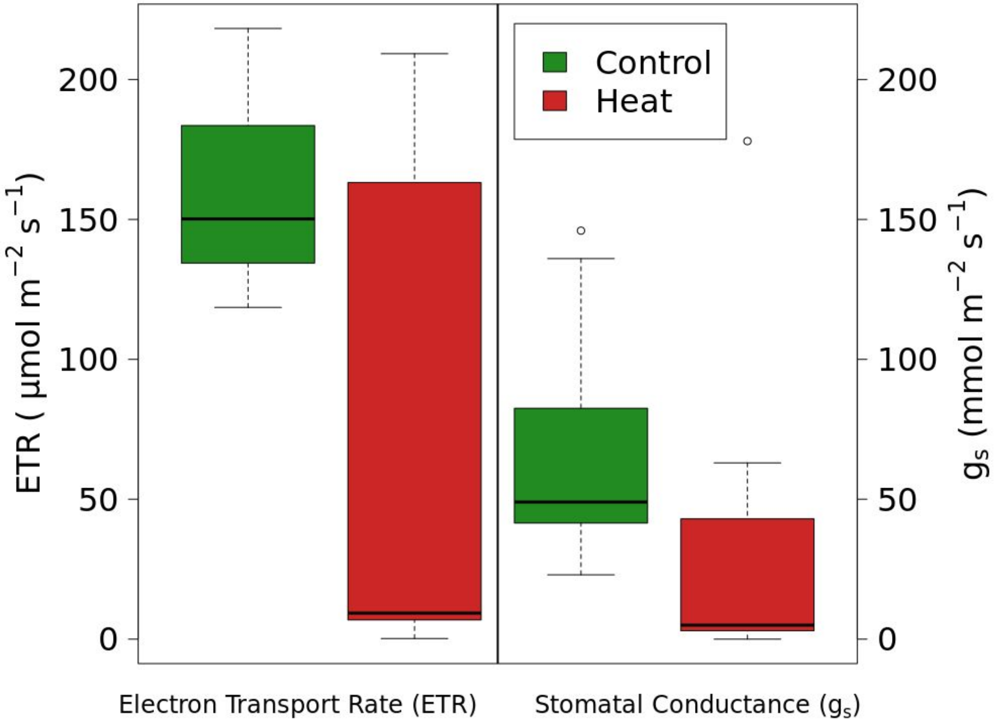
Aerial damage surveys conducted by the U.S. Forest Service indicated that more than 230,000 ha of forest were affected in Oregon and Washington alone.

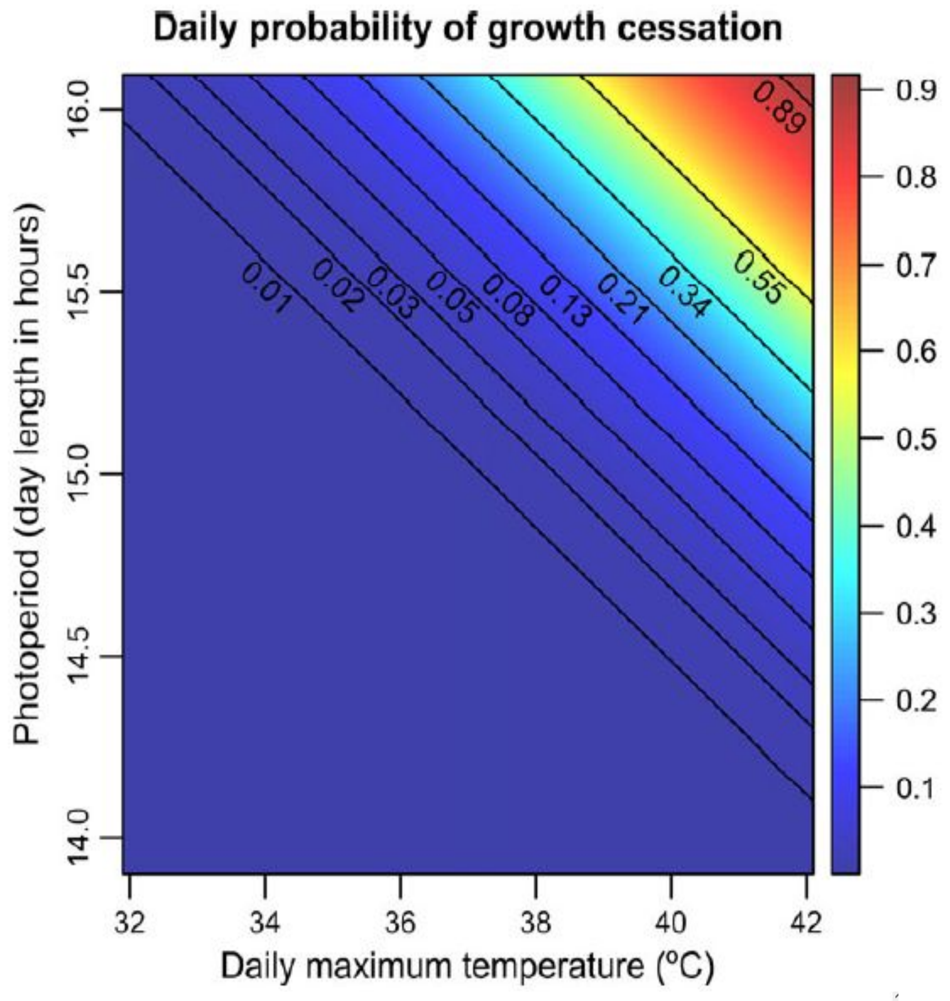
Cyan circle ~represents area in photo at bottom

In situ foliar browning can happen in minutes, and leaf damage can persist for weeks to months

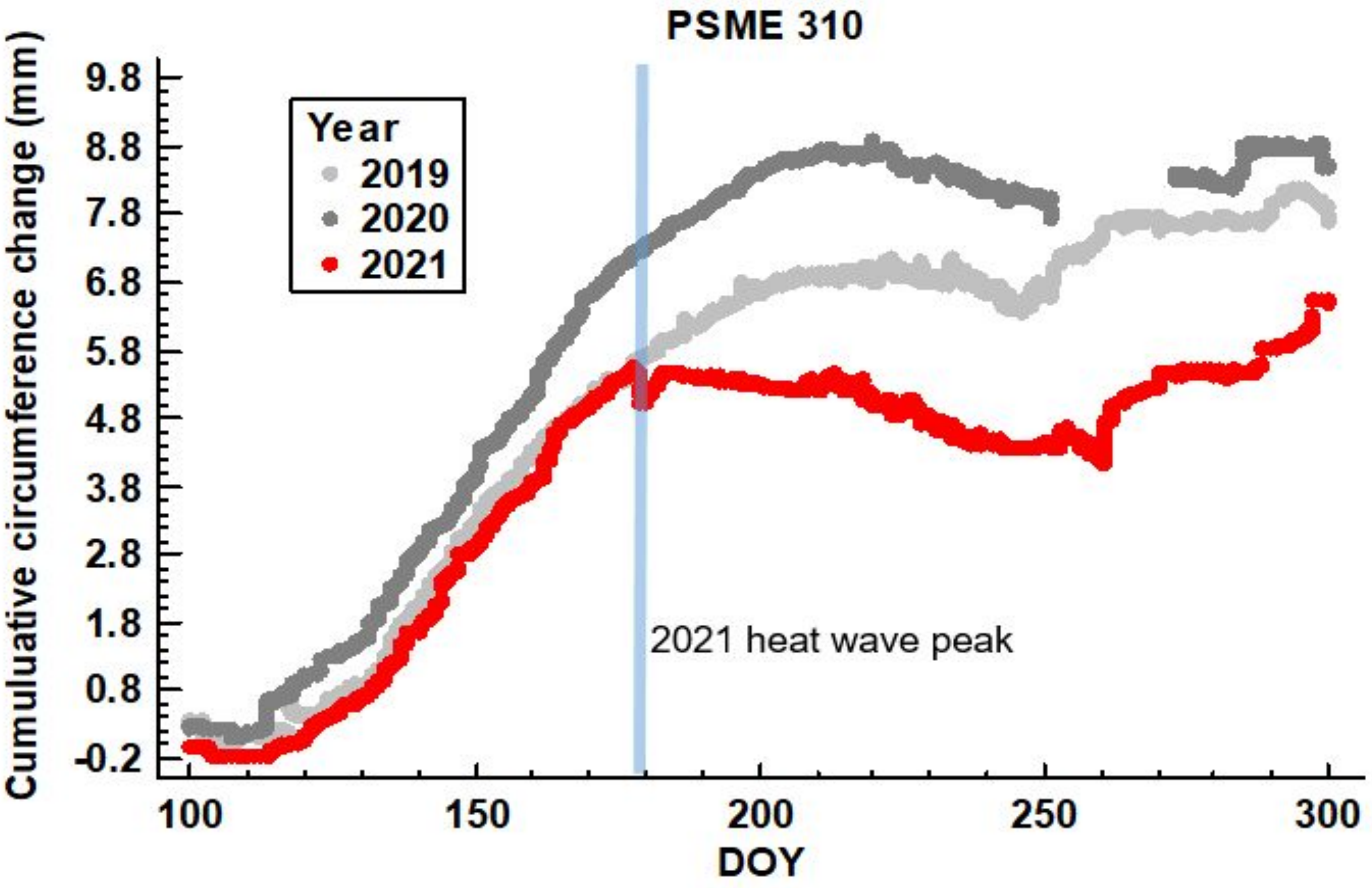








A prior study (left) showed that young Doug-fir trees stopped diameter growth in late June 2015 after another early season heat wave. Similar growth halt in old-growth Doug firs in 2021 (below)



Received: 16 October 2016 | Revised: 27 January 2017 | Accepted: 23 February 2017

DOI: 10.1111/gcb.13690

PRIMARY RESEARCH ARTICLE

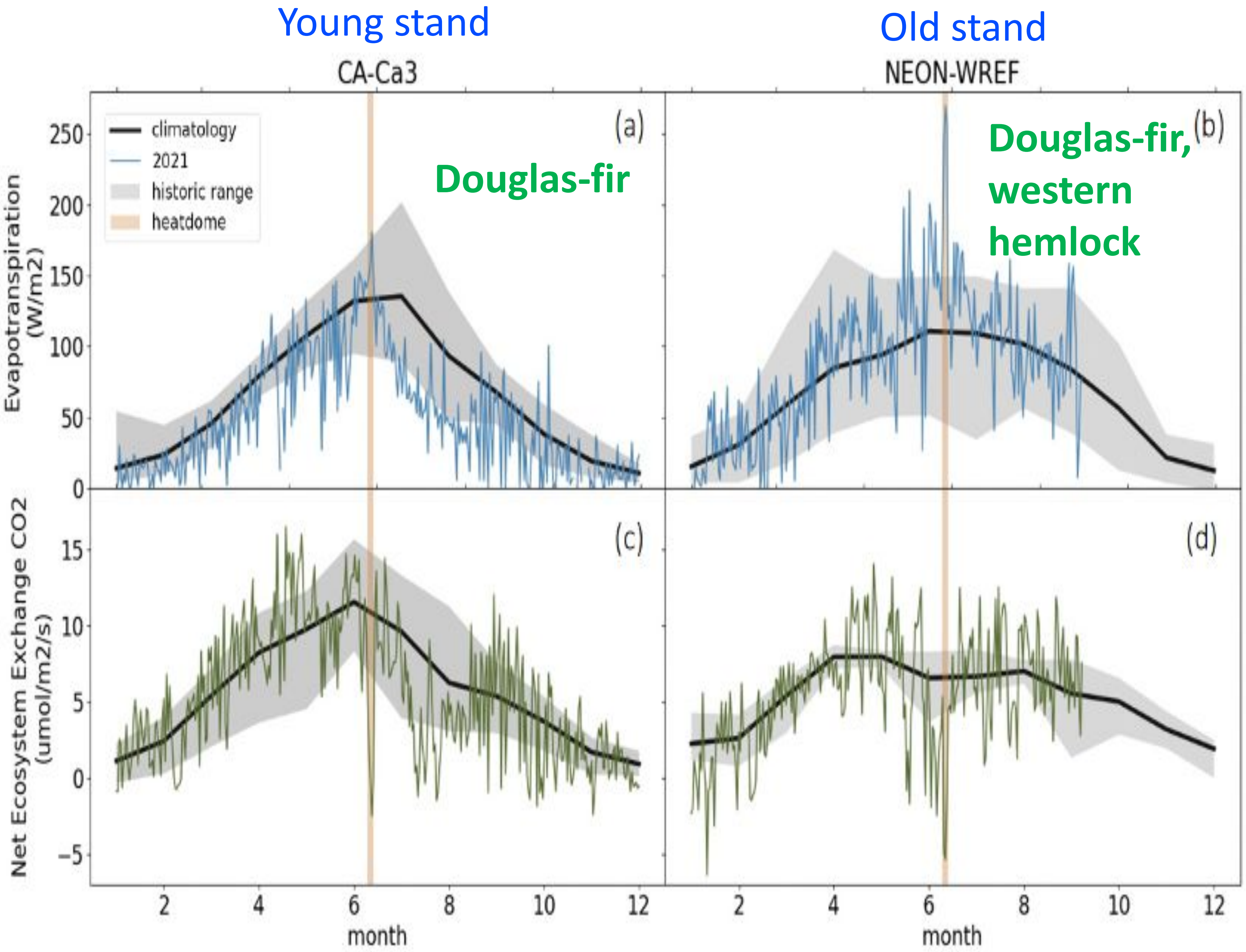
WILEY Global Change Biology

Photoperiod cues and patterns of genetic variation limit phenological responses to climate change in warm parts of species' range: Modeling diameter-growth cessation in coast Douglas-fir

Kevin R. Ford[1] | Constance A. Harrington[1] | J. Bradley St. Clair[2]

Evapotranspiration of H_2O (top) and net ecosystem exchange of CO_2 (bottom) at two Douglas-fir dominated forest ecosystems in British Columbia, Canada (CA-Ca3, left panels) and the US Pacific Northwest (NEON-WREF, right panels).

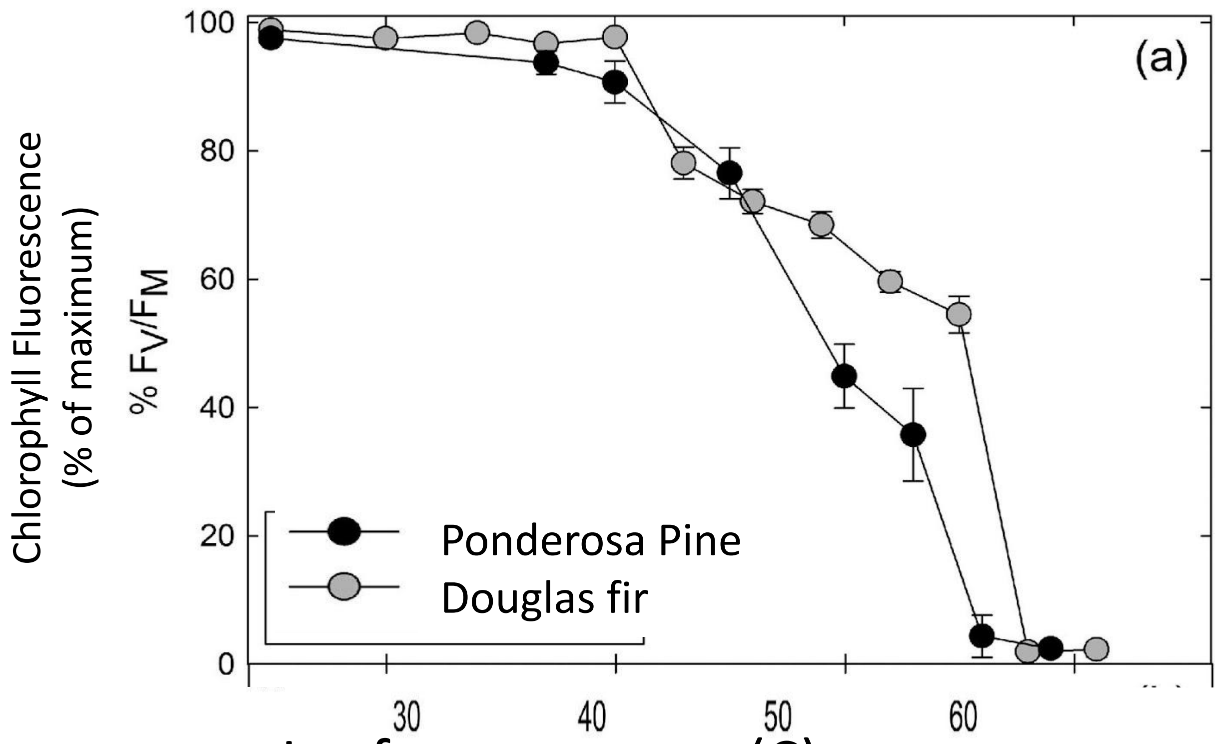
The forest at the NEON-WREF was able to recover fluxes while the CA-Ca3 site appears to have experienced prolonged stress throughout the remainder of the growing season



Modeling: Elastic heat stress

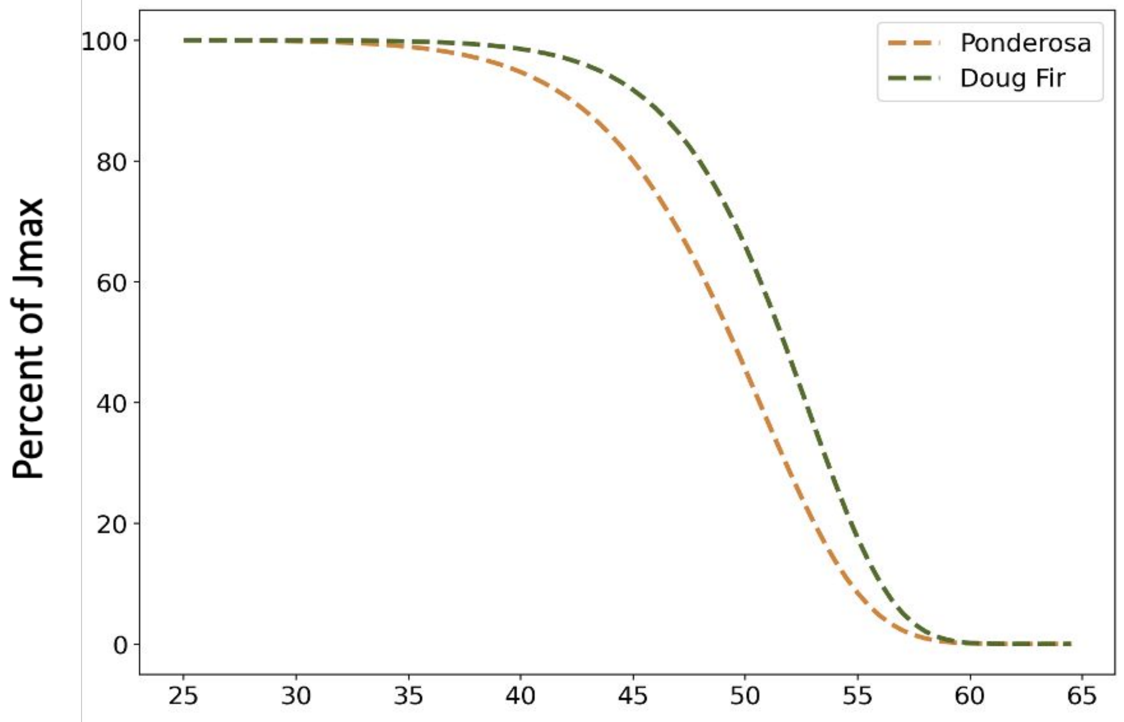
Soil-Plant-Atmosphere model
Williams et al., (1999)

Observed



Leaf temperature (C)

Modeled

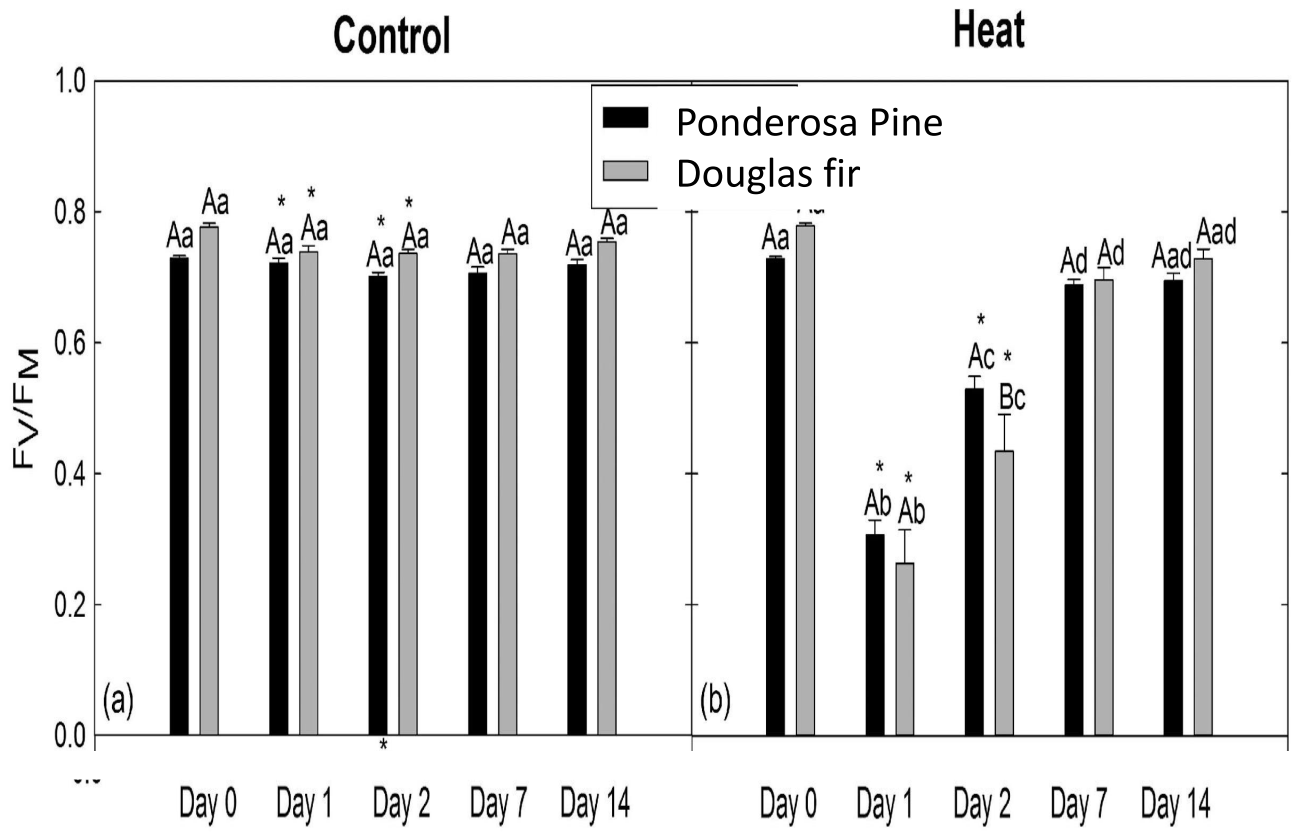


Leaf temperature (C)

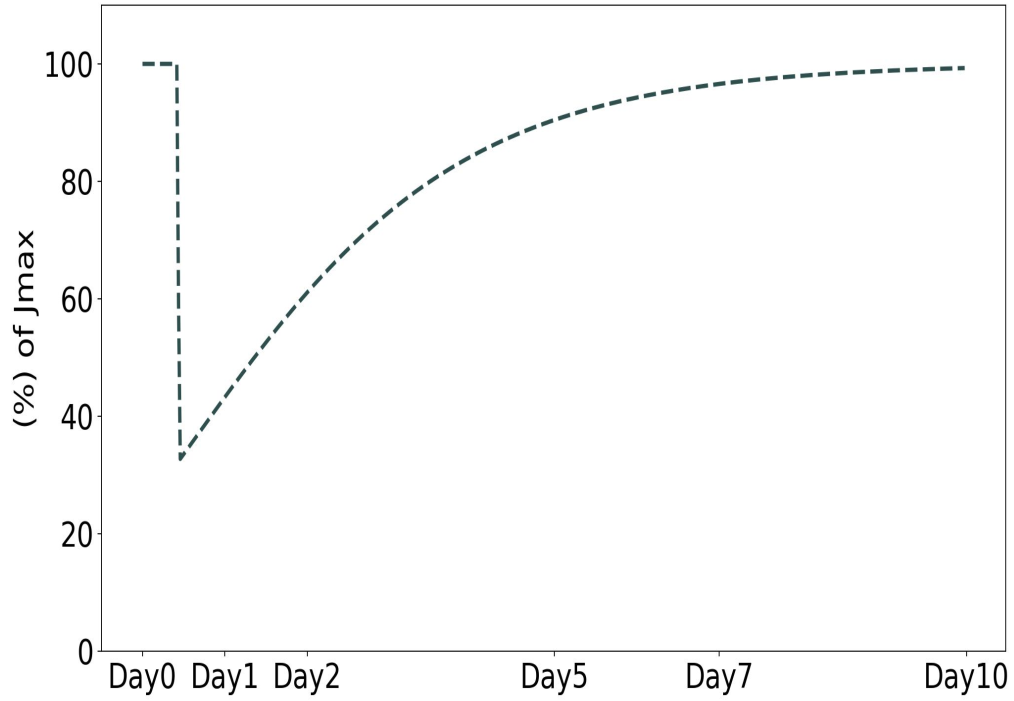
Marias et al., (2017) Tree Physiology

Modeling Inelastic heat stress

Observed



Modeled



Marias et al., (2017) Tree Physiology

Conclusions

The response was individualistic (tree level) and site-specific (ecosystem level)

Responses varied from visual foliage scorch to non-obvious leaf damage to tree growth impacts to anomalous ecosystem fluxes. The role of phenology in the response (timing of heat wave relative to seasonal development) was important.

Models need to incorporate heat damage and lagged responses

Thank you!