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Simulating ecosystem response to climate change by capturing plant functional adaptation and trait evolution

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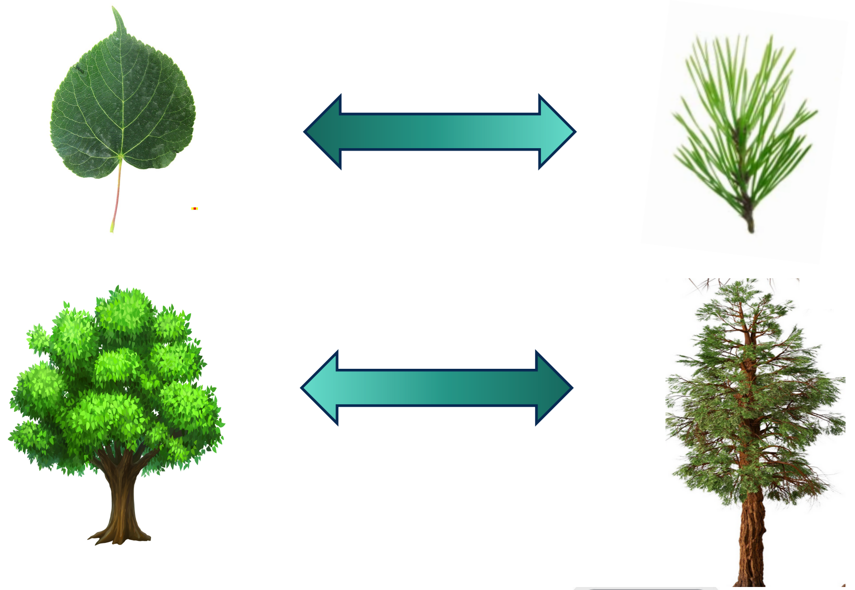
Biodiversity and Natural Resources

Contact

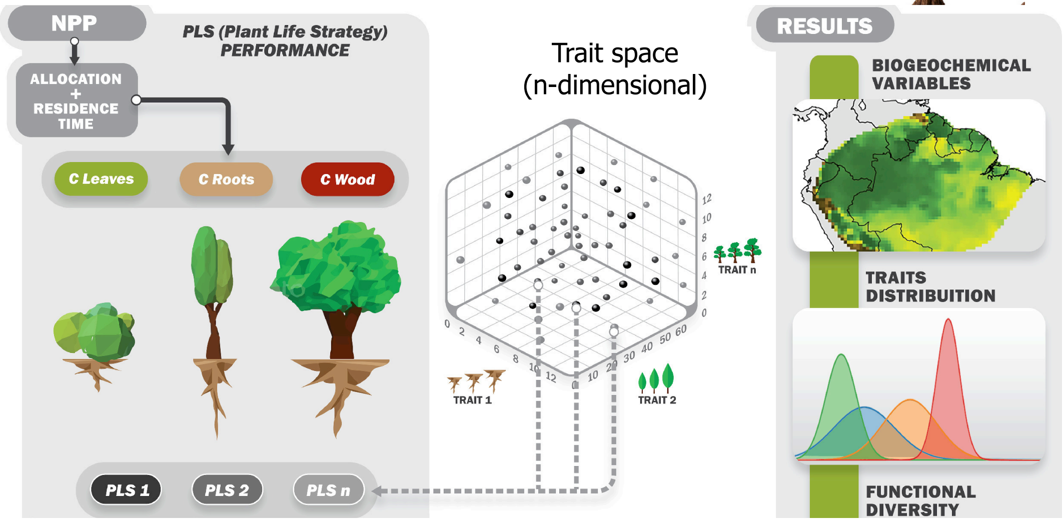
Intro: functional ecology and trait-based applications (TBA)

Plant functional traits defined as *morphological*, *physiological* and *phenological* attributes of living organisms that modulate their overall fitness (Violle *et al.*, 2007).



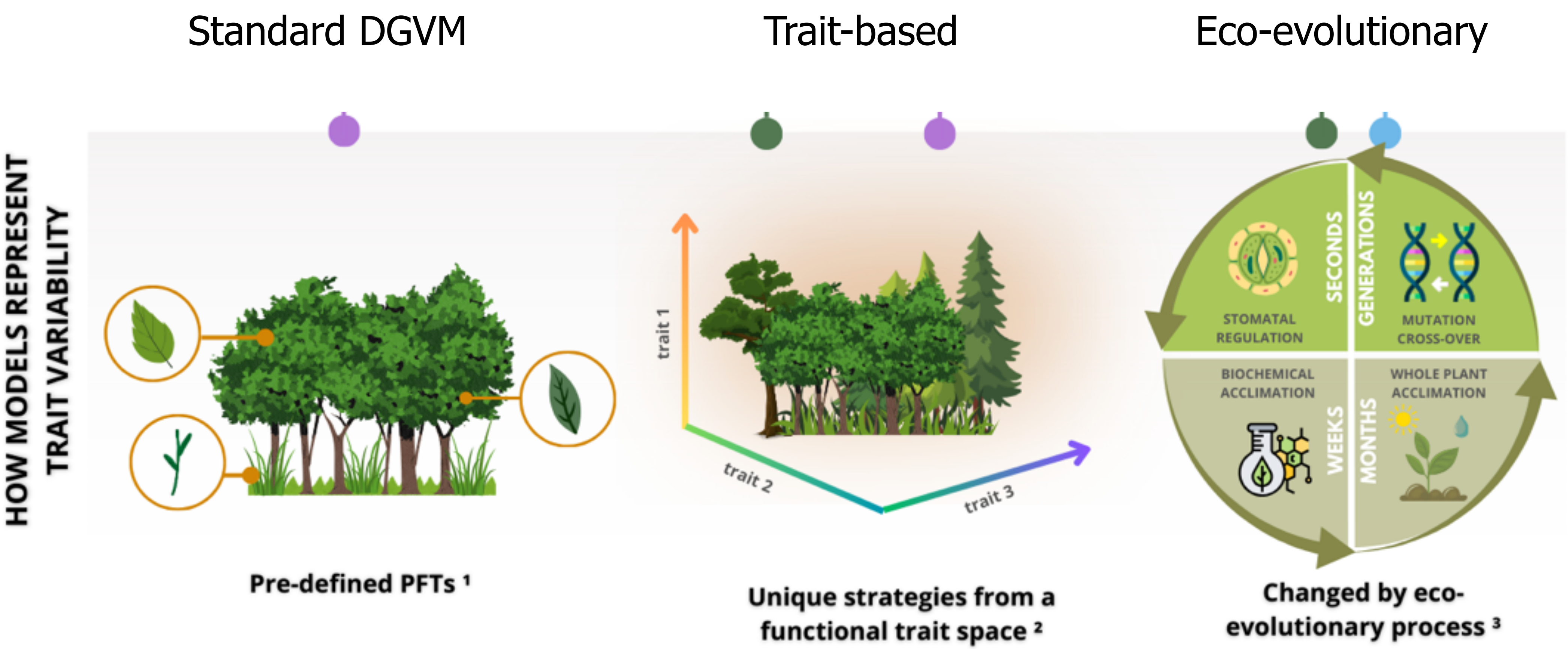
Plant life history strategies defined by combinations of functional traits that are filtered by the biotic and abiotic environment (Díaz *et al.*, 1998).

Trait-based approach (TBA) allows a functional perspective, on ecosystem response to the environment (Aguirre–Gutiérrez *et al.*, 2022; Chacón-Labella *et al.*, 2022).



Rius, B.F., et al., (2023). Higher functional diversity improves modeling of Amazon forest carbon storage. Ecological Modelling. 481, e110323.

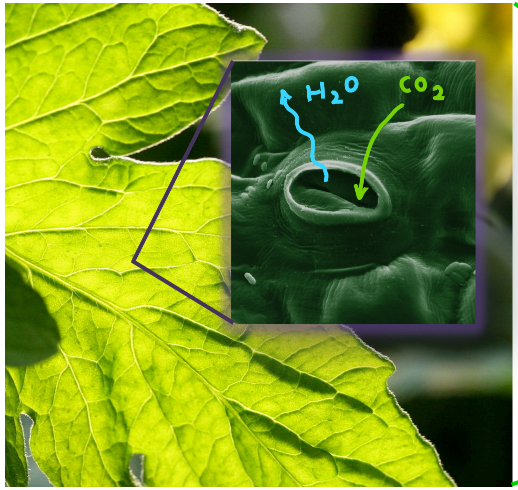
Intro: representation of plant functional ecology (DGVMs)

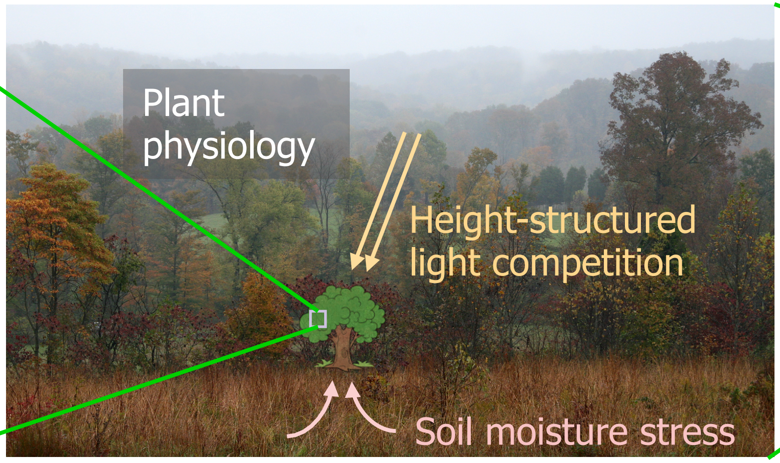


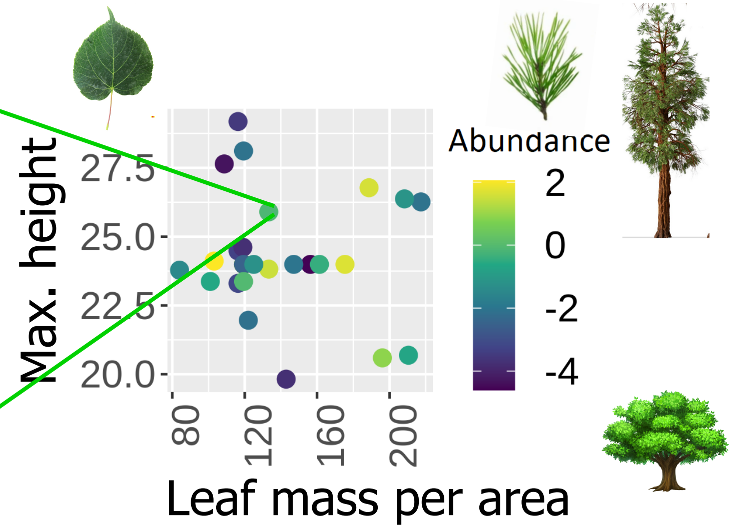
Blanco, et al., (in prep.). Trait-based vegetation modeling and data integration to advance our knowledge on the functional ecology of ecosystems.

Method: simulate ecosystem response by accounting for plant functional adaptation to climate (drought, etc.)

Plant-level adaptations	Species-level adaptations	Ecosystem-level adaptations
Maximise growth / C-uptake	Stress, demographics, mortality	Plant functional diversity
Physiological acclimation	Species composition shifts	Recovery and resilience







Days - Months | Years | Decades

Image Credits: Muffet, Huw Williams, Falster et al. (2017)

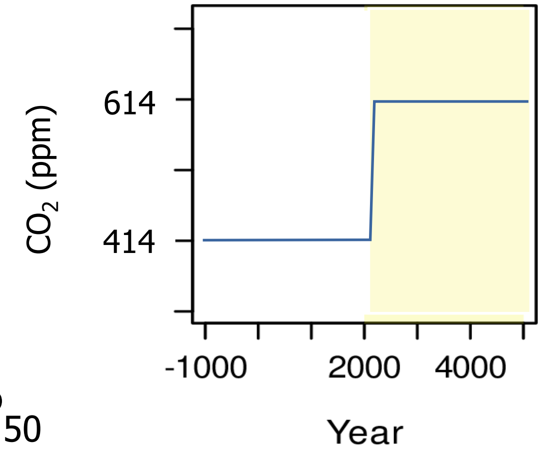
Method: apply model to a hyperdiverse Amazonian forest

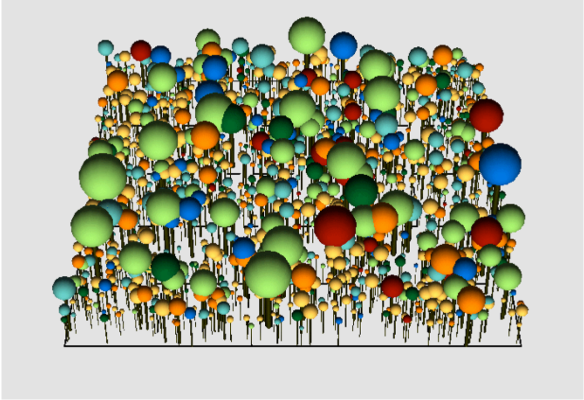
1. Forced with periodic extension of observed meteorological data from 2000-2015 (CO_2+200ppm)

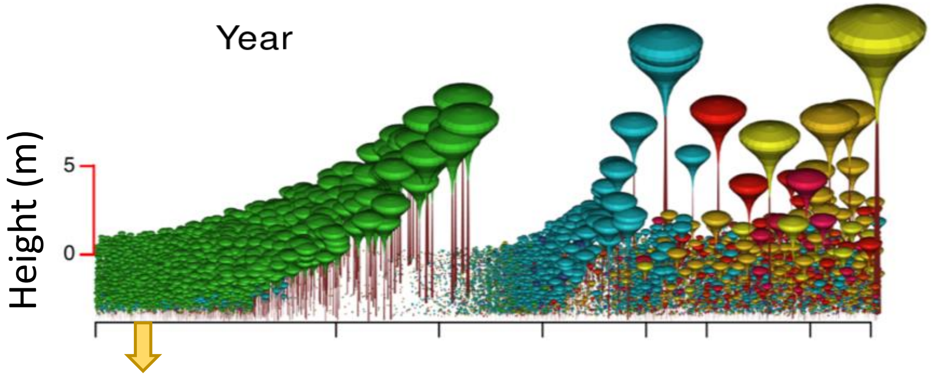
2. Species defined as unique combinations of 4 traits: LMA, max. height, wood density, xylem P_{50}

3. Start with 100 species with random trait values with equal abundance

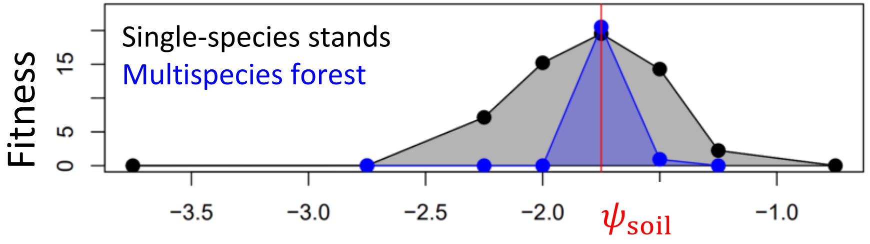
4. Let community composition evolve via competitive exclusion





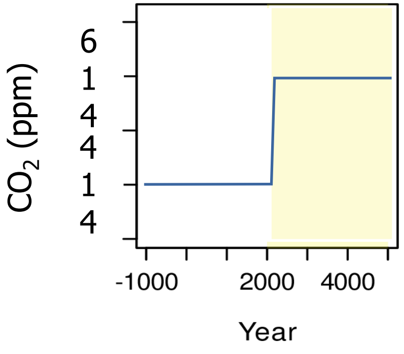


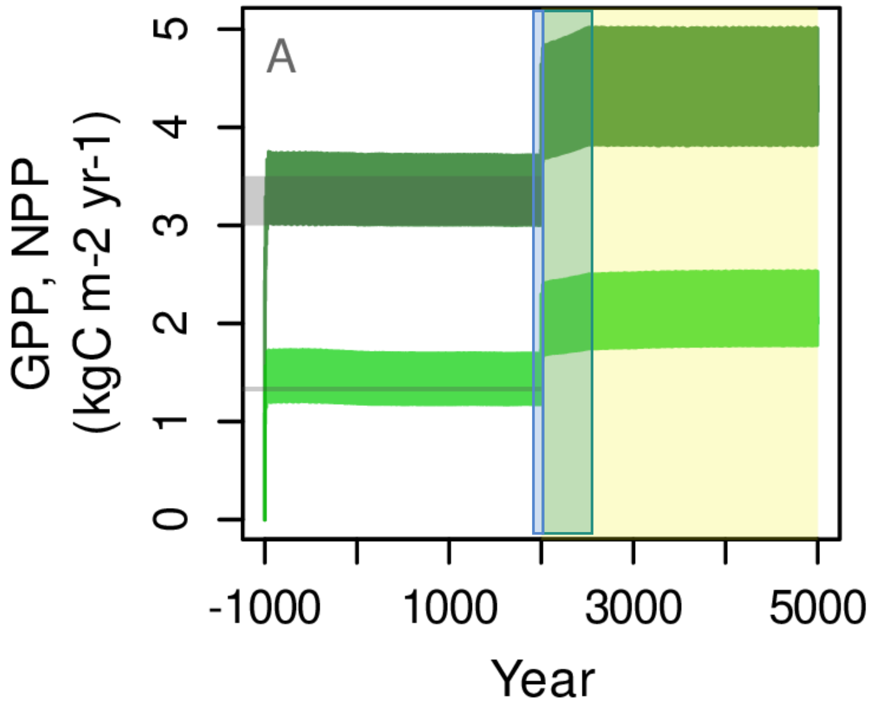
Trait fitness and evolved trait mixture

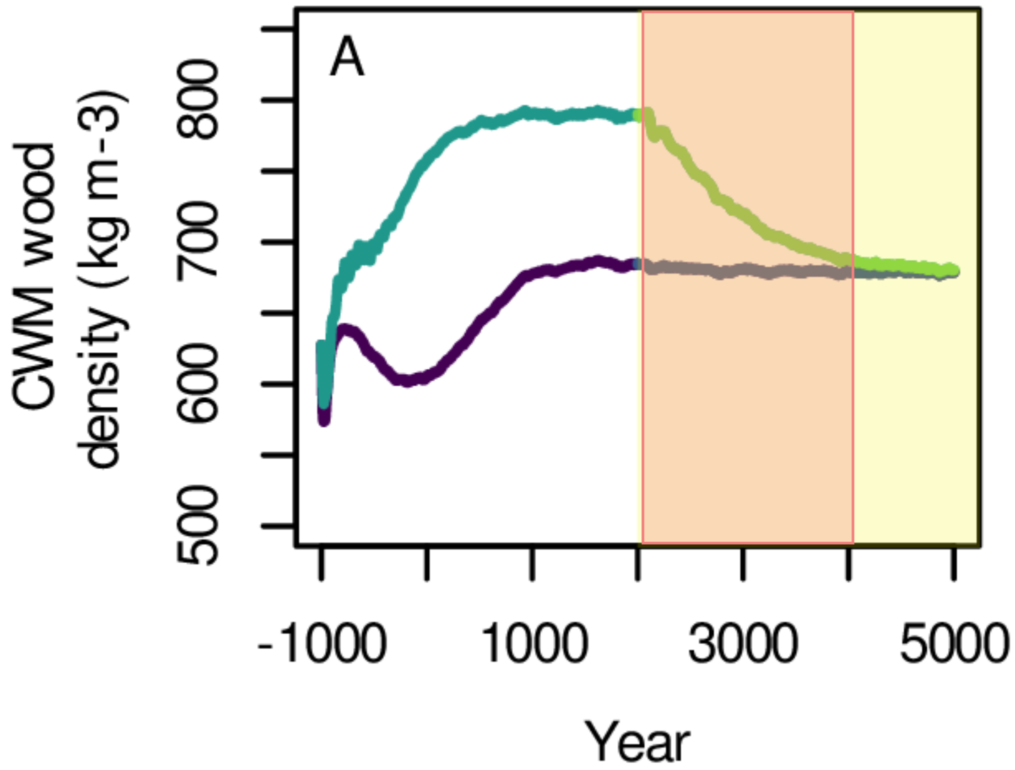


Joshi, Hofhansl *et al.*, (2023). Competition for light can drive adverse species-composition shifts in the Amazon Forest under elevated CO2. *bioRxiv*. https://doi.org/10.1101/2023.07.03.547575

Method: community responds on three timescales (eCO_2)







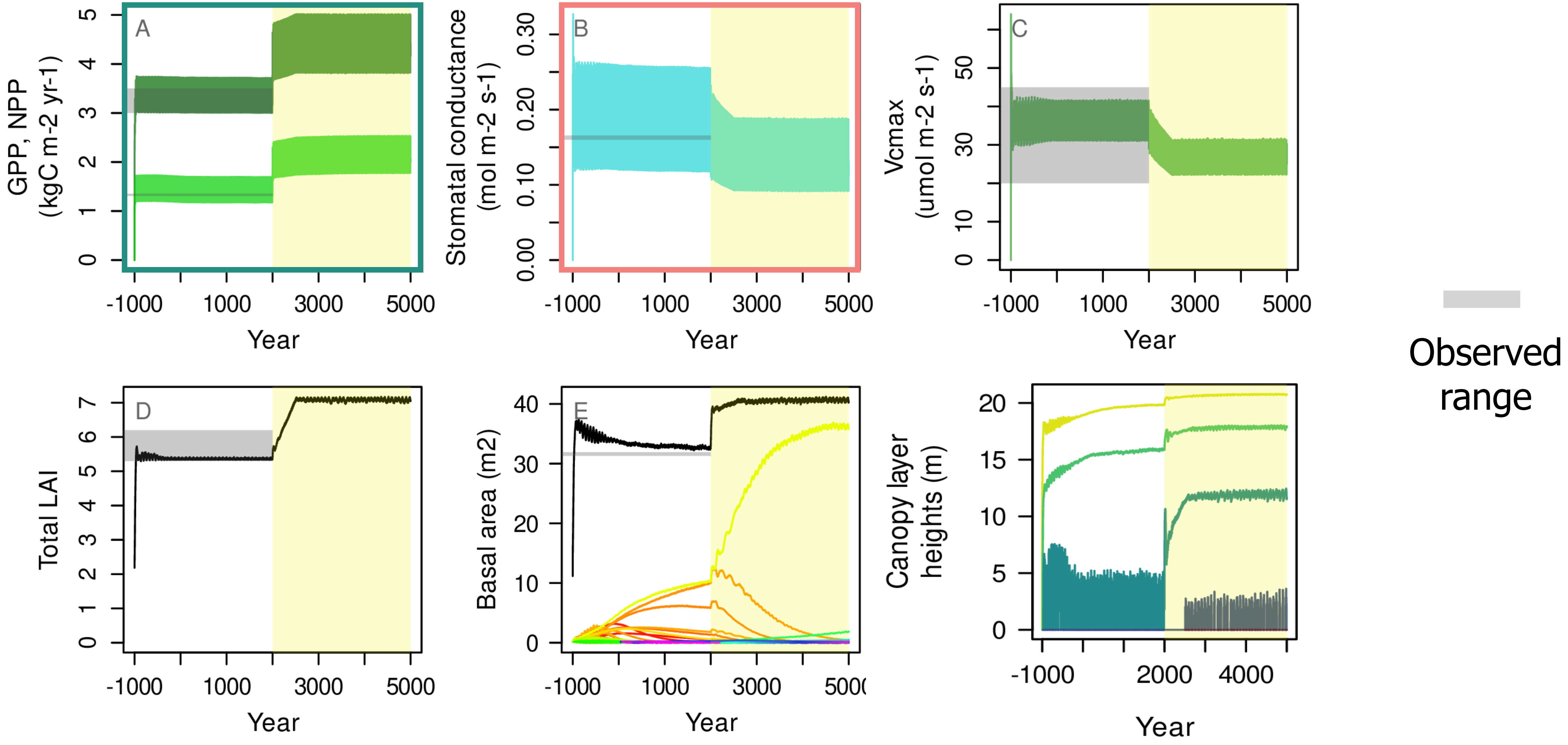
1. Physiological response in increased leaf-level photosynthesis 1 year

2. Demographic change due to changing light environment 500 years

3. Evolutionary change due to changing species composition 2000 years

Joshi, Hofhansl *et al.*, (2023). Competition for light can drive adverse species-composition shifts in the Amazon Forest under elevated CO2. *bioRxiv*. https://doi.org/10.1101/2023.07.03.547575

Method: eCO_2 increases GPP, decreases transpiration (g_s)



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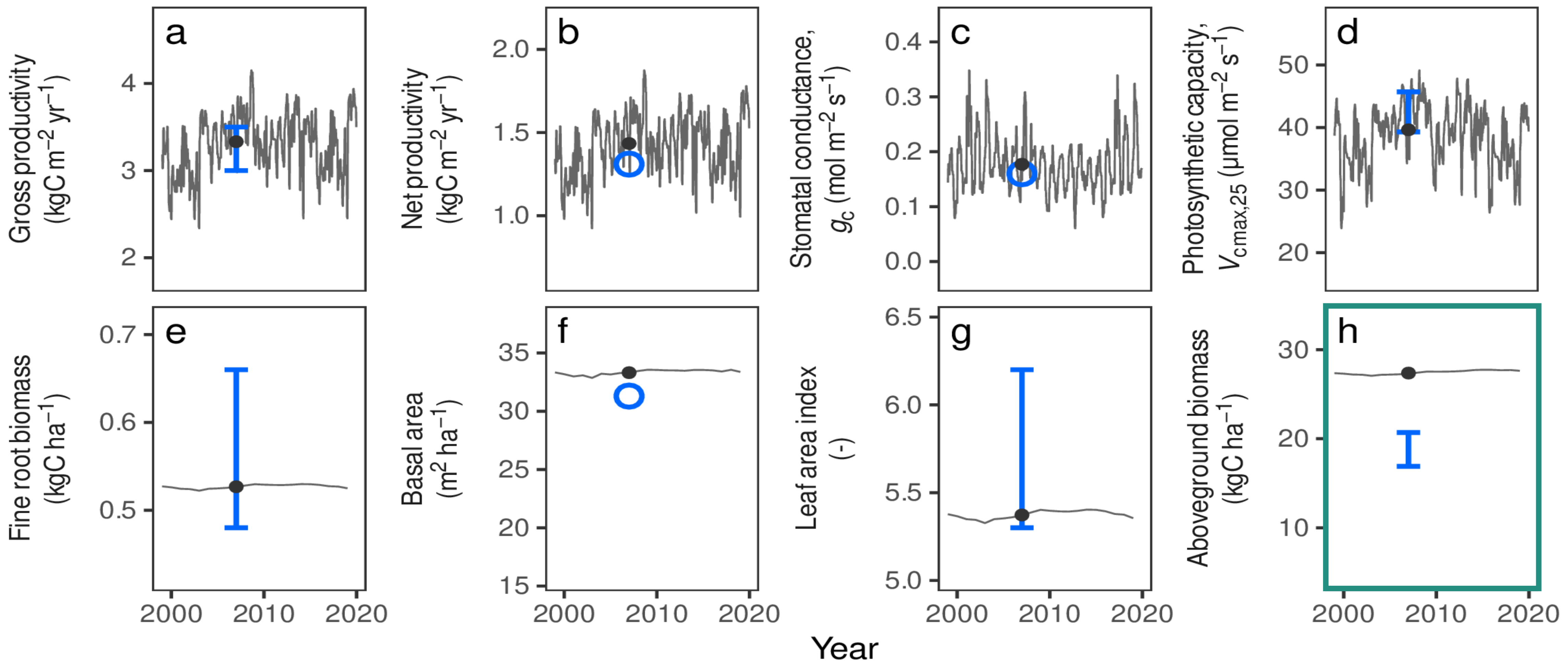
Results: predictions vs. observations (except for biomass)



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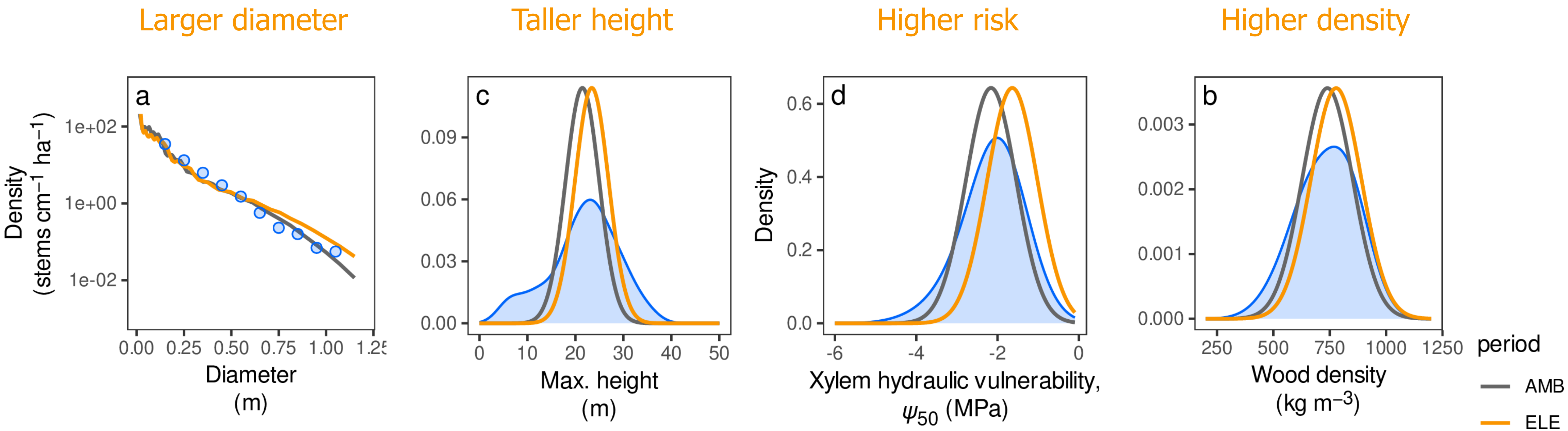
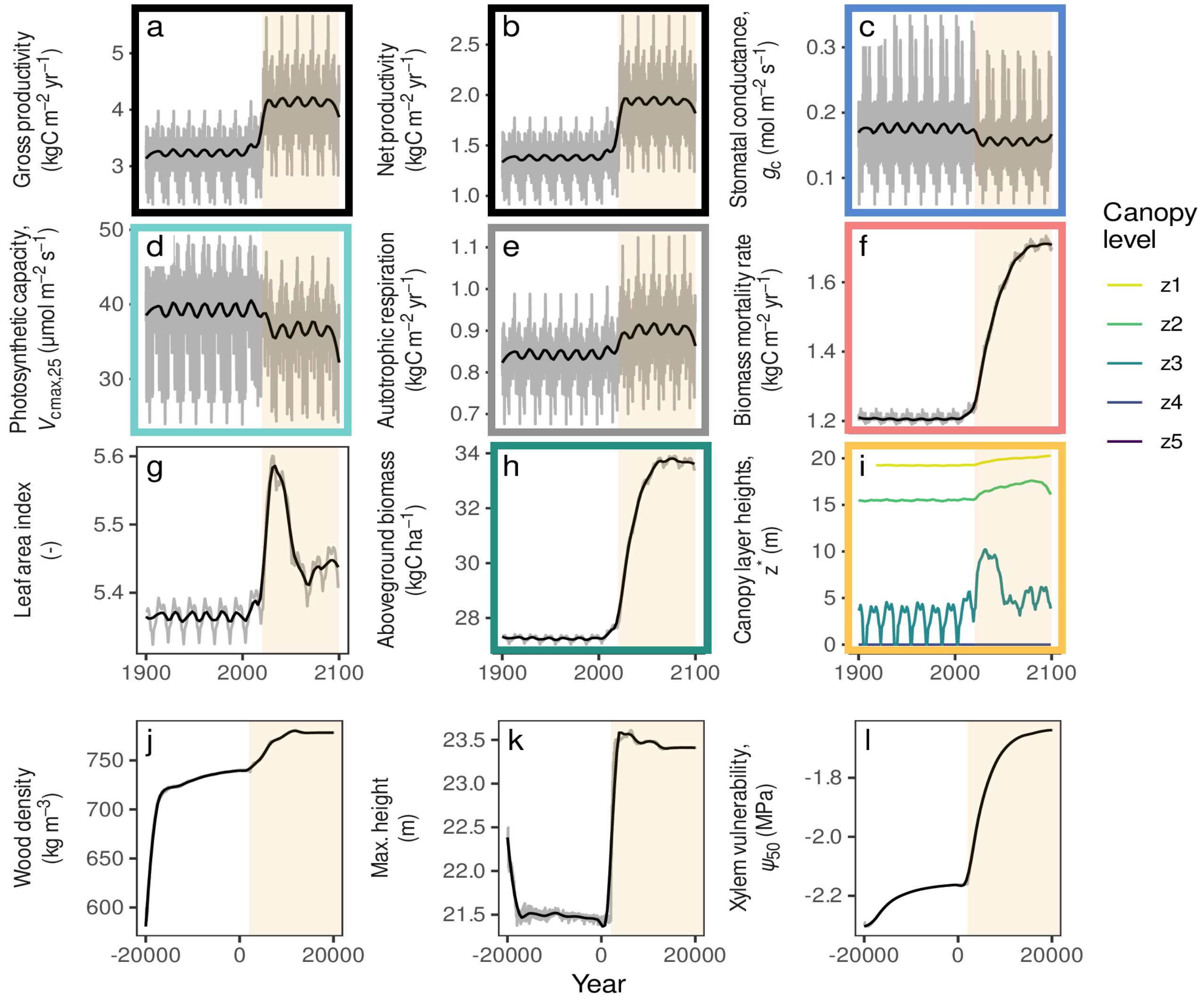
<u>Results</u>: eCO_2 affects plant characteristics (acquisitive traits)



Joshi, Hofhansl *et al.*, (2023). Competition for light can drive adverse species-composition shifts in the Amazon Forest under elevated CO2. *bioRxiv*. https://doi.org/10.1101/2023.07.03.547575

Results: eCO_2 enhances aboveground biomass and turnover



→ increase in **productivity** GPP (a), NPP (b), and **respiration** (e)

→ decrease in stomatal conductance (c) and photosynthetic capacity (d)

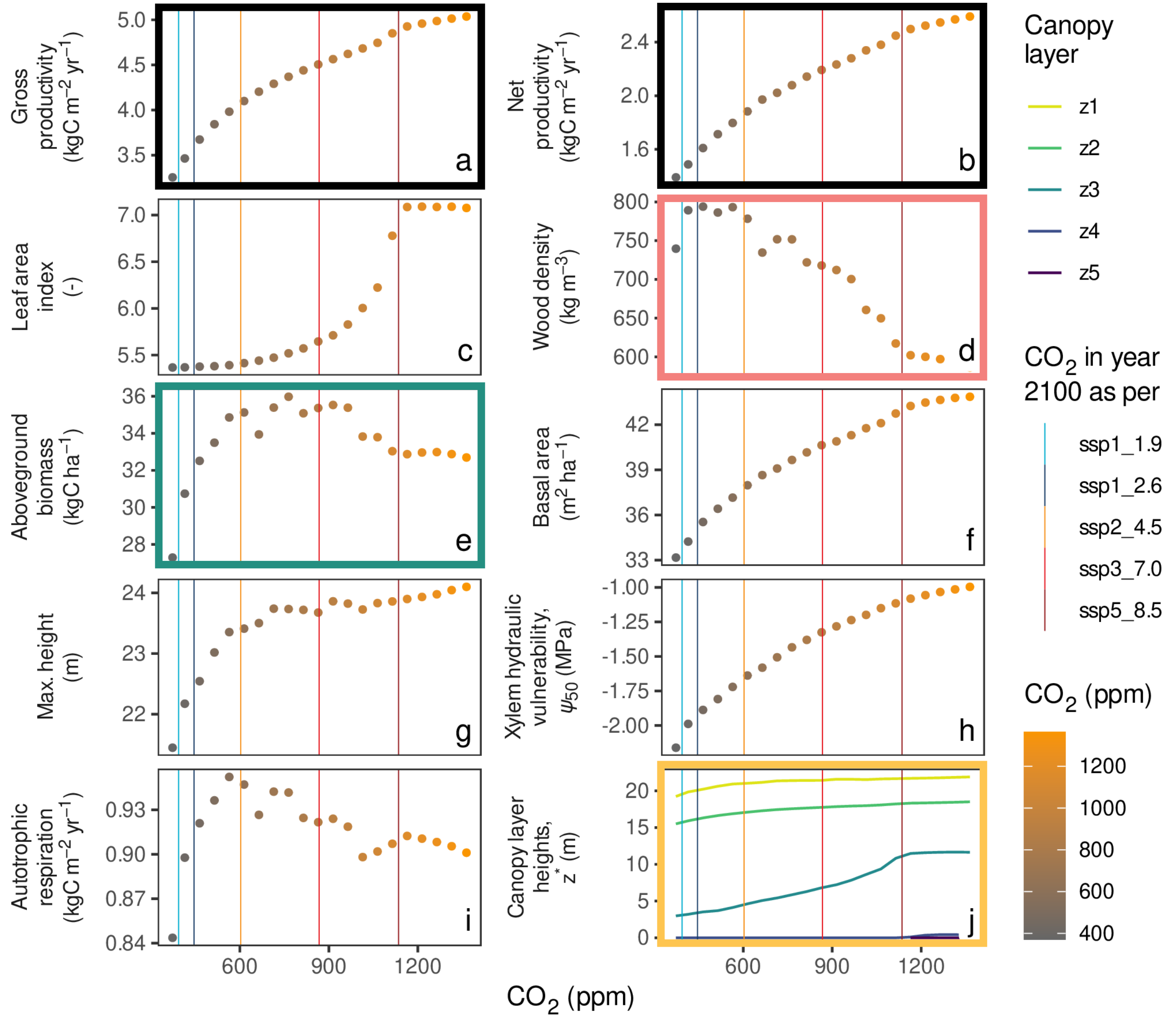
→ Leaf area and aboveground biomass increase (g-h), but also mortality rate (f)

→ Heights of canopy layers increase (i), making the understory darker.

→ Traits evolve towards higher wood density (j), higher maximum height (k), and less negative xylem hydraulic vulnerability (l).

Joshi, Hofhansl *et al.*, (2023). Competition for light can drive adverse species-composition shifts in the Amazon Forest under elevated CO2. *bioRxiv*. https://doi.org/10.1101/2023.07.03.547575

Results: reverse trends with progressively increasing eCO_2



Each point represents the respective steady state with CO_2 level indicated by point color (400 ppm – 1200 ppm)

with increasing CO2 concentrations:

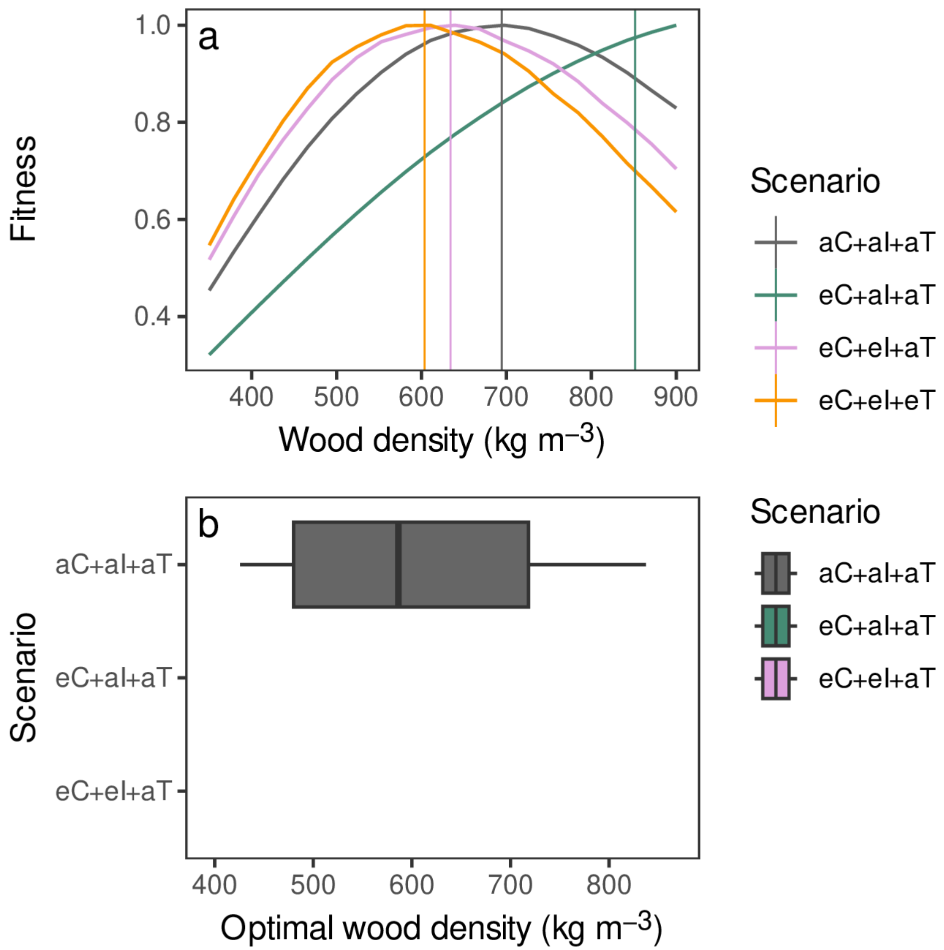
productivity increases monotonically (a,b),

wood density and **aboveground biomass** **initially increase** but then peak and **decrease beyond 600 ppm** (d,e).

canopy layer heights increase, causing intensifying competition for light and thus increasing understory mortality (j).

Joshi, Hofhansl *et al.,* (2023). Competition for light can drive adverse species-composition shifts in the Amazon Forest under elevated CO2. *bioRxiv*. https://doi.org/10.1101/2023.07.03.547575

Results: eCO_2 affects wood density, but feedbacks!



Fitness of individual trees growing in a specified environment, (aC+aI+aT/eC+aI+aT/eC+eI+aT) as a function of wood density:

→ For all scenarios, fitness peaks at intermediate values of wood density (marked by vertical lines), reflecting the **trade-off between growth and survival**.

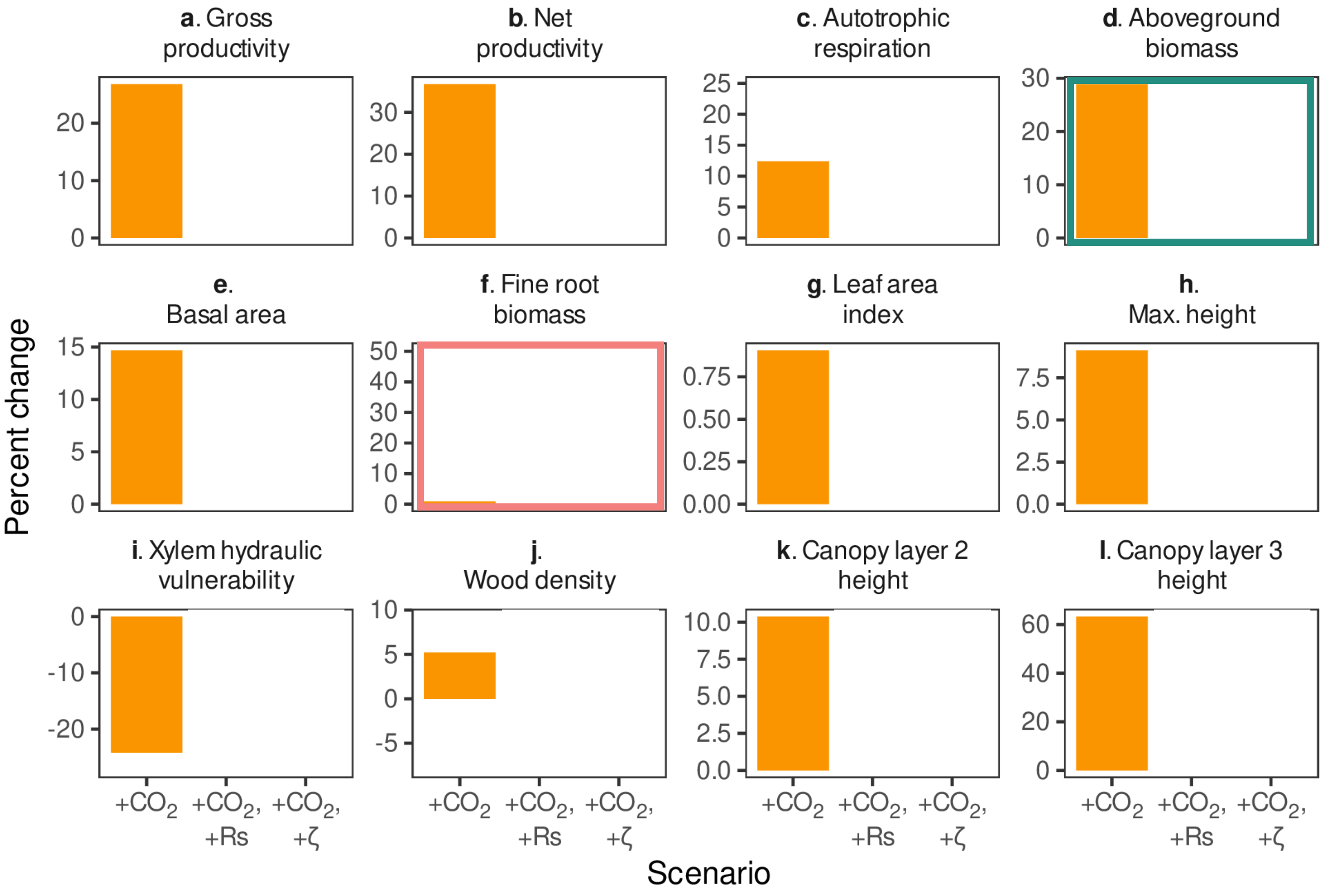
Optimal wood density (corresponding to the fitness maxima):

→ **under elevated CO_2** but in the absence of environmental feedbacks, **trees with higher wood density are fitter.**

→ However, when **environmental feedbacks** are accounted for **optimal wood density decreases** as compared to baseline.

Joshi, Hofhansl *et al.*, (2023). Competition for light can drive adverse species-composition shifts in the Amazon Forest under elevated CO2. *bioRxiv*. https://doi.org/10.1101/2023.07.03.547575

Results: increased respiration and belowground allocation reduce the CO_2-fertilization effect on aboveground biomass



- **Elevated CO_2 (614.2 ppm)**

eCO_2 + 50% increase in feedback

- **sapwood respiration (+Rs)**

increase in sapwood respiration rate, (due to increasing temperature)

- **belowground allocation (+ζ)**

increased belowground allocation (response to nutrient limitation)

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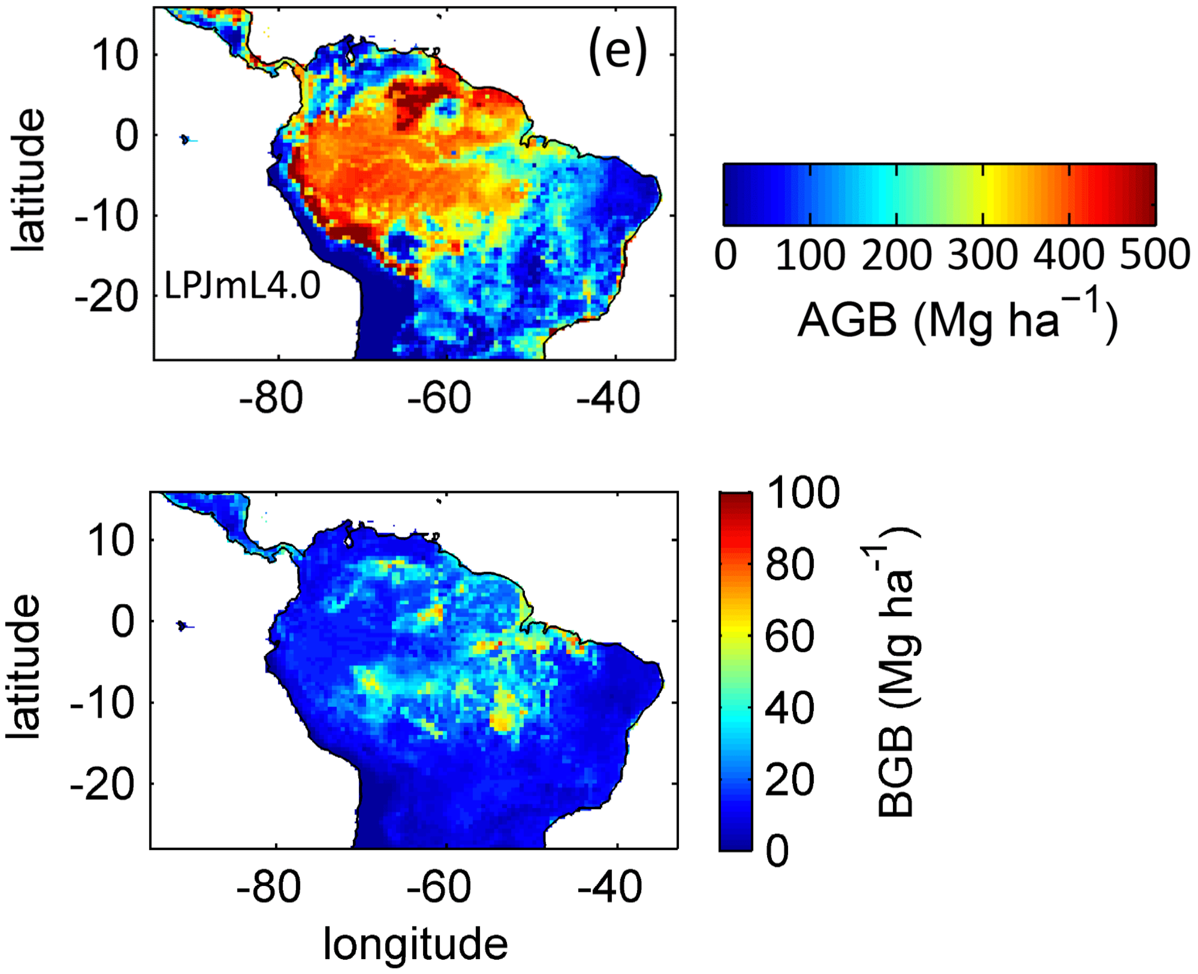
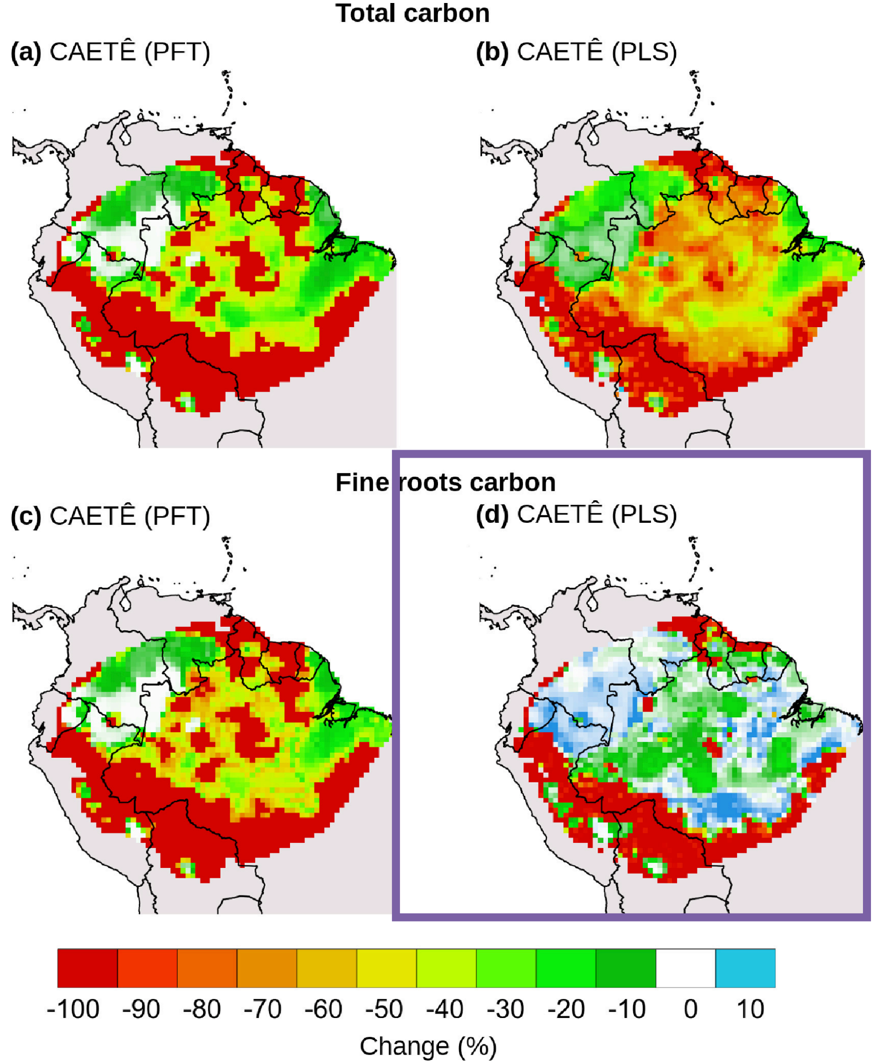
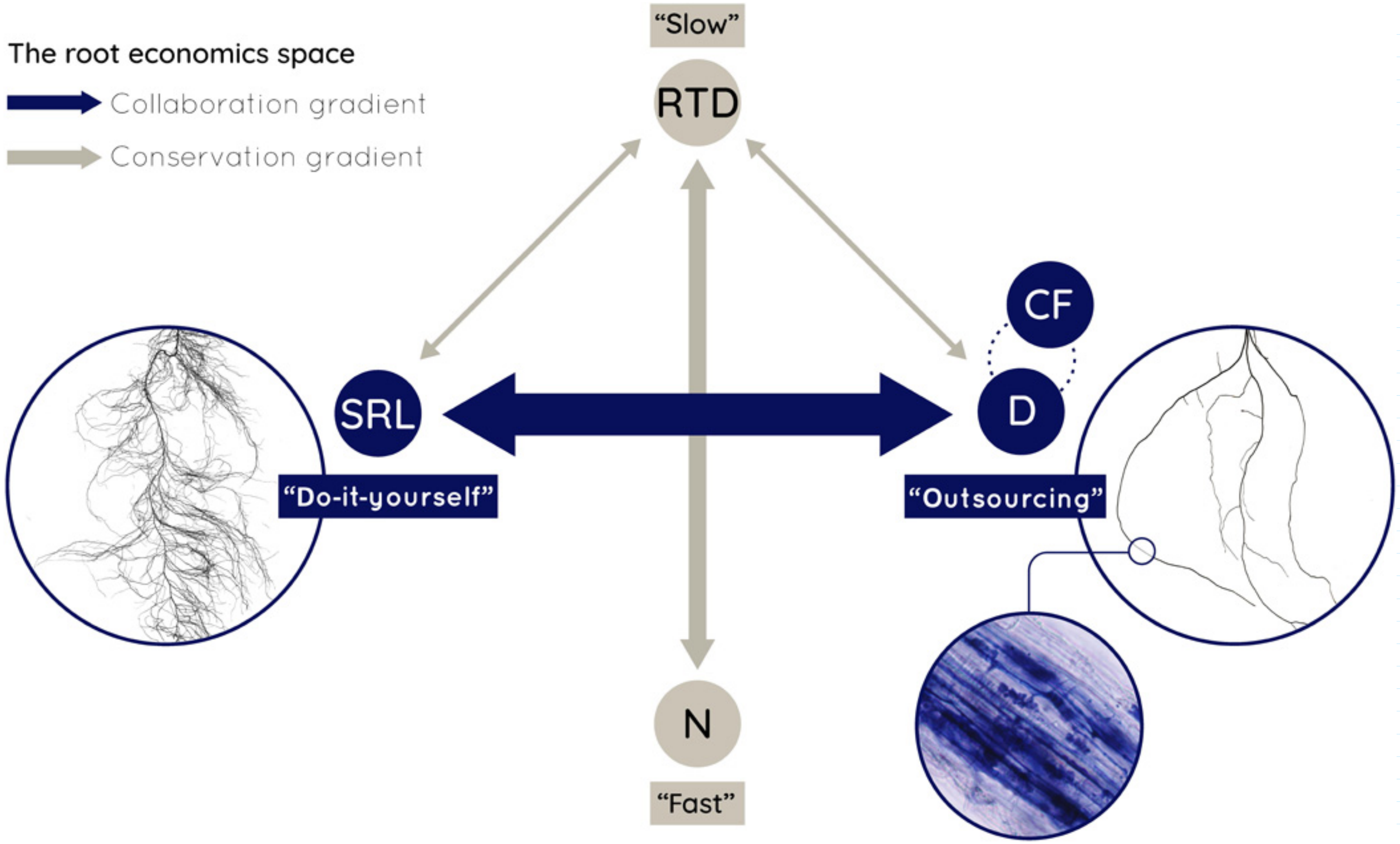
Outlook: trait variability / belowground allocation

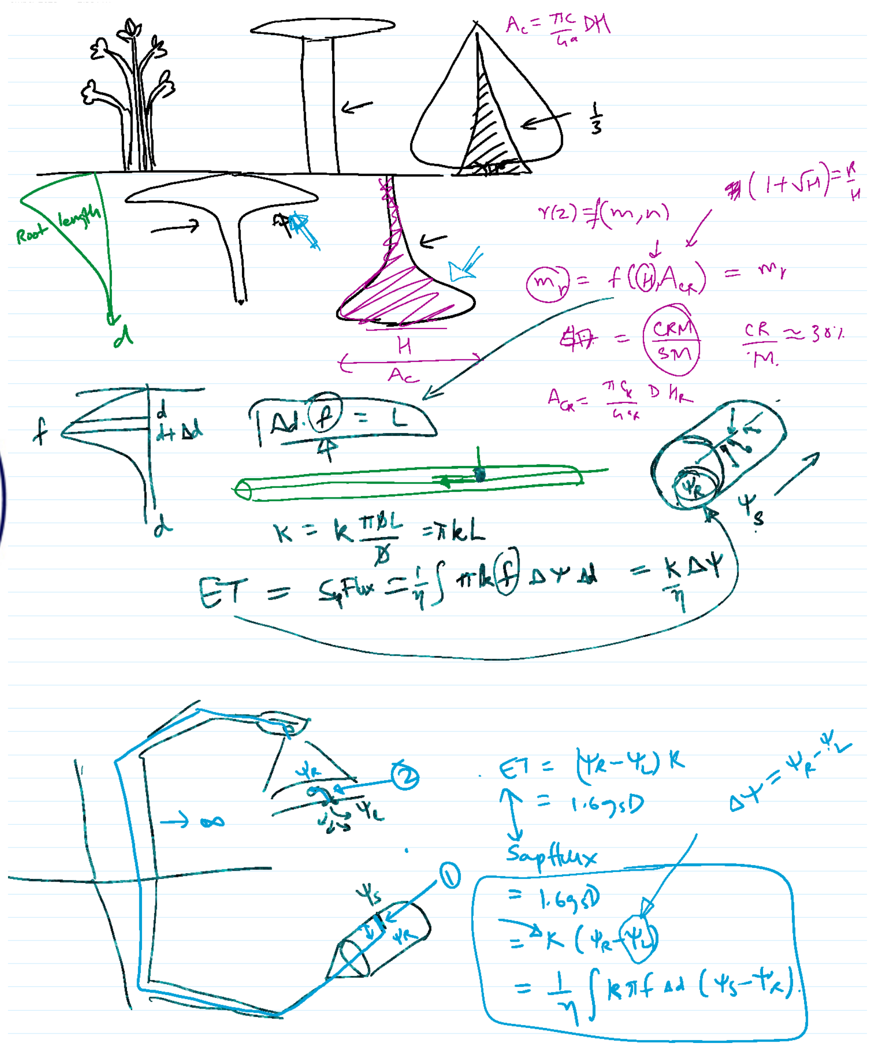




Rius, B.F., et al., (2023). Higher functional diversity improves modeling of Amazon forest carbon storage. Ecological Modelling. 481, e110323.

Outlook: belowground trade-offs (investment)





Root systems display tremendous diversity of growth forms in association with different functions (resource-use)

Bergmann et al., (2020), *Science Advances*, 6(27), 1–10. https://doi.org/10.1126/sciadv.aba3756

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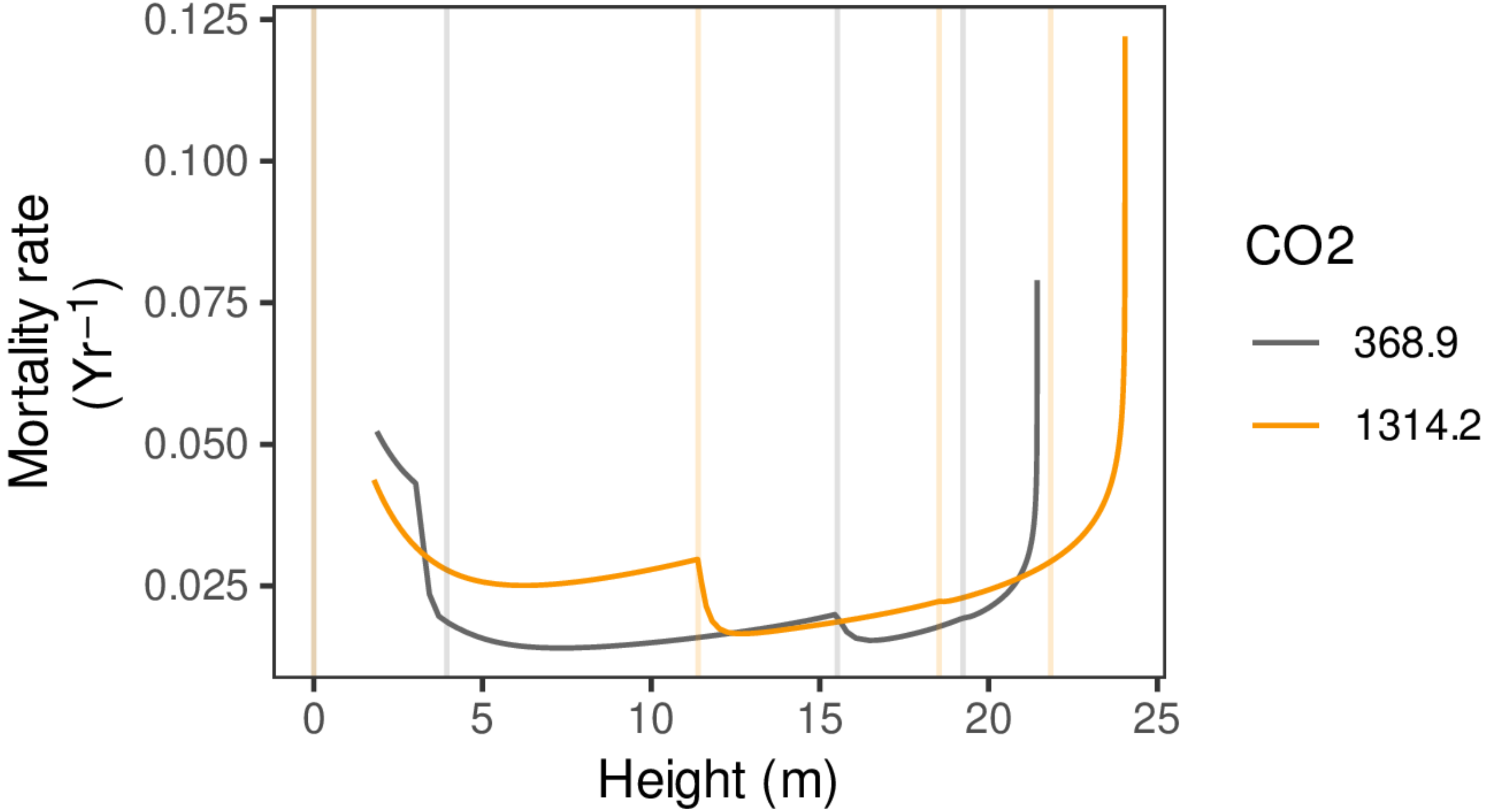
Thank you – questions?

For further questions and a link to the references
please contact me via the QR code shown above!

Joshi, J., Stocker, B.D., Hofhansl, et al., (2022). *Nature Plants* 10.1038/s41477-022-01244-5.

eCO2 triggers increased mortality rates (understory)



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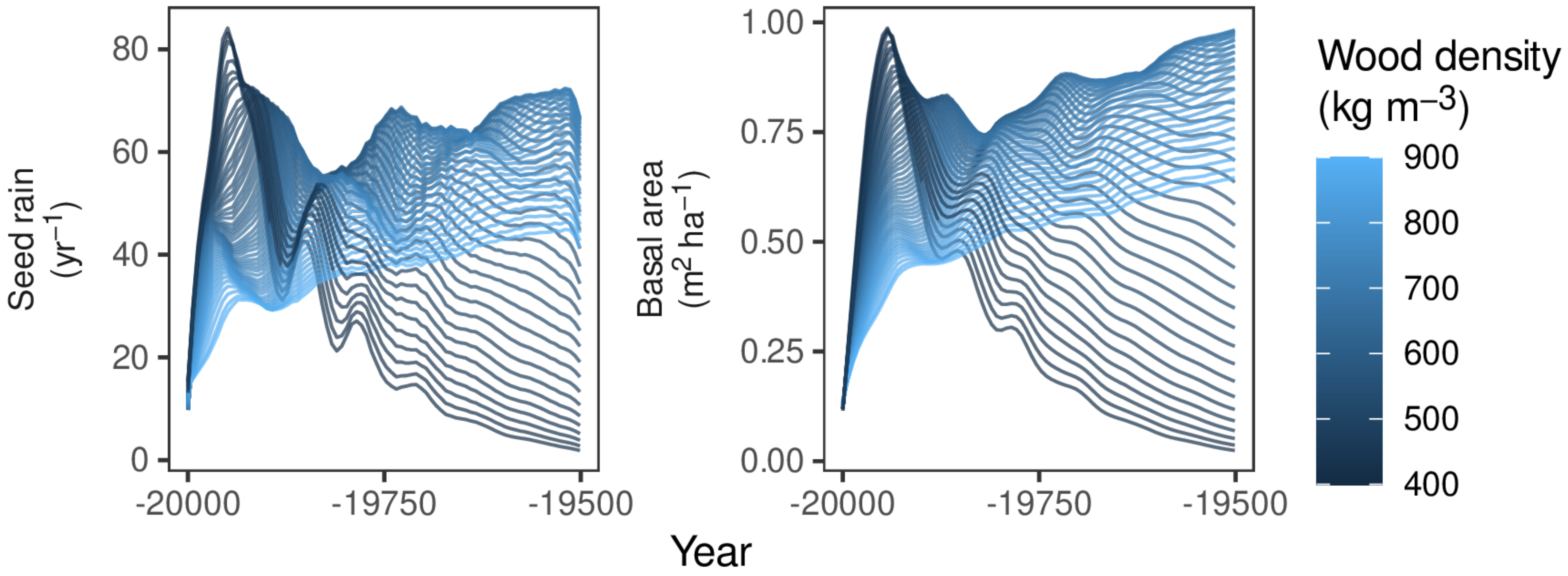
Plant-FATE successional dynamics



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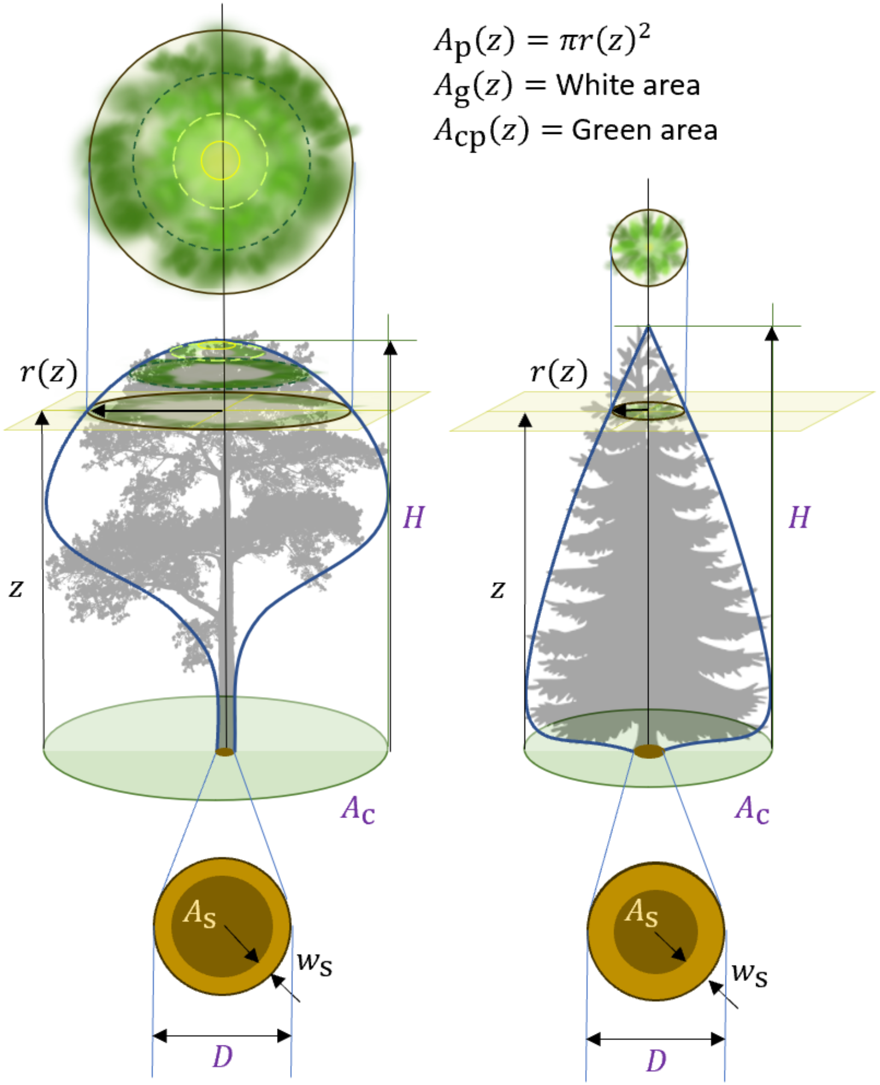
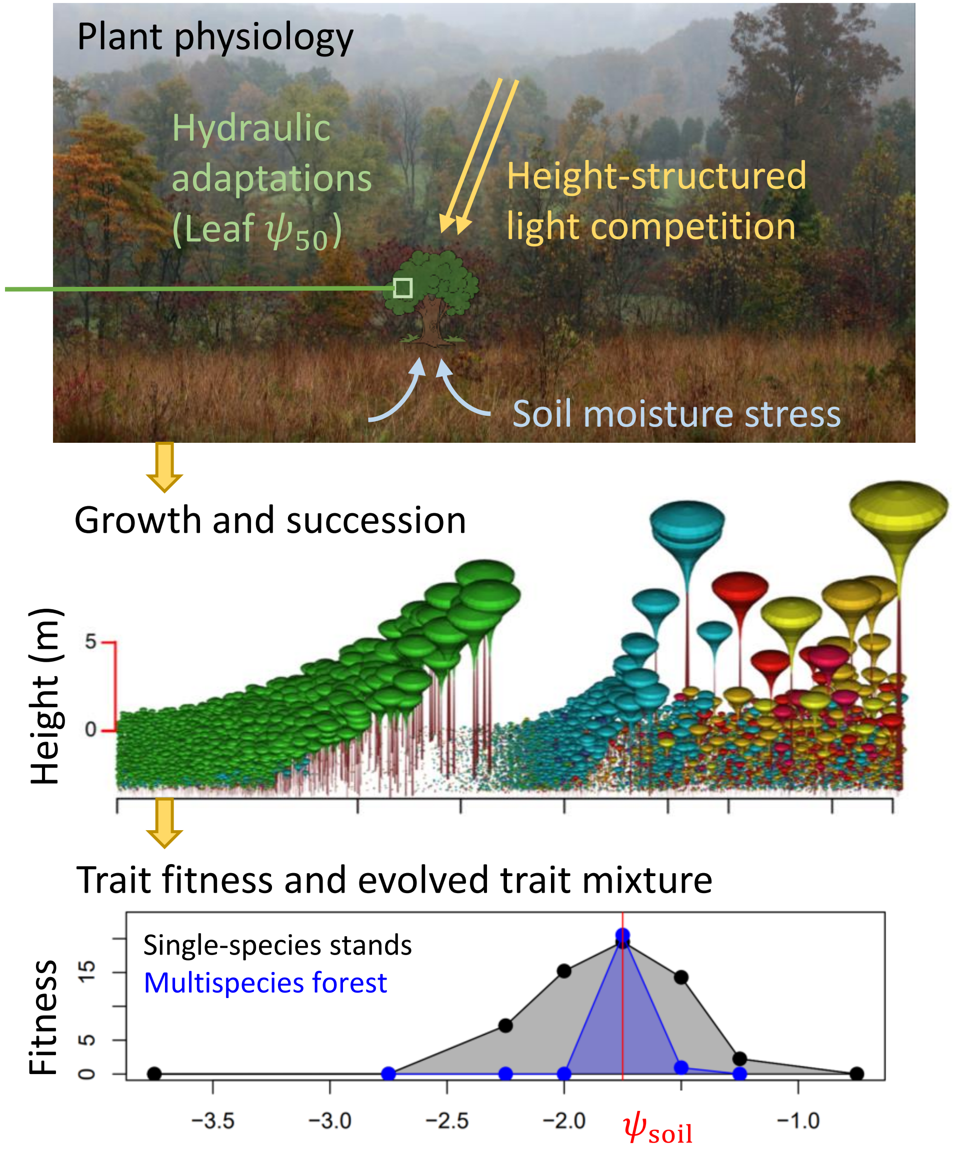
Tree architecture in Plant-FATE





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