Predicting the adaptive responses of biodiverse plant communities using functional trait evolution

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25 Apr 2023, EGU 2023
How does a biodiverse ecosystem respond to climate change?

**Organizational levels**
- Individual
- Species
- Community

**Timescales**
- Hours-months
- Years-decades
- Centuries

- Plastic trait acclimation
- Demographic community shifts
- Species genetic evolution
How does a biodiverse ecosystem respond to climate change?

- **Organizational levels**
  - Individual
  - Species
  - Community

- **Timescales**
  - Hours-months
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- **Fluxes**
  - GPP $\uparrow$
  - $V_{\text{cmax}} \downarrow$
  - $g_s \downarrow$

- **Community composition**
  - ?

- **Evolutionarily stable strategies**
  - ?

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Plant-FATE: Our eco-evolutionary vegetation model

**Physiological acclimation**
Optimality principles

Optimal photosynthesis, hydraulics, allocation

**Vegetation demographics**
Size-structured population modelling

Competition for light and water, optimal crown placement

**Species evolution**
Evolutionary dynamics

Gradual ascension of the fitness landscape

Days - Months

Years - Decades

Centuries

Image Credits: Muffet, Huw Williams
We address four key Questions

1. What are the changes in fluxes (GPP, transpiration) under elevated CO$_2$ (eCO$_2$) compared to ambient CO$_2$ (aCO$_2$)?

2. What are the timescales of responses at the three organizational levels?

3. Are there potential species shifts under eCO$_2$?

4. How do allocation shifts occurring in response to nutrient limitation affect ecosystem responses to eCO2?
We apply the model to a hyperdiverse Amazonian forest

1. Forced with periodic extension of observed meteorological data from 2000-2015

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

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

4. Let community composition evolve via competitive exclusion
GPP increases, transpiration decreases under eCO$_2$

- **Graph A**: GPP, NPP (kgC m$^{-2}$ yr$^{-1}$) over years.
- **Graph B**: Stomatal conductance (mol m$^{-2}$ s$^{-1}$) over years.
- **Graph C**: Vcmax (umol m$^{-2}$ s$^{-1}$) over years.
- **Graph D**: Total LAI over years.
- **Graph E**: Basal area (m$^2$) and Canopy layer heights (m) over years.

Observed range
Community shifts to larger trees and species with lower wood density under eCO$_2$
Community responds on three timescales

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
Population-environment feedbacks alter the direction of the community shift

**Predicted optimal wood density**
(for different combinations of LMA, Max Height, and P50)

- **Baseline**
- **eCO2 but no change in vertical light profile**
- **eCO2 with demographic feedbacks on light profile**

![Wood density (kg m-3)](image)
Nutrient limitation diminishes the said response
Take home messages

1. The Plant-FATE model correctly predicts ecosystem fluxes, forest structure, and species composition under ambient CO$_2$
2. Under elevated CO$_2$, productivity increases but community shifts to lower wood density
3. The direction of the shift is determined by feedbacks between forest structure and the environment: not accounting for environmental feedbacks can predict opposite outcomes
4. Increased root-zone allocation dampens the increase in productivity but also prevents community shift
Thank you

Questions?

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