Using plant ecophysiological theory to derive mechanisms from large-scale datasets

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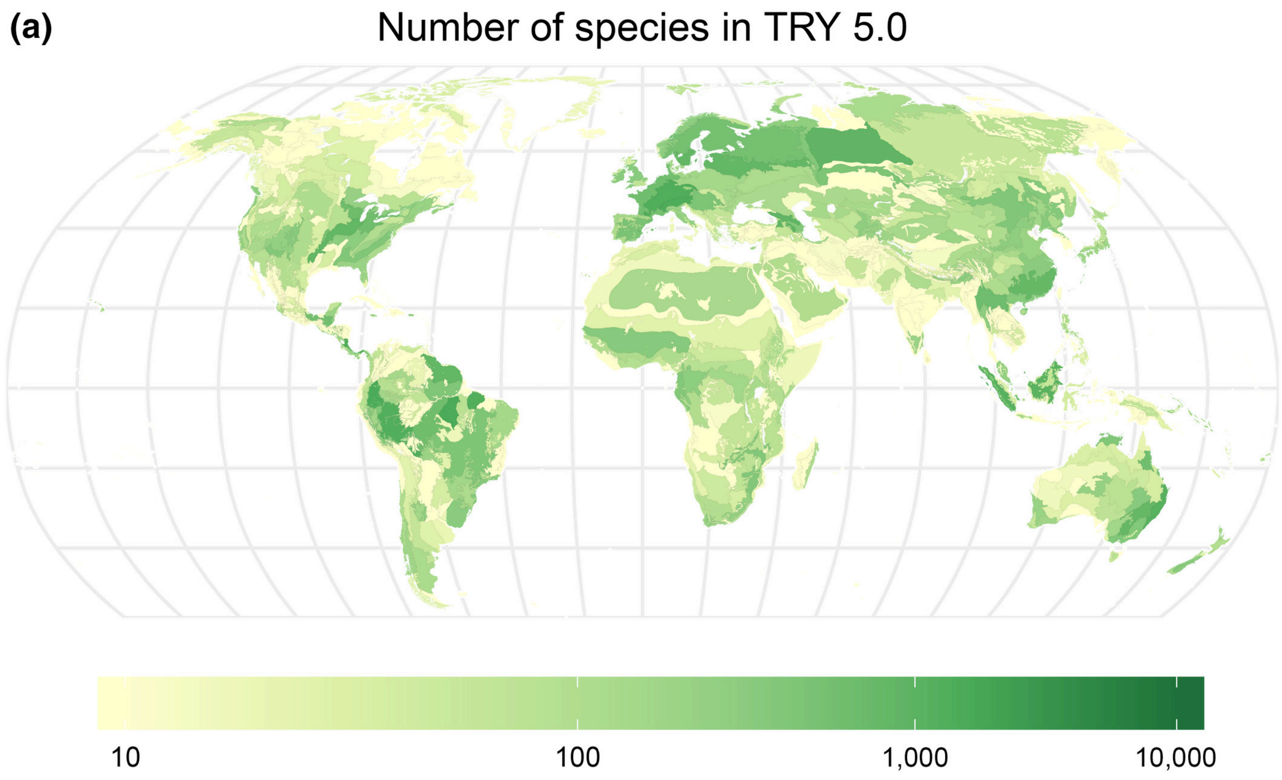
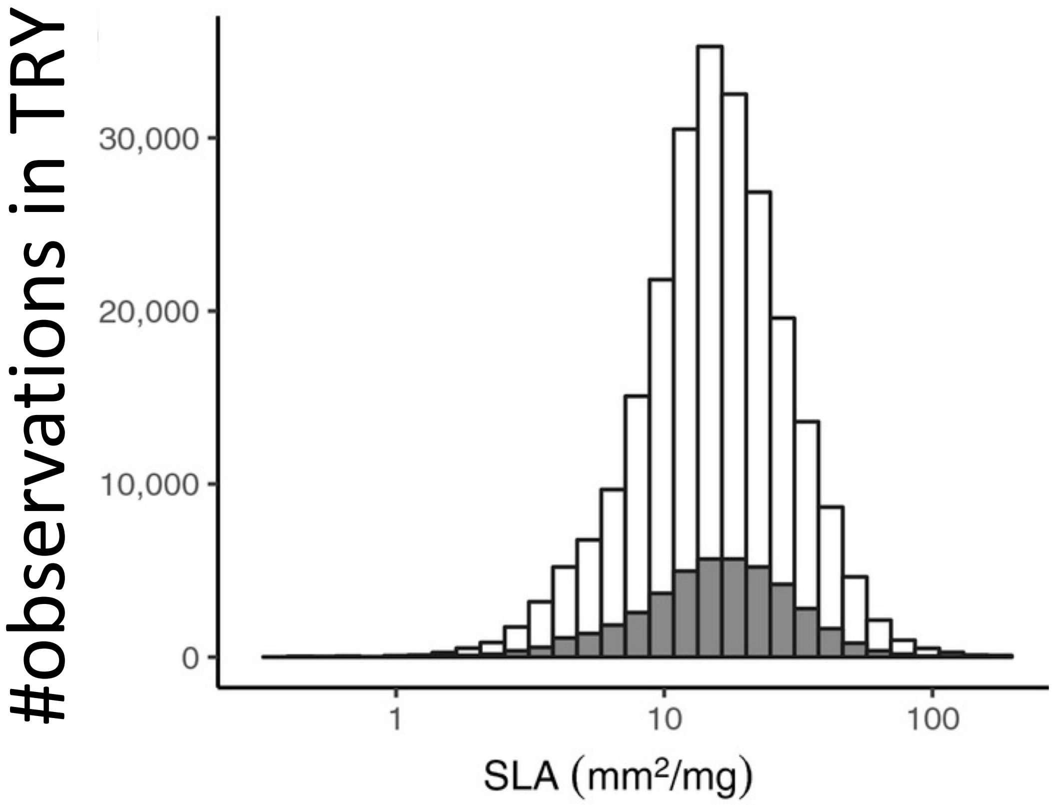
Plant ecophysiologists now have access to a TON of data!





>10 million trait observations in TRY alone

Kattge et al. (2020)

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But what does one do with all these data?

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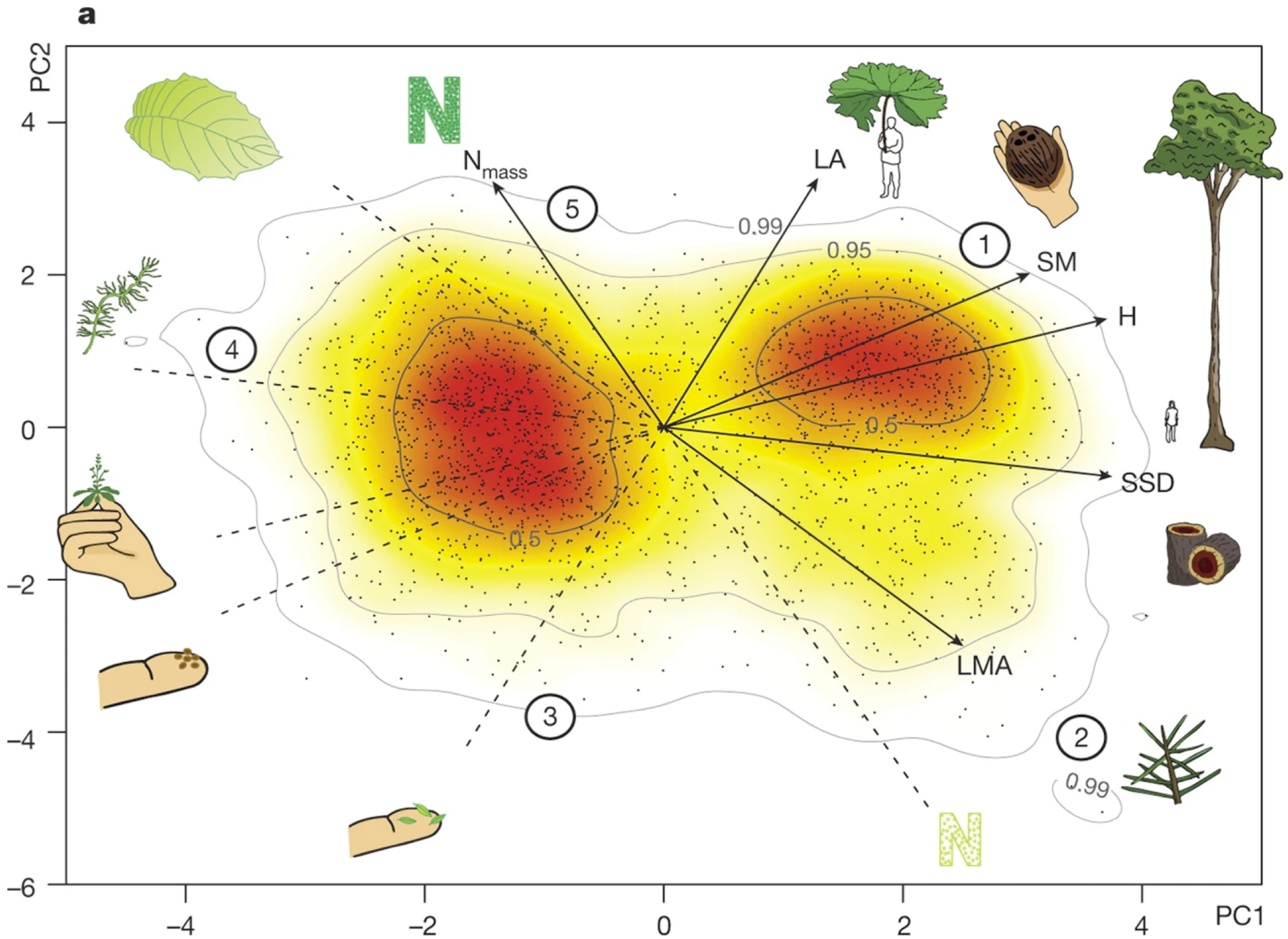
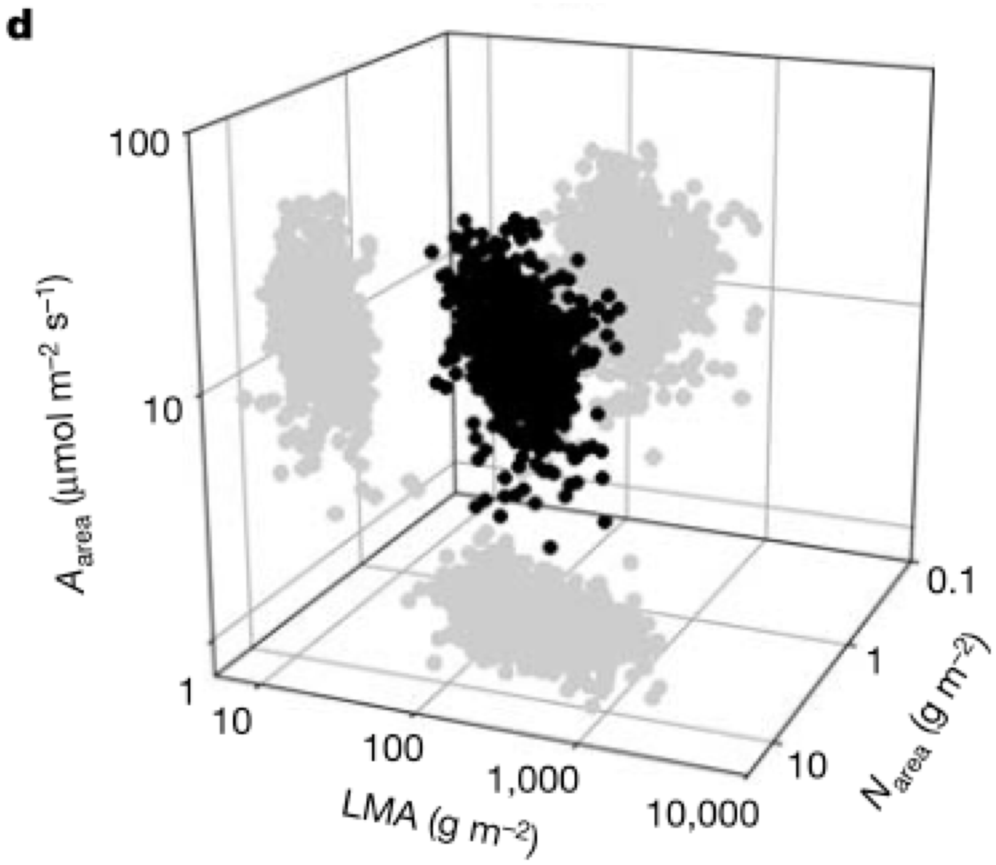
Assess variability and trade-offs in plant form and function with trait relationships





Diaz et al. (2016)

Wright et al. (2004)

Problems with the traditional approach

- Hard to quantify
  - Results reveal patterns with lots of unexplained variation
  - Multiple correlated drivers
- Difficult to create a reliable, predictive framework
  - Scaling (up or down) is tricky
  - Projections under novel conditions based on empirical trends is unreliable

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Solution: use a quantitative theory as a null model

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Example: photosynthetic least cost theory

Least cost theory

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

Wright et al. (2003)

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Optimal photosynthesis

Photosynthesis = *f*{stomatal conductance,
photosynthetic biochemistry}

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Optimal photosynthesis

Photosynthesis = *f*{stomatal conductance,
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Least cost theory can predict optimal that maximize photosynthesis at the lowest resource cost

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Optimal photosynthesis

Photosynthesis = *f*{stomatal conductance,
photosynthetic biochemistry}

Contact me to discuss the math!

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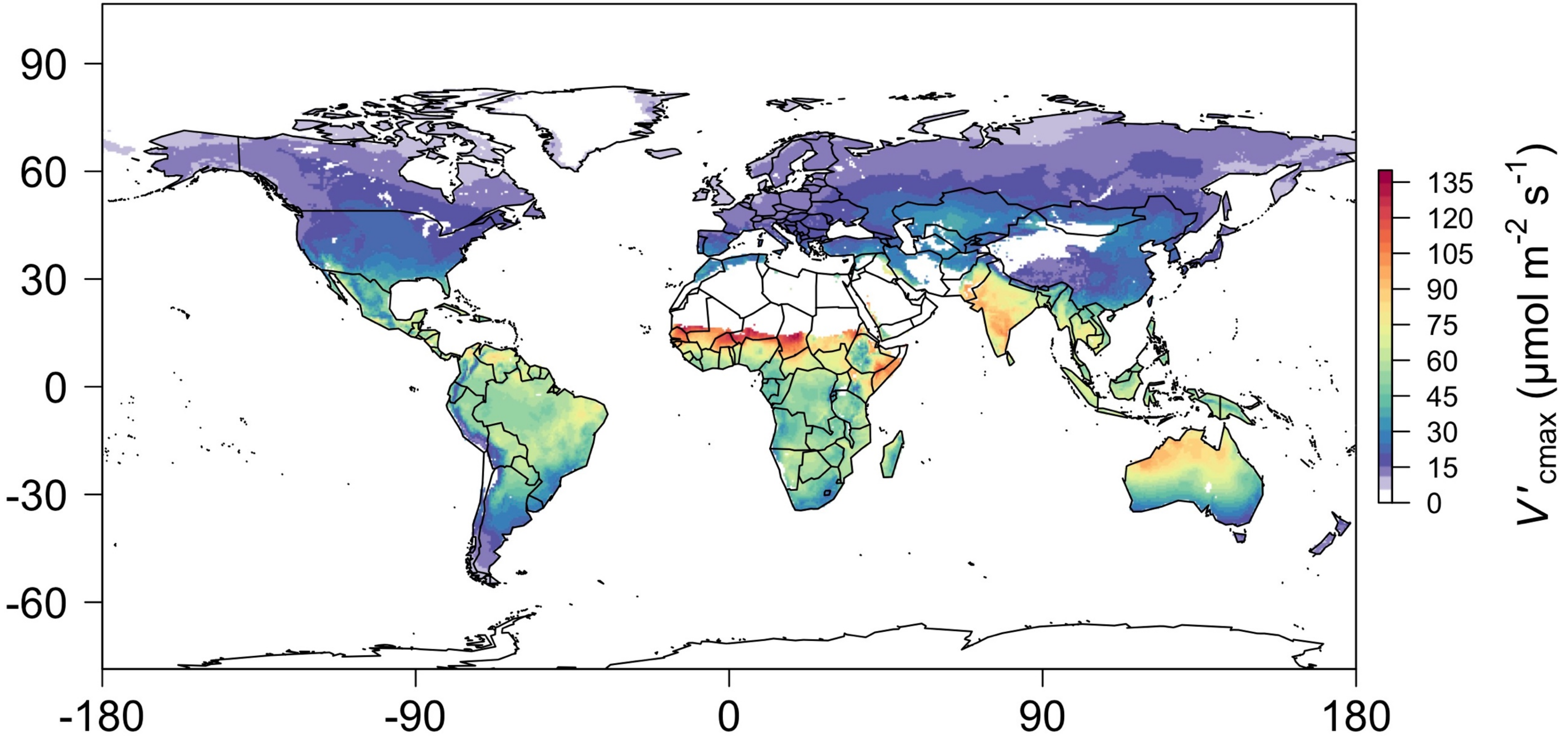
Global, optimally acclimated traits!



Smith et al. (2019)

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Different approach to data analysis

1. Gather data
2. Make theoretical predictions of measured trait
3. Compare predictions with observations to either:
    - Confirm theory
    - Identify biases that would indicate poor understanding and necessitate further theory development and testing

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Example insights from theory-data comparisons

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1. Is photosynthetic biochemistry is optimized to climate?

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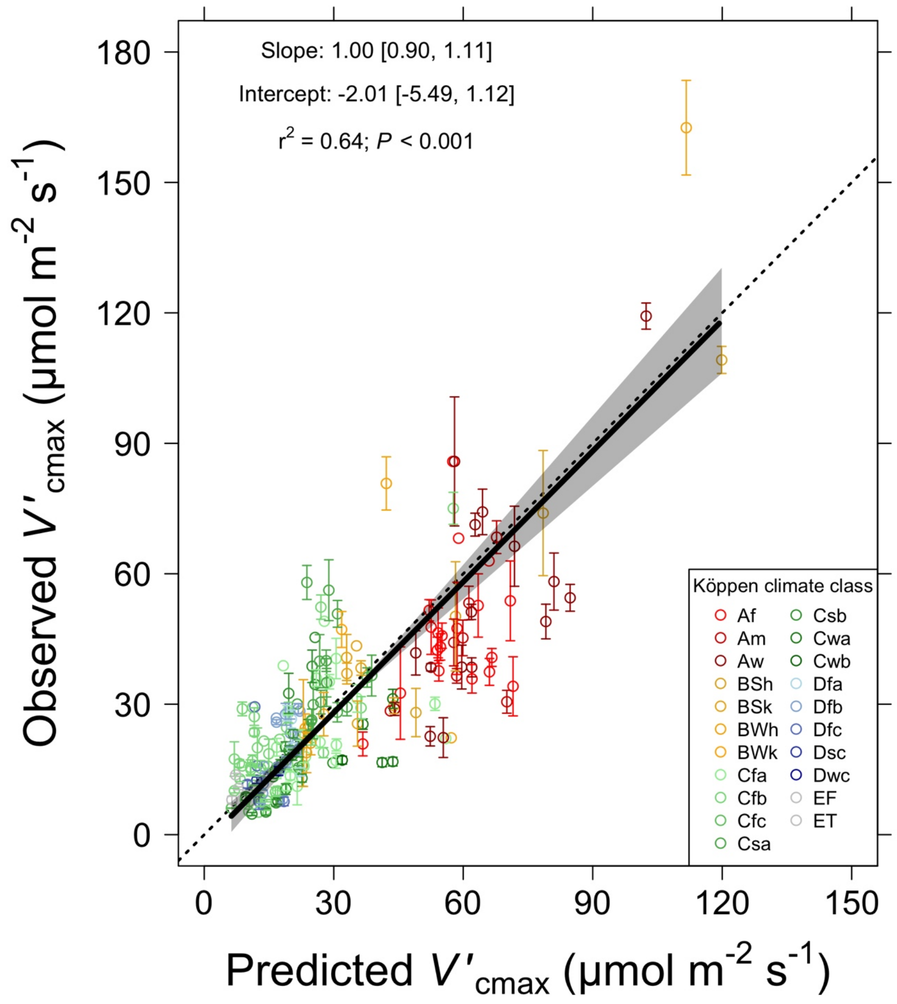
Is photosynthetic biochemistry is optimized to climate?



V_{cmax} predicted from photosynthetic least cost (multiple climatic drivers) is similar to observed values

Smith et al. (2019)

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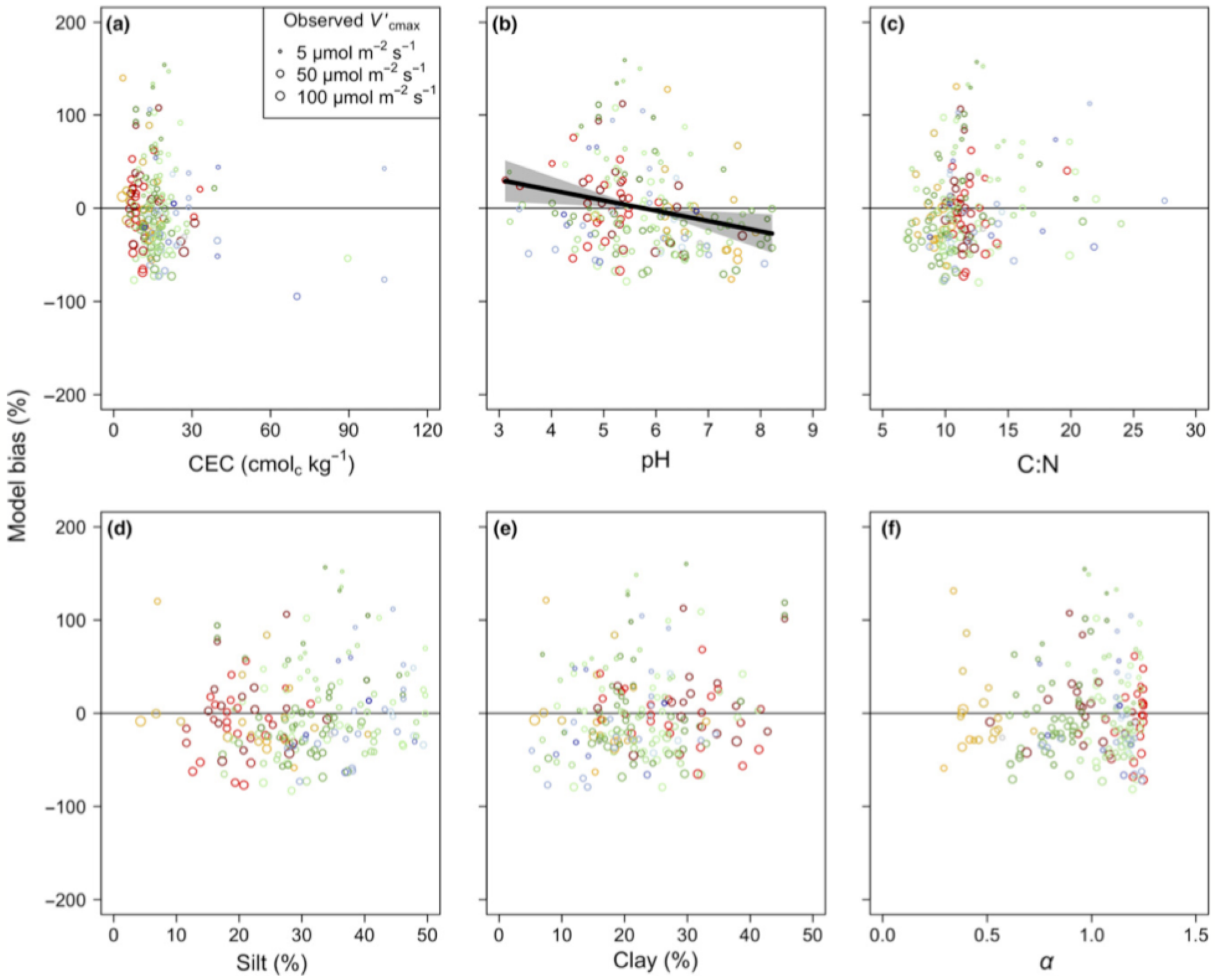
Is photosynthetic biochemistry is optimized to climate?



Soil increased explained variation from 64% to 68% compared to climate response alone. A missing mechanism?!

Smith et al. (2019)

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2. Is photosynthetic acclimation to CO_2 is the result of optimal downregulation?

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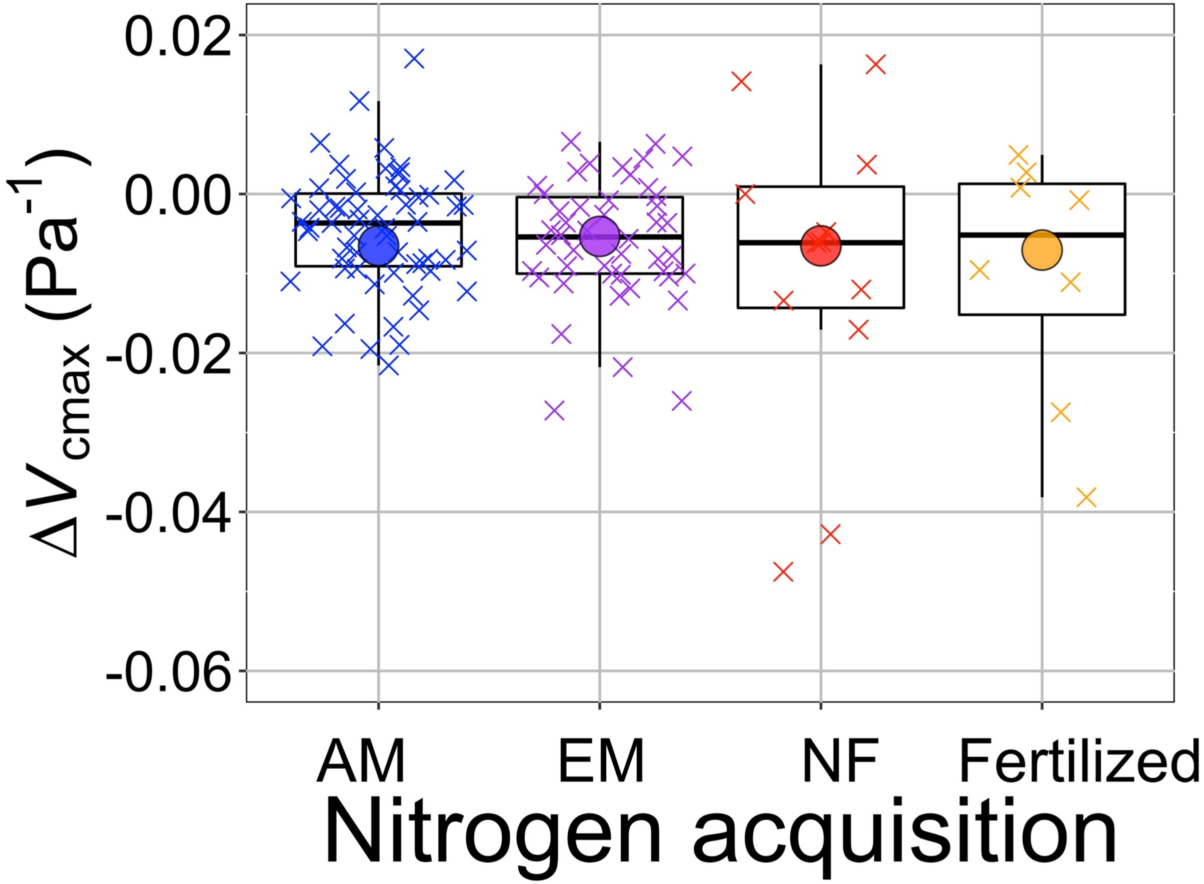
Is photosynthetic acclimation to CO_2 is the result of optimal downregulation?

(b)



The observed change in V_{cmax} under elevated CO_2 (ΔV_{cmax}; boxes and exes) is similar to that predicted by theory (dots), regardless of fertilization or symbiotic association

Smith & Keenan (2020)

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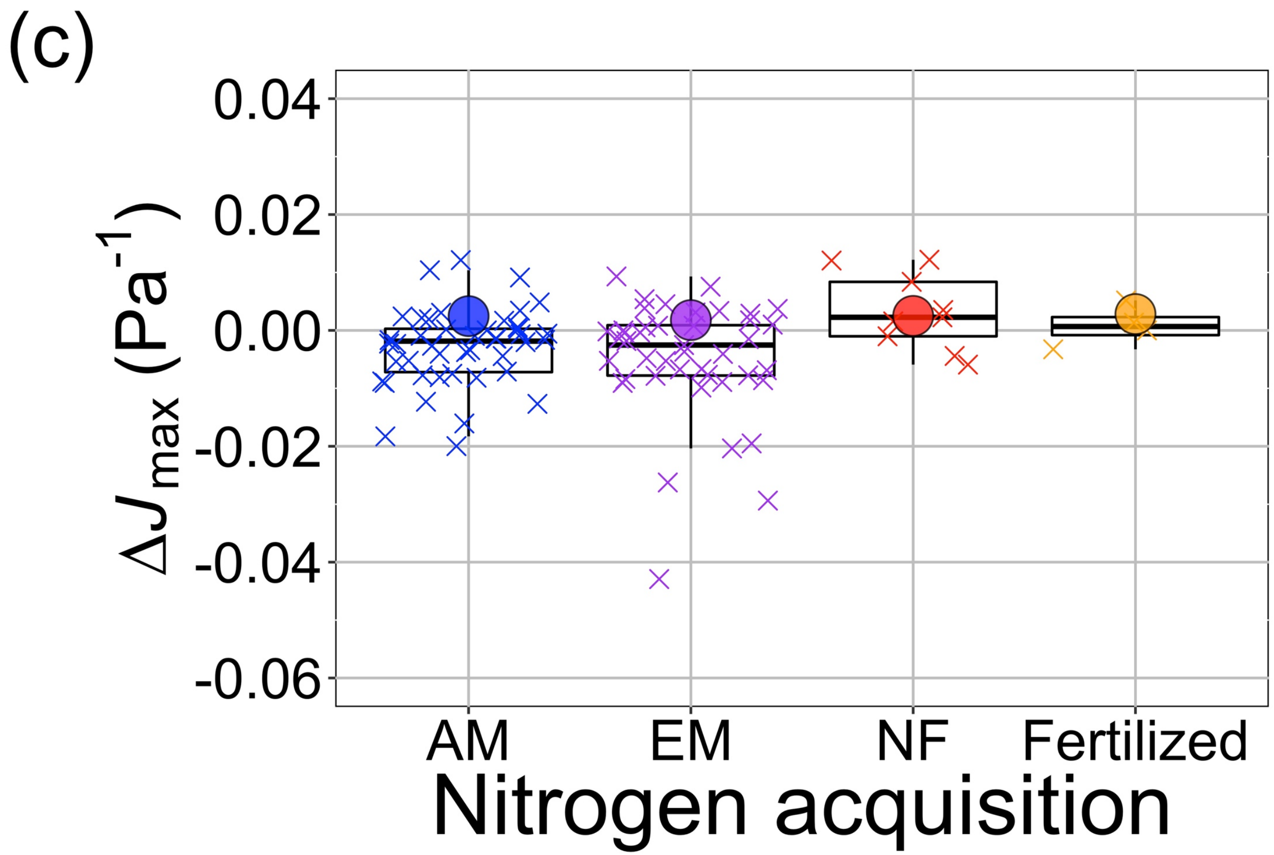
Is photosynthetic acclimation to CO_2 is the result of optimal downregulation?



The fit is not nearly as good for J_{max}. This implies we are missing something important in our theory/understanding!

Smith & Keenan (2020)

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3. Does increased O_2 specificity drive shifts in photosynthetic investment to Rubisco under warming?

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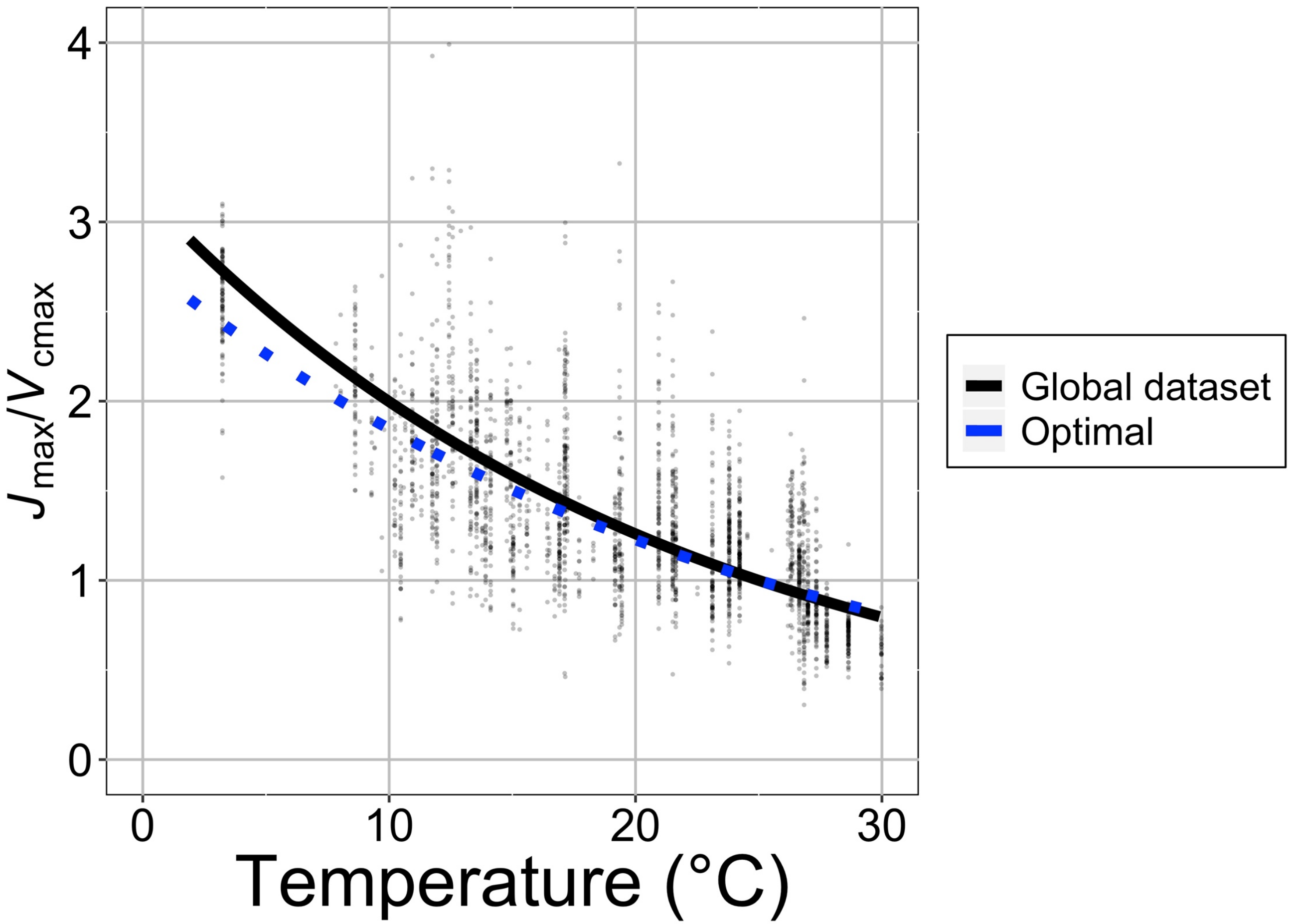
Does increased O_2 specificity drive shifts in photosynthetic investment to Rubisco under warming?



Plants invest more in Rubisco carboxylation (V_{cmax}) relative to electron transport (J_{max}) as temperatures increase (black line), as expected from theory (blue line), indicating that this is due to the increase in Rubisco O_2 specificity as temperatures warm

Smith & Keenan (2020)

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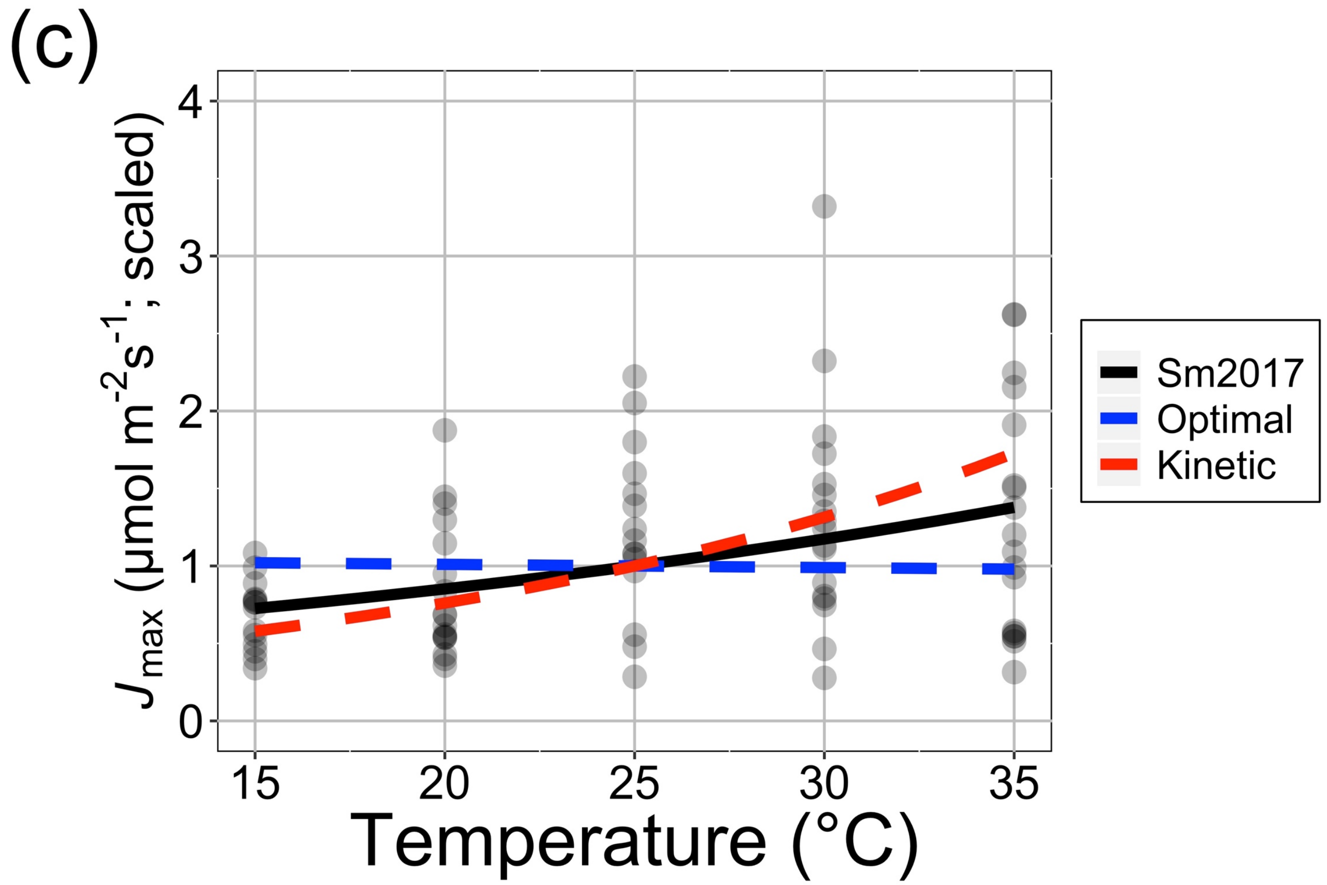
Does increased O_2 specificity drive shifts in photosynthetic investment to Rubisco under warming?



J_{max} sensitivity alone is poorly predicted (compare black observed and blue modeled lines). Maybe our understanding of electron transport is limited compared to carboxylation?

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4. Can differences in optimal photosynthesis explain patterns in C_3/C_4 abundance?

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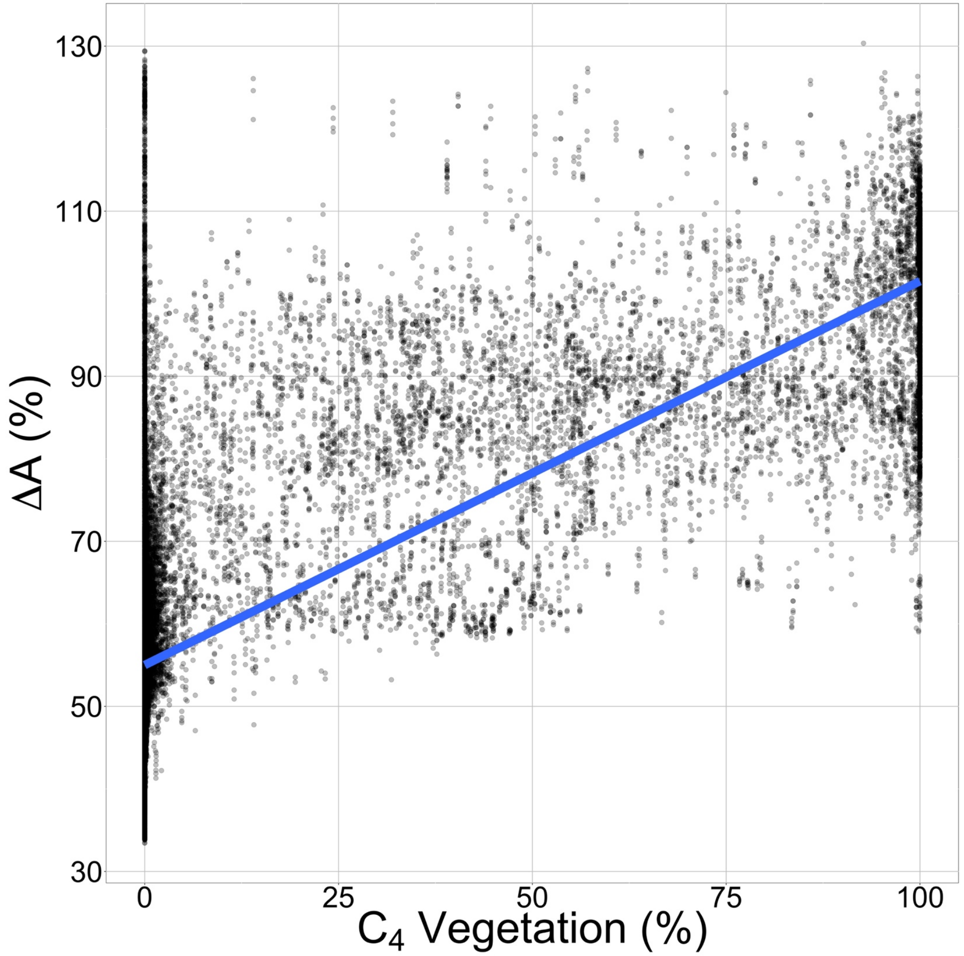
Can differences in optimal photosynthesis explain patterns in C_3/C_4 abundance?



The relative advantage of optimal C_4 photosynthesis in 1° gridcells across the globe (y-axis) scales well with the observed amount of C_4 vegetation in those gridcells (x-axis) (r^2=0.56; $P < 0.001$)

Scott & Smith (in prep)

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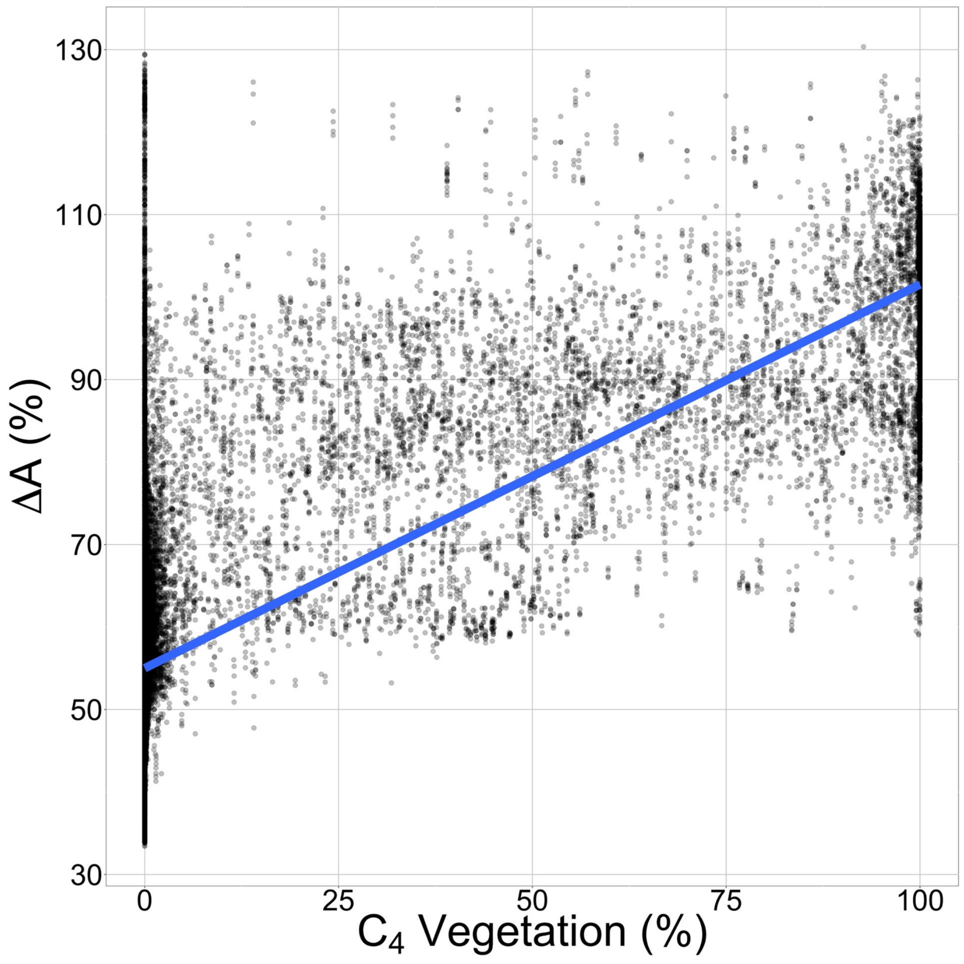
Can differences in optimal photosynthesis explain patterns in C_3/C_4 abundance?



This is a model-model comparison; necessary because few relevant data exist. Could be used to argue for funding to gather more data!

Scott & Smith (in prep)

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Apply wuantitative theory to your analyses today!! Theoretical models exist for a number of other ecophysiological traits and processes!

ECOLOGY LETTERS
Ecology Letters, (2017) 20: 1097–1106 doi: 10.1111/ele.12804
LETTER

Variations of leaf longevity in tropical moist forests predicted by a trait-driven carbon optimality model

Xiangtao Xu,[1]* David Medvigy,[1,2] Stuart Joseph Wright,[3] Kaoru Kitajima,[3,4] Jin Wu,[5] Loren P. Albert,[6] Giordane A. Martins,[7] Scott R. Saleska,[6] and Stephen W. Pacala[8]

Abstract
Leaf longevity (LL) varies more than 20-fold in tropical evergreen forests, but it remains unclear how to capture these variations using predictive models. Current theories of LL that are based on carbon optimisation principles are challenging to quantitatively assess because of uncertainty across species in the 'ageing rate:' the rate at which leaf photosynthetic capacity declines with age. Here, we present a meta-analysis of 49 species across temperate and tropical biomes, demonstrating that the ageing rate of photosynthetic capacity is positively correlated with the mass-based carboxylation rate of mature leaves. We assess an improved trait-driven carbon optimality model with *in situ* LL data for 105 species in two Panamanian forests. We show that our model explains

Plant, Cell & Environment
Plant, Cell and Environment (2017) 40, 816–830 doi: 10.1111/pce.12852
Original Article

Predicting stomatal responses to the environment from the optimization of photosynthetic gain and hydraulic cost

John S. Sperry[1], Martin D. Venturas[1], William R. L. Anderegg[1], Maurizio Mencuccini[2,3], D. Scott Mackay[4], Yujie Wang[1] & David M. Love[1]

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AGU100 ADVANCING EARTH AND SPACE SCIENCE
Journal of Advances in Modeling Earth Systems
RESEARCH ARTICLE
10.1029/2017MS001169

Applying the Concept of Ecohydrological Equilibrium to Predict Steady State Leaf Area Index

J. Yang[1], B. E. Medlyn[1], M. G. De Kauwe[2], and R. A. Duursma[1]

[1]Hawkesbury Institute for the Environment, Western Sydney University, Sydney, New South Wales, Australia, [2]ARC Centre of Excellence for Climate Extremes, University of New South Wales, Sydney, New South Wales, Australia

Key Points:
- An optimality model incorporating ecohydrological theory can predict long-term average steady state leaf area index
- Terrestrial vegetation models could

Biogeosciences, 14, 481–495, 2017
www.biogeosciences.net/14/481/2017/
doi:10.5194/bg-14-481-2017

Biogeosciences Open Access EGU

Leaf nitrogen from first principles: field evidence for adaptive variation with climate

Ning Dong[1,3,4], Iain Colin Prentice[1,2], Bradley J. Evans[1,3,4], Stefan Caddy-Retalic[5,6], Andrew J. Lowe[5,6,7], and Ian J. Wright[1]

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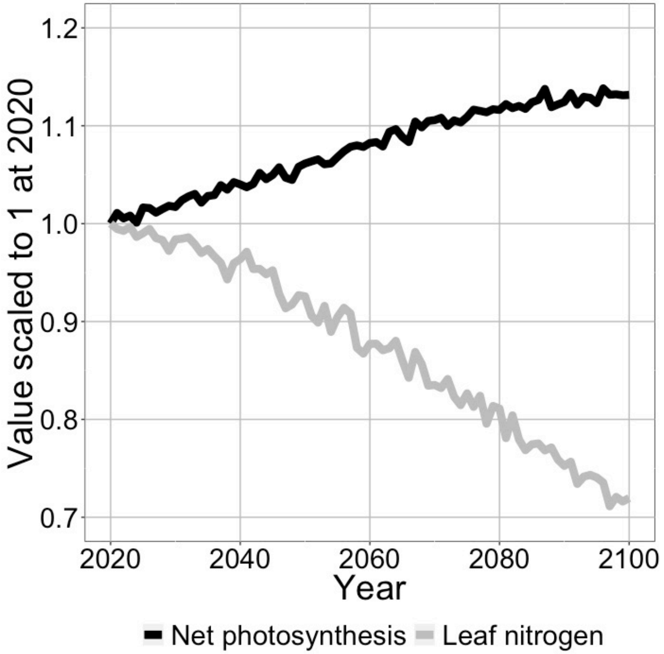
Conclusions

- Quantified theory can be invaluable for:
  - Testing mechanisms with large-scale data
  - Identifying knowledge gaps
- Makes post analysis model incorporation much easier



Example land surface model simulation with incorporated photosynthetic least cost theory

Smith et al. (in prep)

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Presentation available at:
www.github.com/SmithEcophysLab/ESA_2020