Photosynthetic acclimation through the lens of optimality

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Photosynthesis is important!

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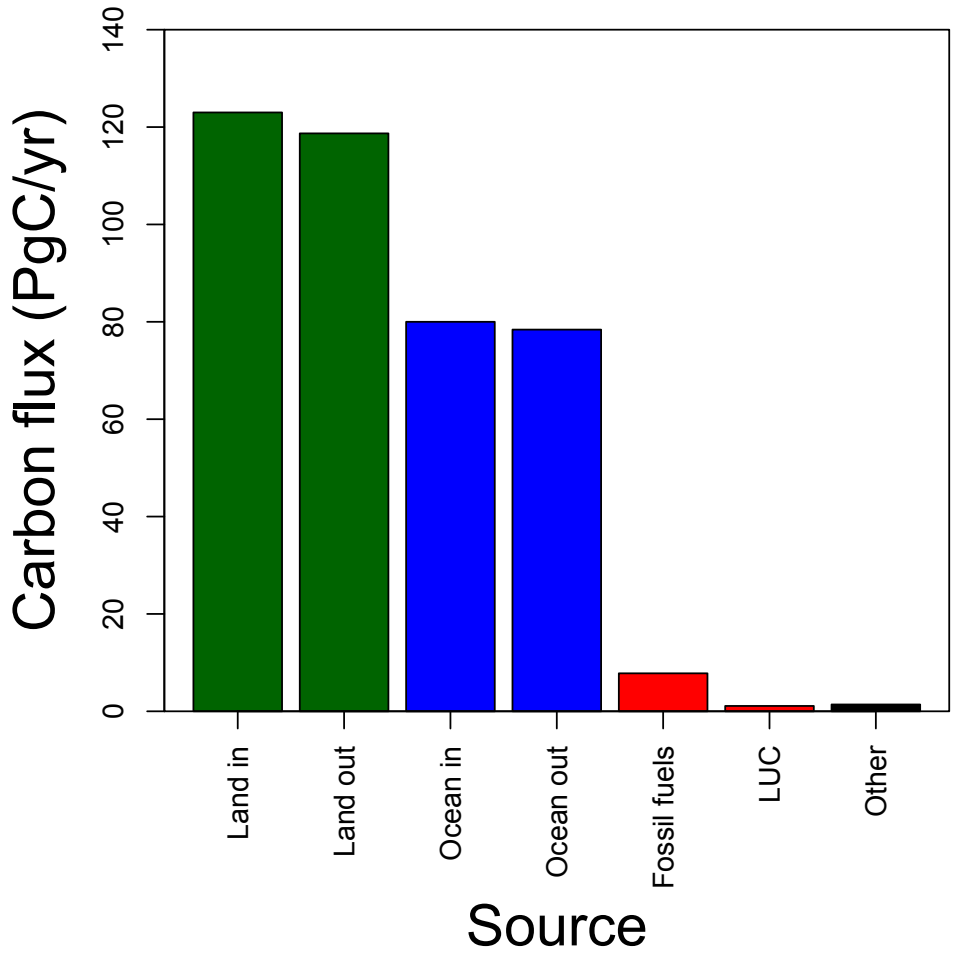

Data from IPCC (2013)

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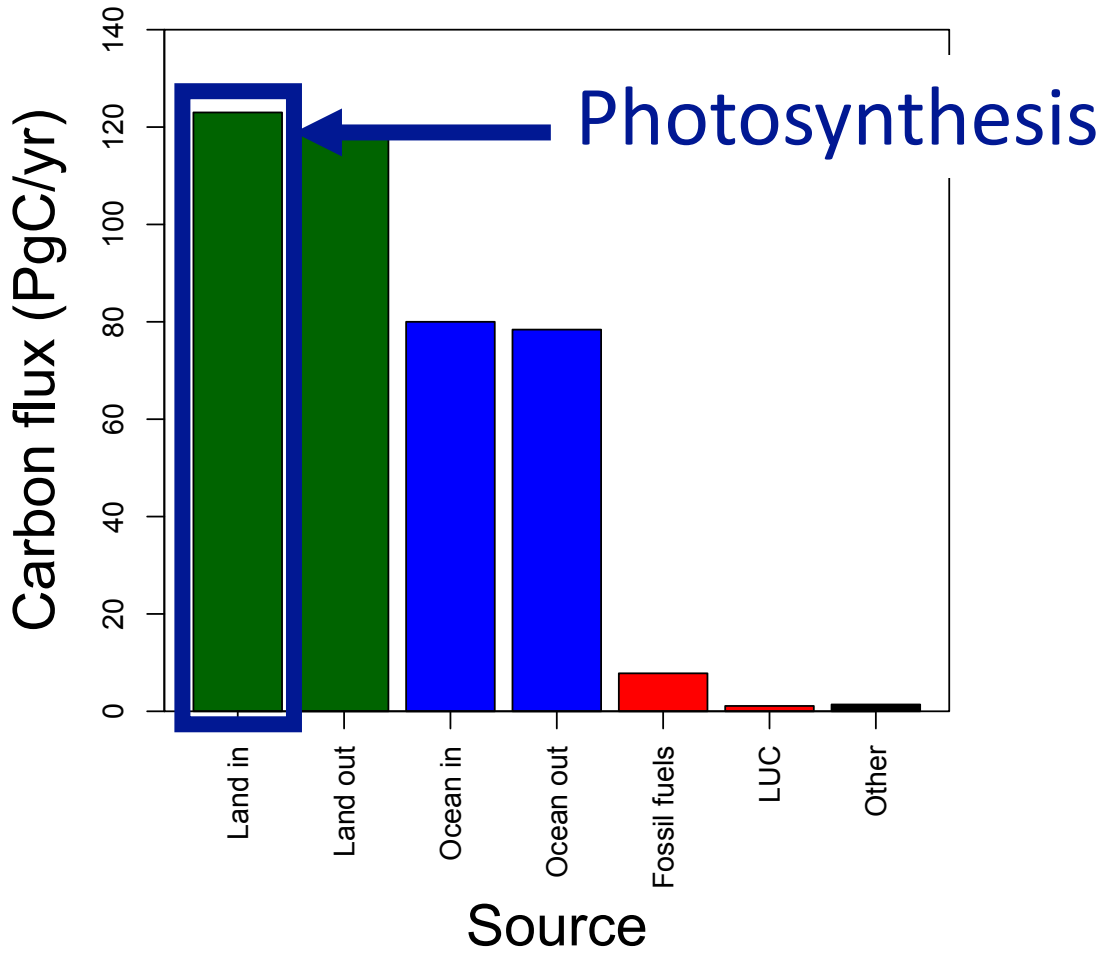
Photosynthesis is important!



Data from IPCC (2013)

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Theoretical models for photosynthesis exist

Planta 149, 78–90 (1980)

Planta

A Biochemical Model of Photosynthetic CO_2 Assimilation in Leaves of C_3 Species

G.D. Farquhar[1], S. von Caemmerer[1], and J.A. Berry[2]

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[2] Carnegie Institution of Washington, Department of Plant Biology, Stanford, Cal. 94305, USA

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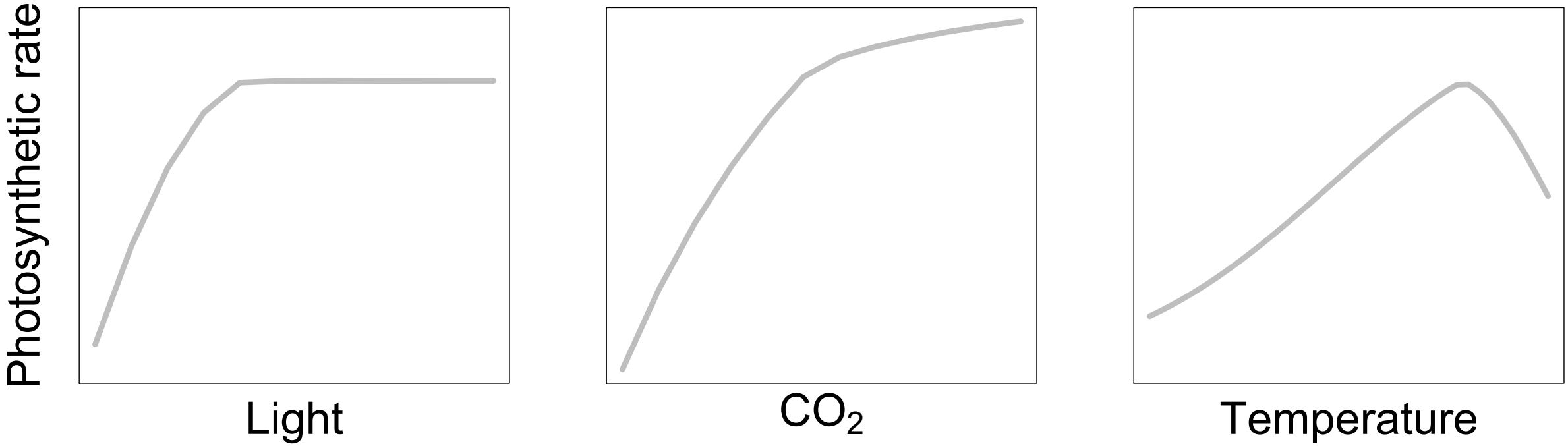
And short-term responses are well known!



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Long-term responses can differ from short-term responses due to acclimation

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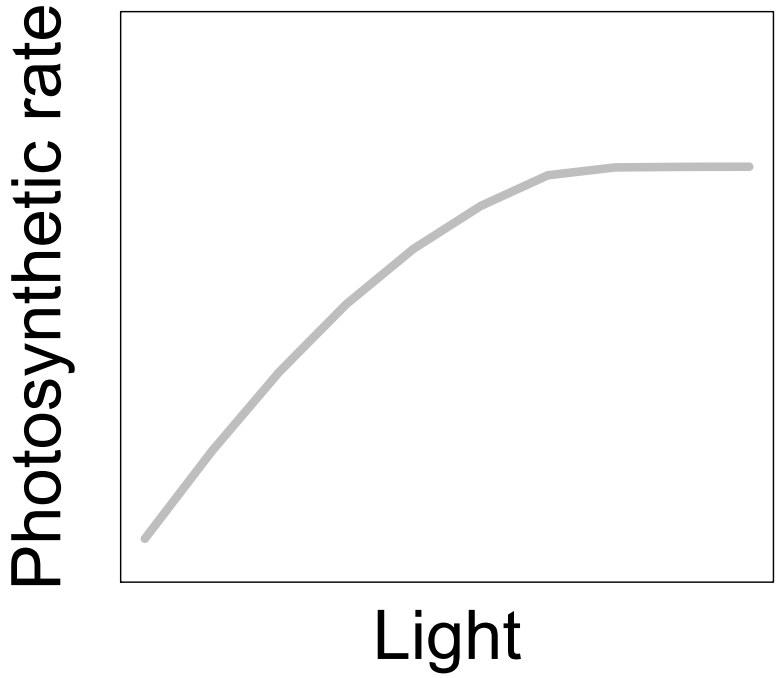
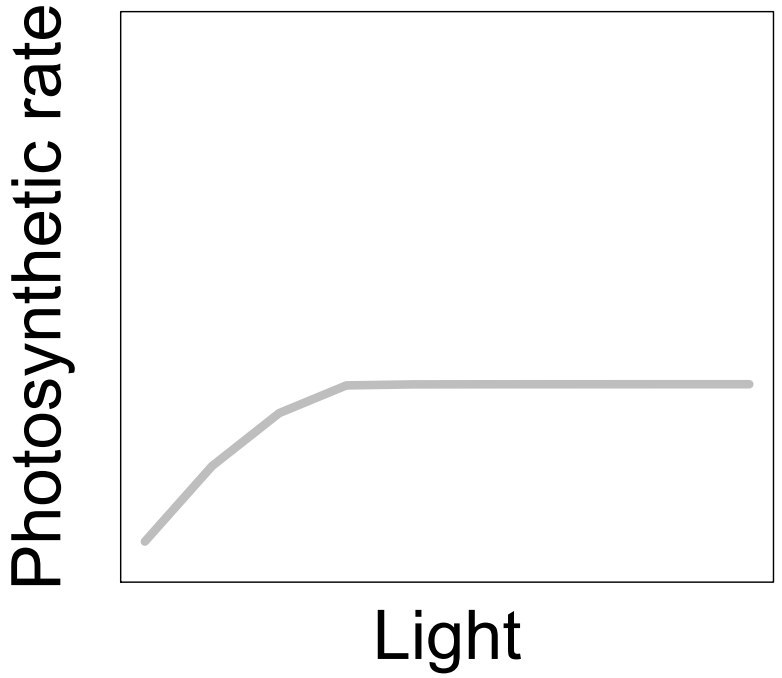
Long-term responses can differ from short-term responses due to acclimation

Acclimated to high light



Acclimated to low light



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Acclimation is ubiquitous and well known…

CO_2: Bazzaz (1990)

Annu. Rev. Ecol. Syst. 1990. 21:167–96

THE RESPONSE OF NATURAL ECOSYSTEMS TO THE RISING GLOBAL CO_2 LEVELS

F. A. Bazzaz

Light: Boardman (1977)

Ann. Rev. Plant Physiol. 1977. 28:355–77

COMPARATIVE PHOTOSYNTHESIS OF SUN AND SHADE PLANTS

N. K. Boardman
Division of Plant Industry, CSIRO, Canberra City, A.C.T. 2601, Australia

Temperature: Berry & Björkman (1980)

Ann. Rev. Plant Physiol. 1980. 31:491–543

PHOTOSYNTHETIC RESPONSE AND ADAPTATION TO TEMPERATURE IN HIGHER PLANTS

Joseph Berry and Olle Björkman[1]

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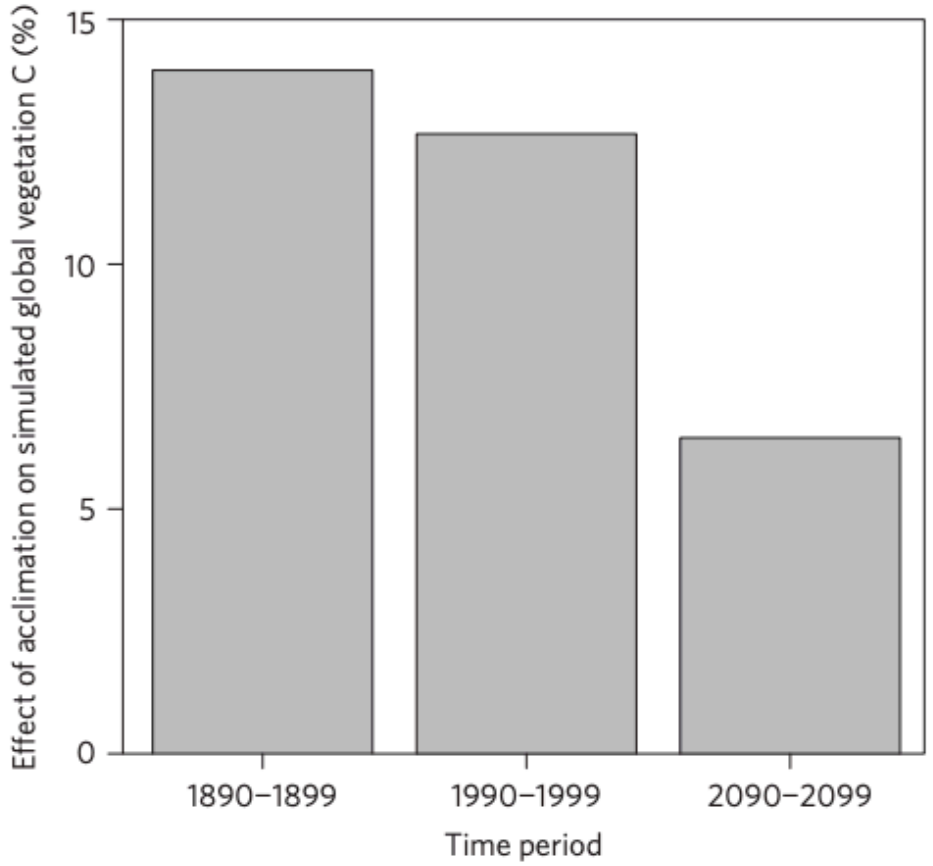
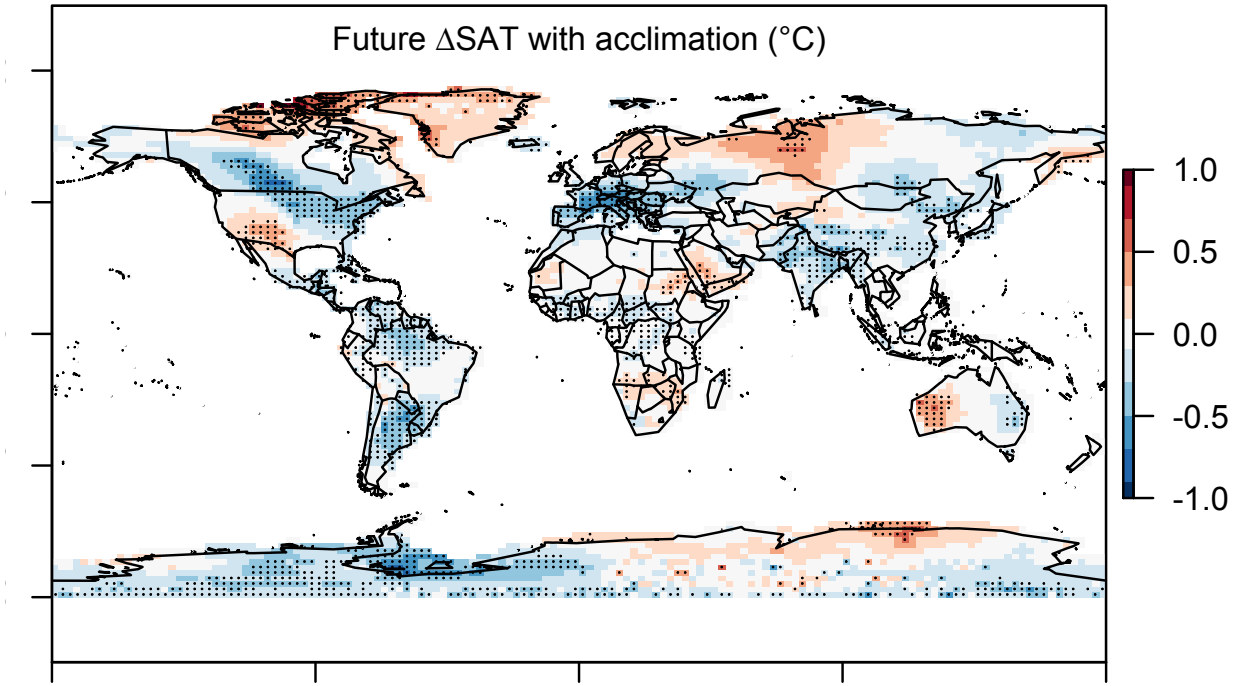
…and can impact carbon cycling and climate…

Acclimation increase future C storage by ~6%



Acclimation alters future temperature by >1°C



Smith et al. (2017) *Nature Climate Change*

Smith et al. (2017) *JAMES*

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…but the mechanisms underlying photosynthetic acclimation are not well known

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Solution: A testable, theoretical model!

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Least cost theory

Maintain fastest rate of photosynthesis at the lowest cost (water and nutrient use)

Wright et al. (2003) *American Naturalist*

Biochemistry optimization: Coordination hypothesis

Photosynthesis may be limited by **multiple processes**

Biochemistry optimization: Coordination hypothesis

Photosynthesis may be limited by **multiple processes**

Optimally, plants will coordinate their biochemistry to be equally limited by these processes

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Coordination of photosynthesis

Optimally…

$$A_c = A_j$$

Carboxylation-limited photosynthesis

Electron transport-limited photosynthesis

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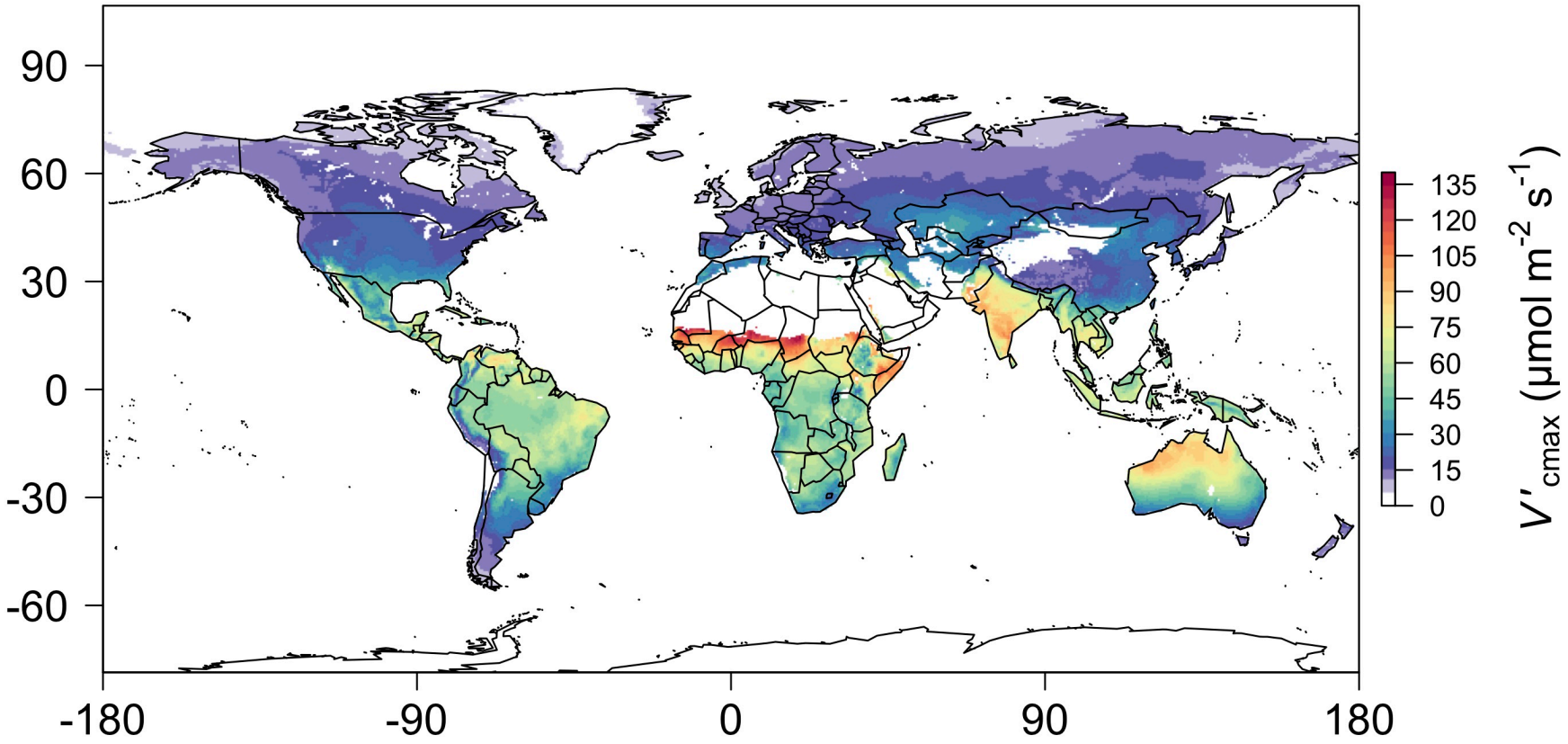
We can predict optimal traits in different envionrments



Smith et al. (2019) *Ecology Letters*

Ok, great, but now what?

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Let’s tackle some big questions in plant ecophysiology!

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Question 1: Is photosynthesis optimized to the environment?

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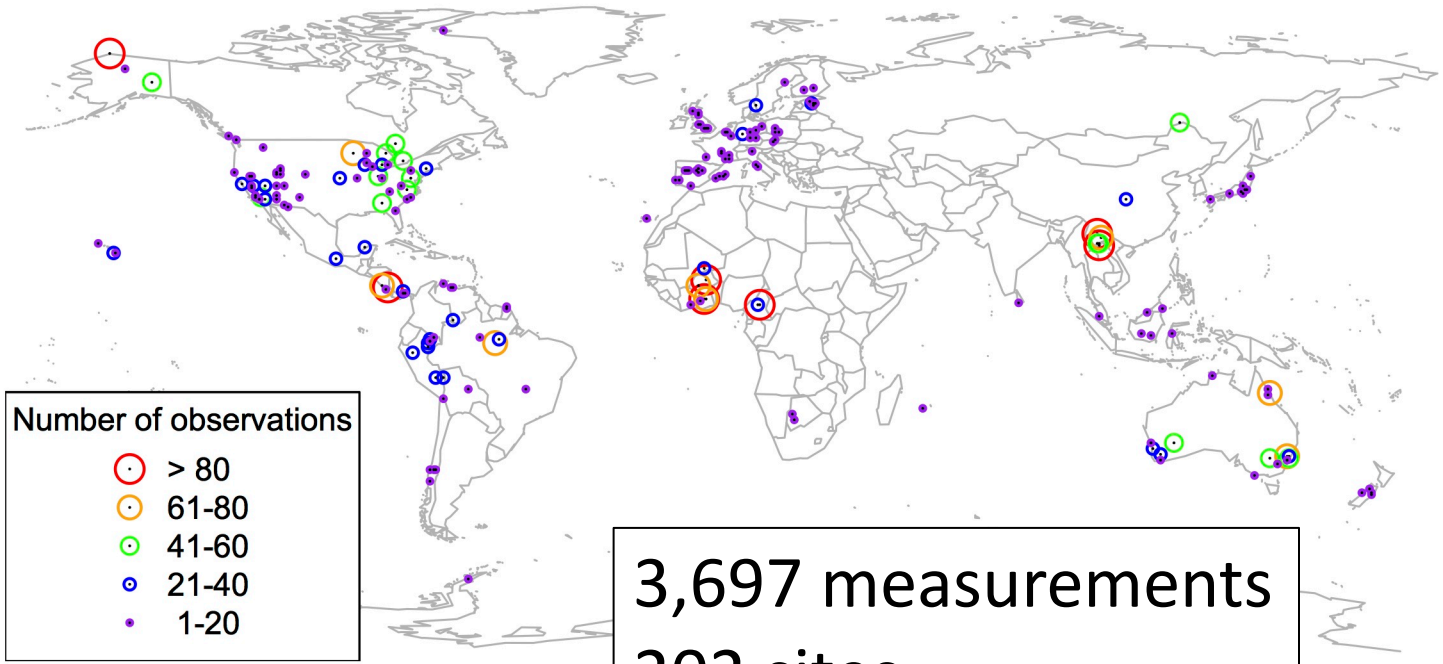
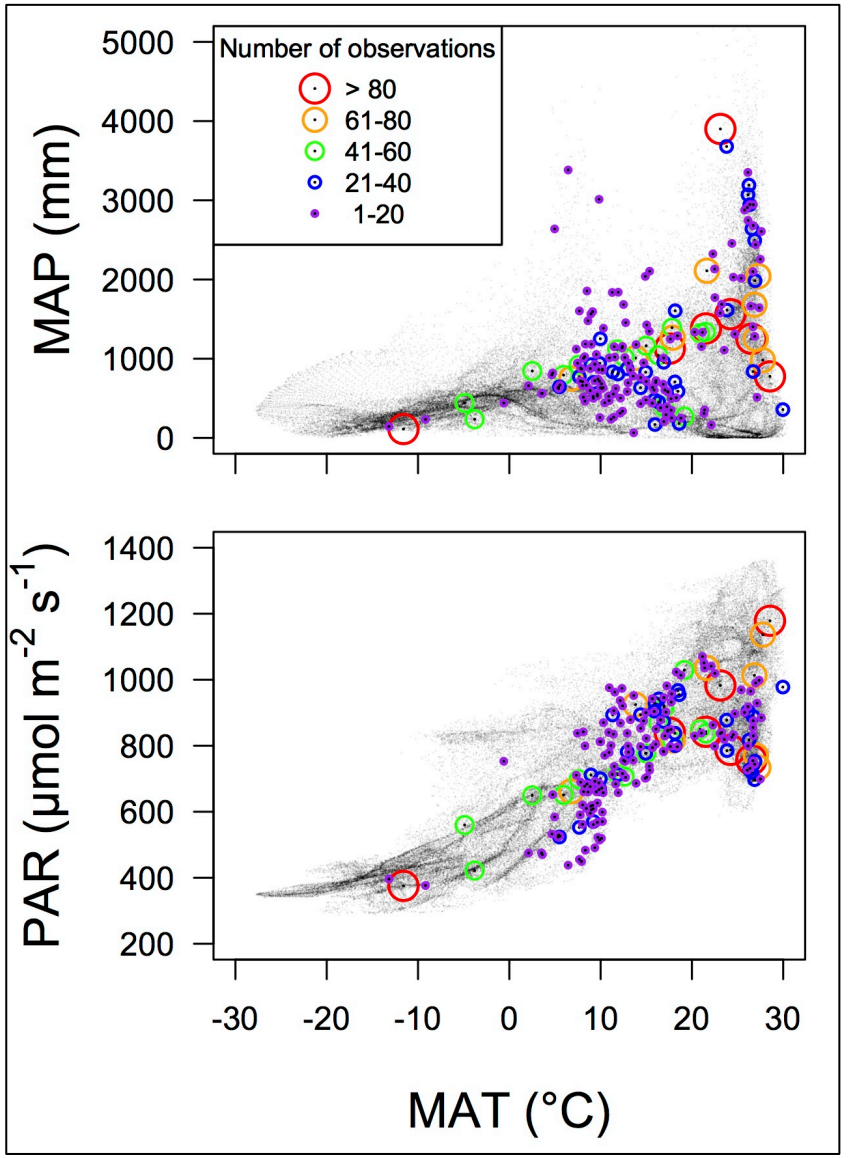
Global V_{cmax} dataset



3,697 measurements
202 sites
> 600 genera



Smith et al. (2019) *Ecology Letters*

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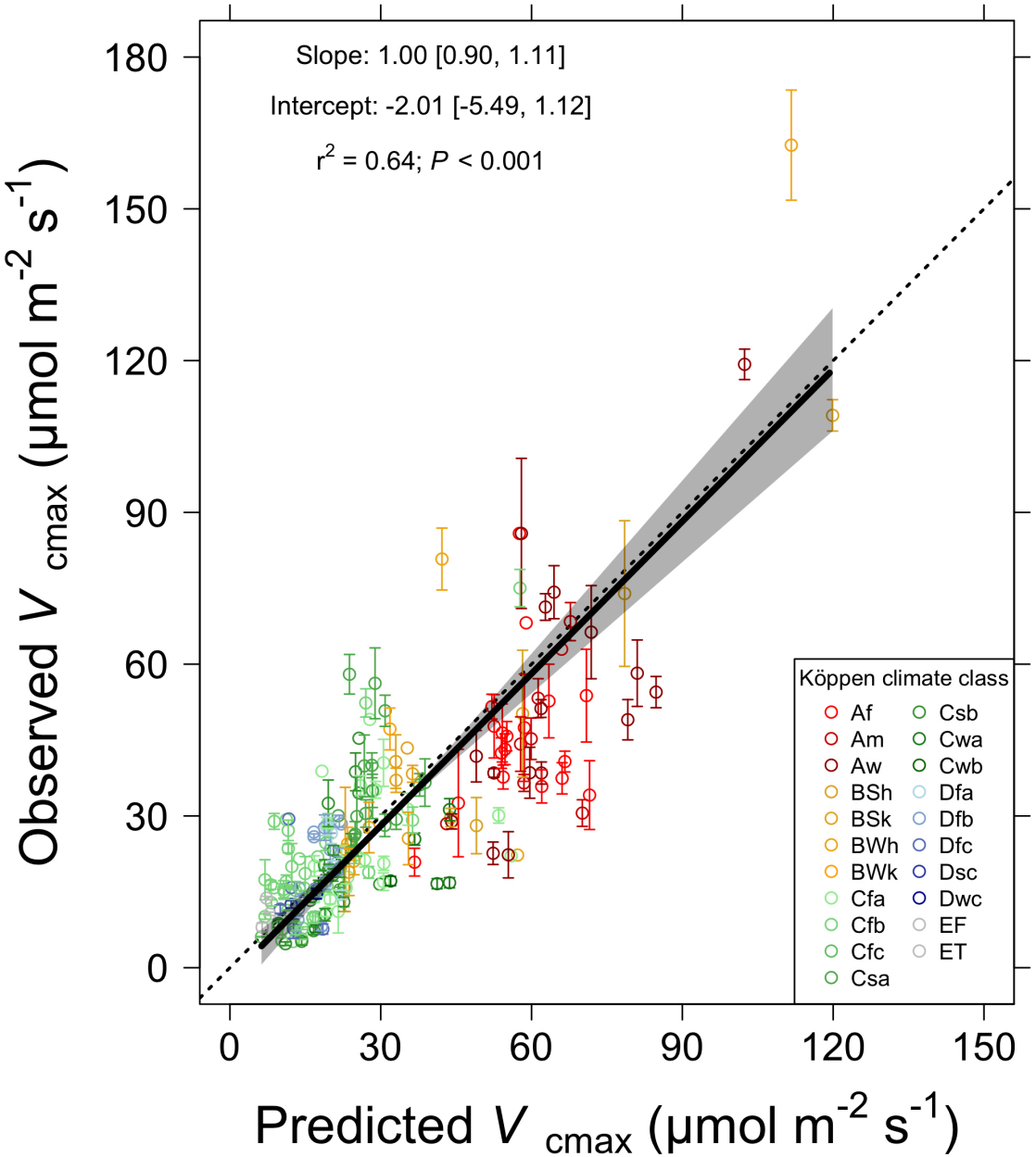

Smith et al. (2019) *Ecology Letters*

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Question 1: Is photosynthesis optimized to the environment?

YES! Photosynthesis acclimates spatially as expected from optimization

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Question 2: How will photosynthesis acclimate to future conditions?

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Photosynthetic traits change with temperature and CO_2 in ways expected from optimization

Smith and Keenan (in prep)

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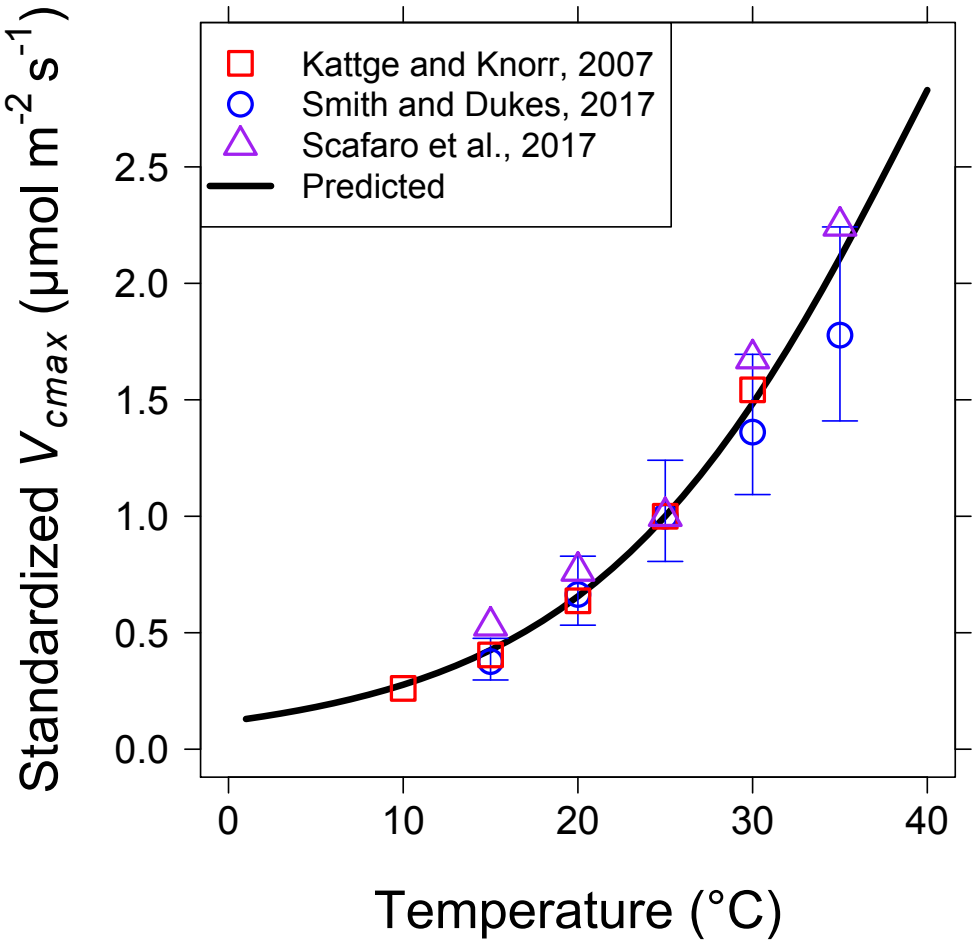
Photosynthetic traits change with temperature and CO_2 in ways expected from optimization



← Fully acclimated response

Smith and Keenan (in prep)

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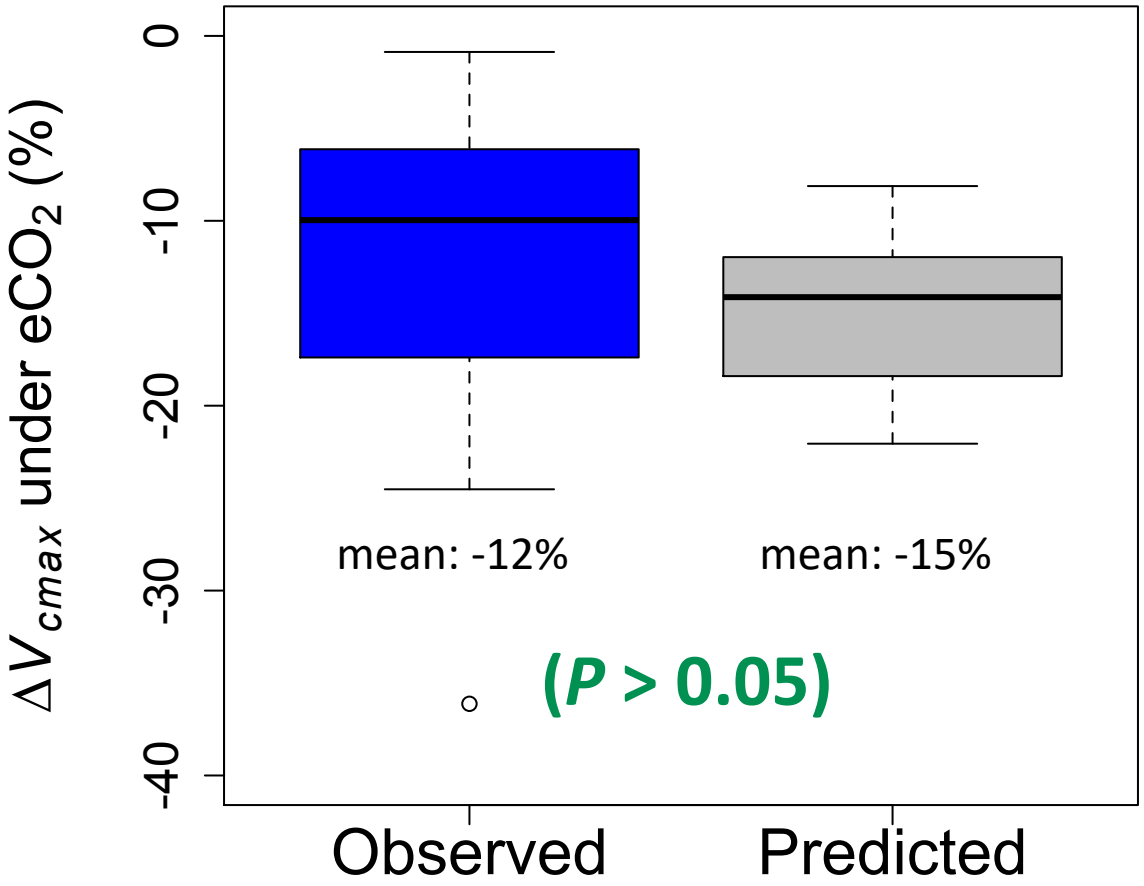
Photosynthetic traits change with temperature and CO_2 in ways expected from optimization



Smith and Keenan (in prep)

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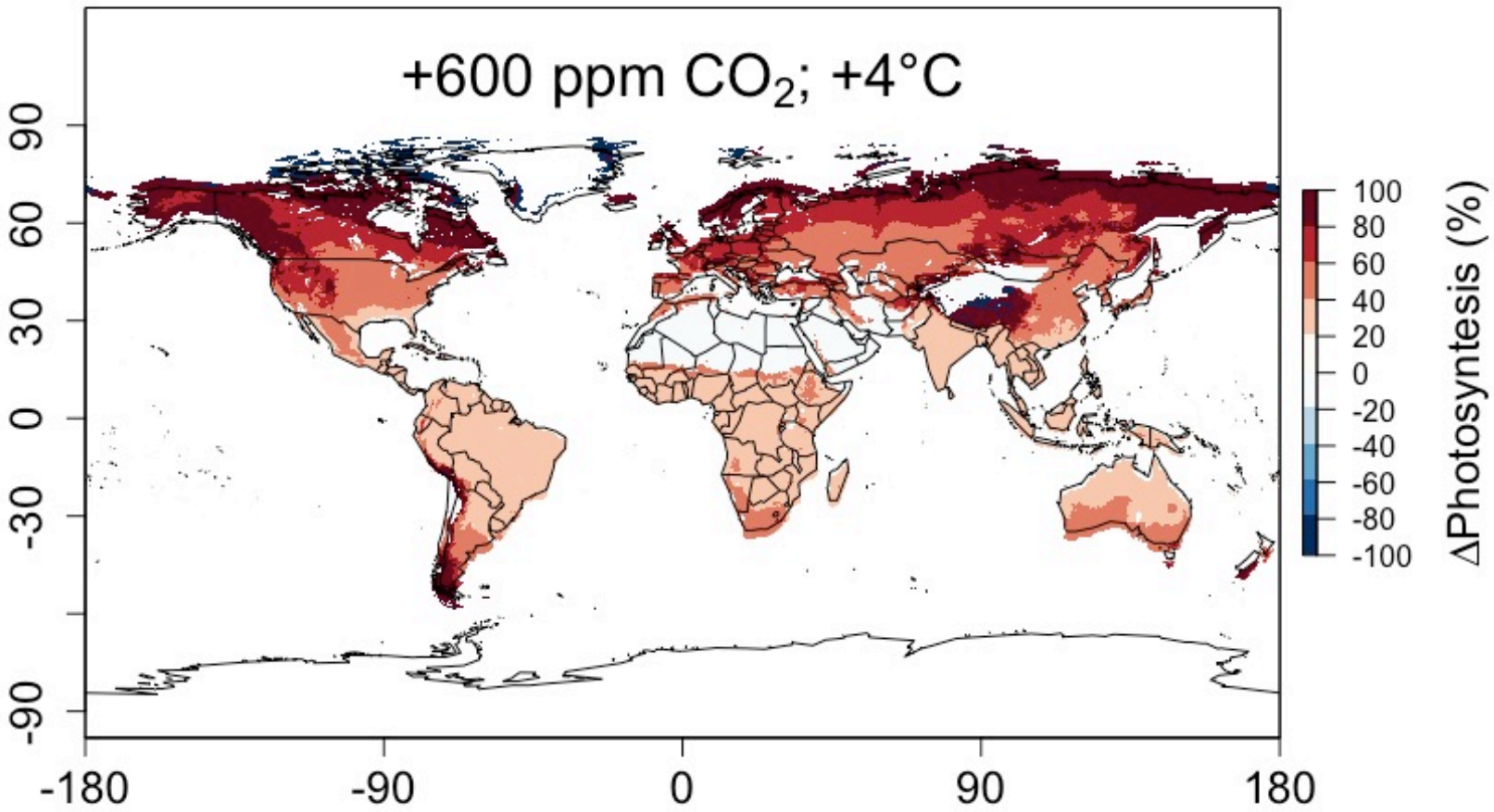
Higher CO_2 and increased temperatures increase future photosynthesis



Smith and Keenan (in prep)

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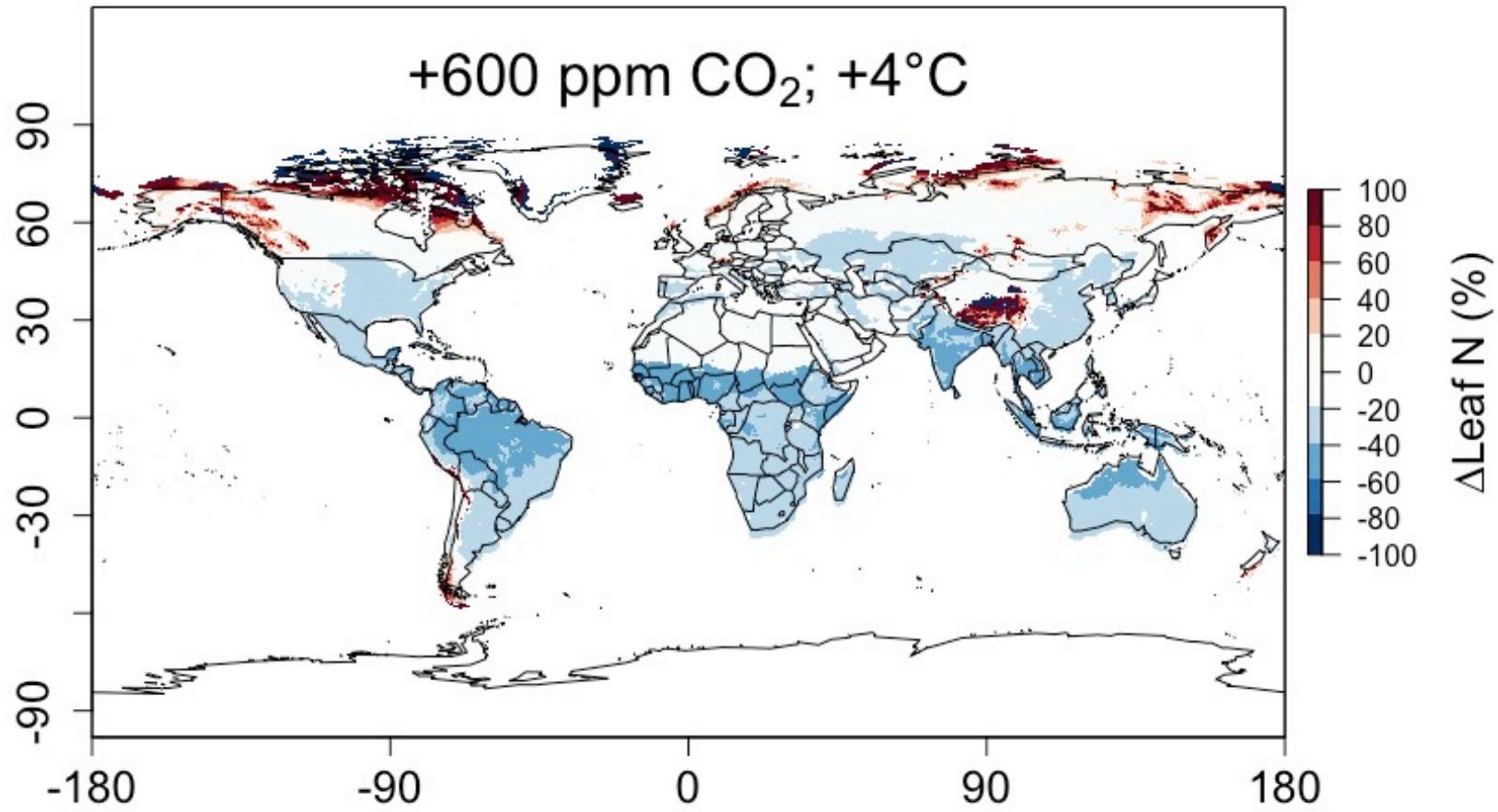
Higher CO_2 and increased temperatures increase future photosynthesis (at lower nutrient use)



Smith and Keenan (in prep)

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Question 2: How will photosynthesis acclimate to future conditions?

Photosynthesis will increase and per-leaf-area nutrient use will decrease

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Question 3: Does photosynthesis respond to nutrient addition?

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From the least cost hypothesis…

Added nutrients will not increase photosynthesis because light limitation will kick in

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From the least cost hypothesis…

Added nutrients will not increase photosynthesis because light limitation will kick in

Optimal response would be to increase leaf area

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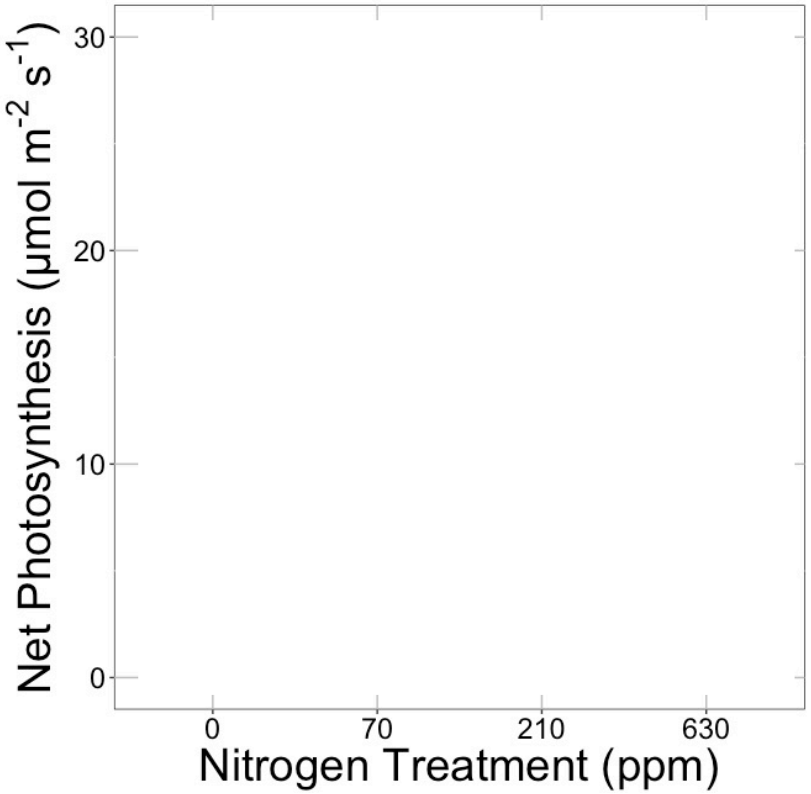
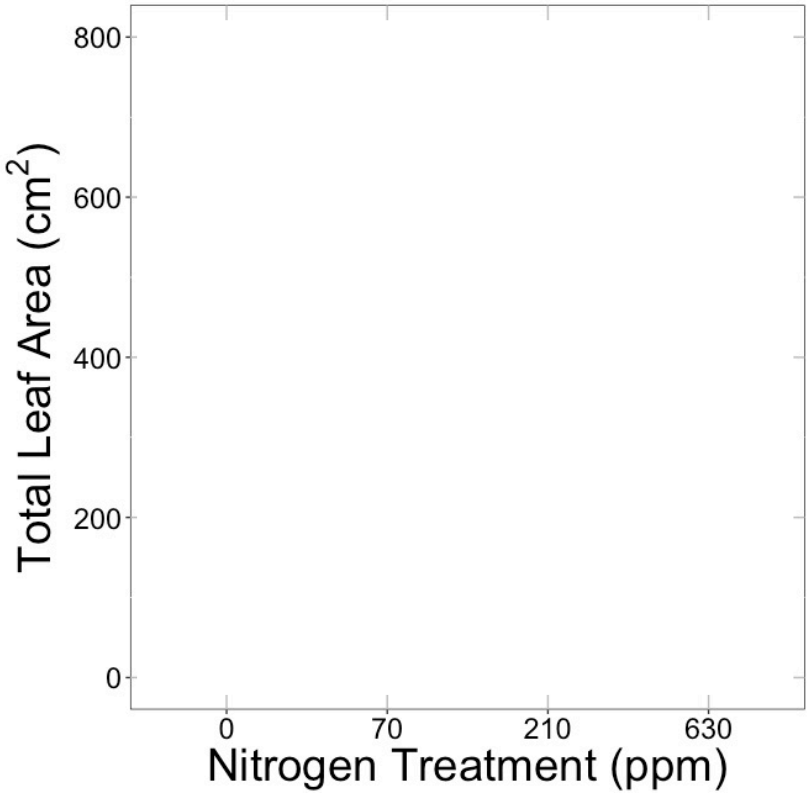
Leaf area, but not photosynthesis increases with N addition





Waring and Smith (in prep)

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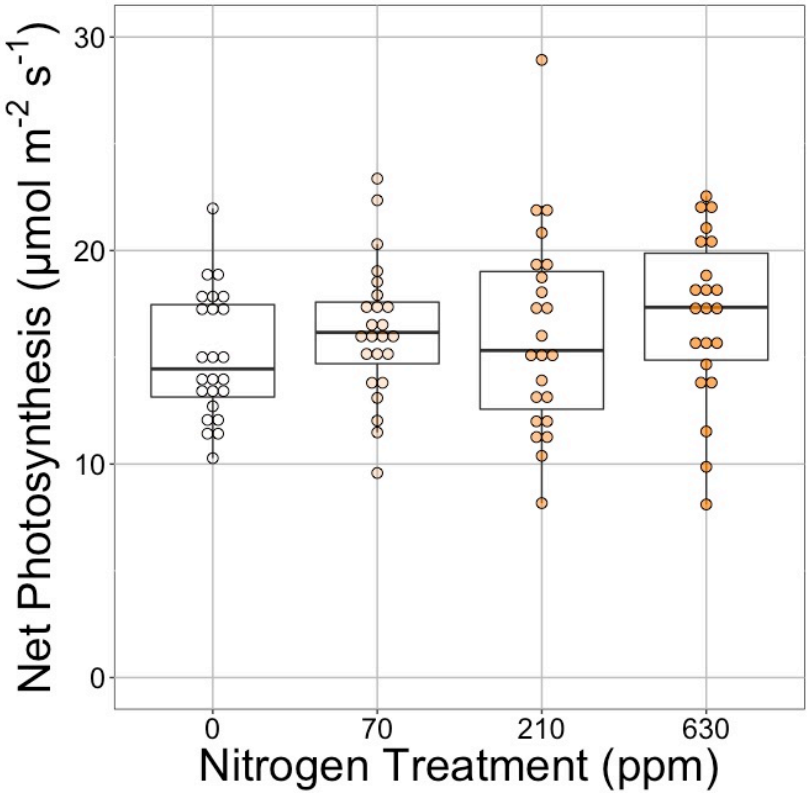
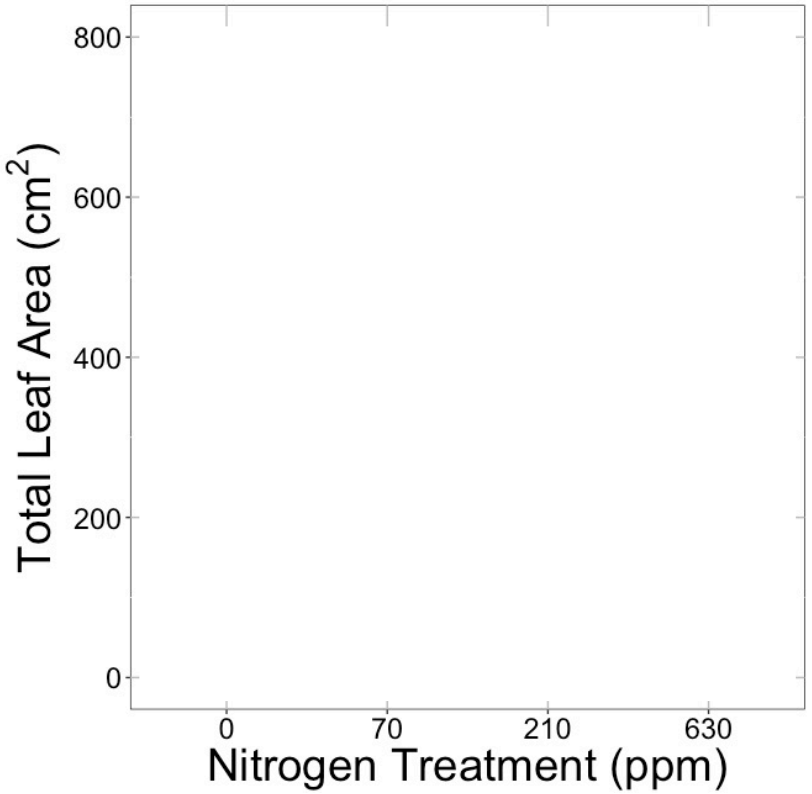
Leaf area, but not photosynthesis increases with N addition





Waring and Smith (in prep)

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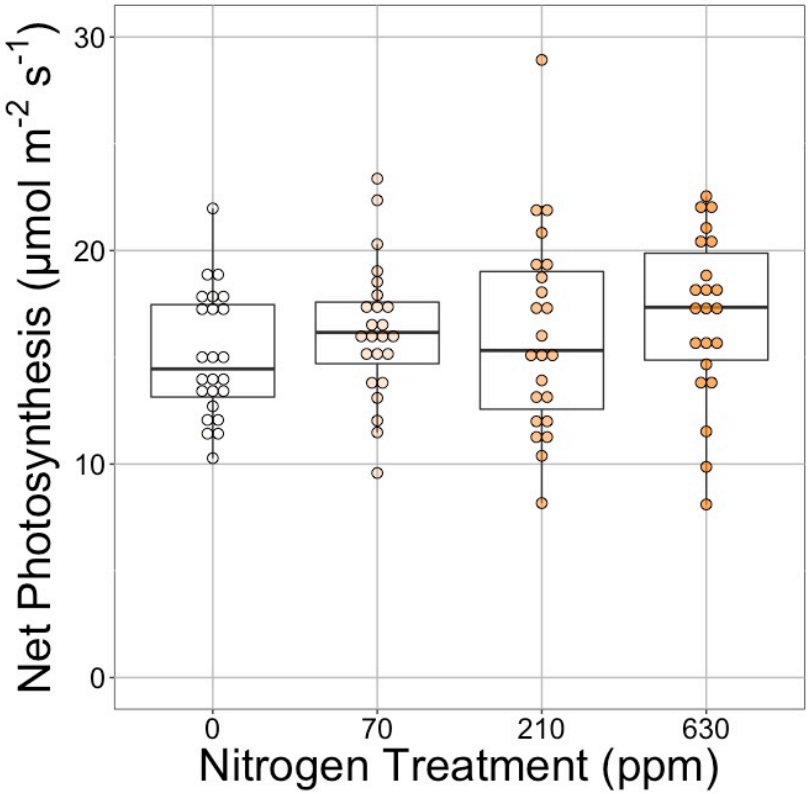
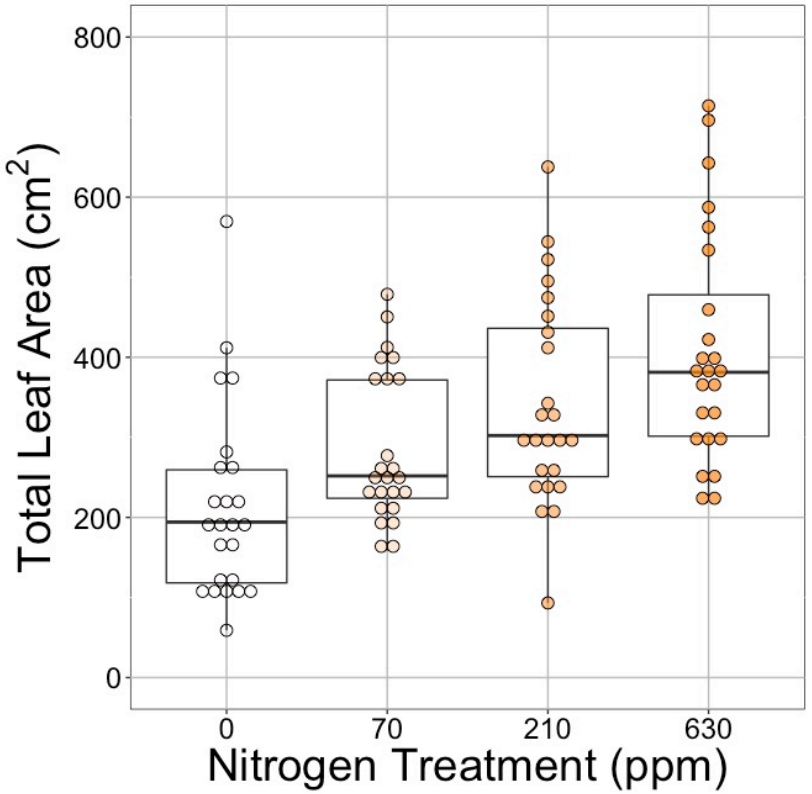
Leaf area, but not photosynthesis increases with N addition





Waring and Smith (in prep)

But do greenhouse experiments translate to the field?

Grassland soil nutrient addition network:

1. Leaf area index
2. Per-leaf-area nitrogen (photosynthetic proxy)

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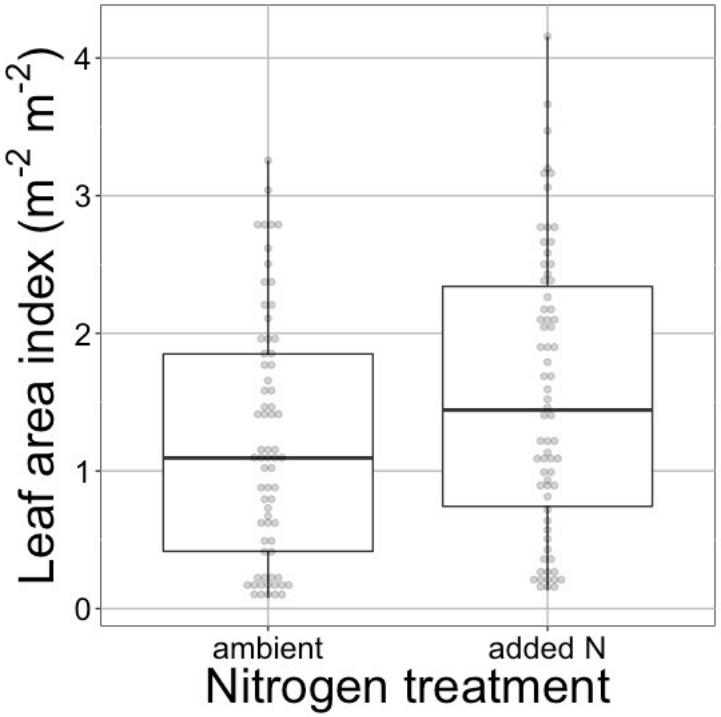
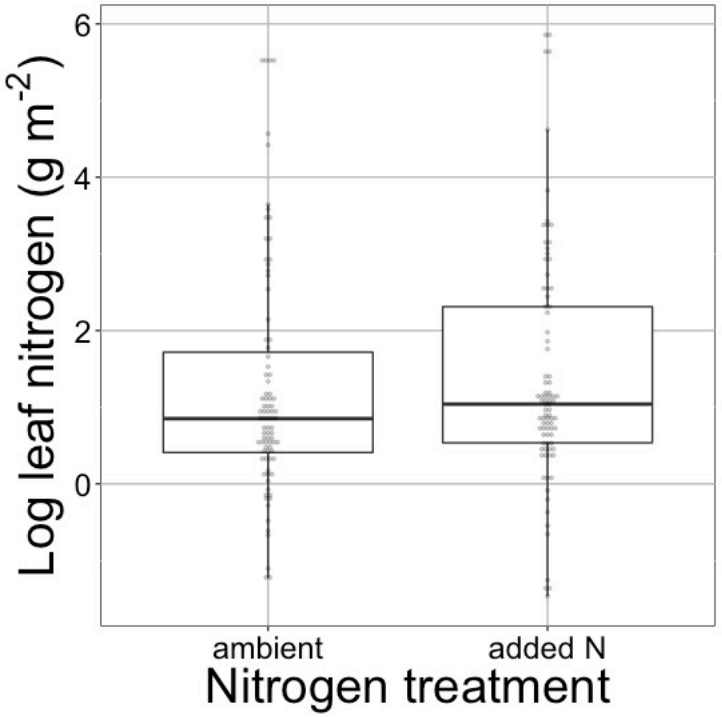
Globally, N addition increases leaf area, not leaf N

41% increase (P < 0.05)



No change (P = 0.42)



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nutrient network

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Question 3: Does photosynthesis respond to nitrogen addition?

No, plants respond to added nitrogen by increasing leaf area, not photosynthesis

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Question 4: Will C_4 be advantageous in the future?

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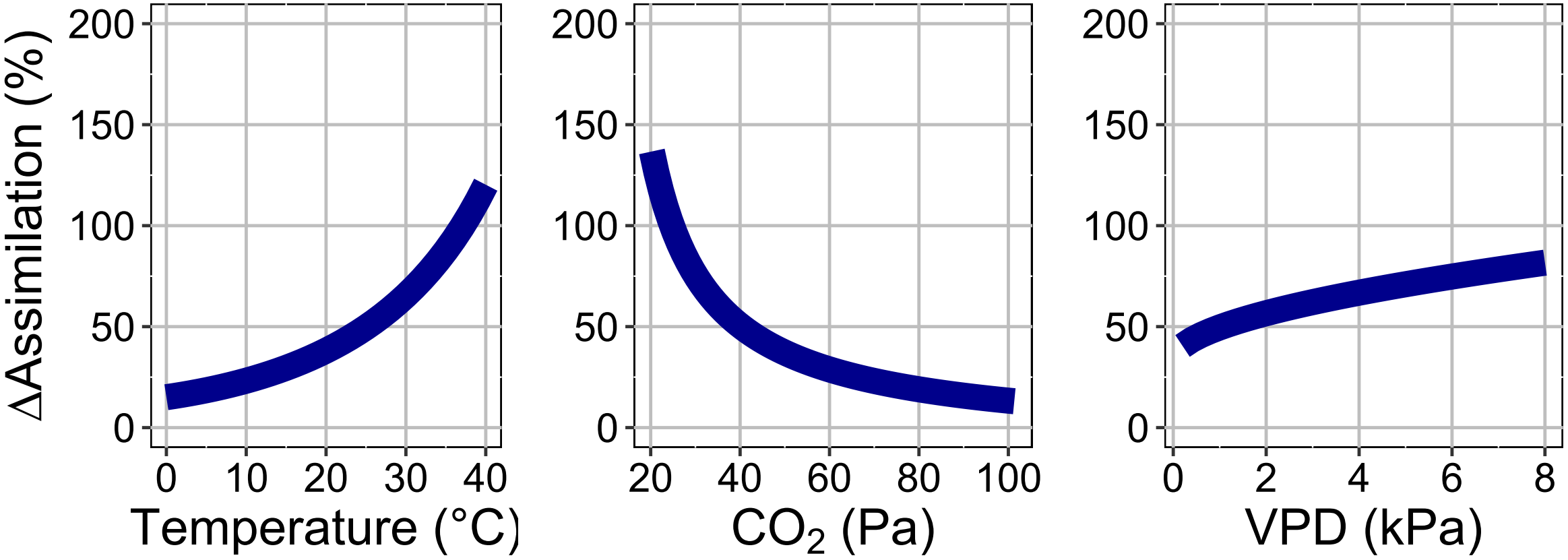
Relative advantage of C_4 physiology



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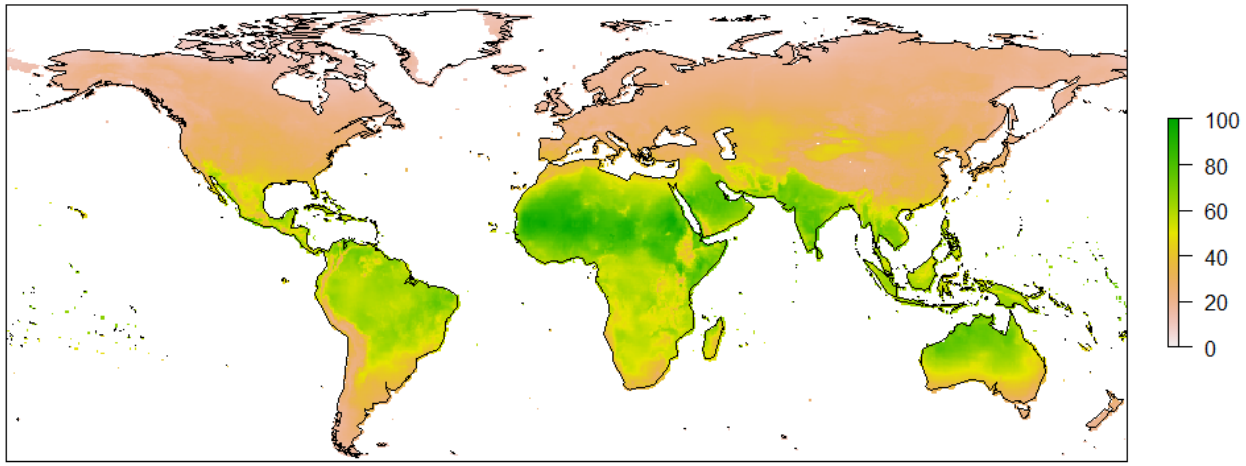
Current relative advantage of C_4 (%)



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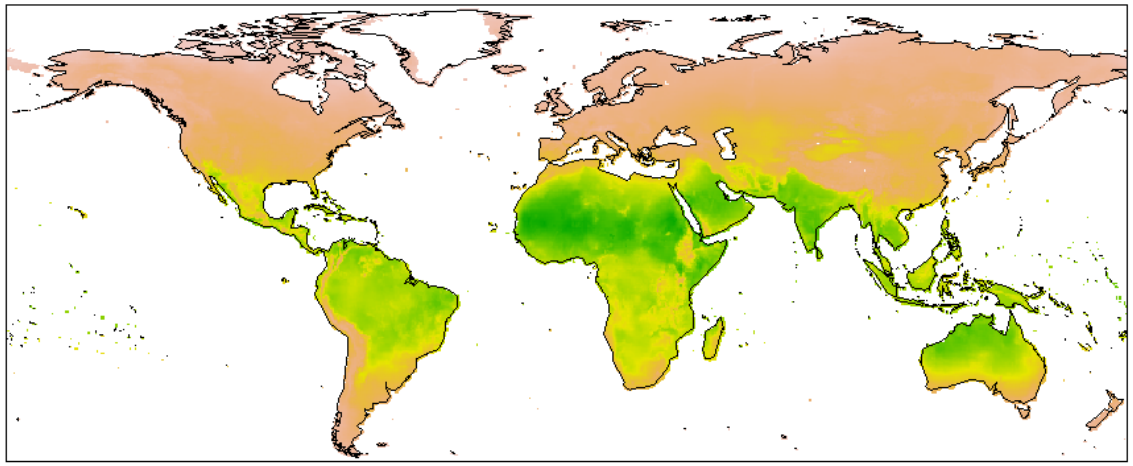
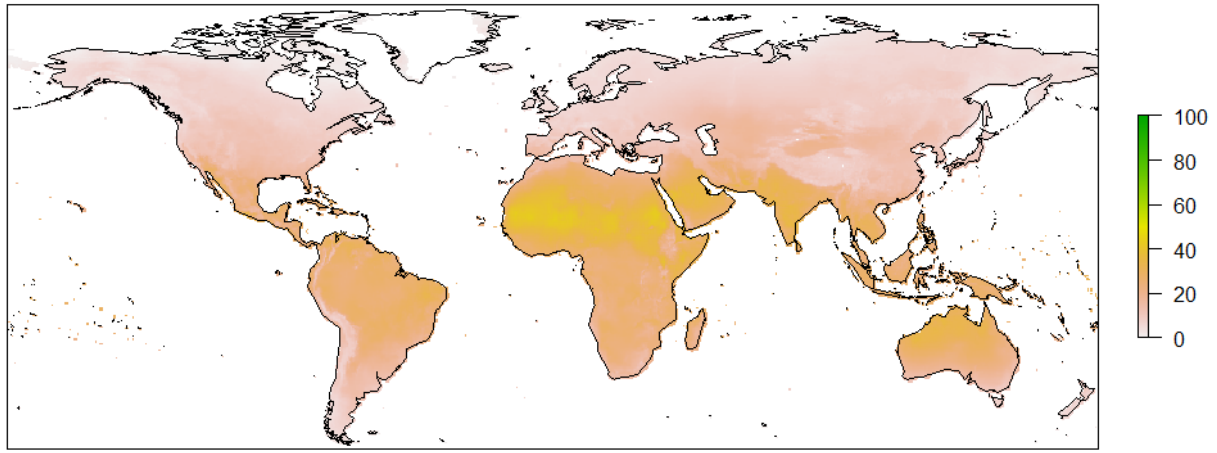
Current relative advantage of C_4 (%)



Future relative advantage of C_4 (%)



Scott and Smith (in prep)

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Question 4: Will C_4 be advantageous in the future?

Elevated CO_2 will negate C_4 advantages in the future

Conclusions

Theory can be useful!

- Improving the reliability of climate models
- Acting as a null model for understanding mechanisms

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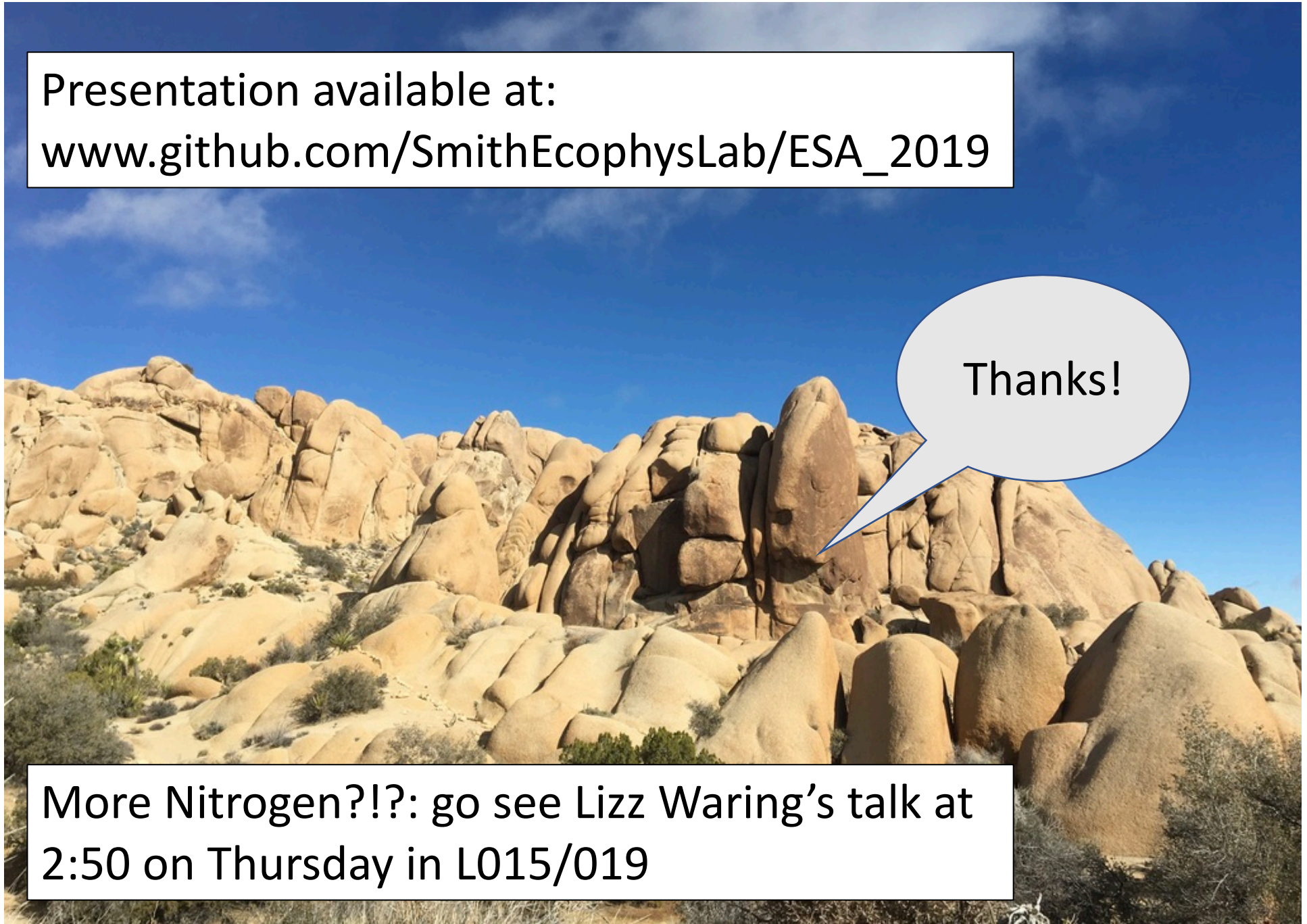

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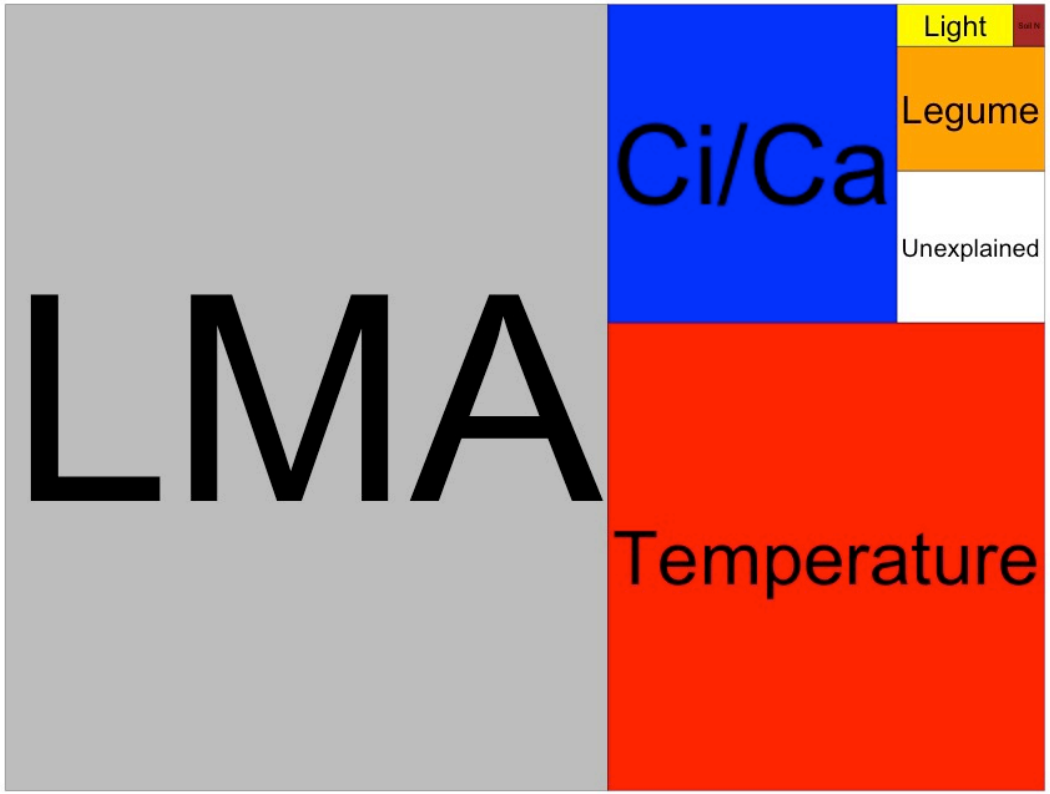
Globally, N addition has no impact on leaf N



Each box is proportional to the variance in leaf N explained by each variable

Waring and Smith (in prep)

nutrient network