The Impact of Seasonal Phenology on Photosynthetic Water Use Efficiency: an Evaluation of Patterns and Drivers in Temperate Deciduous Forests

Kenneth Davidson[1], Julien Lamour[1], Anna McPherran[2], Alistair Rogers[1], and Shawn Serbin[1]

[1]Brookhaven National Laboratory
[2]Stony Brook University

January 20, 2023

Abstract

Vegetation acts as a critical link between the geosphere, biosphere, and atmosphere, regulating the flux of water to the atmosphere via transpiration (E) and the input of carbon from the atmosphere to plants and soil via photosynthetic carbon assimilation (A). The rate of A is known to be seasonally dynamic, however, few studies have investigated how the ratio between E and A, known as the water use efficiency (WUE), changes with phenology. WUE directly impacts regional to global carbon and water cycles and lack of knowledge regarding the dynamics of WUE remains among the largest uncertainties in current earth system model (ESM) projections of carbon and water exchange in temperate forests. Here we attempt to reduce this knowledge gap by studying these dynamics across a range of eight deciduous tree species common to temperate forests of North America. Using gas exchange and spectroscopic measurements, we investigated seasonal patterns in leaf level physiological, biochemical, and anatomical properties, including the seasonal progress of WUE and foliar capacity for carbon assimilation, which corollate with seasonal leaf phenology. We incorporate these findings into a modeling framework that contains the same representation of A, E, and canopy scaling found in ESMs to explore the impact of parameterization, which tracks phenological status, on model forecasts. Our results indicate that both photosynthetic capacity and WUE are seasonally dynamic processes which are not synchronized. WUE increased from a minimum at leaf out toward a more conservative behavior at the mid-summer growth peak. This pattern was explained by a decreased stomatal aperture and a decrease in cuticular leakage with leaf aging. We also observed a seasonal increase in maximum carboxylation capacity, with maximum rates of A and modeled tree net primary productivity (NPP) occurring later toward the end of the summer. This change was primarily driven by an increase in foliar nitrogen content, and a shift in the ratio of V_{cmax} to J_{max} between expanding and mature leaves. By applying our revised parameterization, which captures seasonal dynamics of gas exchange, into our model framework we aim to improve the process representation of leaf function in a temperate forest, and more faithfully represent dynamics of NPP and E in the early and late growth season.

Evaluating Patterns and Drivers of Leaf Water Use Efficiency with Ontogeny in Eastern Deciduous Forests of New York State

Kenneth J. Davidson[1,2], Julien Lamour[1], Anna T. McPherran[2], Alistair Rogers[1], Shawn P. Serbin[1,2]

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Motivation: *What is the current state of model representation of seasonality?*

Research paper

Seasonal trends in photosynthesis and leaf traits in scarlet oak

Angela C. Burnett[1,2,3], Shawn P. Serbin[1], Julien Lamour[1], Jeremiah Anderson[1], Kenneth J. Davidson[1], Dedi Yang[1] and Alistair Rogers[1]

[1]Environmental and Climate Sciences Department, Brookhaven National Laboratory, Upton, NY 11973, USA; [2]Present address: Department of Plant Sciences, University of Cambridge, Downing Street, Cambridge CB2 3EA, UK; [3]Corresponding author (acb219@cam.ac.uk)

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Effects of seasonal variation of photosynthetic capacity on the carbon fluxes of a temperate deciduous forest

David Medvigy,[1] Su-Jong Jeong,[1] Kenneth L. Clark,[2] Nicholas S. Skowronski,[3] and Karina V. R. Schäfer[4]

Received 17 June 2013; revised 14 November 2013; accepted 16 November 2013.

RESEARCH ARTICLE

Check for updates

Photoperiodic regulation of the seasonal pattern of photosynthetic capacity and the implications for carbon cycling

William L. Bauerle, Ram Oren, Danielle A. Way, Song S. Qian, Paul C. Stoy, Peter E. Thornton,...

+ See all authors and affiliations

PNAS May 29, 2012 109 (22) 8612-8617; https://doi.org/10.1073/pnas.1119131109

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Ecological Indicators

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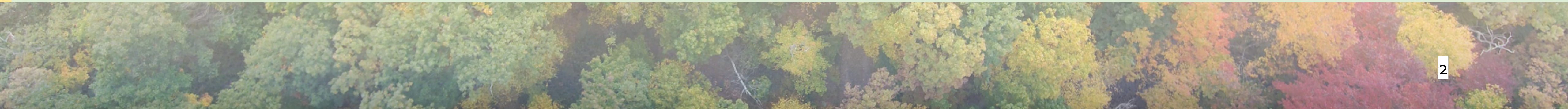
Original Articles

Water use efficiency in response to interannual variations in flux-based photosynthetic onset in temperate deciduous broadleaf forests

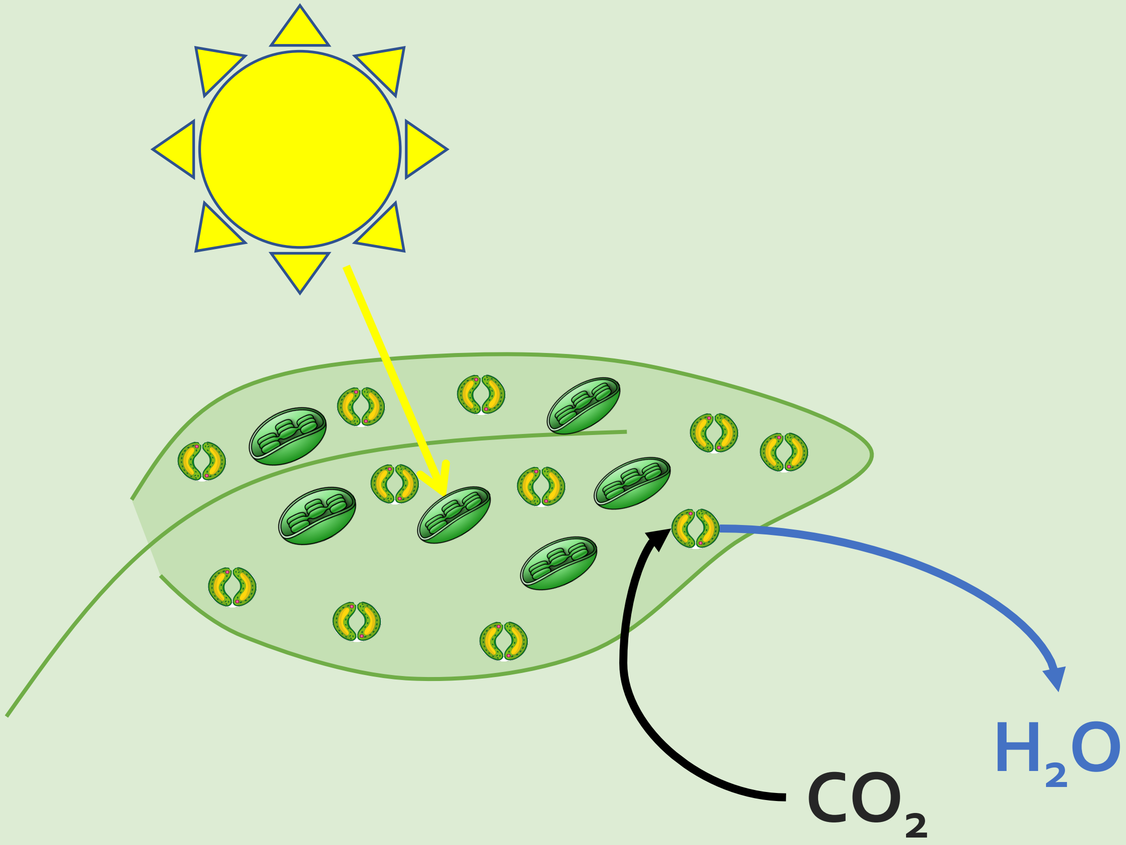
CrossMark

Jiaxin Jin[a], Wenfeng Zhan[a], Ying Wang[b], Baojing Gu[c], Weifeng Wang[d], Hong Jiang[a,*], Xuehe Lu[a], Xiuying Zhang[a]

[a] International Institute for Earth System Science, Nanjing University, Nanjing, Jiangsu, China
[b] Nanjing Institute of Geography & Limnology, Chinese Academy of Sciences, Nanjing, Jiangsu, China
[c] Department of Land Management, Zhejiang University, Hangzhou, Zhejiang, China
[d] College of Biology and the Environment, Nanjing Forestry University, Nanjing, Jiangsu, China



Background: *Leaf level models*



- **Photosynthesis model (FvCB)**

$$A_n = min(A_c, A_j) - R_{dark}$$

V_{cmax} → A_c; J_{max} → A_j

- **Conductance model (USO)**

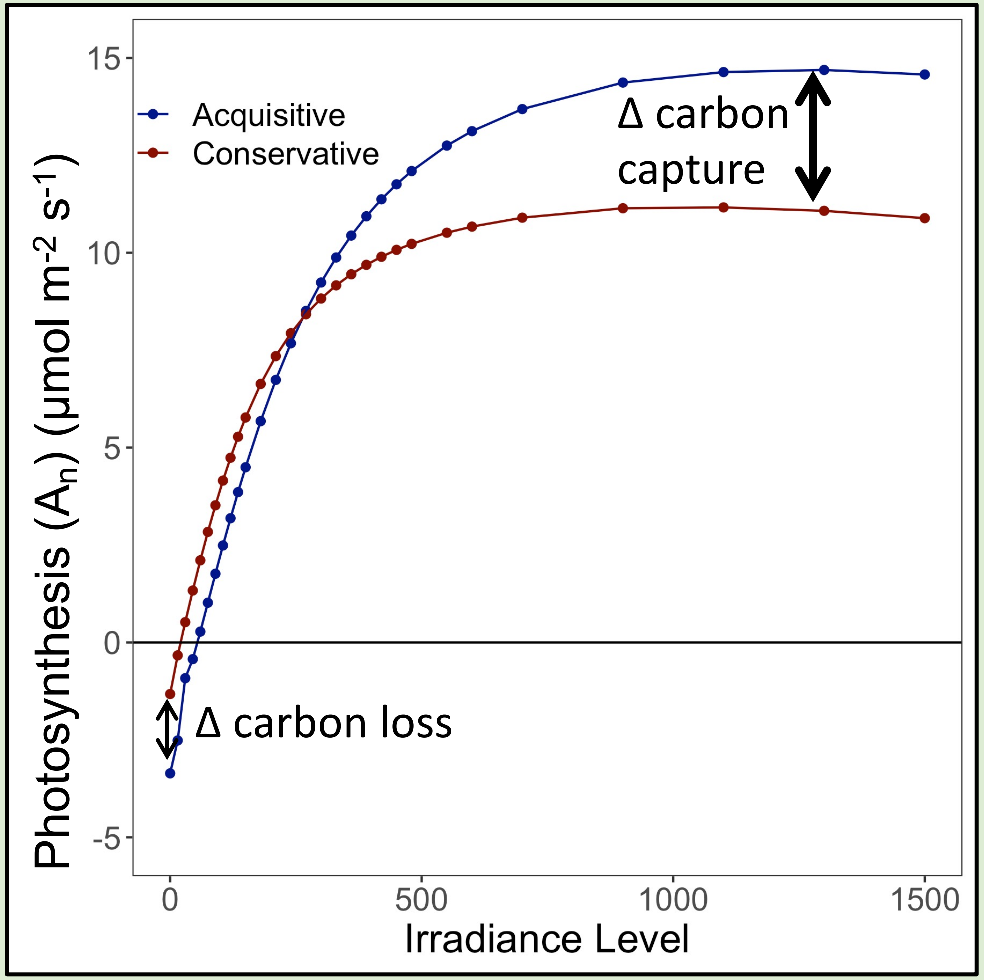
$$g_s = g_0 + 1.6\left(1 + \frac{g_1}{\sqrt{D}}\right)\frac{A_n}{C_a}$$

Background: *Photosynthetic capacity*

- $A_n = min(A_c, A_j) - R_{dark}$
- $min(A_c, A_j)$: dictates carbon capture

  V_{cmax} J_{max}

- R_{dark}: dictates respiration loss of carbon

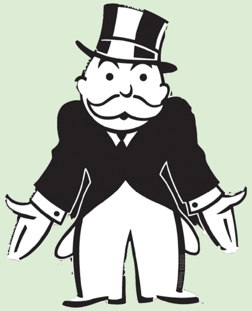


Background: *Stomatal optimality*

- Optimality theory predicts that…
  - Plants maximize carbon gain with respect to water loss (WUE)
  - Carbon has a cost in terms of water

Profligate VS **Conservative**

(Low WUE) (High WUE)



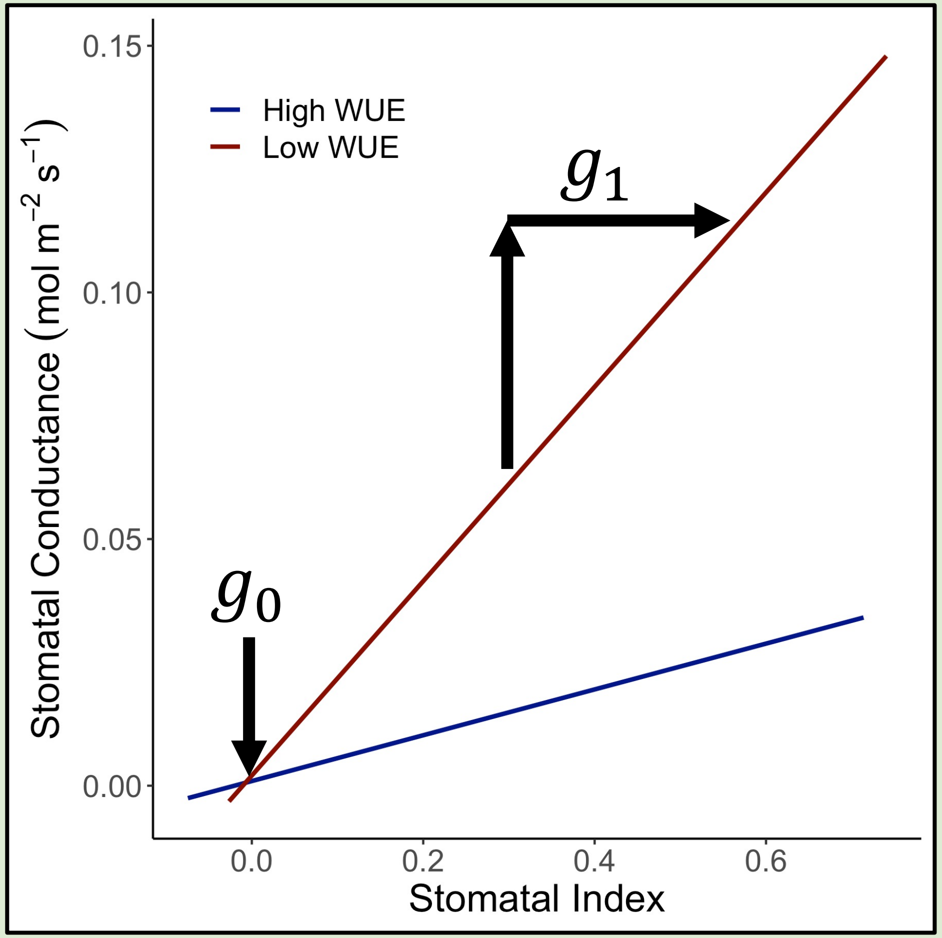
Background: *Stomatal optimality*

g_1

- Slope of relationship between the stomatal index and g_s
- Inversely proportional to WUE

g_0

- g_s when A_n is 0
- Minimum g_s in the light



Background: *Stomatal optimality*

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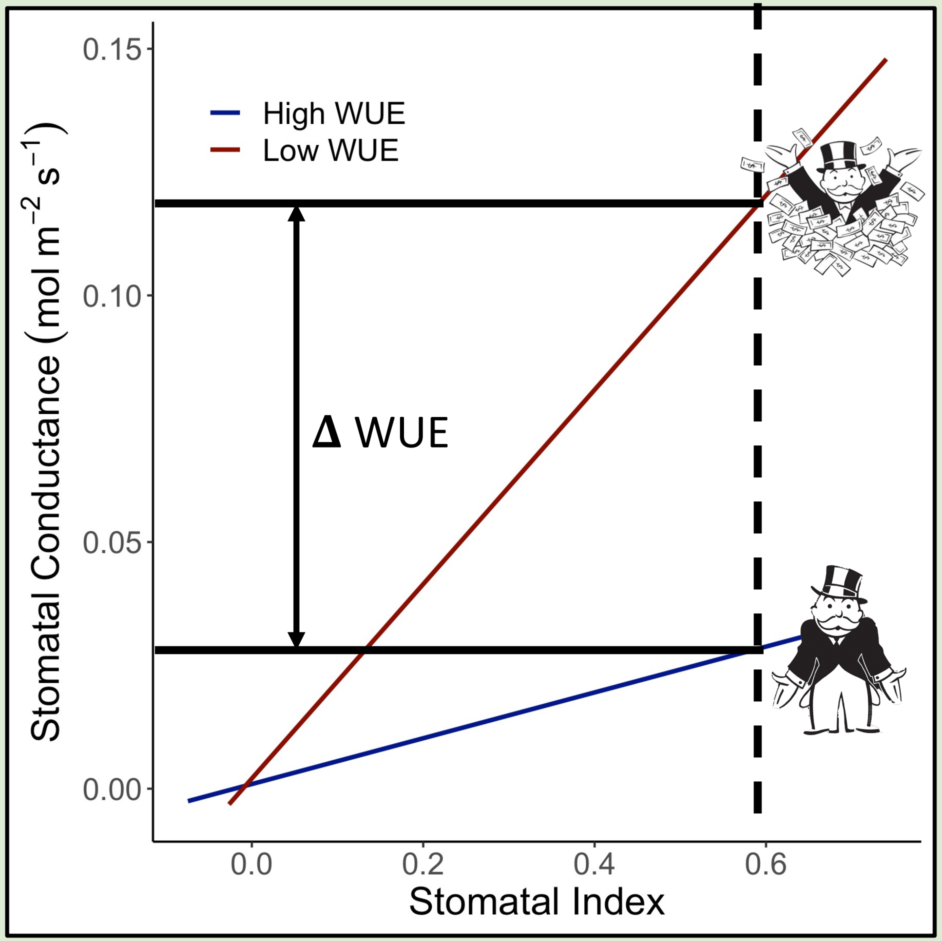
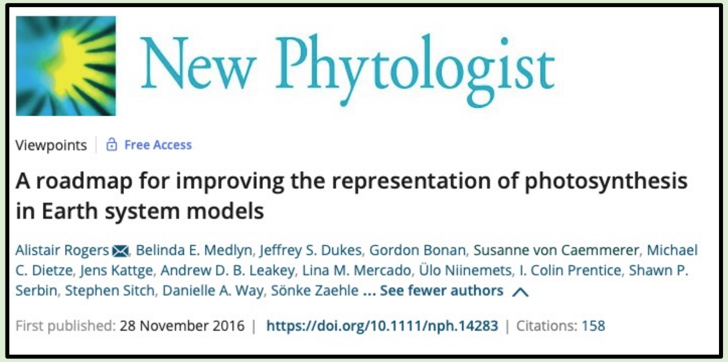


Motivation: *Why does this matter?*


New Phytologist

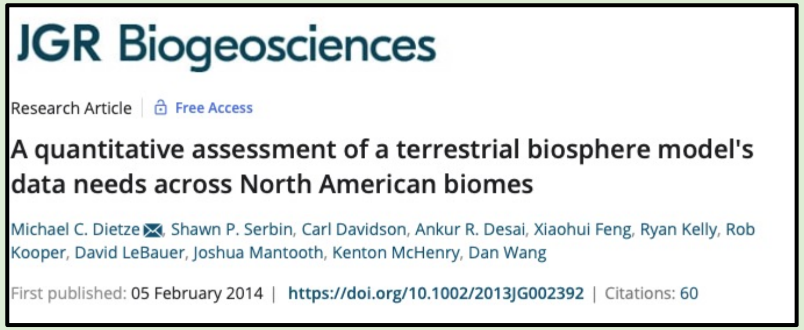
Viewpoints | Free Access

A roadmap for improving the representation of photosynthesis in Earth system models

Alistair Rogers, Belinda E. Medlyn, Jeffrey S. Dukes, Gordon Bonan, Susanne von Caemmerer, Michael C. Dietze, Jens Kattge, Andrew D. B. Leakey, Lina M. Mercado, Ülo Niinemets, I. Colin Prentice, Shawn P. Serbin, Stephen Sitch, Danielle A. Way, Sönke Zaehle ... See fewer authors

First published: 28 November 2016 | https://doi.org/10.1111/nph.14283 | Citations: 158

"We need to elucidate the mechanism underlying the use of photoperiod scalars to modify photosynthetic parameterization."
-Rogers *et al.* (2017)


JGR Biogeosciences

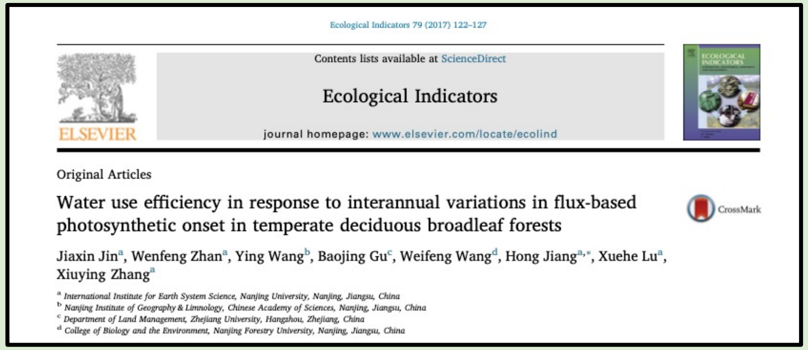
Research Article | Free Access

A quantitative assessment of a terrestrial biosphere model's data needs across North American biomes

Michael C. Dietze, Shawn P. Serbin, Carl Davidson, Ankur R. Desai, Xiaohui Feng, Ryan Kelly, Rob Kooper, David LeBauer, Joshua Mantooth, Kenton McHenry, Dan Wang

First published: 05 February 2014 | https://doi.org/10.1002/2013JG002392 | Citations: 60

"…uncertainties surrounding water relations are more important for understanding and predicting carbon fluxes than the uncertainties surrounding most of the carbon fluxes themselves."
-Dietze *et al*. (2014)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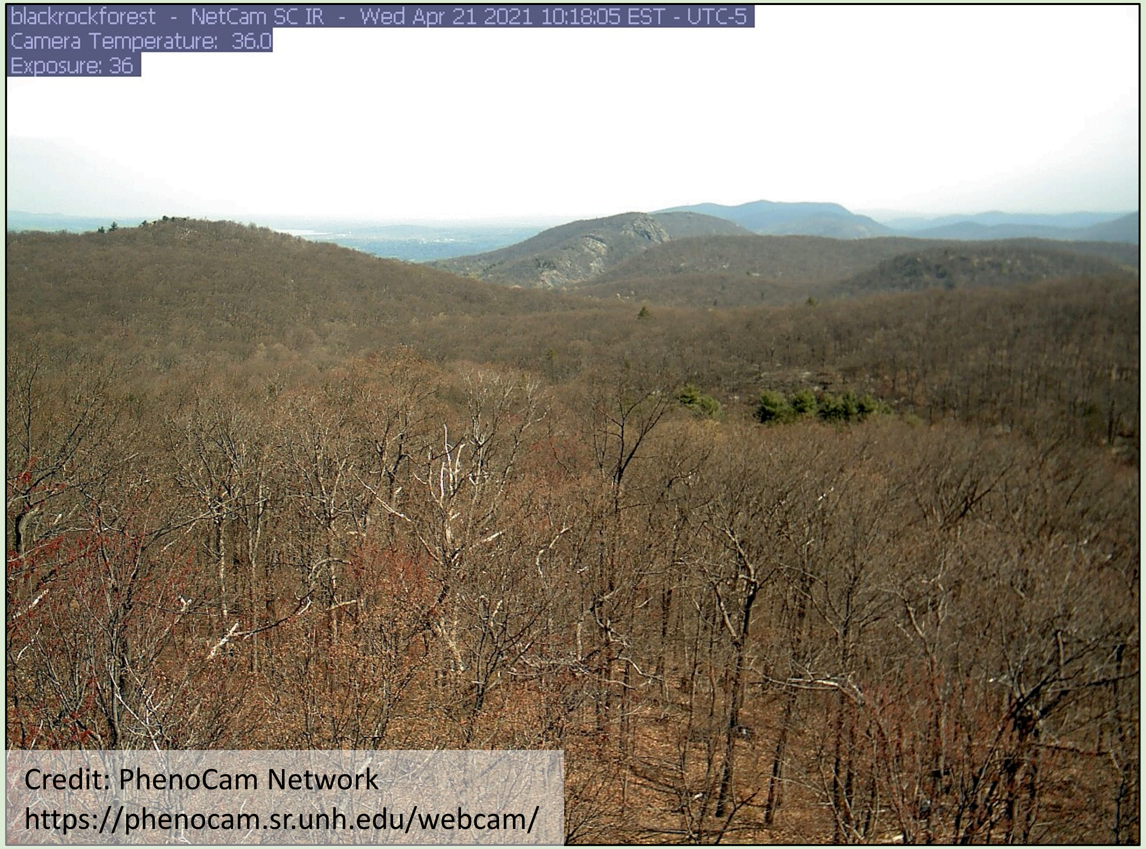
[b] Nanjing Institute of Geography & Limnology, Chinese Academy of Sciences, Nanjing, Jiangsu, China
[c] Department of Land Management, Zhejiang University, Hangzhou, Zhejiang, China
[d] College of Biology and the Environment, Nanjing Forestry University, Nanjing, Jiangsu, China

"Here, we argue that phenology, which exerts critical biotic control over most ecological processes, plays a larger role than expected in the regulation of the seasonal WUE and cannot be ignored in earth system models."
–Jin *et al.* (2017)

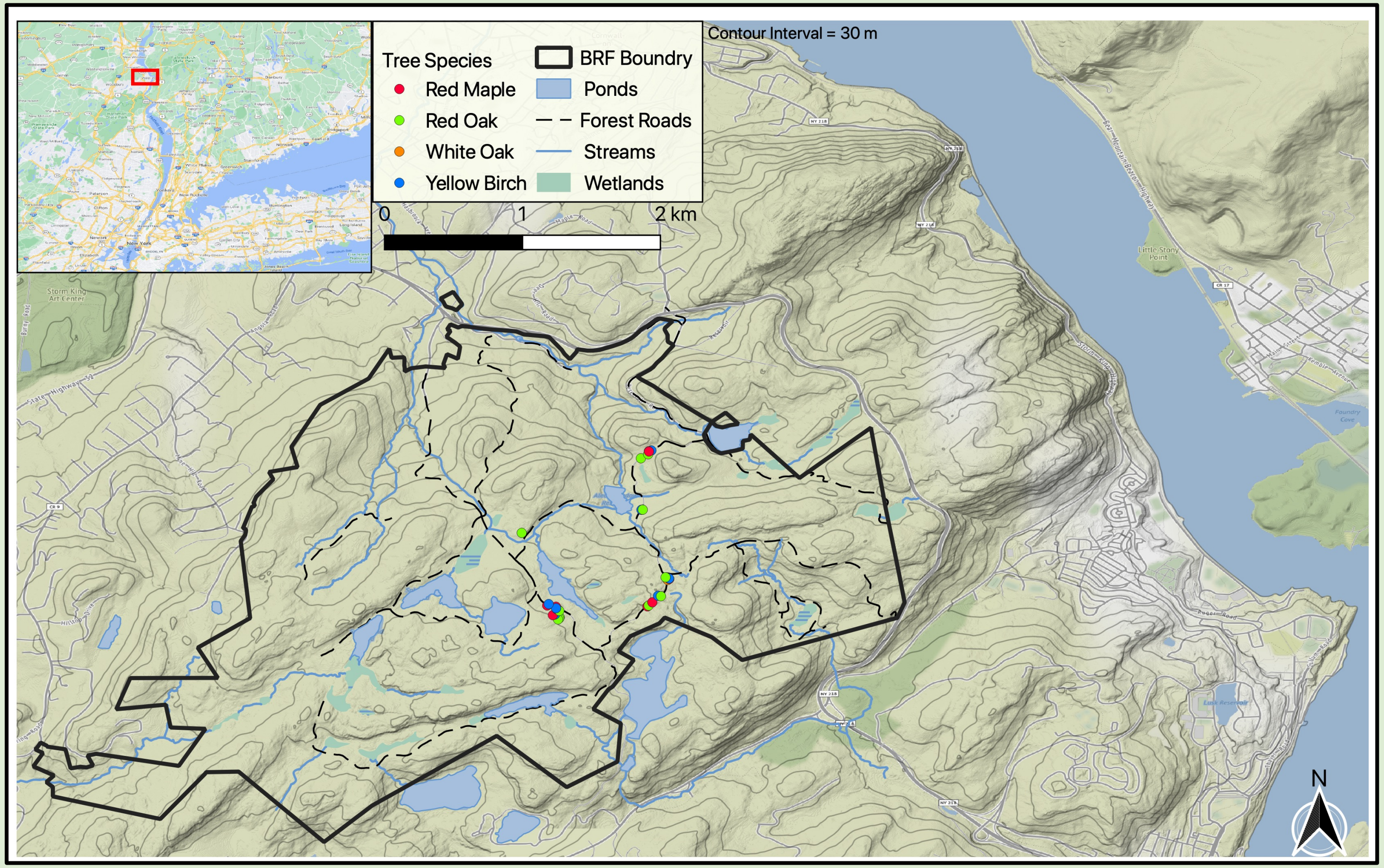
<u>Our models are only as good as our weakest assumptions</u>

Research Questions:

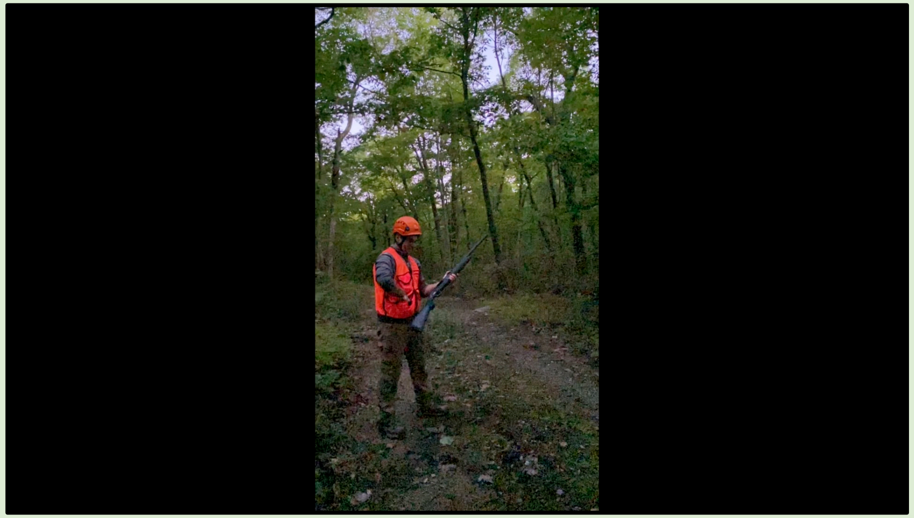
- What are the seasonal patterns of WUE and photosynthetic capacity?
- What are the biotic mediators of these patterns?
- How does a seasonal parameterization of leaf WUE and photosynthetic capacity impact the modeling of *E* and NPP?



Methods: *Study site*



Methods: *Canopy access*



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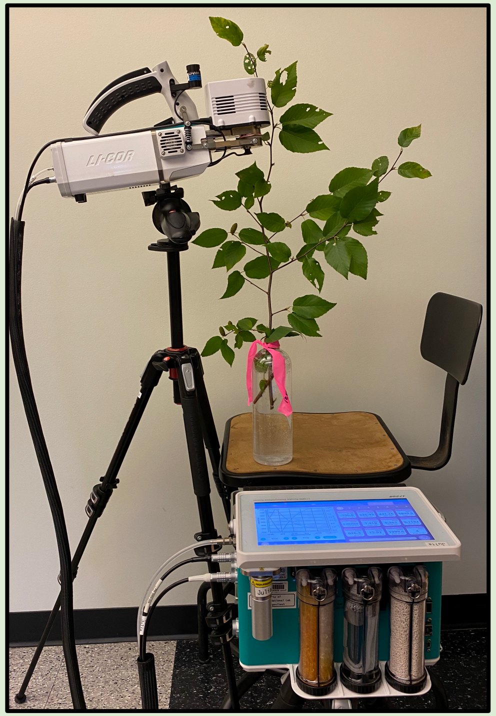
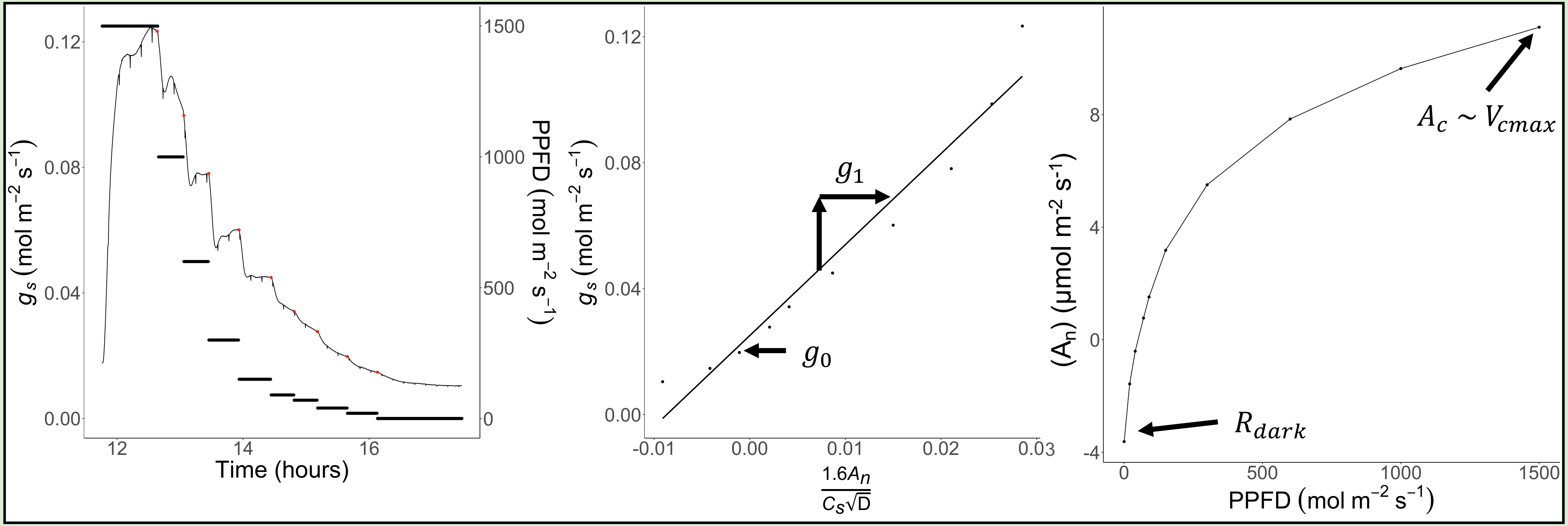
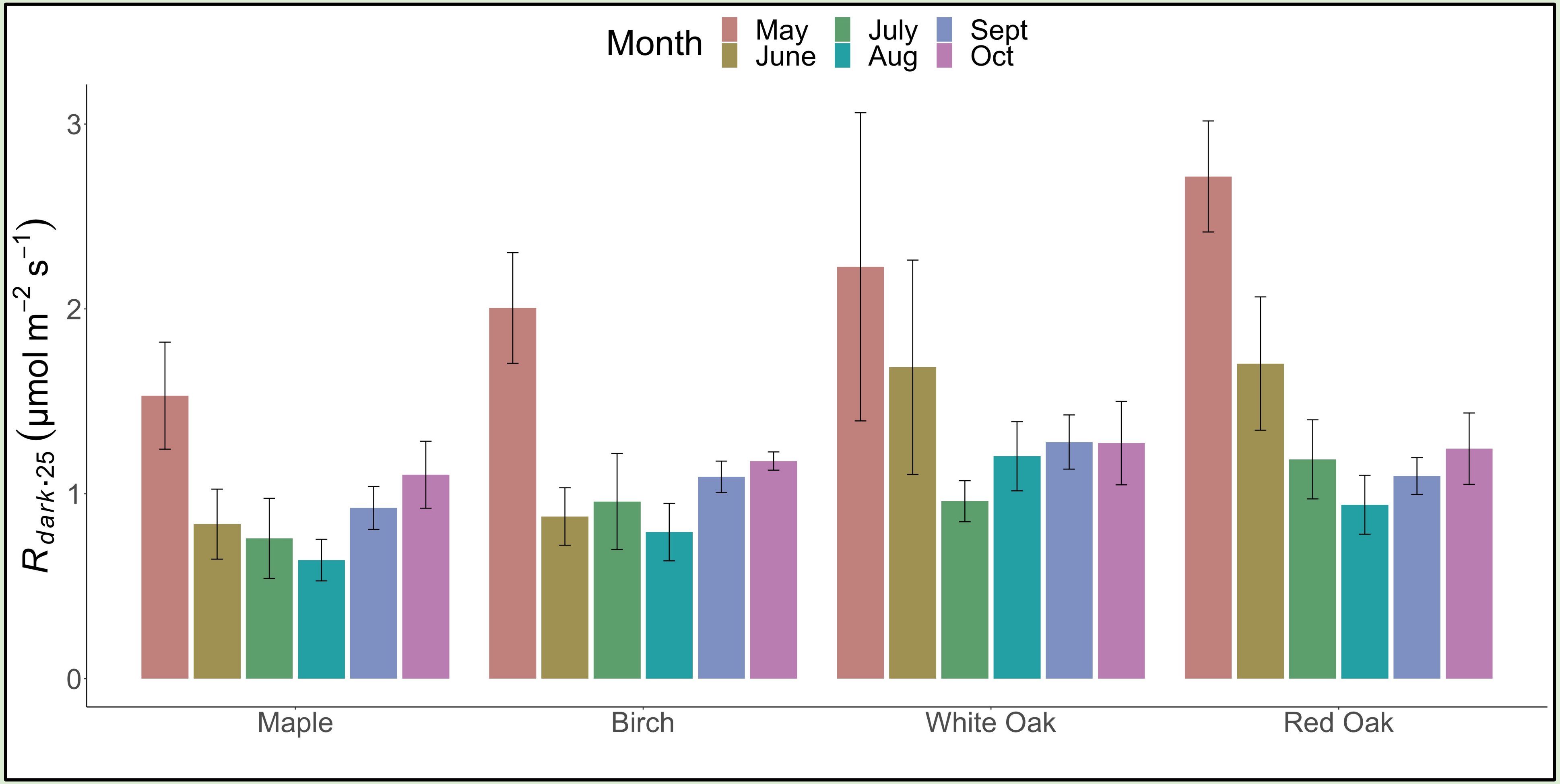


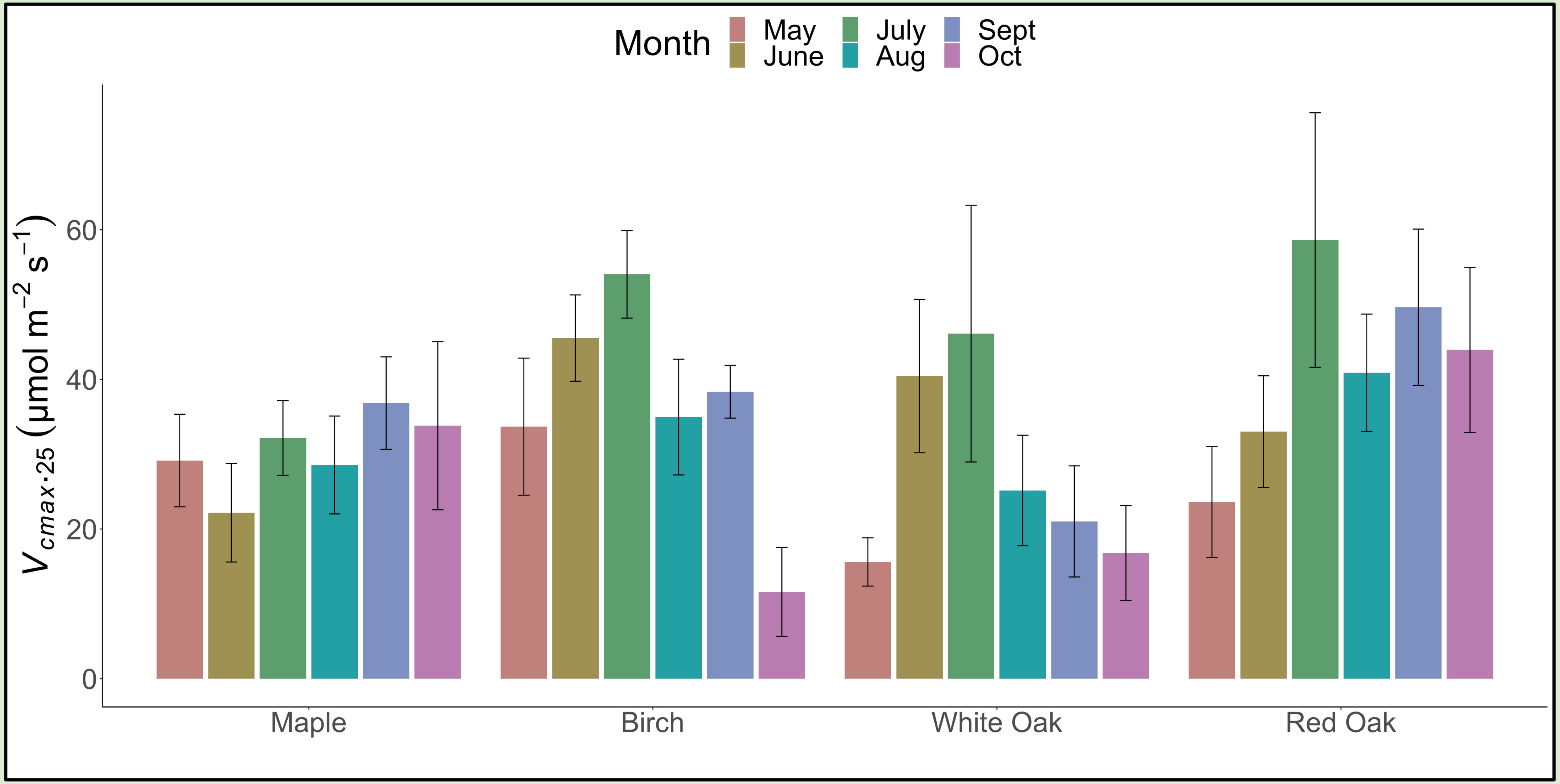
Methods: *Gas exchange*



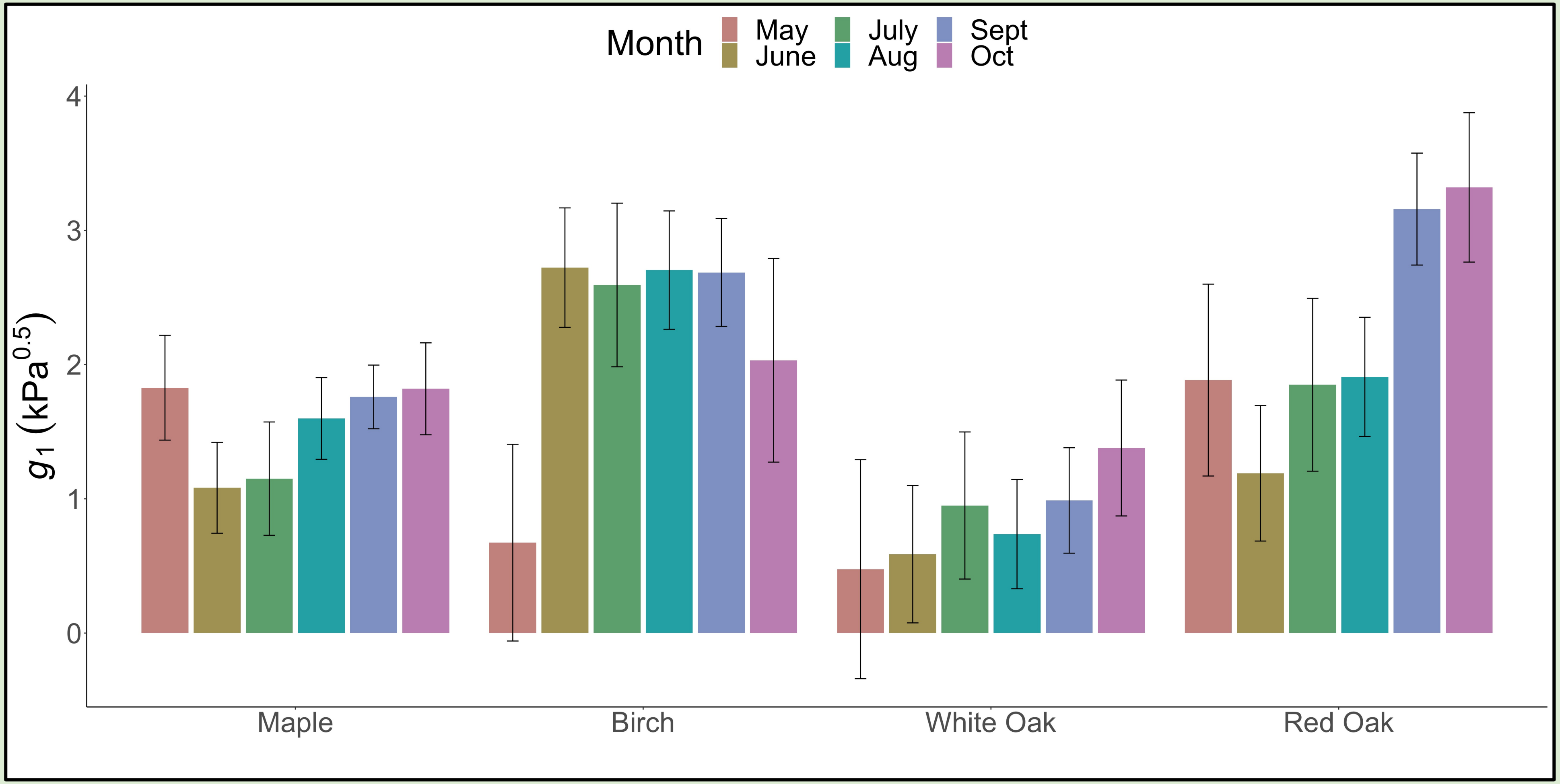
Results: *Dynamics of Photosynthesis*



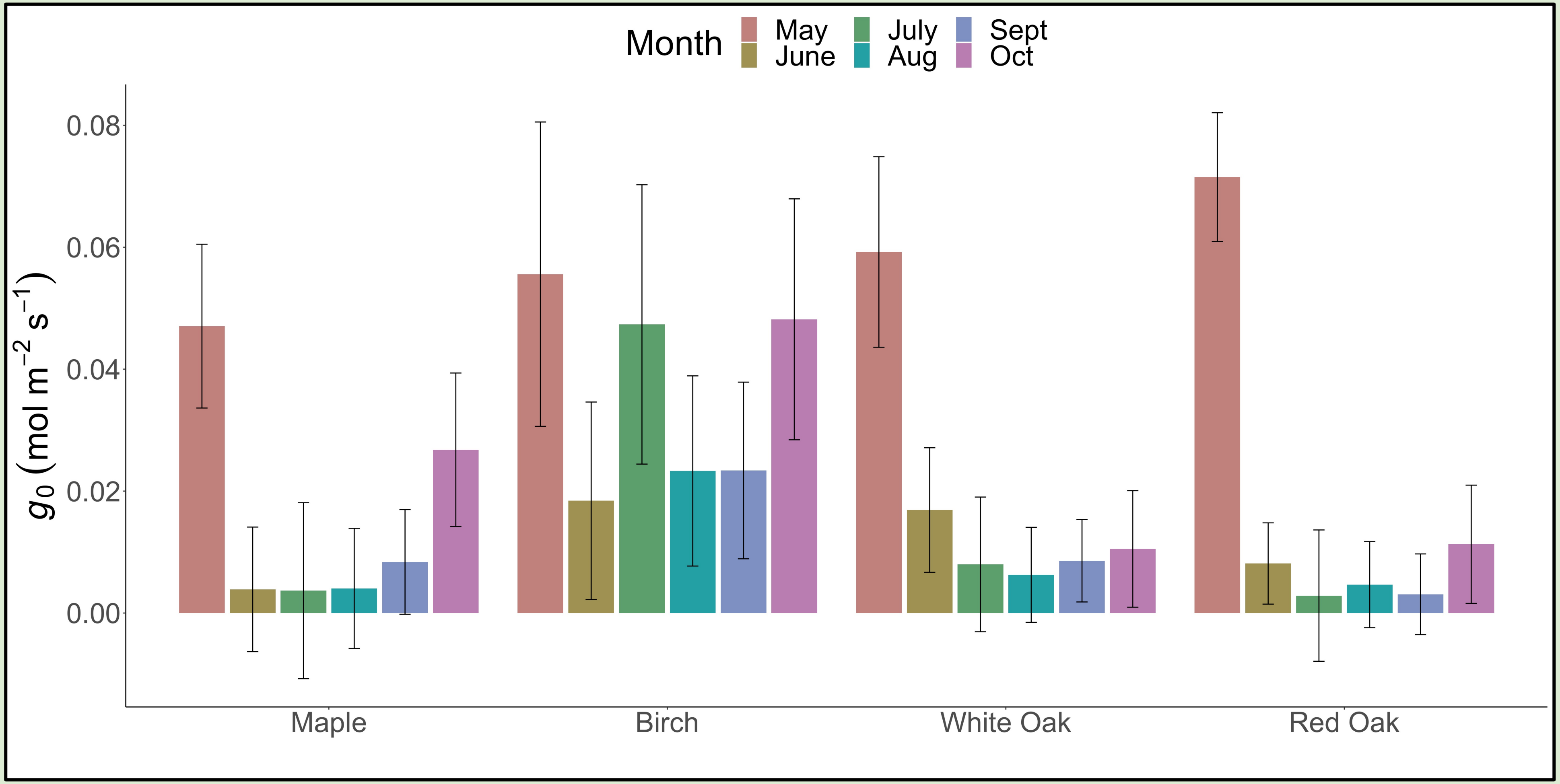
Results: *Dynamics of Photosynthesis*



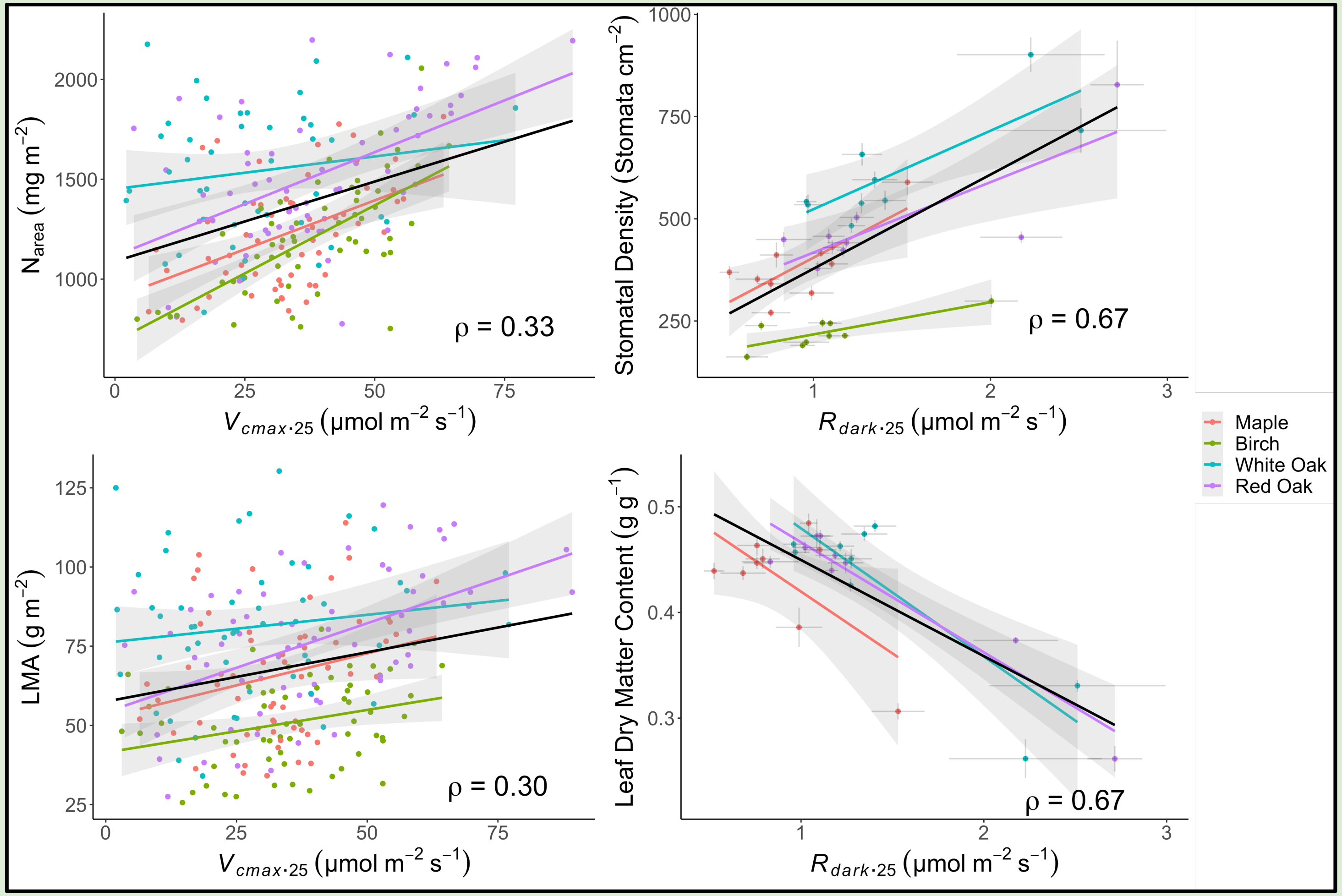
Results: *Dynamics of WUE*



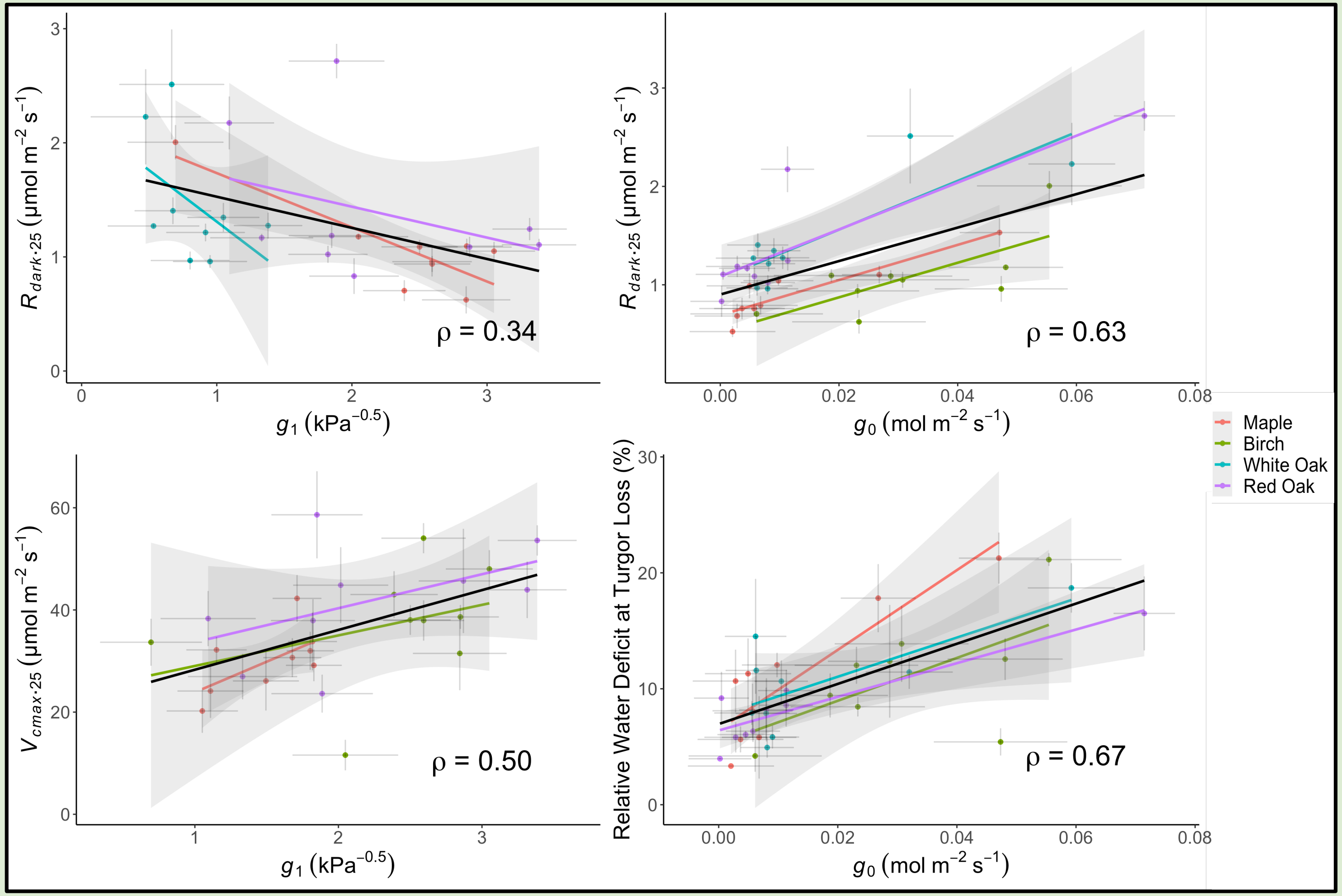
Results: *Dynamics of WUE*



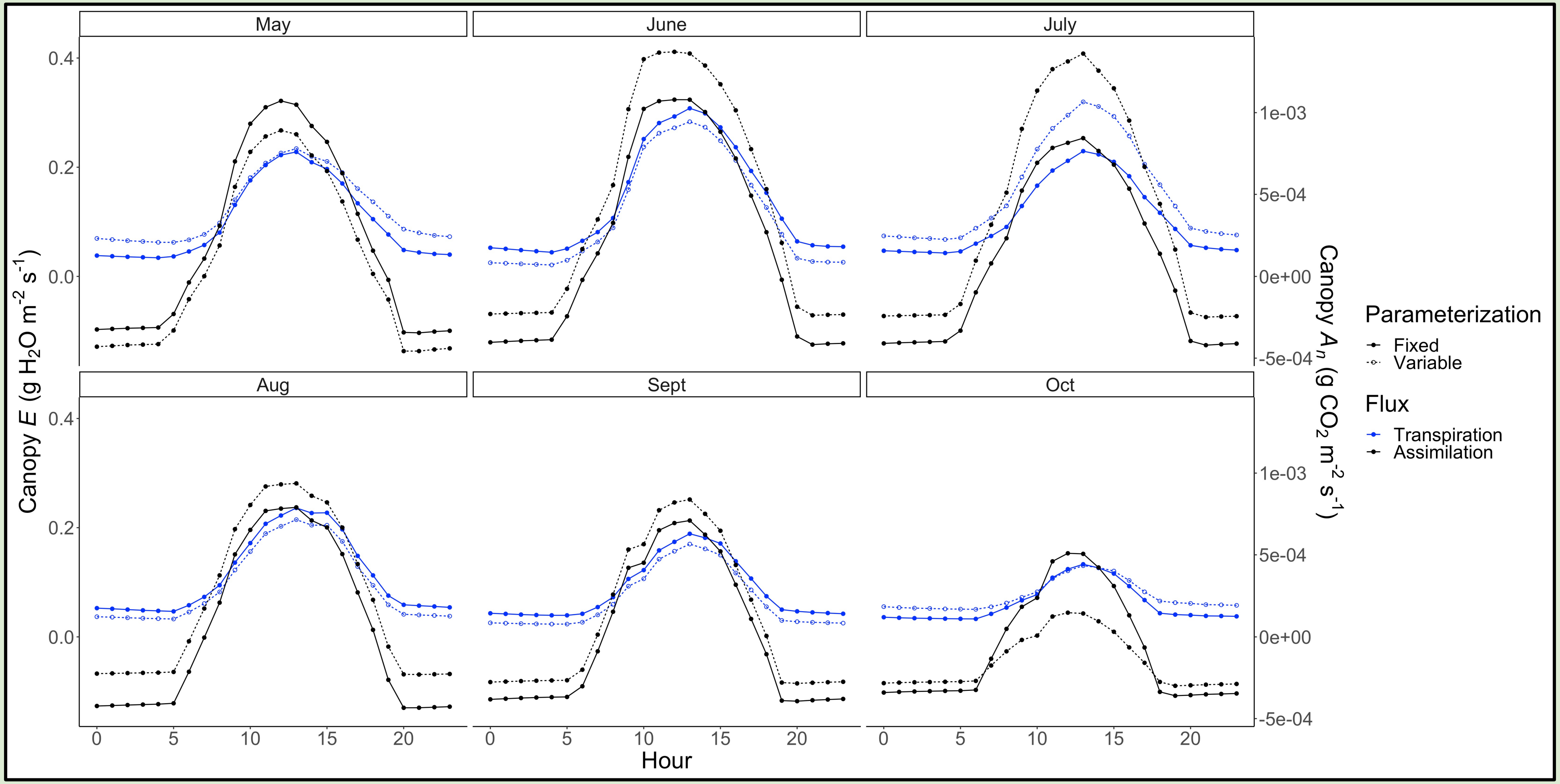
Results: *Biotic mediators of photosynthesis*



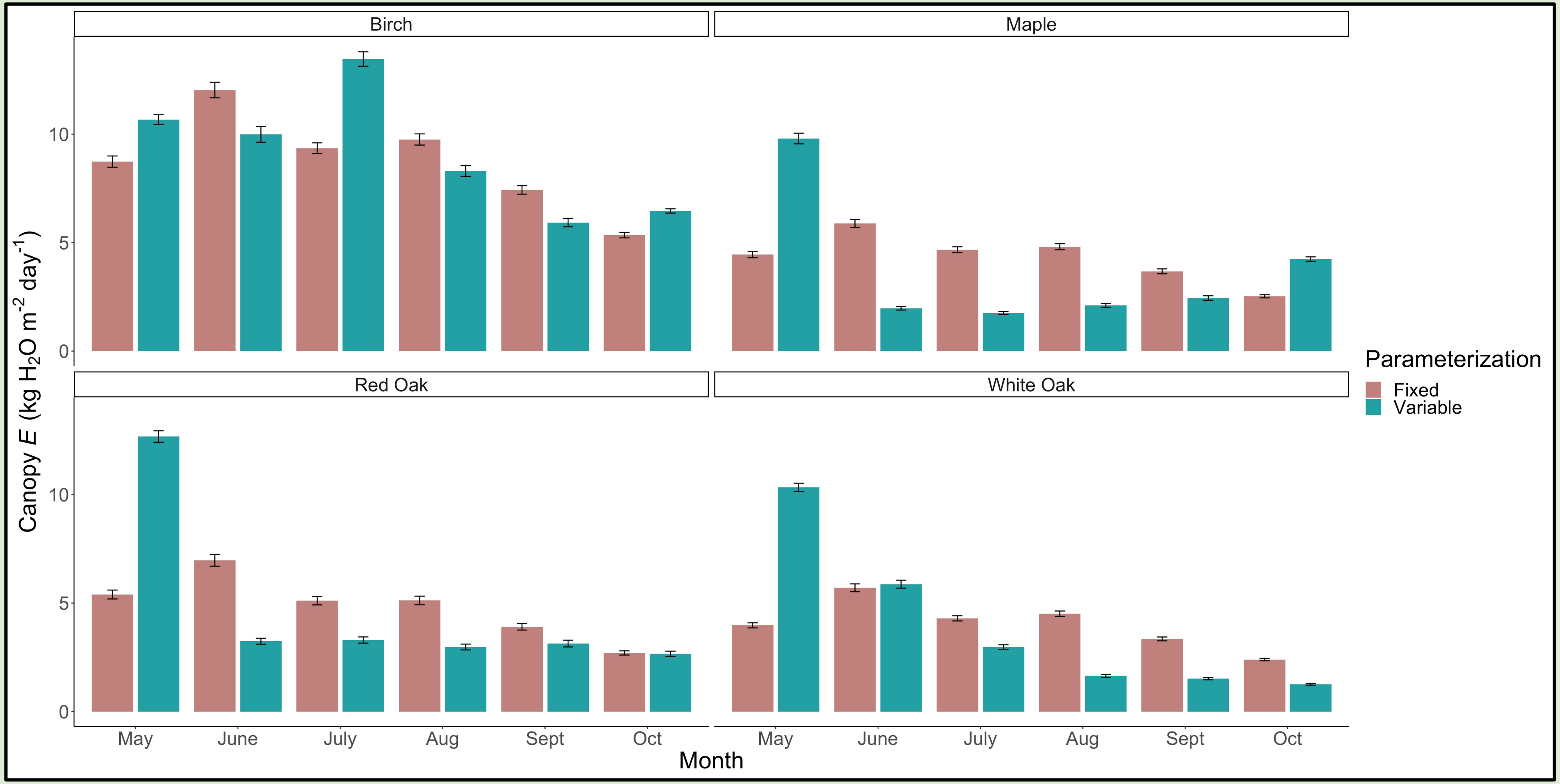
Results: *Biotic mediators of WUE*



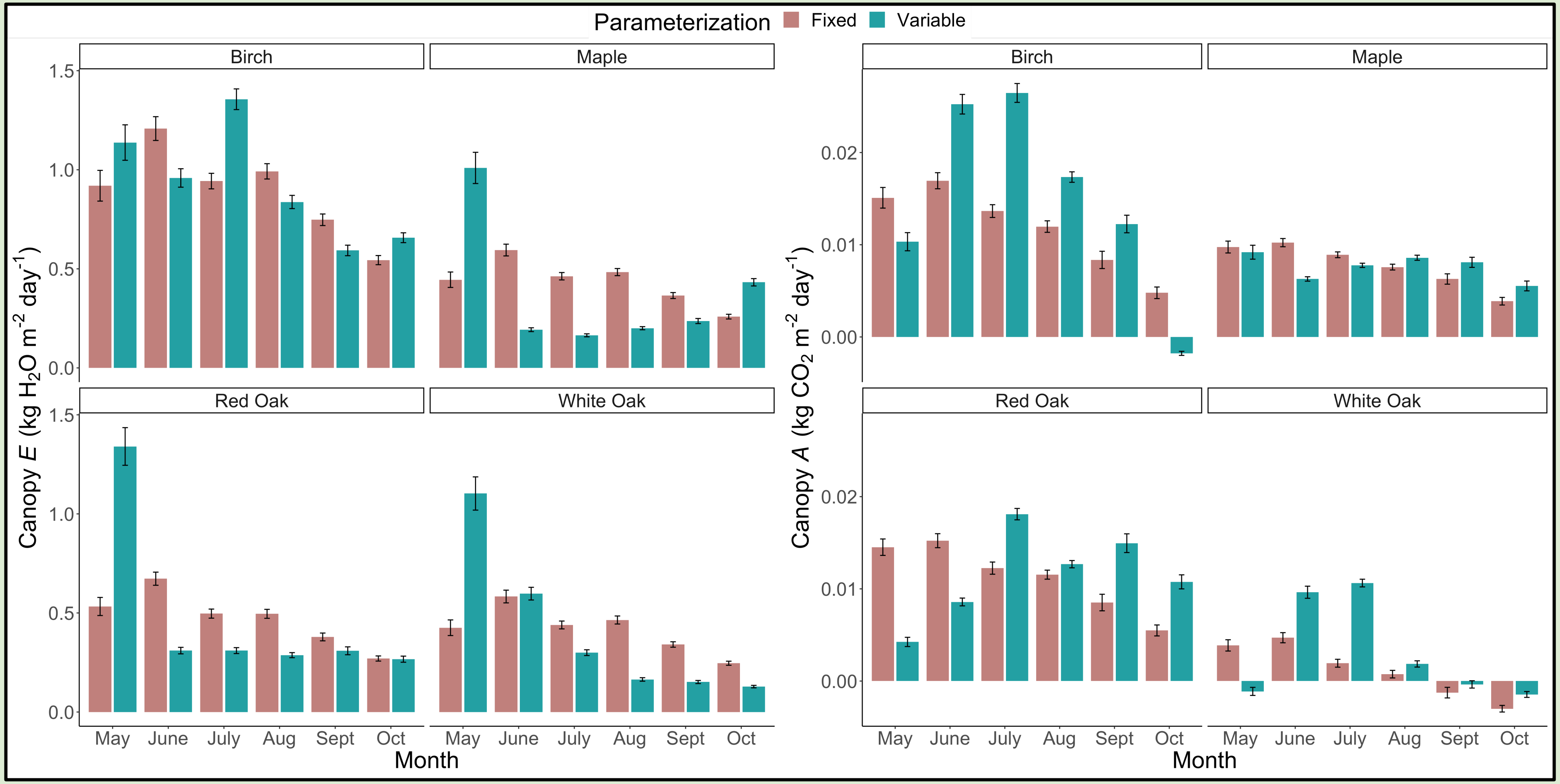
Results: *Diurnal patterns*



Results: *Seasonal patterns*



Results: *Seasonal patterns*



Using fixed values…

- 3% lower estimate of assimilation
- 16% lower estimate of transpiration

Implications: *Why does this matter?*

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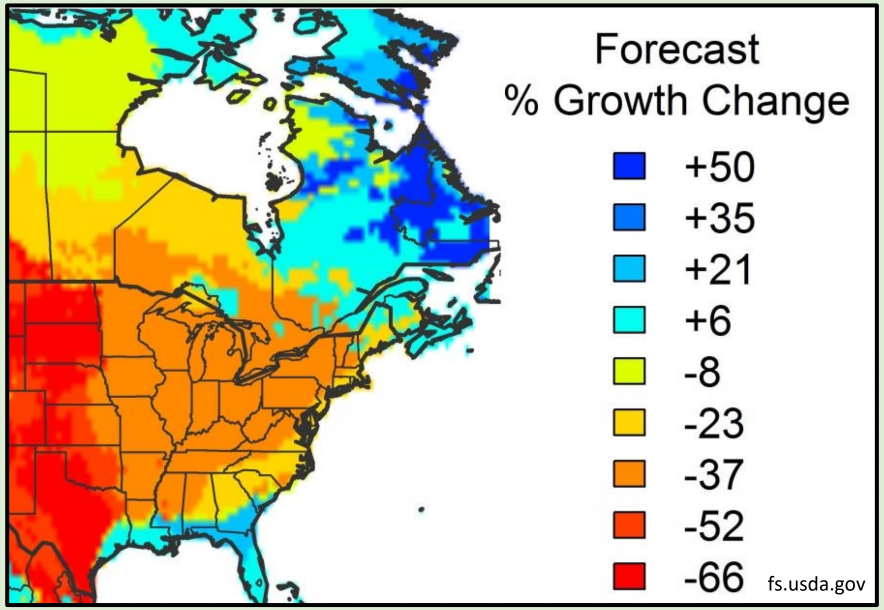

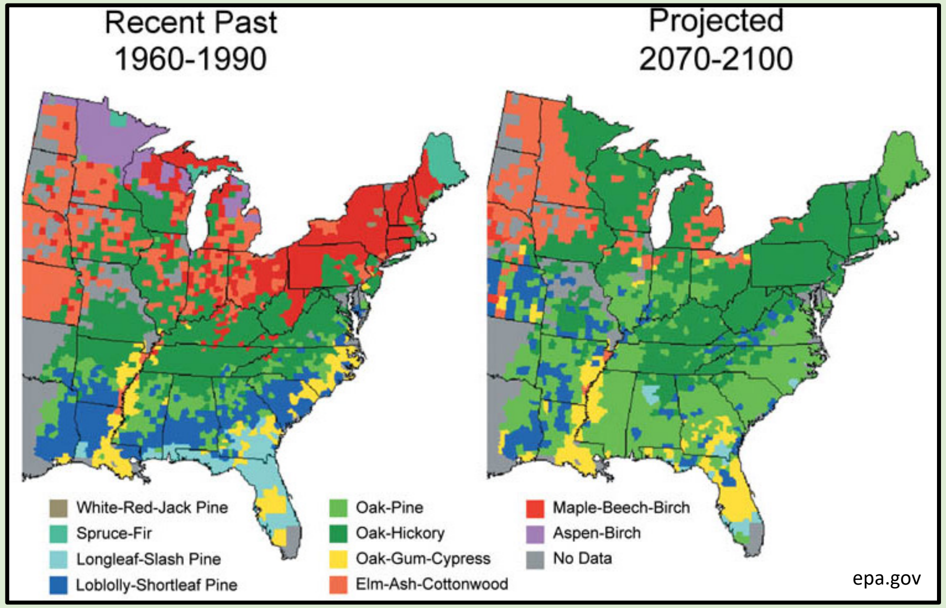

"In New York, habitat for red maple (*Acer rubrum*) and sugar maple (*Acer saccharum*) would decline substantially but not disappear, while most of the habitat is projected to disappear for yellow birch (*Betula alleghaniensis*)…. Species with a high possibility of dramatic increases include several oak species" –USFS Climate Change Atlas

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Julien Lamour (BNL)

Shawn Serbin (BNL)

Anna McPherran (SBU)

Brookhaven National Laboratory

U.S. DEPARTMENT OF ENERGY Office of Science

Next-Generation Ecosystem Experiments-Tropics

Stony Brook University

Questions?

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