UCSB GROVE Lab NCAR NSF

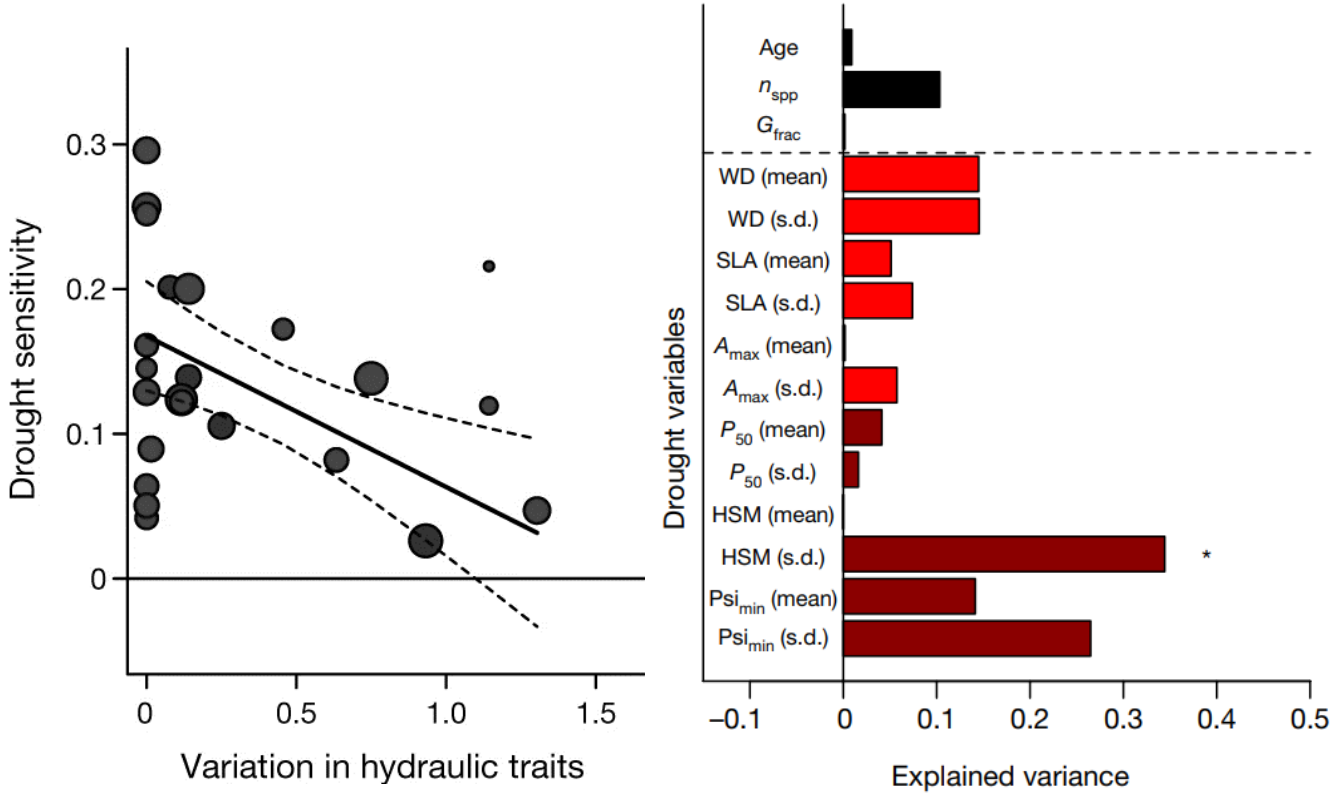
Parameter Perturbation Shows the Importance of Functional Diversity in Moderating Ecosystem Biogeochemistry

Evan Margiotta[1] – emargiotta@ucsb.edu
Anna Trugman[1], Daniel Kennedy[1,2], Linnia Hawkins[2,3]

1 - UCSB 2 - NCAR 3 - Columbia University

Evidence from observations on the importance of functional diversity

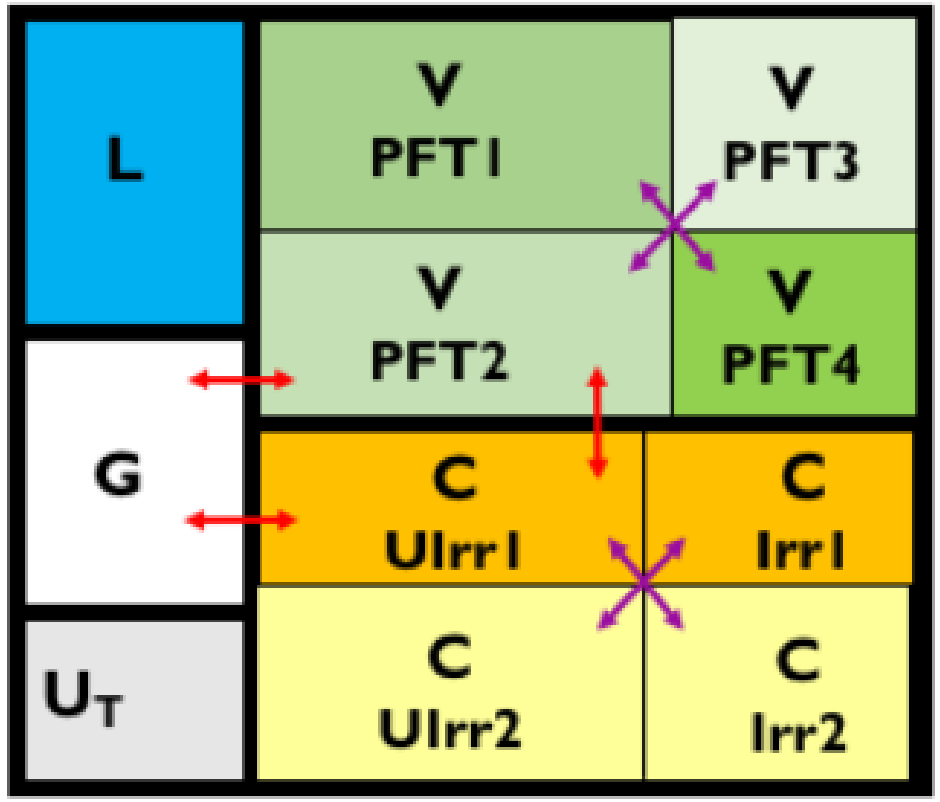
Strong evidence from community ecology theory and observations that functional diversity serves important ecosystem functions.



From Anderegg et al. (2018)

"Critically, diversity–stability effects are mostly absent in most global land-surface models, most of which represent each biome or plant functional type with a single set of functional traits, partly owing to a lack of understanding of which functional traits are the most important at ecosystem scales."

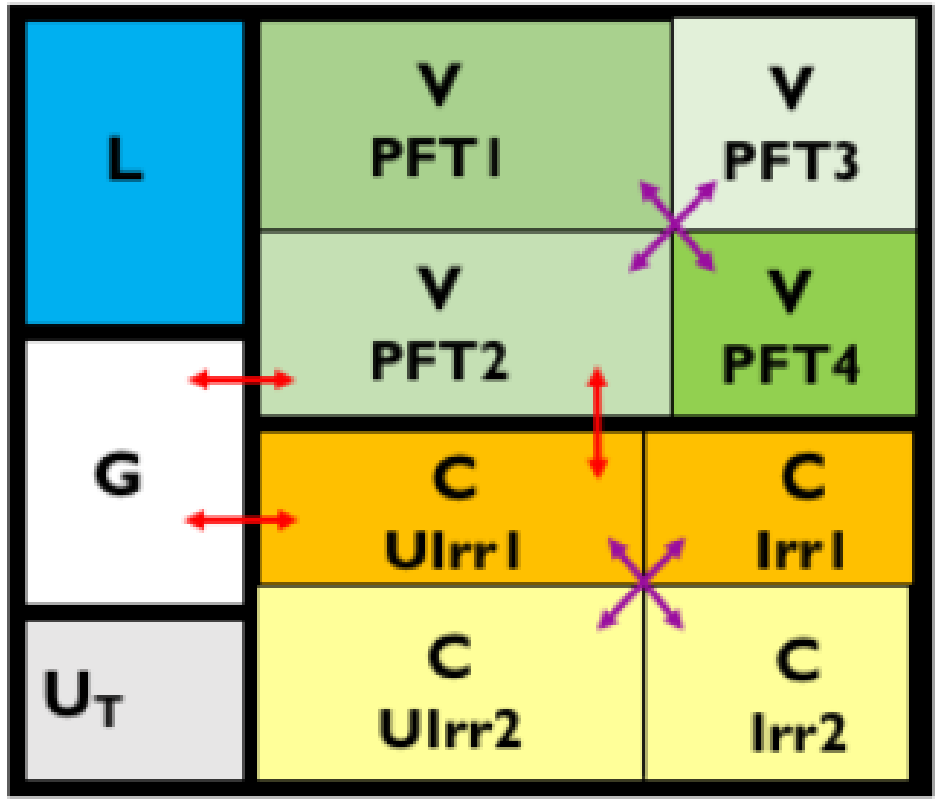
Evidence from observations on the importance of functional diversity



- 16 natural vegetation PFTs
- Lack of process representation of light competition, or disturbance (beetles) that might express competitive fitness
- However, PFTs still compete for water

"Critically, diversity–stability effects are mostly absent in most global land-surface models, most of which represent each biome or plant functional type with a single set of functional traits, partly owing to a lack of understanding of which functional traits are the most important at ecosystem scales."

Evidence from observations on the importance of functional diversity



Research Questions:

In CLM's coarse representation of plant functional types:

1. Do diversity-stability relationships emerge from PFT competition for water?

2. How does the strength of the diversity effect vary across space?

3. What kind of diversity matters?

Parameter perturbation as a tool to explore diversity-stability effects

Parameter Perturbation Experiment

- Perturbation of 32 traits associated with plant hydraulics, photosynthesis, and stomatal regulation across 500 ensemble member (Linnia's wave 1 simulations)
- **12 traits are perturbed separately for each PFT**
- Across ensemble members, grid cell level trait means and trait diversity can vary

Research Questions:

In CLM's coarse representation of plant functional type:

1. Do diversity-stability relationships emerge from PFT competition for water?

2. How does the strength of the diversity effect vary across space?

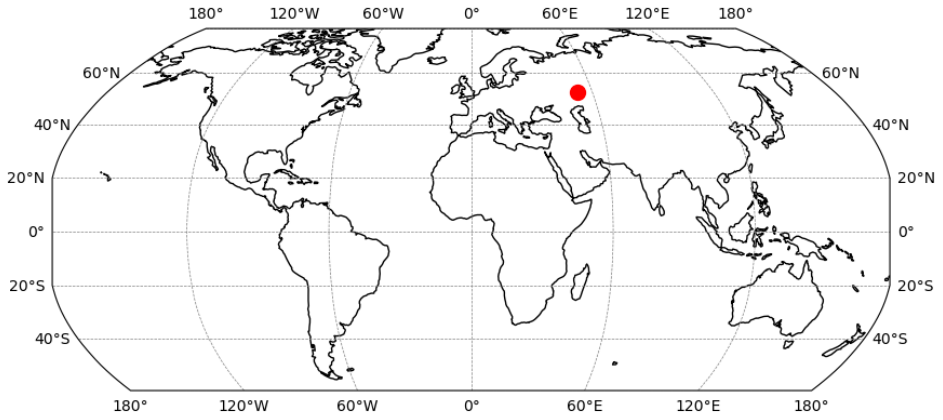
3. What kind of diversity matters?

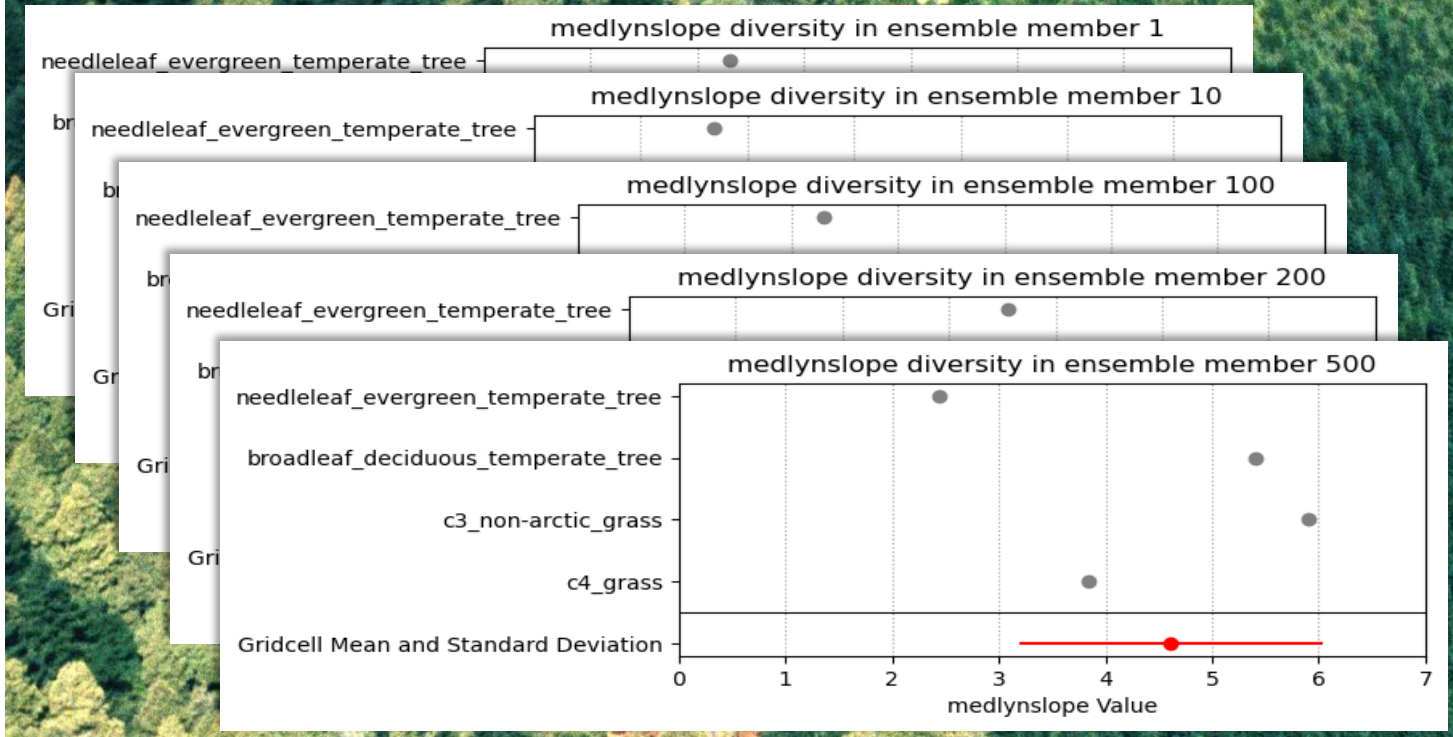
Parameter perturbation as a tool to explore diversity-stability effects

Parameter Perturbation Experiment

- Perturbation of 32 traits associated with plant hydraulics, photosynthesis, and stomatal regulation across 500 ensemble member (Linnia's wave 1 simulations)
- **12 traits are perturbed separately for each PFT**
- Across ensemble members, grid cell level trait means and trait diversity can vary

Temperate Forest Site





Drought Sensitivity ~ $Trait_i$_Mean + $Trait_i$_SD

$$\frac{GPP_{Minimum\ \beta\ Month} - GPP_{Mean}}{GPP_{Mean}}$$

Diversity Effect

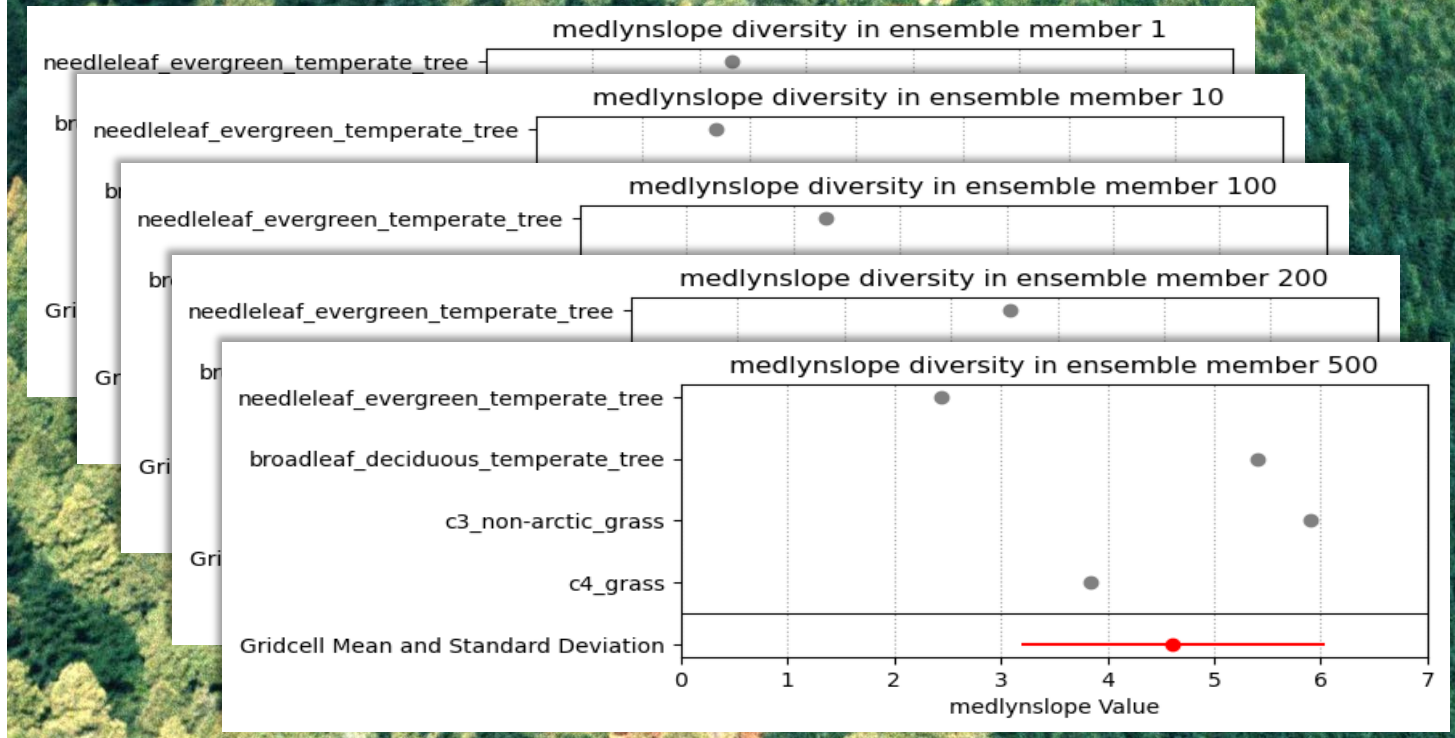
Parameter perturbation as a tool to explore diversity-stability effects

Parameter Perturbation Experiment

- Perturbation of 32 traits associated with plant hydraulics, photosynthesis, and stomatal regulation across 500 ensemble member (Linnia's wave 1 simulations)
- **12 traits are perturbed separately for each PFT**
- Across ensemble members, grid cell level trait means and trait diversity can vary

Partitioning of Model Variance

- Gaussian process emulator to partition model variance in drought sensitivity between trait means and trait standard deviations
- Partition variance procedure at every grid cell
- Novel use of the CLM-PPE for understanding competition processes which emerge from grid cell scale interaction between parameters



Drought Sensitivity ~ $Trait_i$_Mean + $Trait_i$_SD

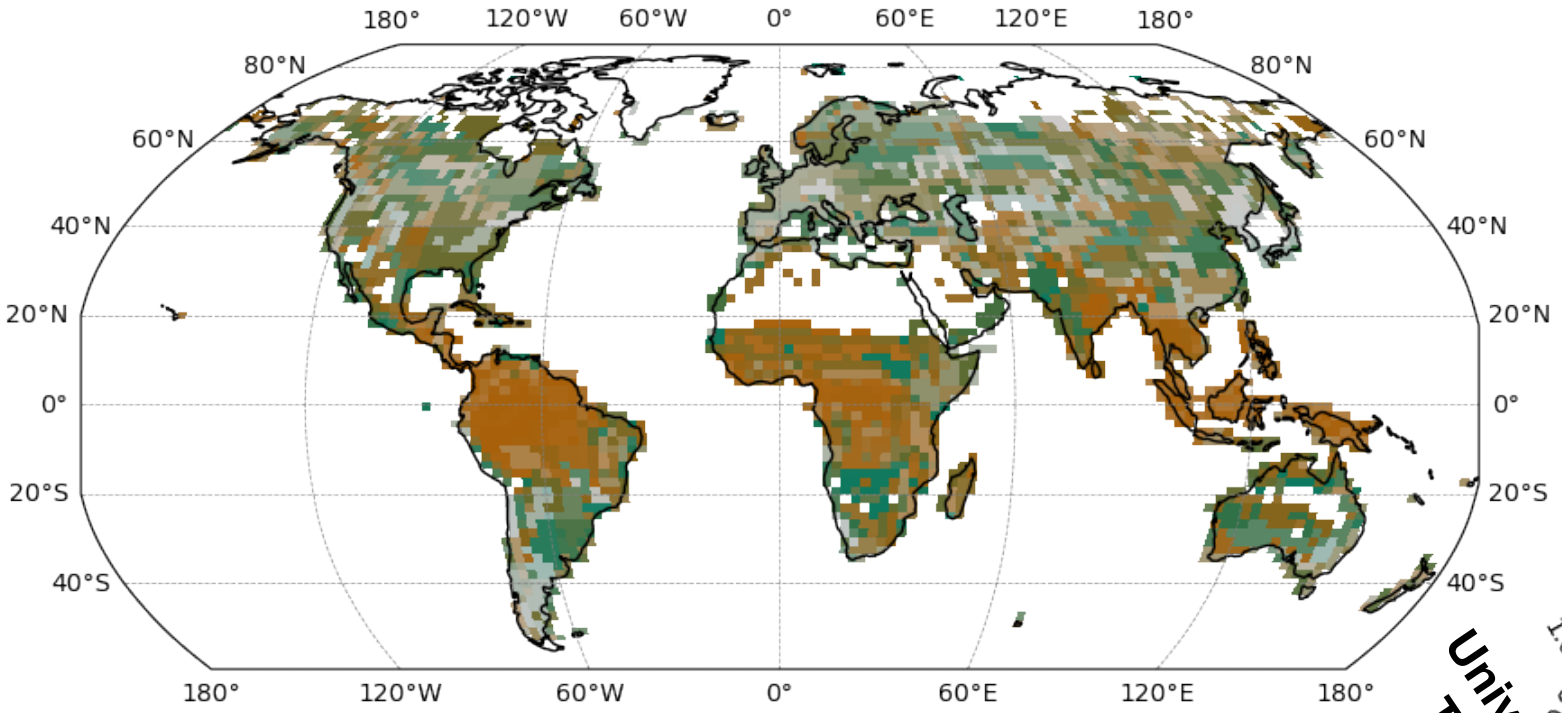
$$\frac{GPP_{Minimum\ \beta\ Month} - GPP_{Mean}}{GPP_{Mean}}$$

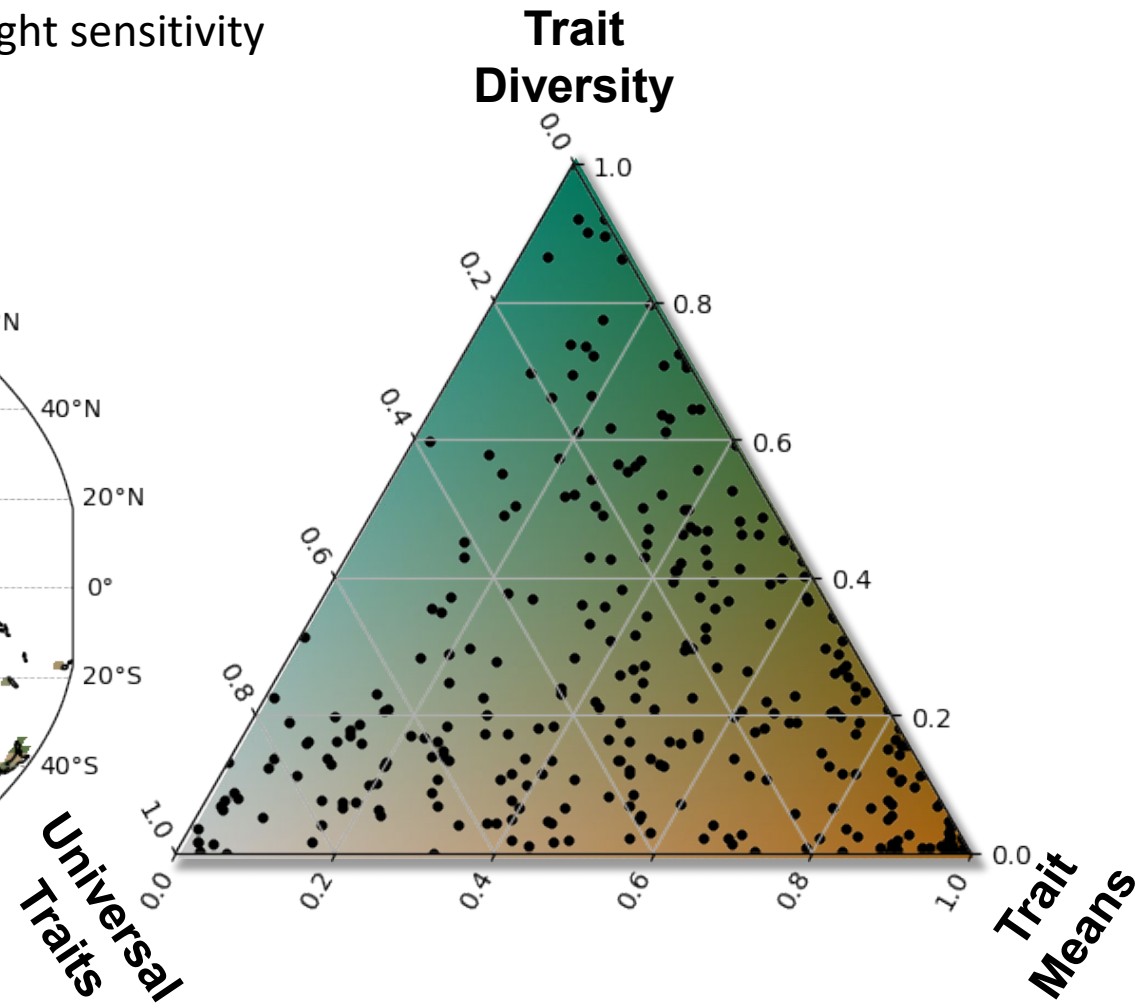
Diversity Effect

Trait diversity appears to control variation in drought response

On average, trait diversity explains **22%** of variation in ecosystem drought sensitivity

However, that response **varies significantly across the globe**



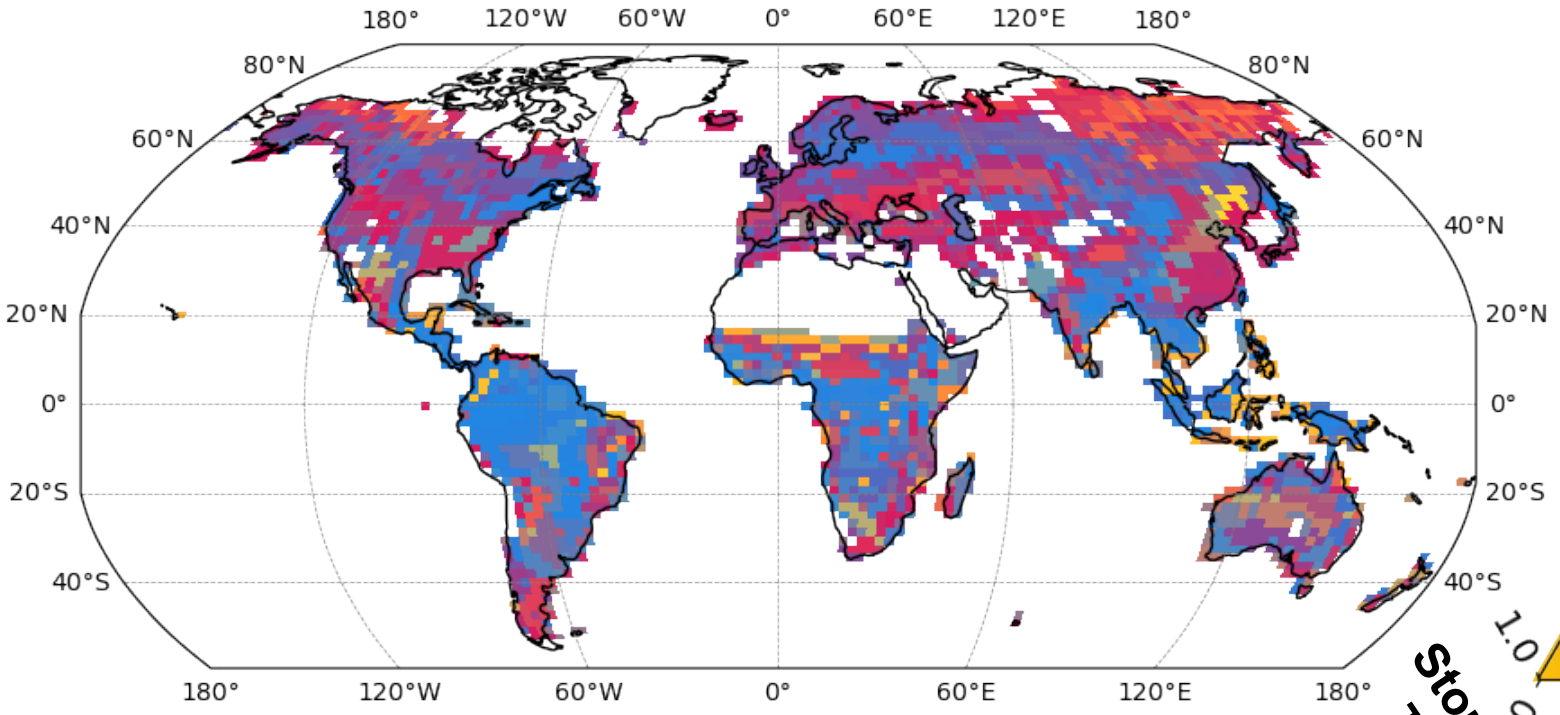


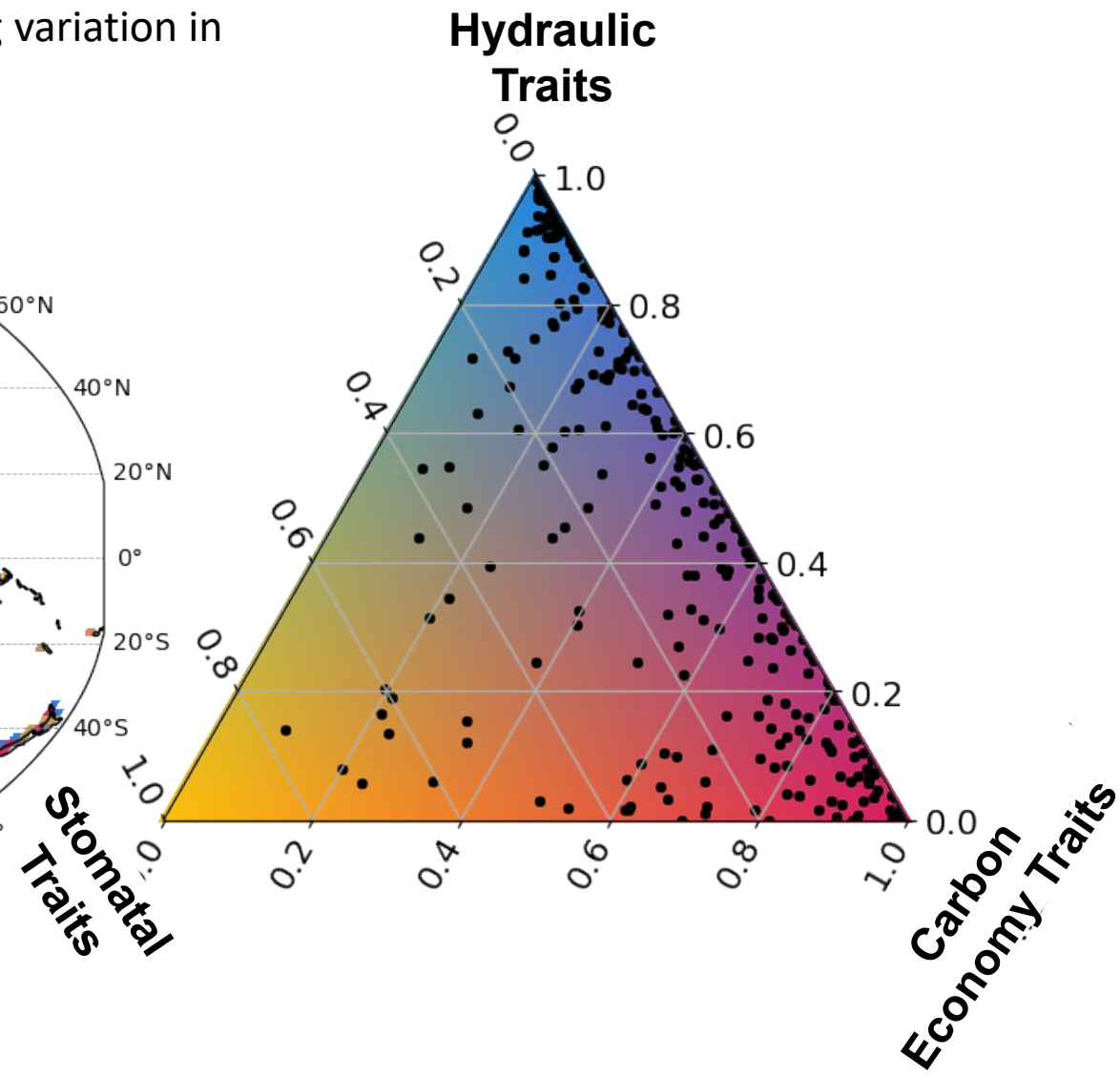
In tropical forests, trait diversity only explains **2%** of drought sensitivity

In contrast, trait diversity explains **31%** of **drought sensitivity** in boreal forests

Traits controlling drought sensitivity vary across climate types

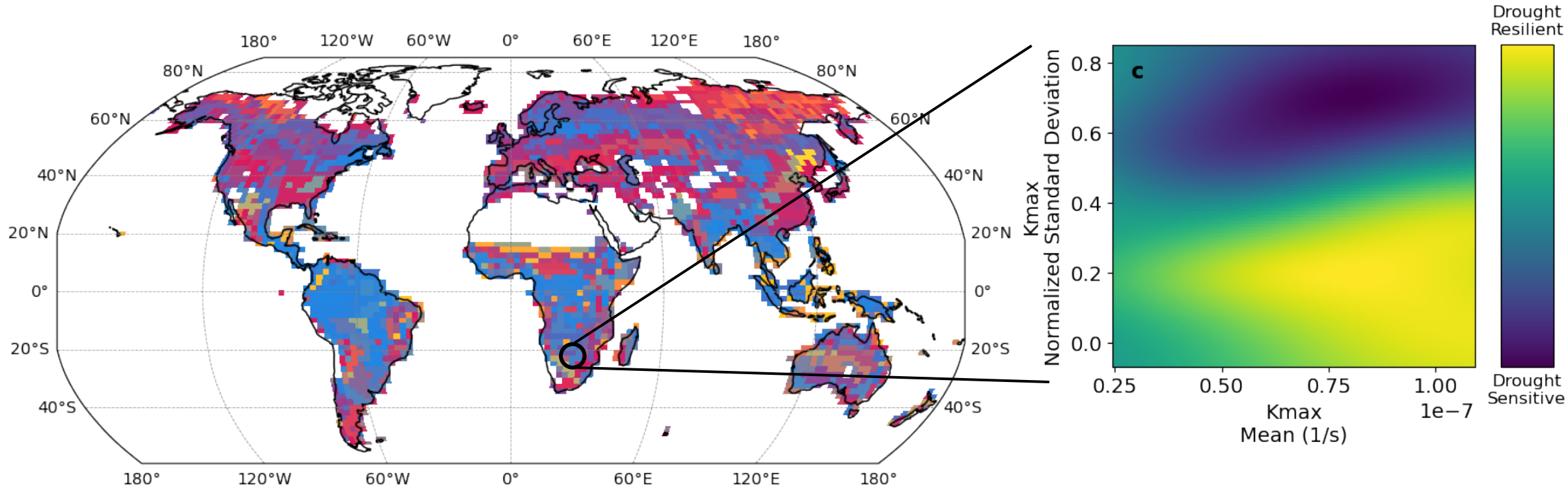
Globally, diversity of **hydraulic traits** is most important for explaining variation in ecosystem drought sensitivity





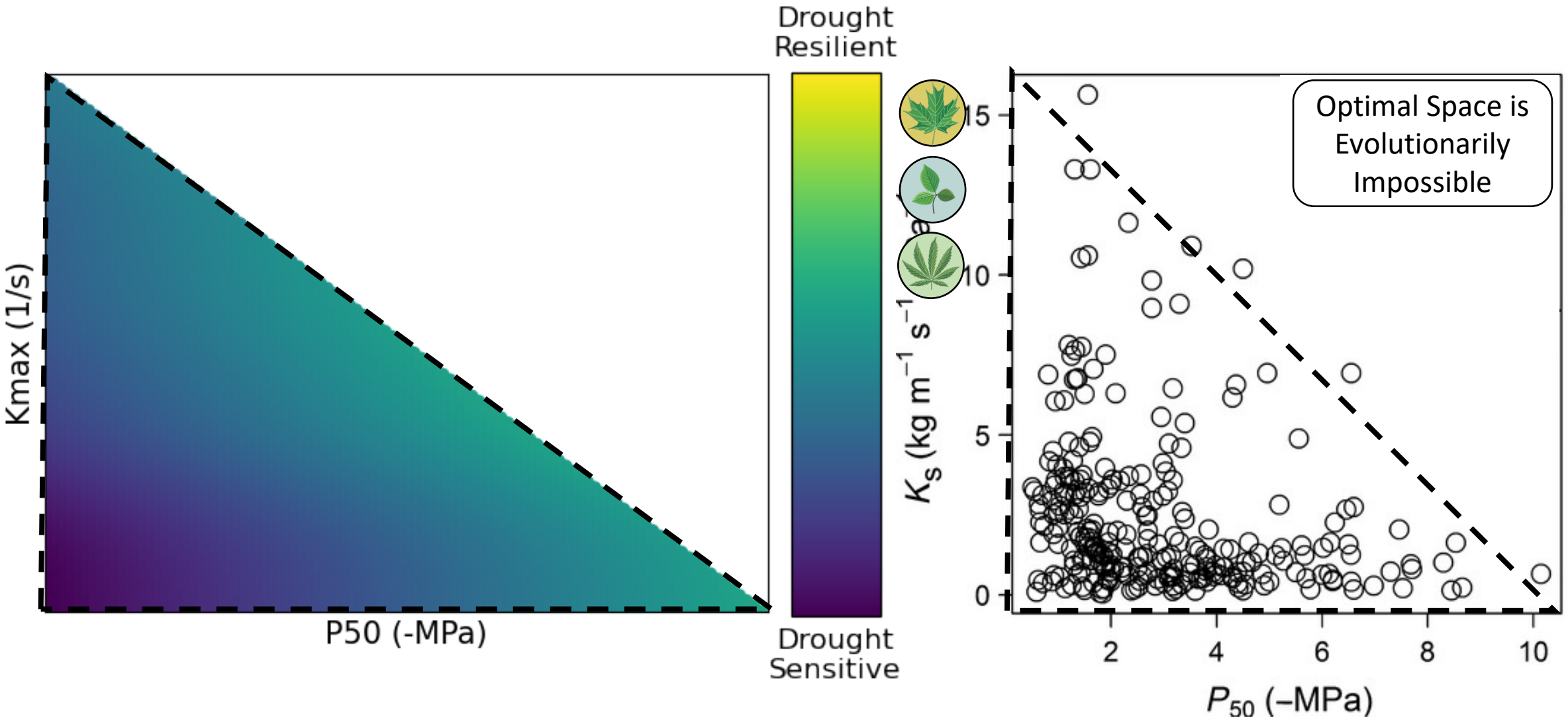
Traits controlling drought sensitivity vary across climate types

Globally, diversity of **hydraulic traits** is most important for explaining variation in ecosystem drought sensitivity



Trait diversity has the **opposite directional relationship with drought sensitivity than expected**.
Rather, the sensitivity analysis reveals that **all PFTs should converge to the same optimal hydraulic strategy**.

Why does increased diversity result in more drought sensitive ecosystems



From Gleason et al., 2015

Take Home Messages

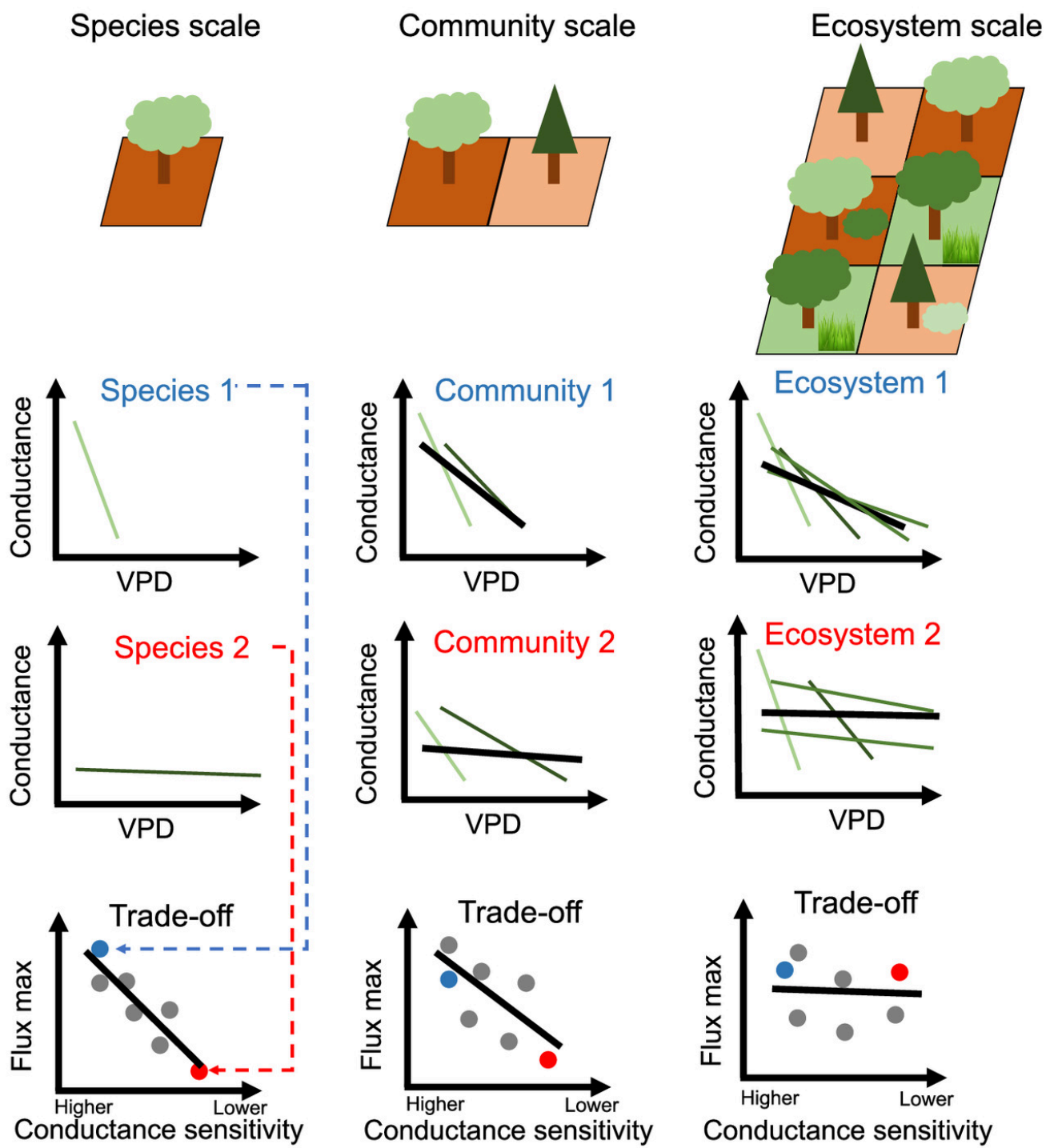
1. CLM-PPE has lots of potential for understanding process representation in the model

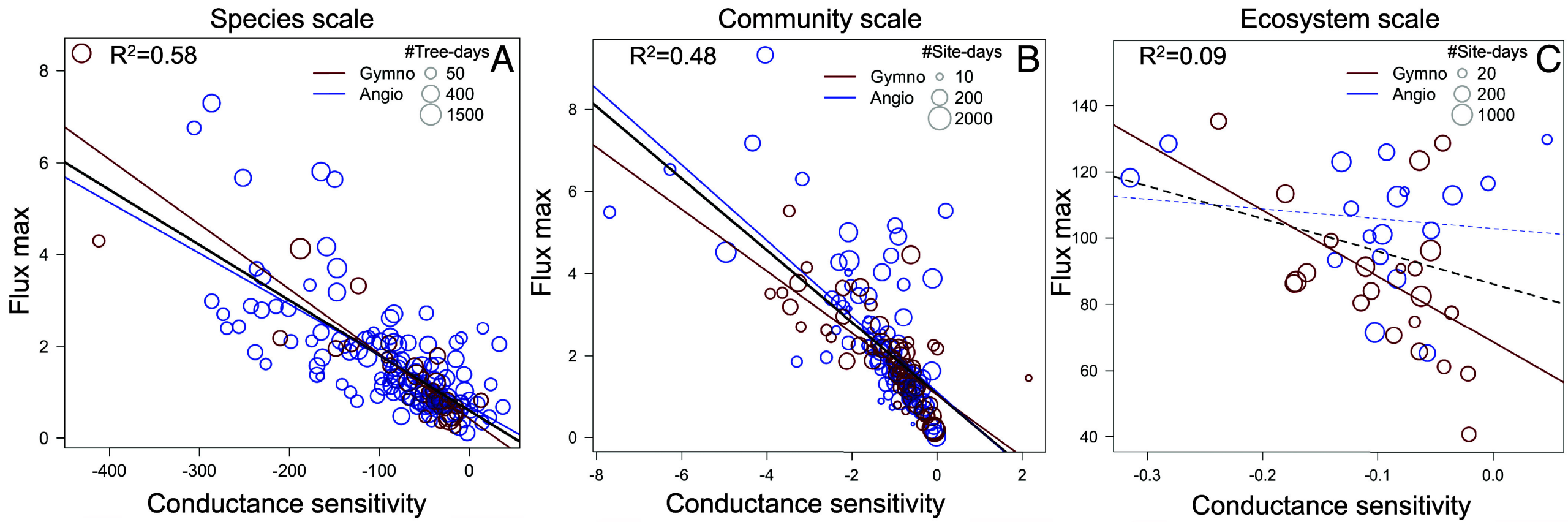
2. Grid cell level analysis shows that trait diversity matters, but only because it signals deviation from optimal hydraulic strategy, not because of stability effects

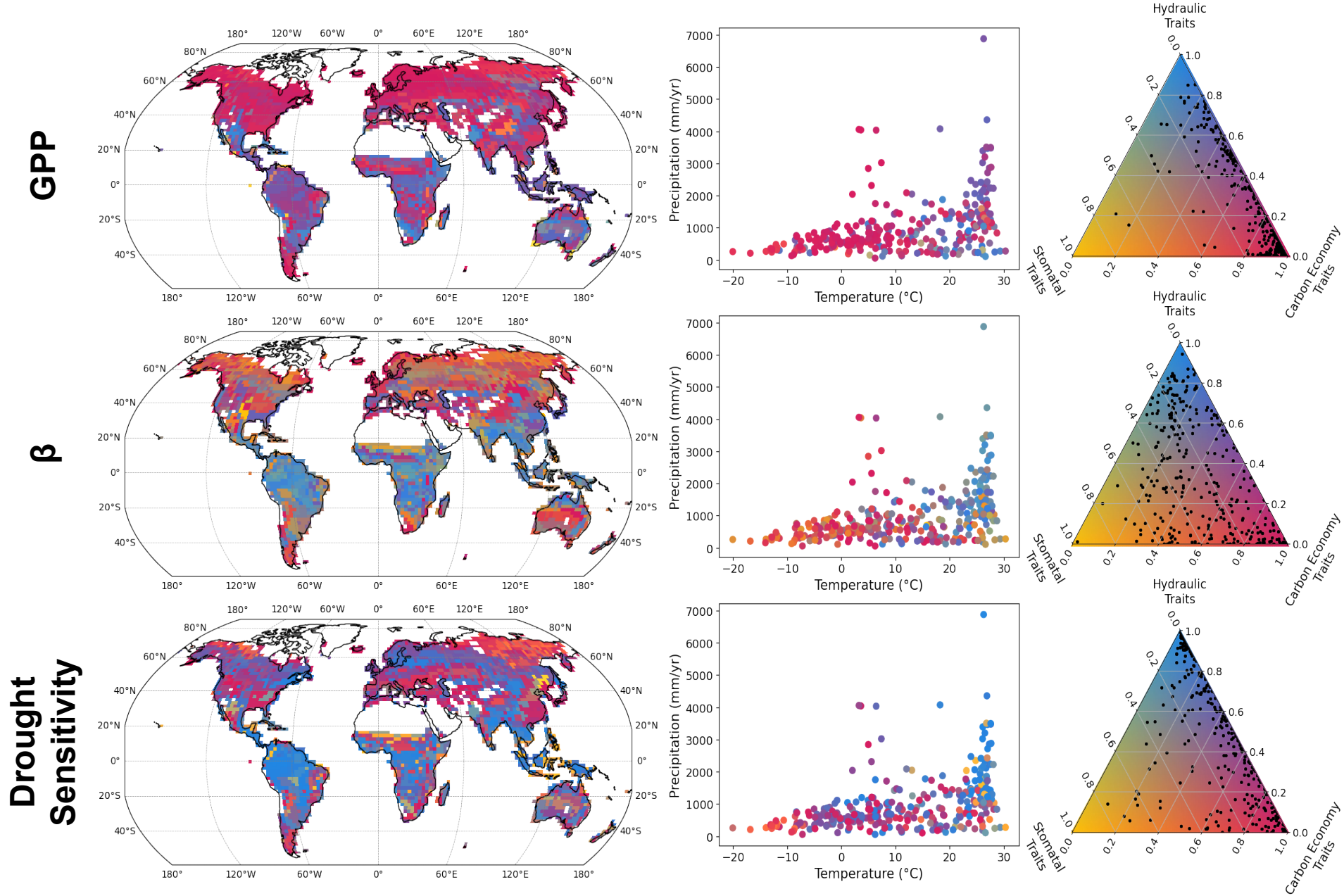
3. Sensitivity tests and efforts to optimize traits can benefit from knowledge of trait trade offs:
   - Can reduce the realistic parameter space without constraining the range of any one trait (sample across strategies, not individual traits)
   - Clarify diversity-stability relationships by removing unachievable optimal strategies
     - Requires knowledge of trait trade offs at the ecosystem/community scale

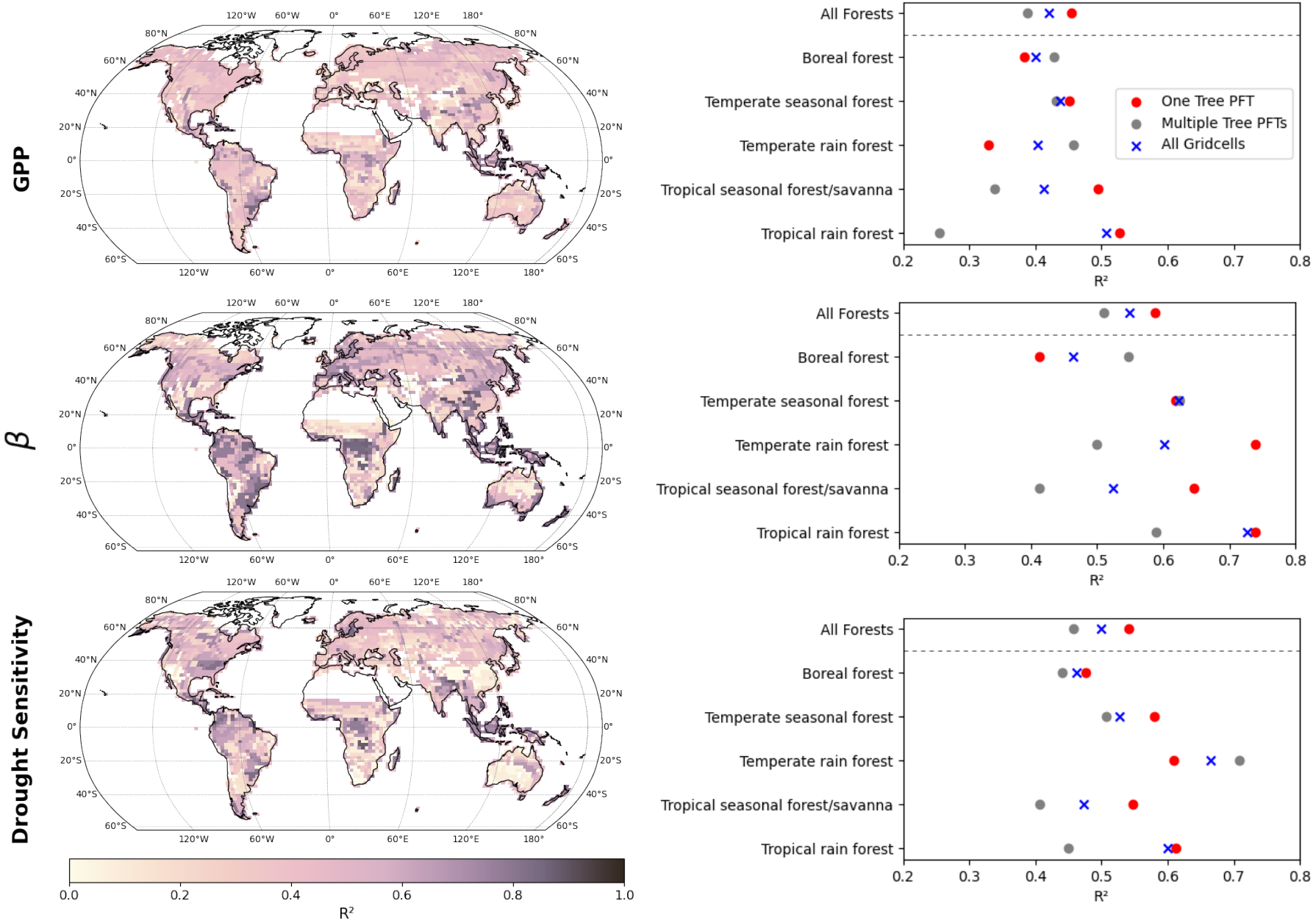
Get in contact: emargiotta@ucsb.edu

Extra Slides

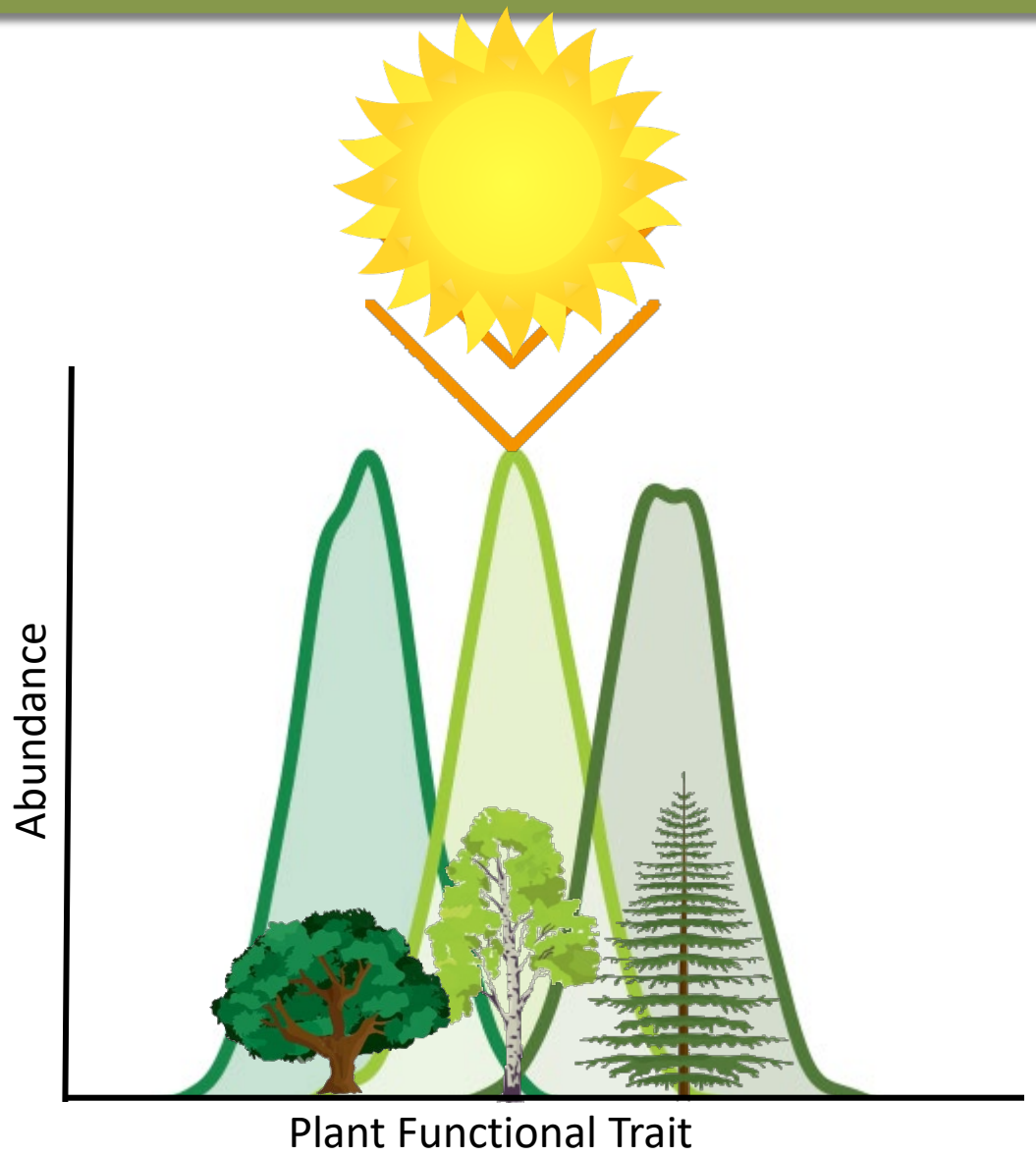

Species scale
Community scale
Ecosystem scale
Species 1
Community 1
Ecosystem 1
Species 2
Community 2
Ecosystem 2
Conductance
VPD
Trade-off
Flux max
Higher
Lower
Conductance sensitivity


Species scale
R²=0.58
#Tree-days
Gymno
Angio
50
400
1500
A
Flux max
Conductance sensitivity
Community scale
R²=0.48
#Site-days
Gymno
Angio
10
200
2000
B
Flux max
Conductance sensitivity
Ecosystem scale
R²=0.09
#Site-days
Gymno
Angio
20
200
1000
C
Flux max
Conductance sensitivity


GPP
β
Drought Sensitivity
Precipitation (mm/yr)
Temperature (°C)
Hydraulic Traits
Stomatal Traits
Carbon Economy Traits


GPP
β
Drought Sensitivity
120°W 60°W 0° 60°E 120°E 180°
80°N 60°N 40°N 20°N 0° 20°S 40°S 60°S
0.0 0.2 0.4 0.6 0.8 1.0
R²
All Forests
Boreal forest
Temperate seasonal forest
Temperate rain forest
Tropical seasonal forest/savanna
Tropical rain forest
One Tree PFT
Multiple Tree PFTs
All Gridcells
0.2 0.3 0.4 0.5 0.6 0.7 0.8
R²

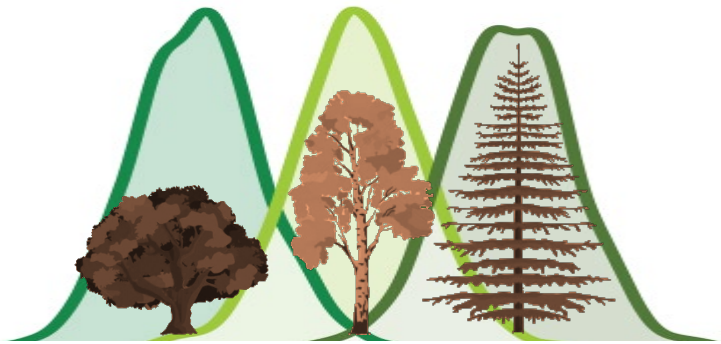
Role of Plant Functional Diversity in Buffering Drought Effects



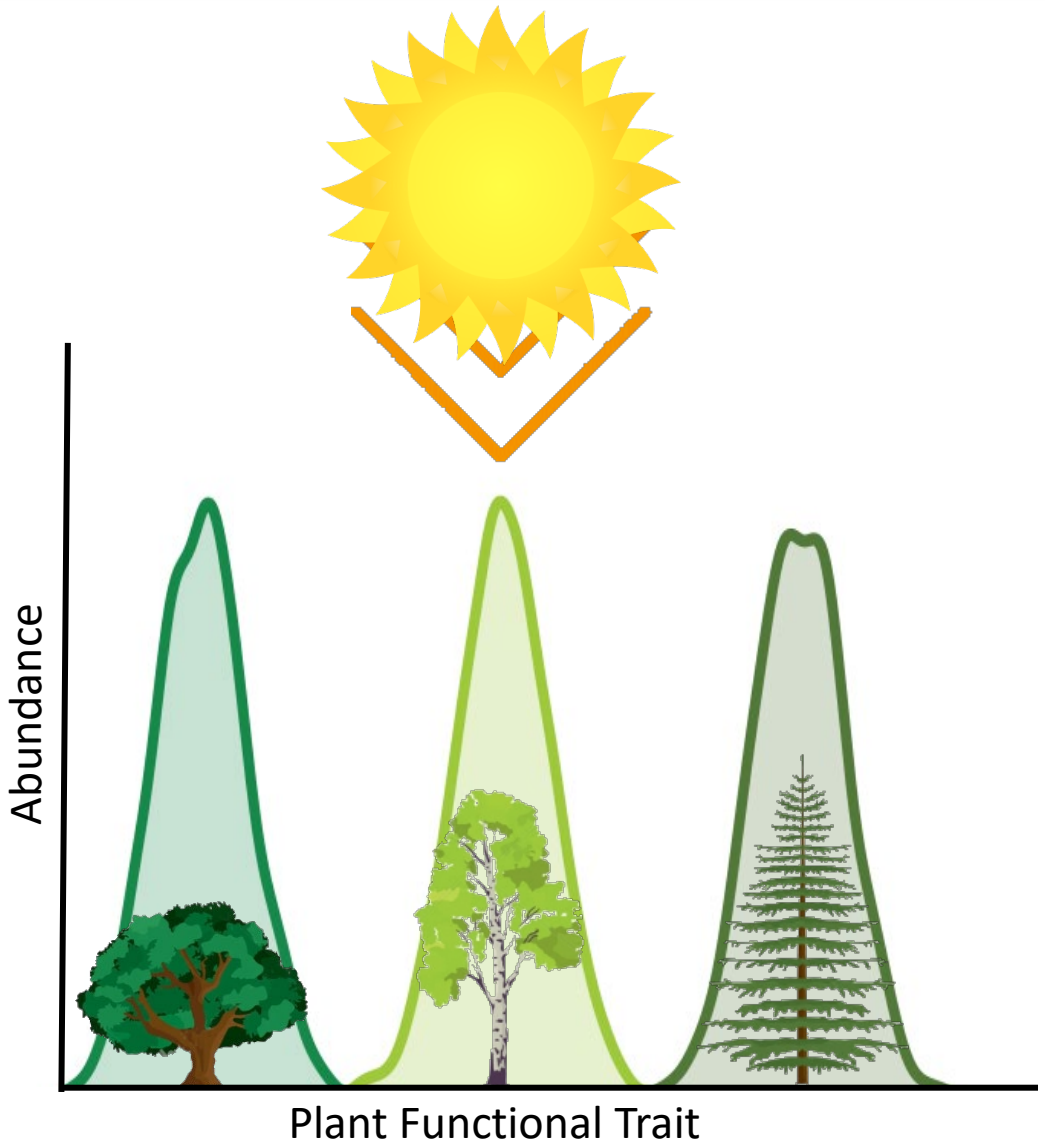
Low Variation in Plant Traits

Species Respond Similarly to Drought

High Ecosystem Drought Sensitivity



Role of Plant Functional Diversity in Buffering Drought Effects



High Variation in Plant Traits

Species Respond Differently to Drought

Low Ecosystem Drought Sensitivity