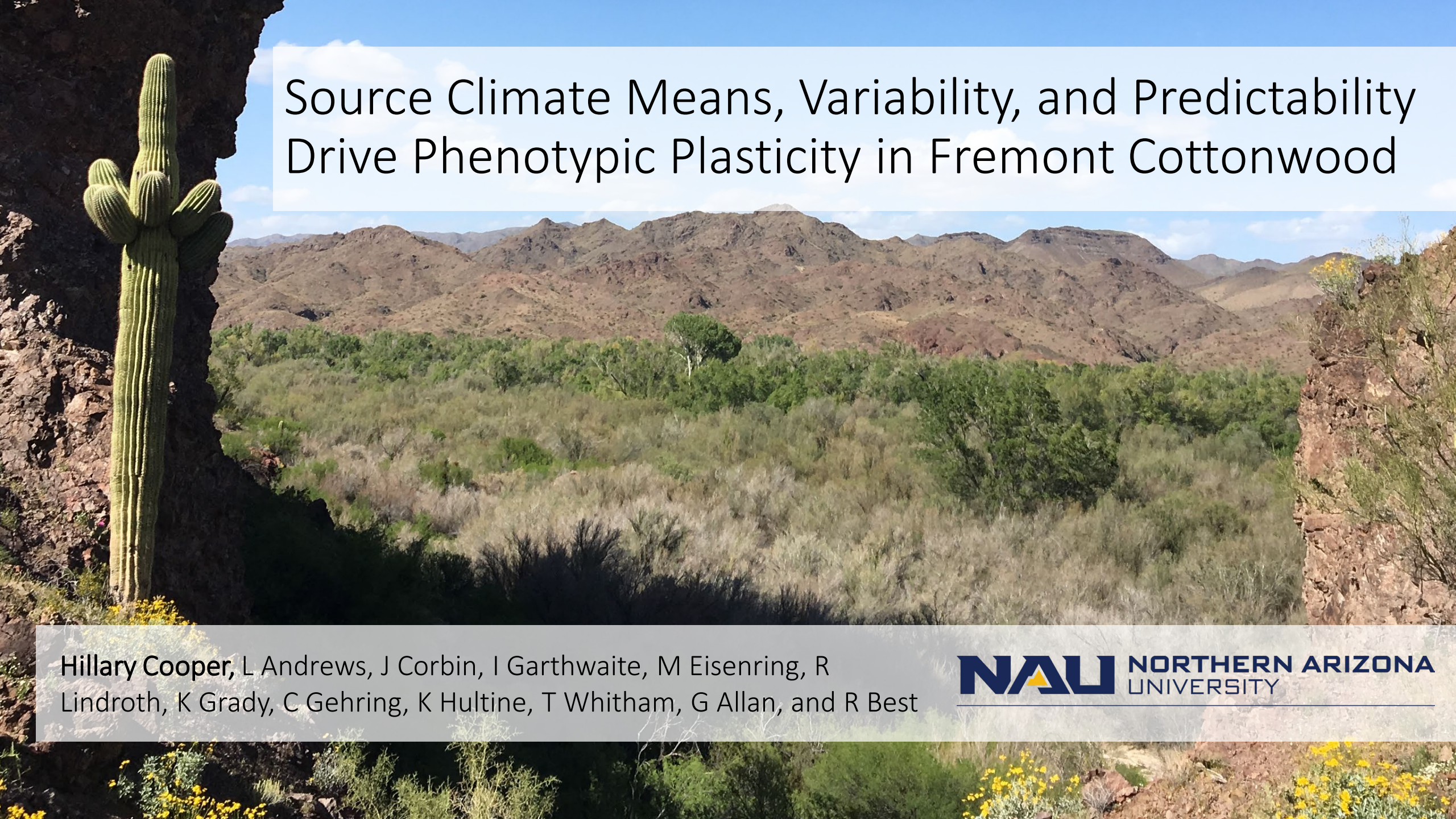
Source Climate Means, Variability, and Predictability Drive Phenotypic Plasticity in Fremont Cottonwood



Hillary Cooper, L Andrews, J Corbin, I Garthwaite, M Eisenring, R Lindroth, K Grady, C Gehring, K Hultine, T Whitham, G Allan, and R Best

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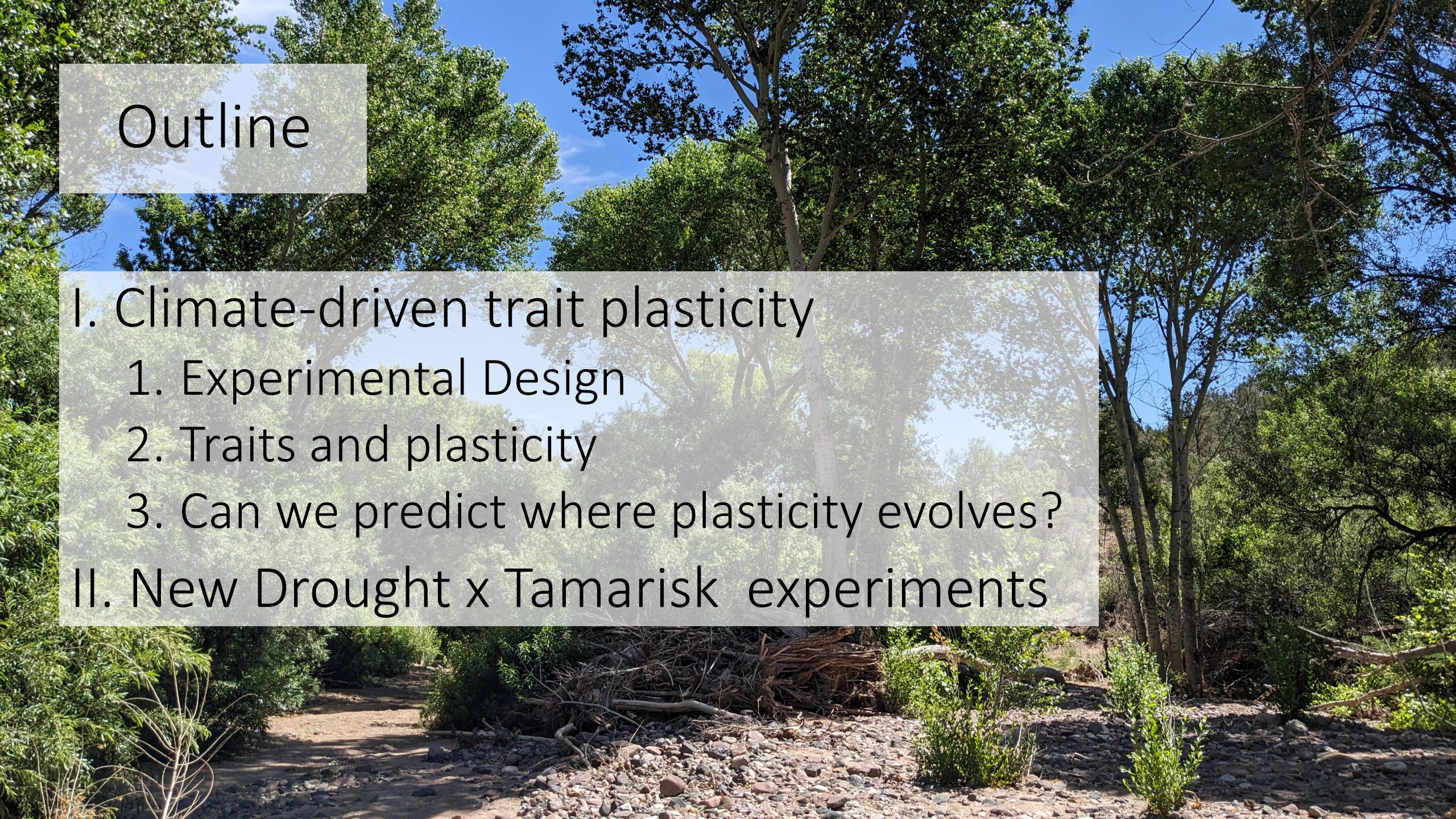
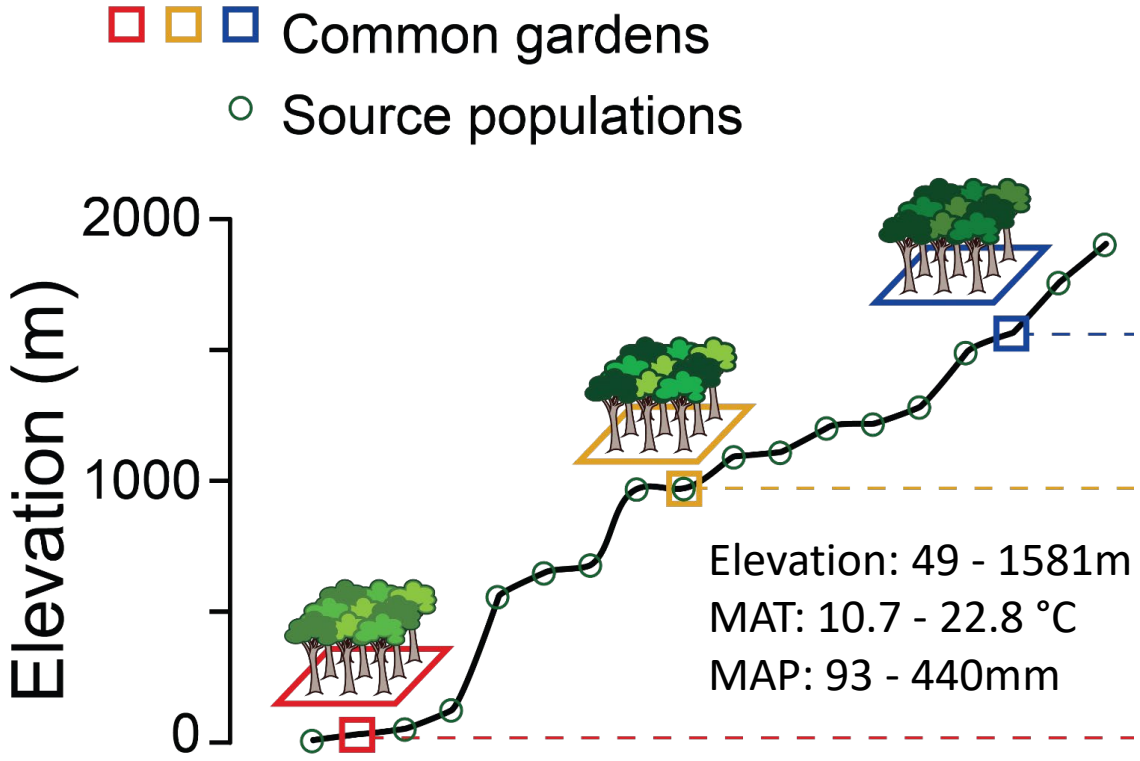


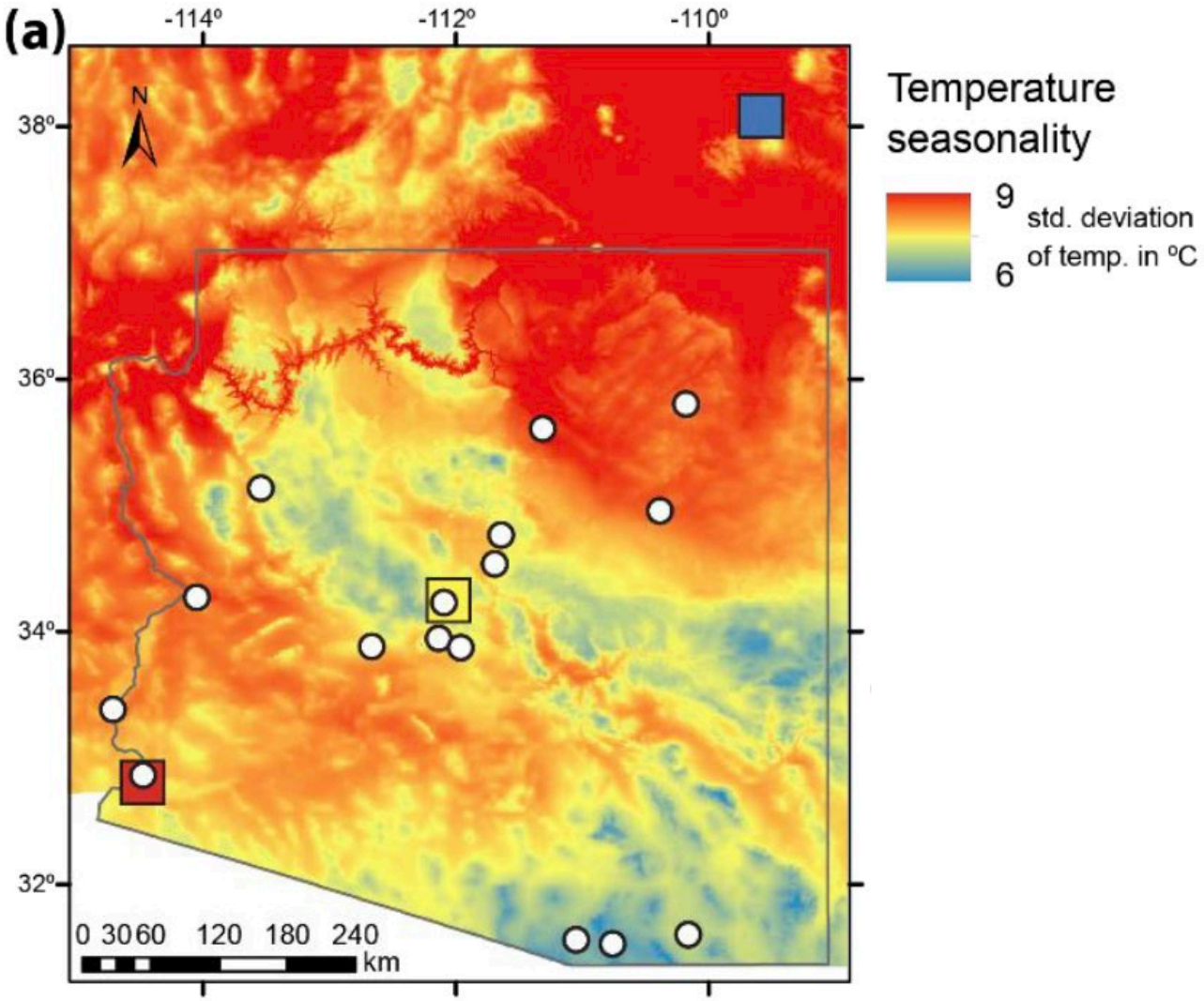
Outline

I. Climate-driven trait plasticity
   1. Experimental Design
   2. Traits and plasticity
   3. Can we predict where plasticity evolves?

II. New Drought x Tamarisk experiments

Replicated common gardens planted with 16 populations of Fremont cottonwood





Simulated herbivory

- 2019-2021
- Hole punched leaves to mimic natural herbivory
- Sprayed Jasmonic Acid on the hole punched branches
- All 3 gardens to look at chemical plasticity across climates and to herbivory

Traits

- Phenology
  - Fall budset
  - Spring bud flush
- Specific Leaf Area
- Phytochemistry
  - Defense: Total phenolic glycosides, tannins
  - Structural: Fiber and lignin
  - N, C, C:N
- Height and trunk diameter


Yuma common garden

Phenotypic plasticity

The ability of a given genotype to change its phenotype in response to environmental variation

With rapid climate change in the Southwest and long generation of forest trees, plasticity is likely a key mechanism by which cottonwoods will respond to and persist in novel climates.

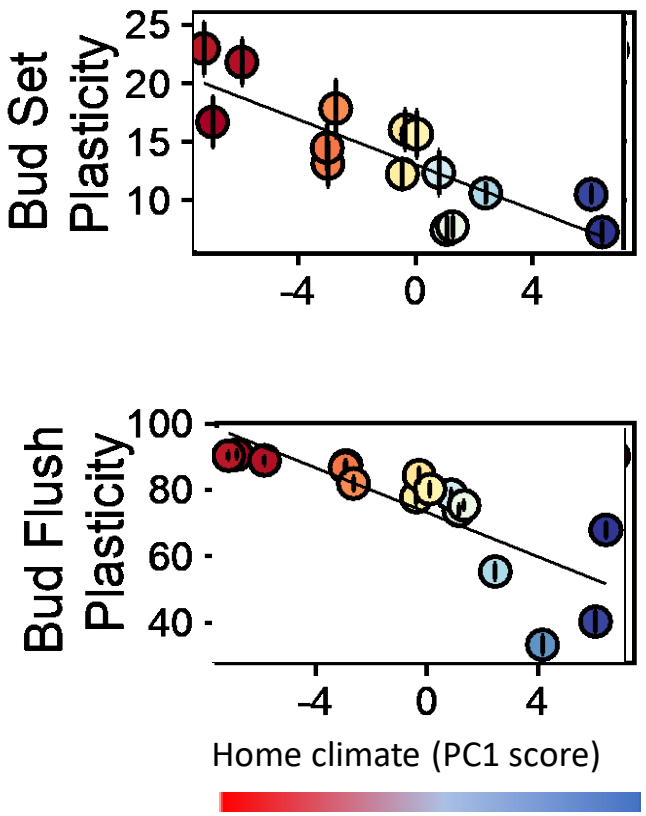
Bill Williams River National Wildlife Refuge

Big Question

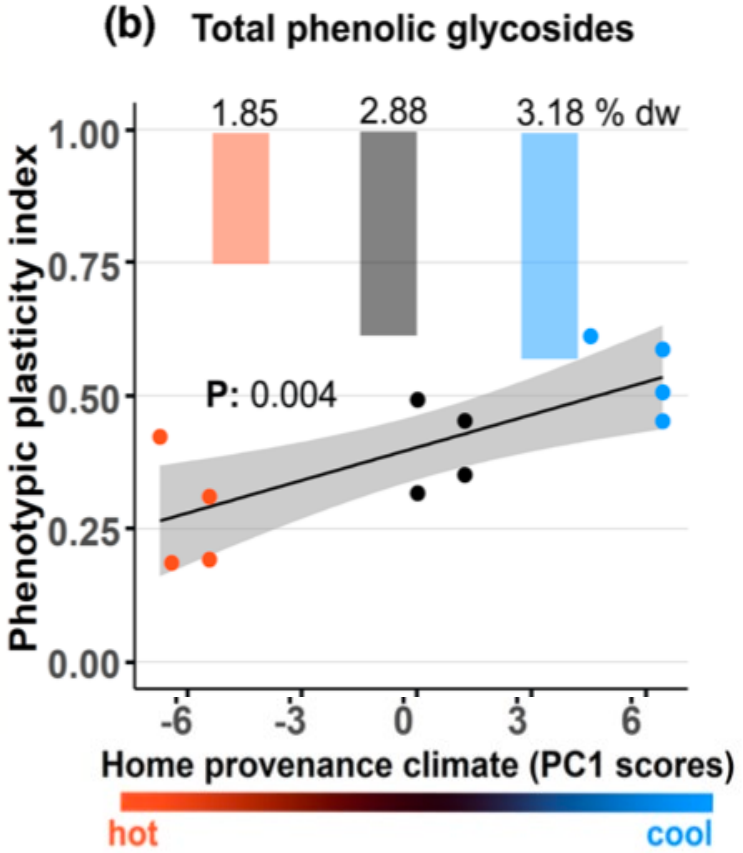
Can we predict where increased plasticity has evolved across the landscape?

Bill Williams River National Wildlife Refuge

Phenotypic plasticity is significantly correlated with source climate



Cooper *et al.* 2022 Mol. Ecol.



Eisenring *et al.* 2022 Glob Chang Biol.

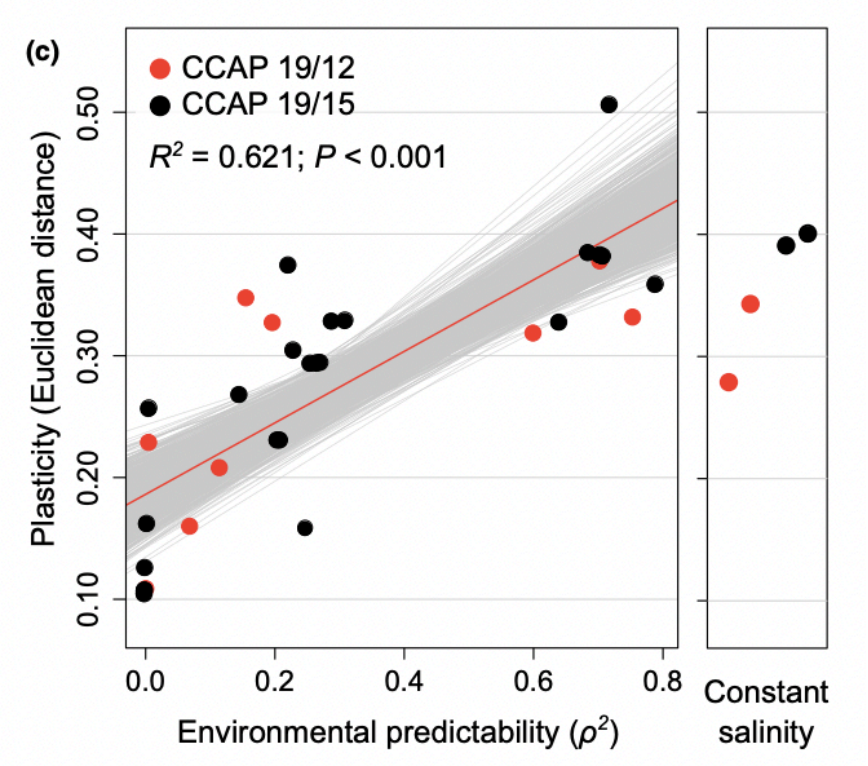
Plasticity Evolution Theory:

Hyp: Increased plasticity evolves in environments that are *variable & predictable*

Plasticity Evolution Theory:

Hyp: Increased plasticity evolves in environments that are *variable* & ***predictable***

Increased plasticity under *more predictable* salinity environments. (Leung et al. 2020 Ecol. Lett.)

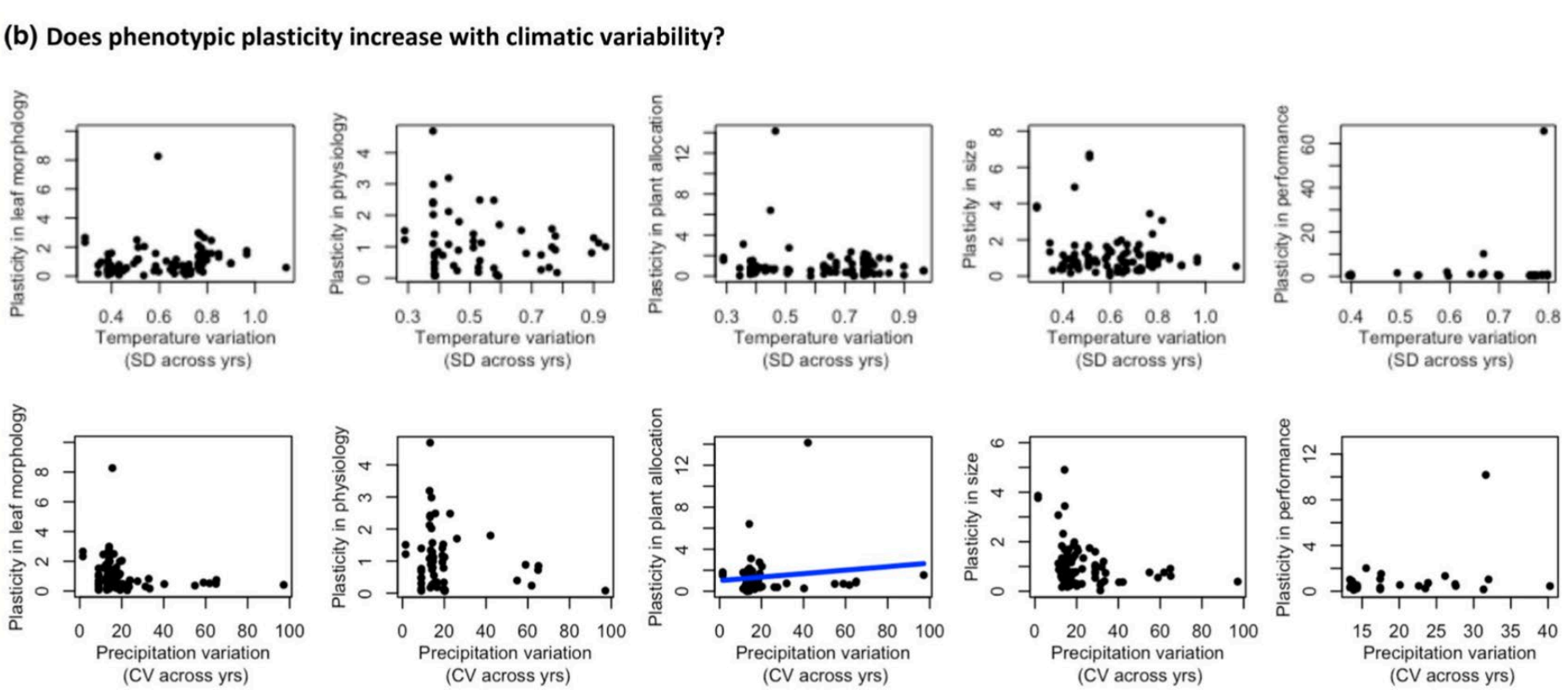


Microalga
Dunaliella salina

Plasticity Evolution Theory:

Hyp: Increased plasticity evolves in environments that are ***variable*** *& predictable*

Recent plant meta-analysis shows low evidence for plasticity- variability relationship.
(Stotz et al. 2021 Ecol. Lett.)

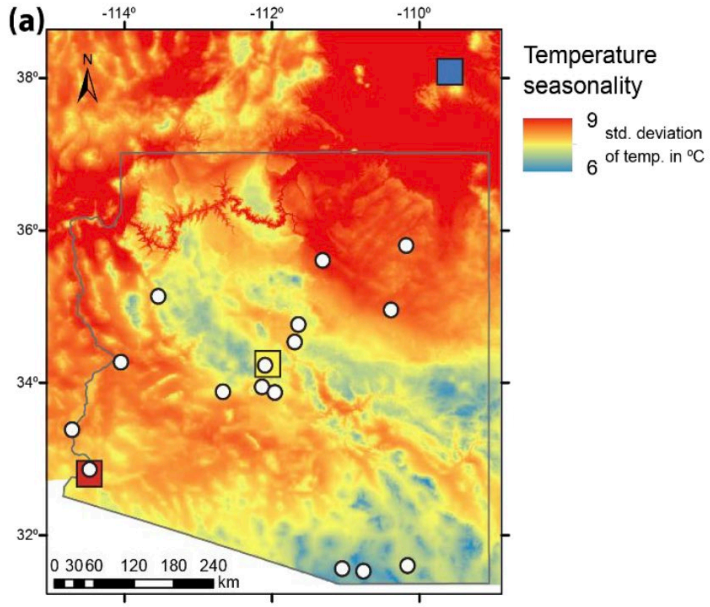


Plasticity Evolution Theory:

Hyp: Increased plasticity evolves in environments that are *variable & predictable*

Our model:

Trait Plasticity ~ climate mean + climate variability + climate predictability



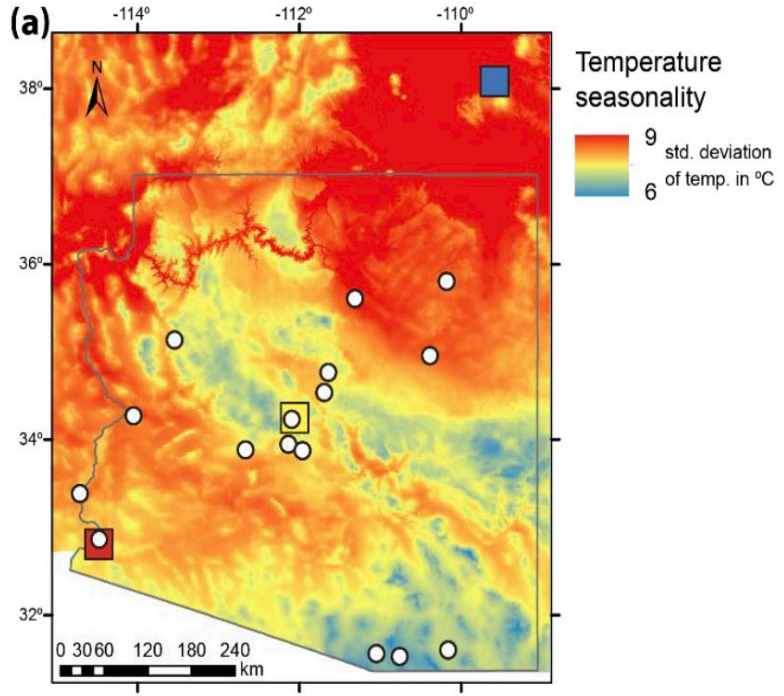
Climate variables: WorldClim and PDSI

120 years of climate data (1900-2020)

1. Temperature variables
   - Bioclim 5 = Max temp of the warmest month
   - Bioclim 6 = Min temp of the coldest month
   - Bioclim 4 = Temperature seasonality

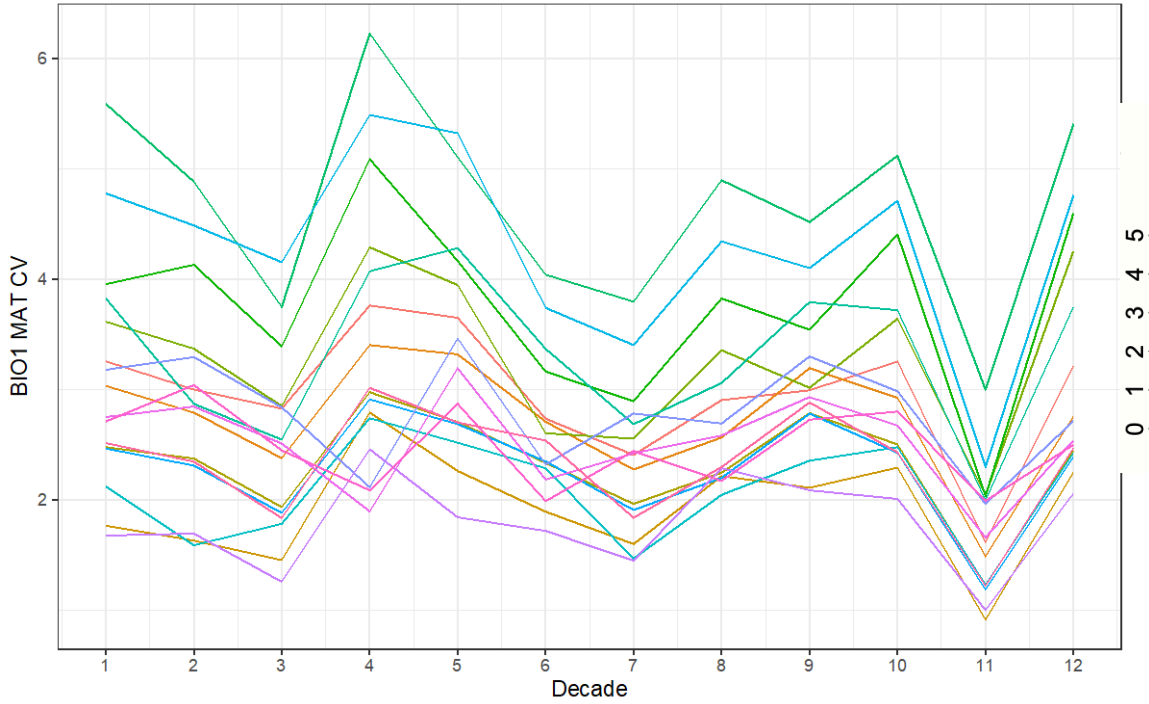
2. Precipitation variables
   - Bioclim 19 = Winter precipitation
   - Bioclim 18 = Summer precipitation
   - Bioclim 15 = Precipitation seasonality

3. Palmer Drought Severity Index (PDSI)

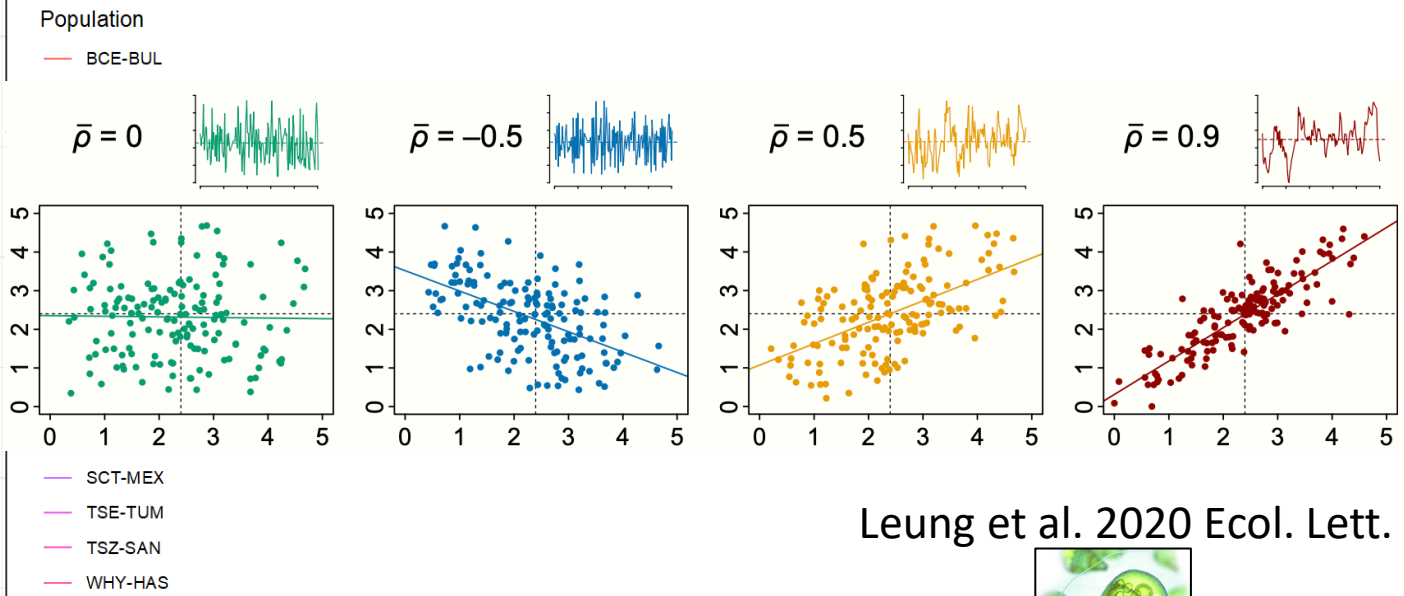


Climate variability = mean of the decadal CVs

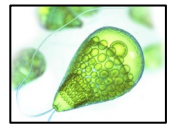
Mean annual temperature (bioclim 1)



Climate predictability = mean temporal autocorrelation coefficient, rho (ρ)

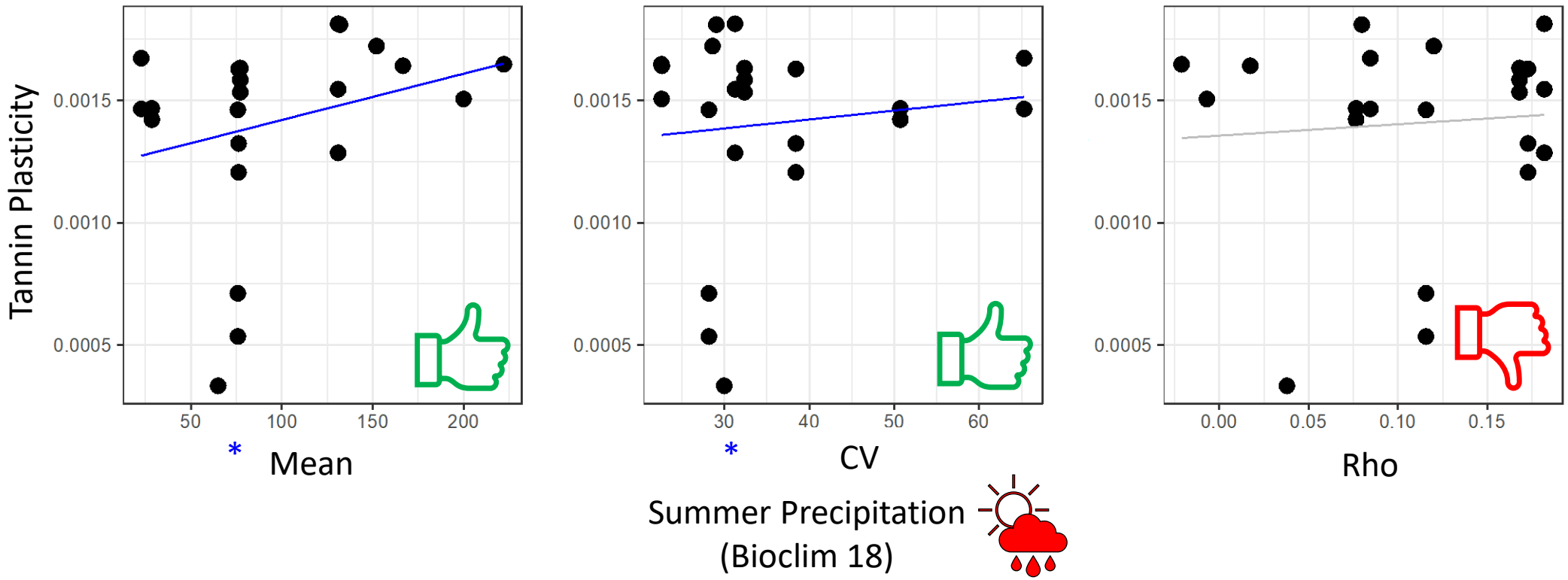


Leung et al. 2020 Ecol. Lett.



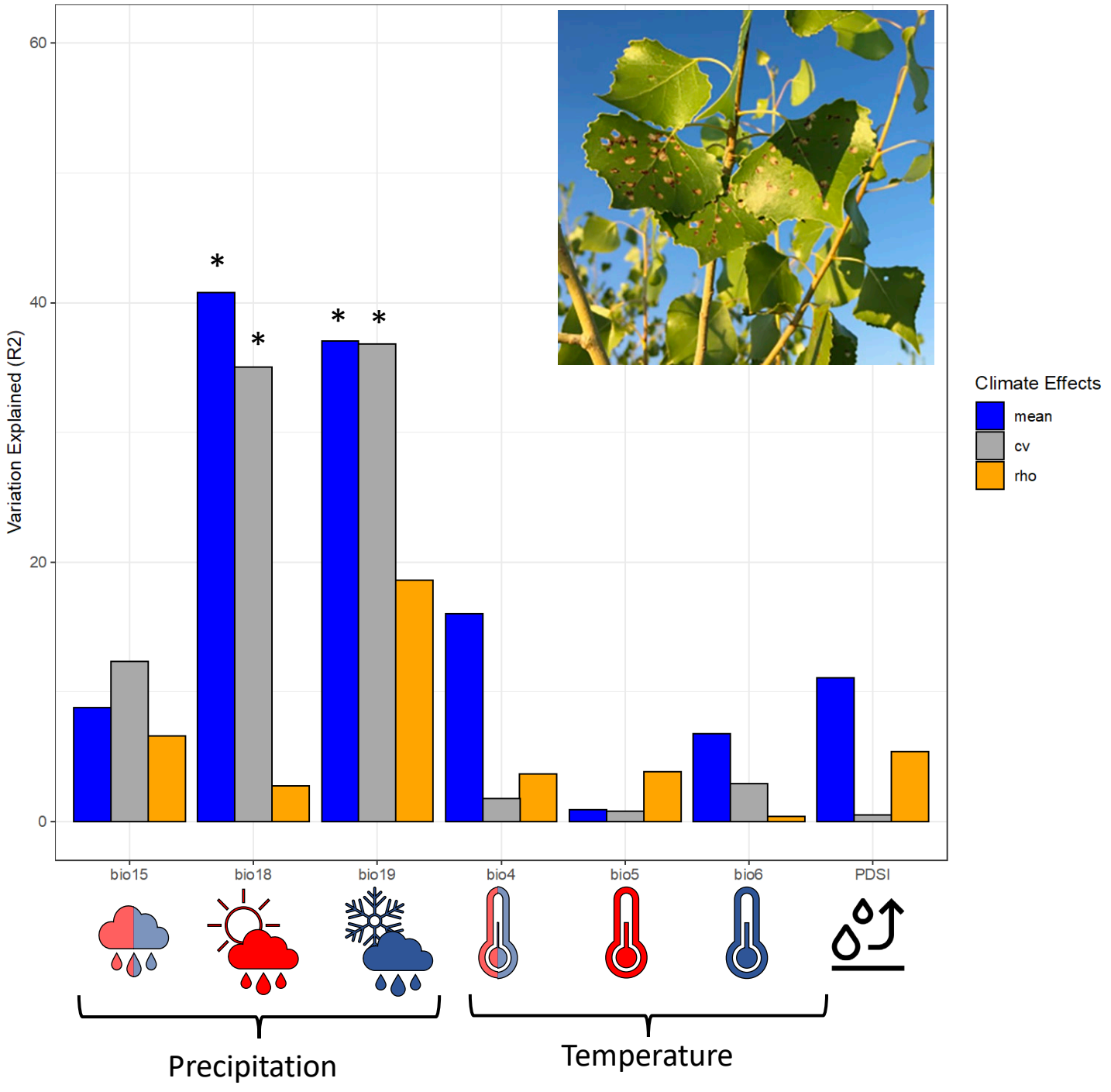
Is plasticity significantly related to climate variability and predictability?

Ex: Tannin plasticity ~ summer precipitation mean + cv + rho



Chemistry:
Total PGs

- Precipitation means and CVs explained the most variation in plasticity



Phenology:
Budset

Many climate variables and all three components of climate were significant, however low explanatory power

Plasticity Evolution Theory:

Hyp: Increased plasticity evolves in environments that are *variable & predictable*

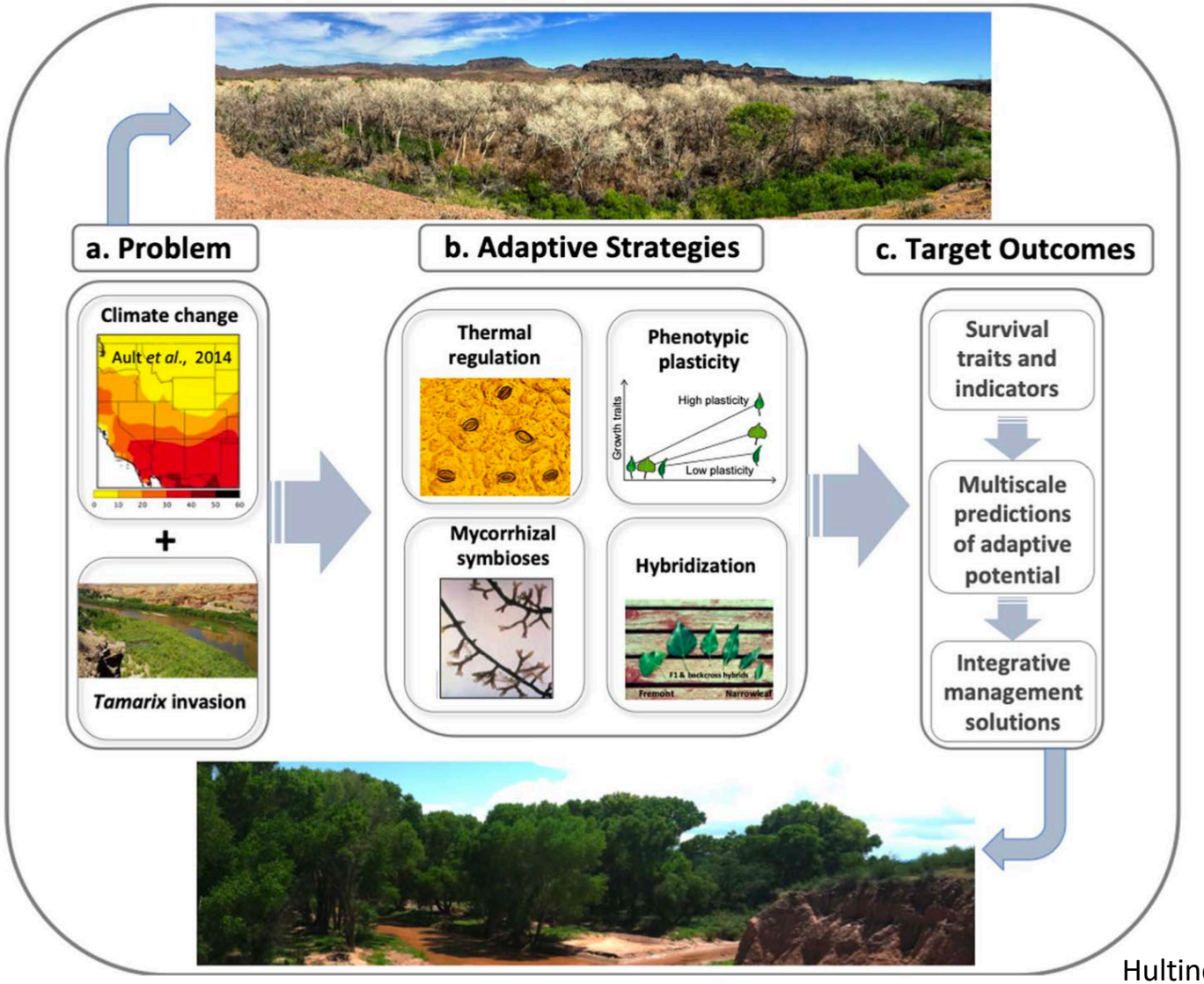
Yes! We found climate **means, variability, & predictability** all explained differences in plasticity across our 16 populations

However, their significance varied by trait and climate variable.

Climate-driven plasticity conclusions

- Earlier work showed climate-driven selection on trait plasticity across populations
- The components of climate (mean, cv, ρ) that drive plasticity depended on the climate variable and trait. Generally,
  - Climate **means** and **variability (CV)** > climate predictability (ρ)
  - **Precipitation** variables > Temperature
    - Summer and Winter Temperatures and PDSI did not explain much variance in plasticity
  - **Seasonality variables** were usually significant
  - In summary, precipitation means & variability along with yearly seasonality variables (temp & precip) best explained plasticity differences among populations.

Continuing work: specific climate change impacts of **drought** and **tamarisk** across cottonwood hybrid zones



Hultine *et al.* 2020 Cons. Phys.

I. Common Garden: drought

II. Greenhouse experiment: drought x tamarisk

	Cottonwood	Tamarisk
Watered	Control	Tamarisk
Drought	Drought	Both

Thank you!

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Center for Adaptable Western Landscapes

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT

The Nature Conservancy

CANYONLANDS RESEARCH CENTER

ARIZONA GAME & FISH

SEGA
Southwest Experimental Garden Array

Management implications: Can we predict anything?

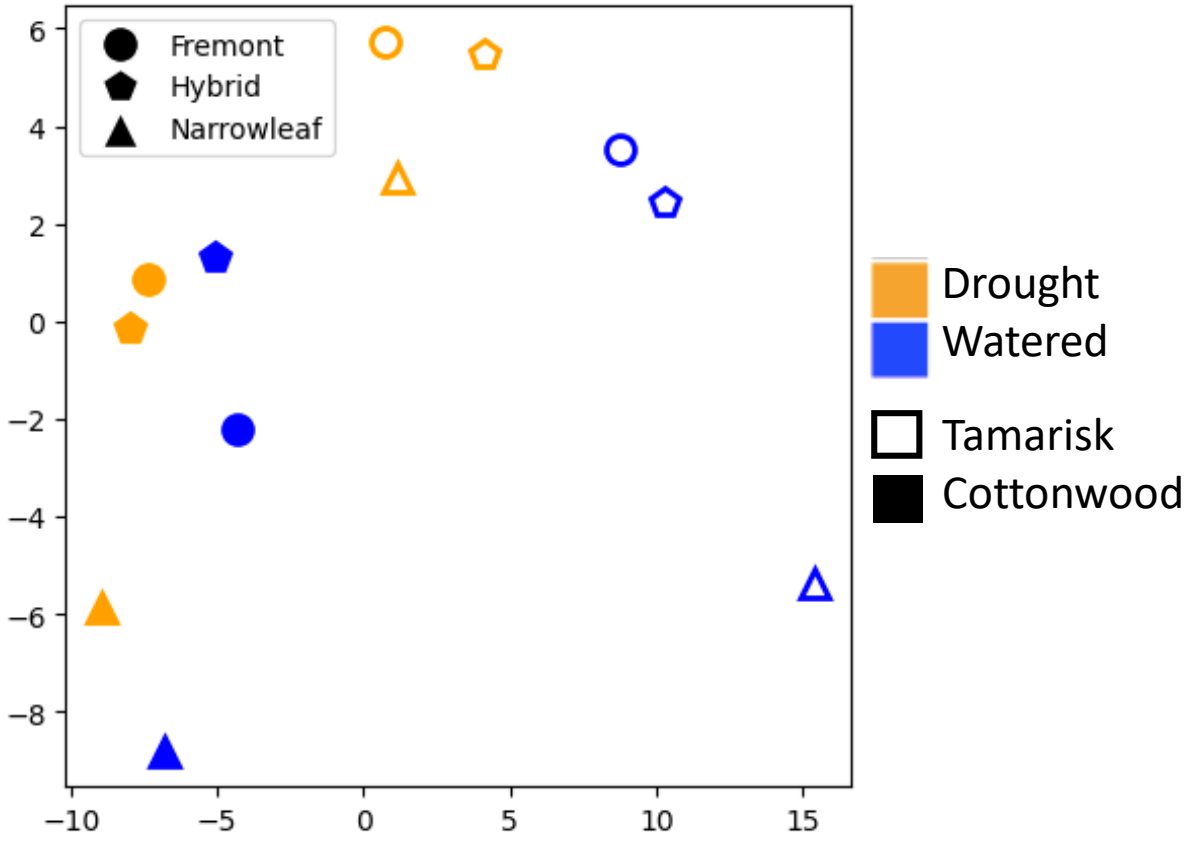
Trait and plastic responses are *highly* context-dependent.

Therefore, restoration efforts should:

1. Prioritize traits of interest for restoration goals (not all traits perform the same).
2. Account for both the past evolutionary history of source populations and the future environments of restoration sites to have predictive power.

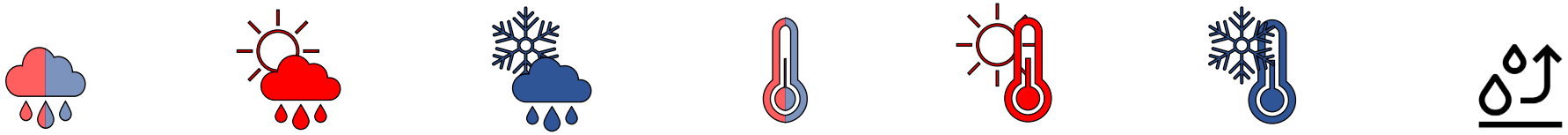
Leaf spectra

Entire spectra shows a large signal of tamarisk competition. Drought effects are next, followed by differences among crosstypes. We are working to scale up this remote sensing to landscape levels to detect river systems under both invasive and drought stress.



Model results for 4 traits

Plasticity ~ mean + CV + rho



Trait Plasticity	Precip Seasonality			Summer Precip			Winter Precip			Temp Seasonality			Summer Temp			Winter Temp			PDSI		
	Mean	CV	Rho	Mean	CV	Rho	Mean	CV	Rho	Mean	CV	Rho	Mean	CV	Rho	Mean	CV	Rho	Mean	CV	Rho
Total PGs																					
Nitrogen																					
SLA																					
Budset																					

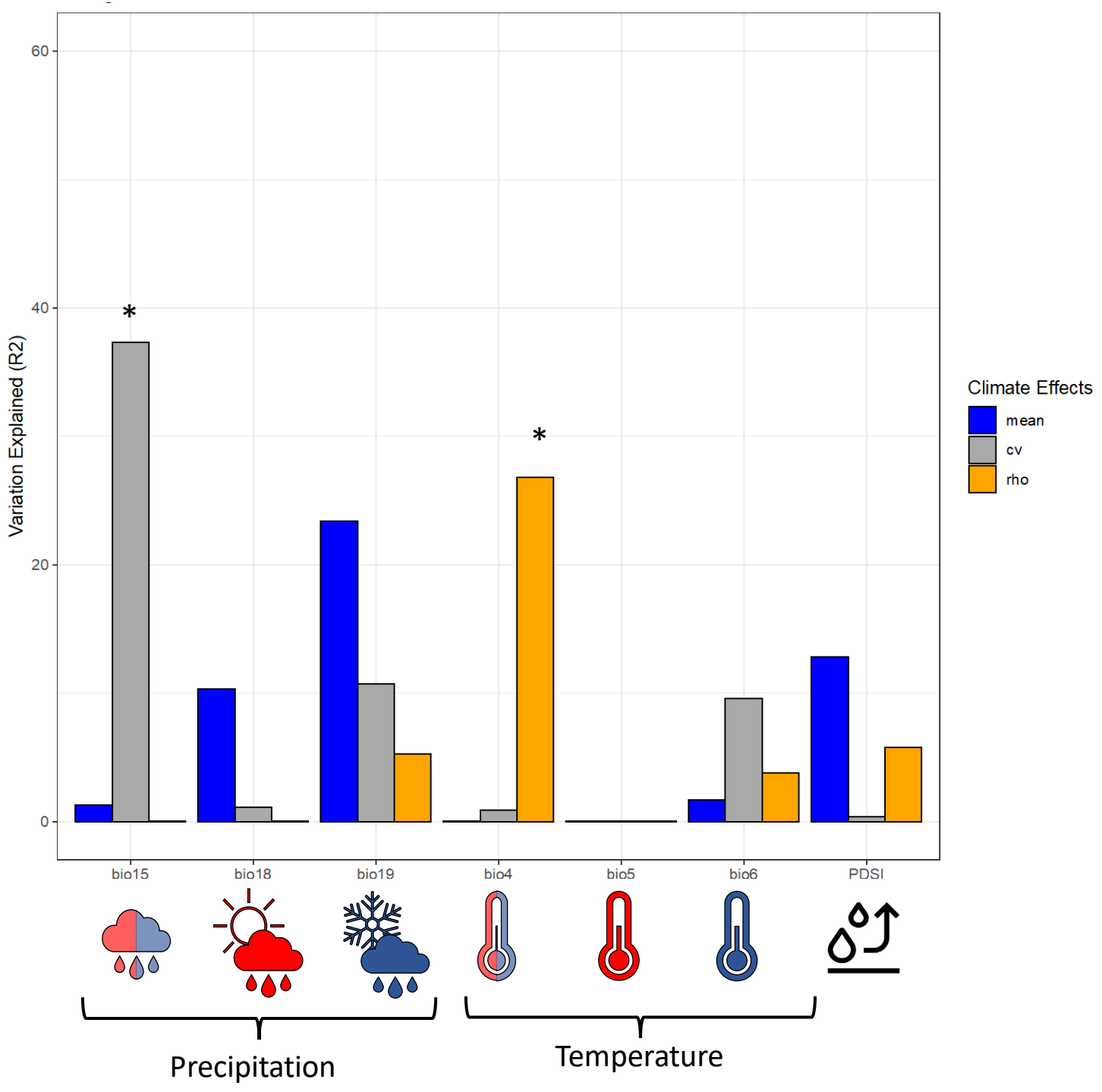
Mean: significant for 3 traits (in 5/7 climate variables)

CV: significant for 4 traits (in 4/7 climate variables)

Rho: significant for 2 traits (in 3/7 climate variable)

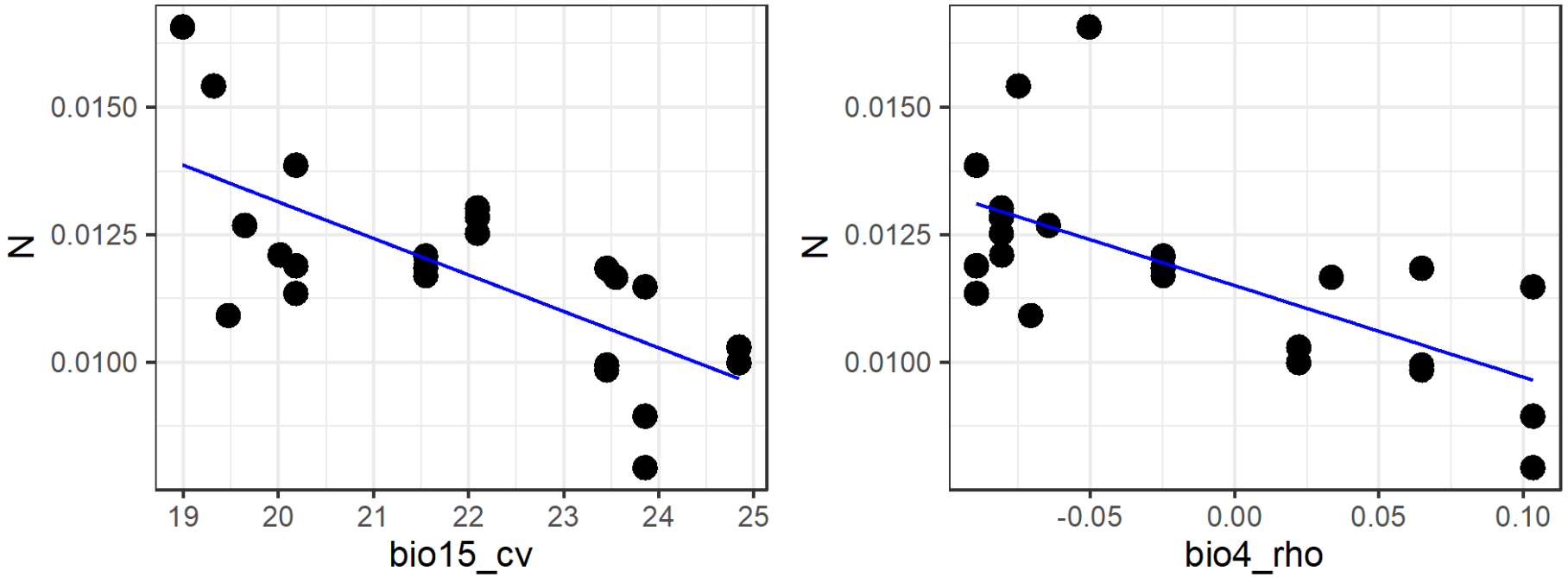
Chemistry:
Nitrogen

Seasonality variables CV and rho were most important



Not always high CV and rho! Some trait plasticities are higher in low variability or low predictability environments!

Ex: N plasticity to



Tamarisk collections

Mixed Model

- Licor traits so far: conductance, photosynthesis, leaf temperature
- Explanatory variables:
    1. River (random)
    2. Crosstype (fixed)
    3. Drought (fixed)
    4. Neighbor (Tam vs CW) (fixed)

Model results

1. Leaf Temperature

   XT, Drought, Neighbor, Drought*Neighbor significant

   River NS

2. Photosynthesis

   River, XT, Neighbor significant

   Drought marginal (p=0.09)

   Drought*Neighbor NS

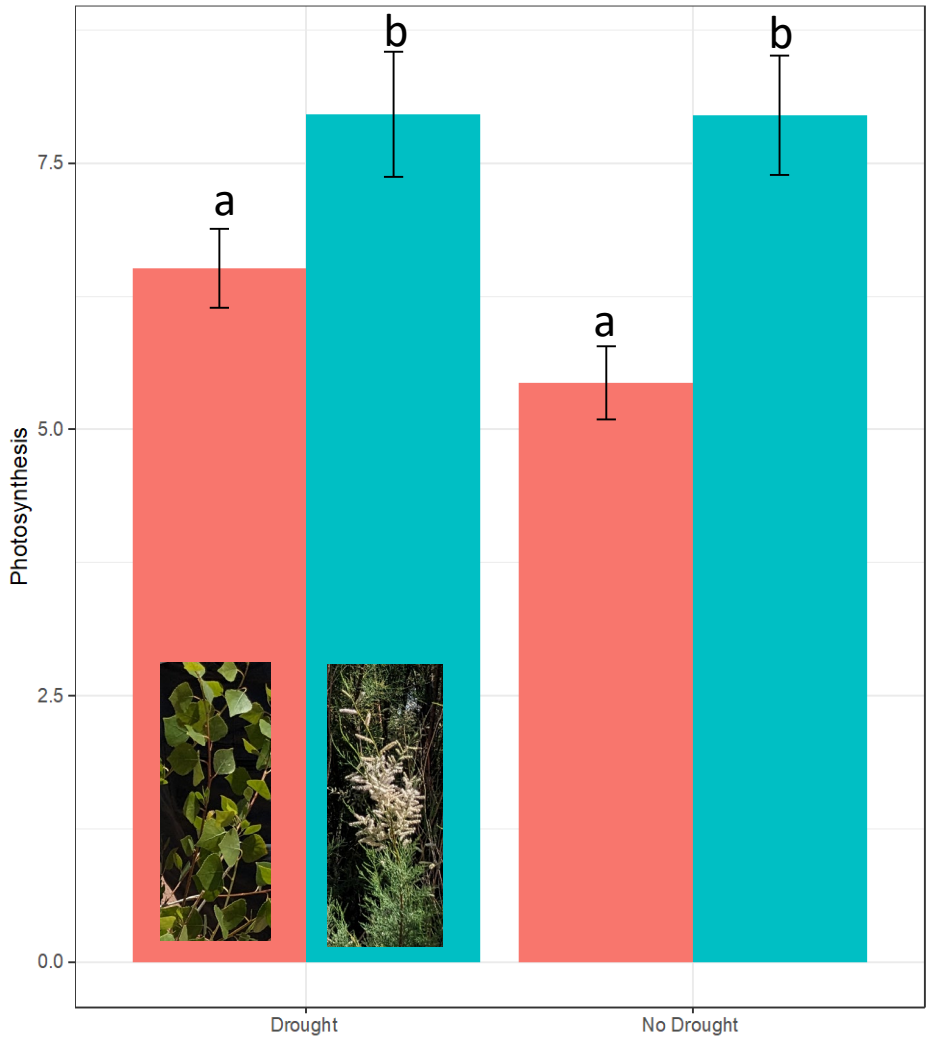
3. Conductance

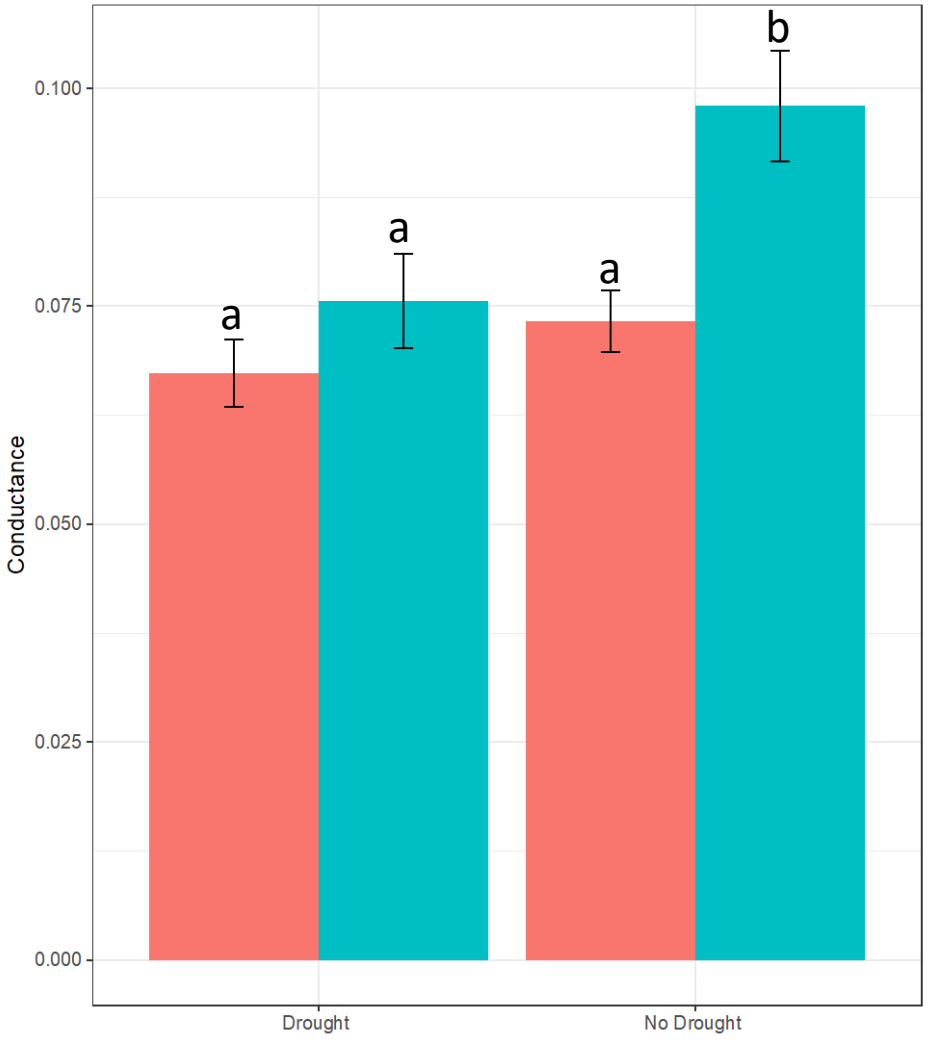
   River, XT, Drought, Neighbor, and Drought*Neighbor all significant

Drought x Neighbor interactions

Higher overall Photosynthesis with a tam neighbor regardless of watering treatment.

Higher conductance with tamarisk only when well watered

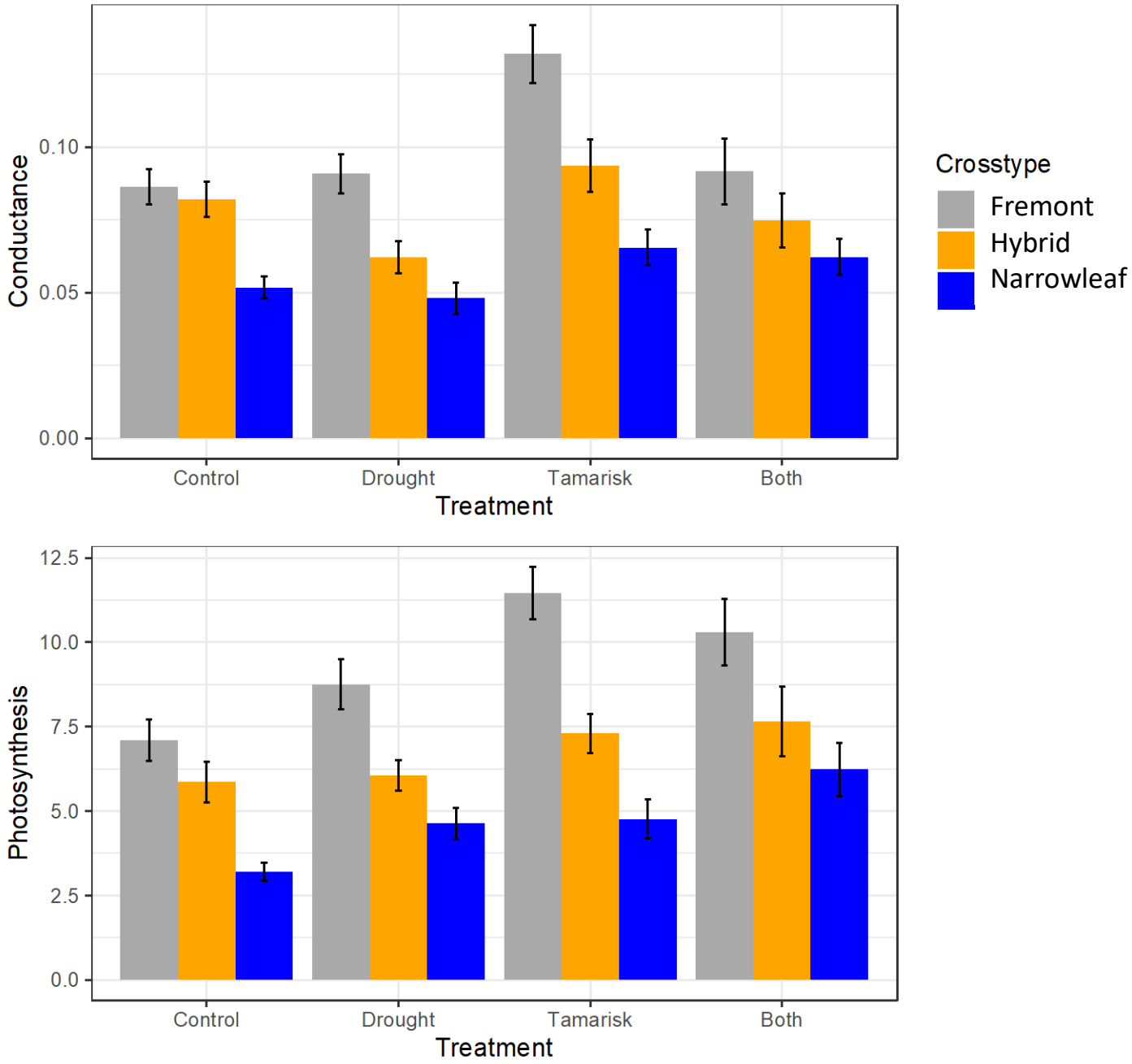




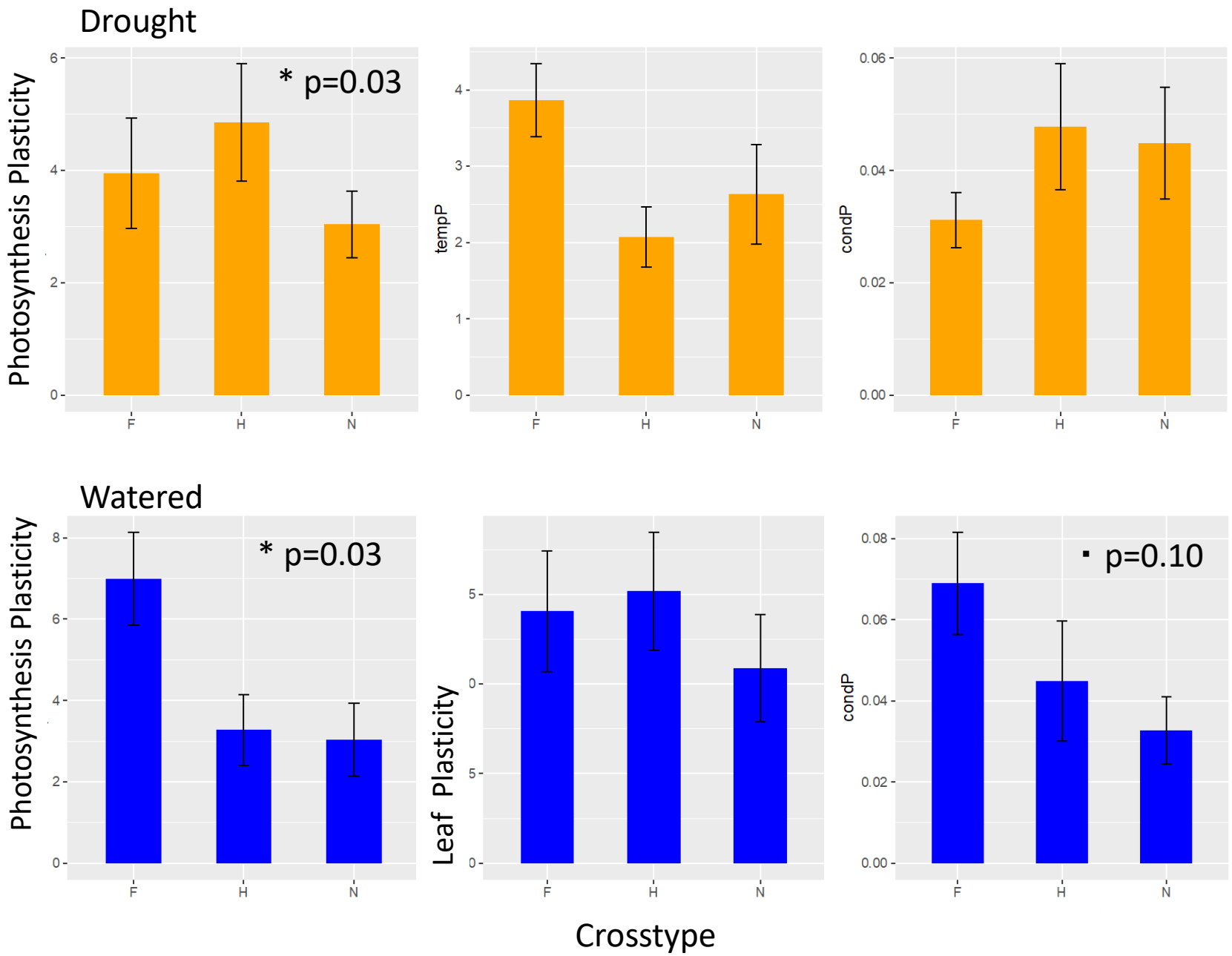
Neighbor
Cottonwood
Tamarisk

Watering Treatment

Fremont cottonwoods have higher conductance and photosynthesis across all treatments. The presence of tamarisk increases these traits for every crosstype

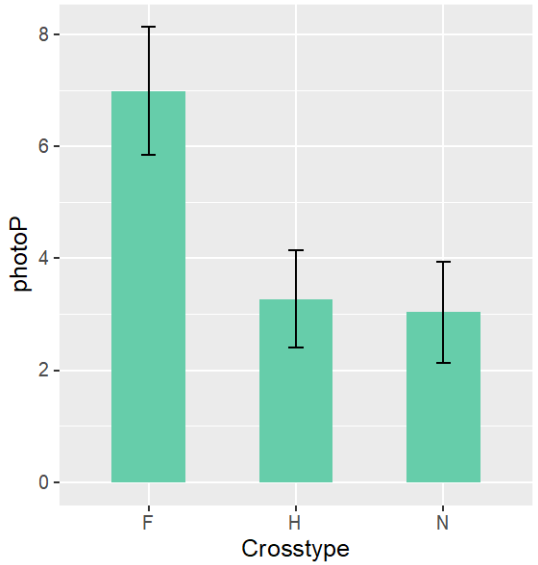


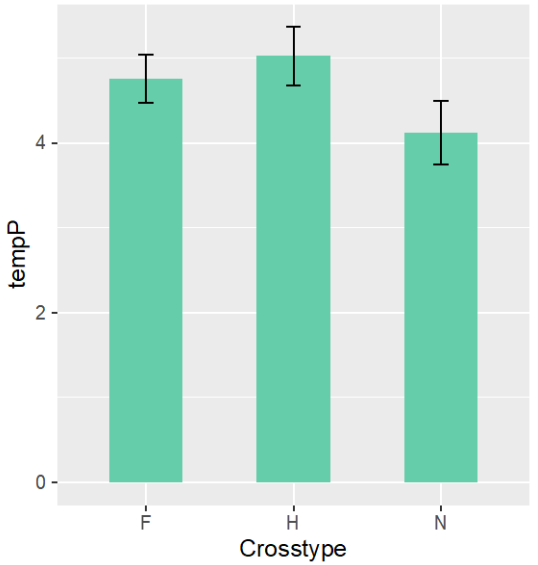
Plasticity to Tamarisk

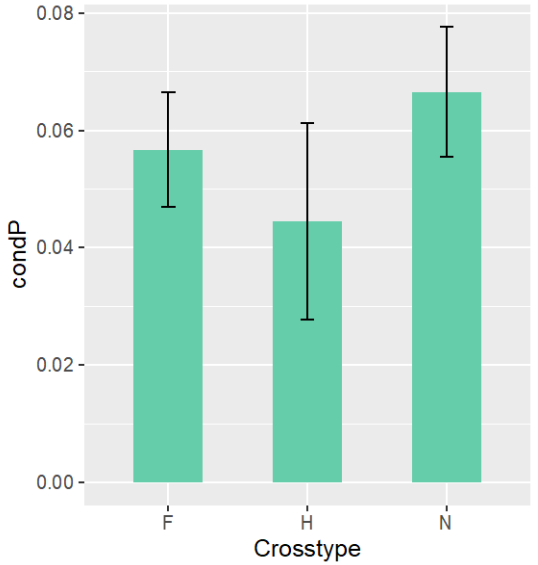


Plasticity to Drought

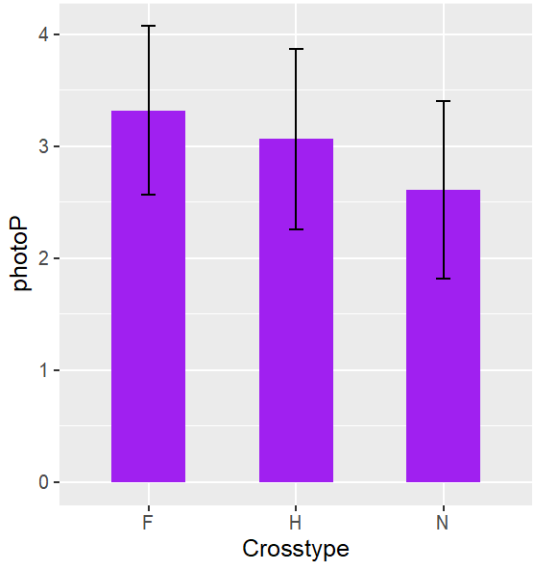
Cottonwood Neighbor

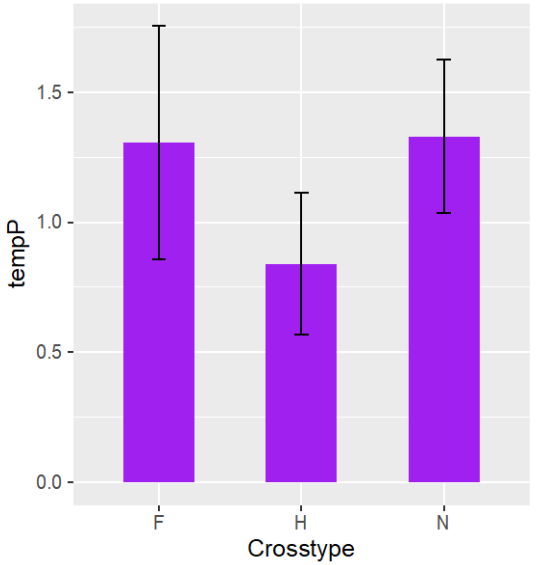


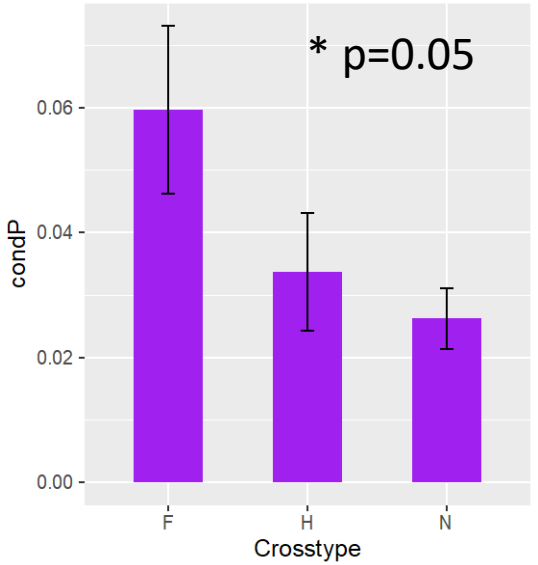




Tamarisk Neighbor

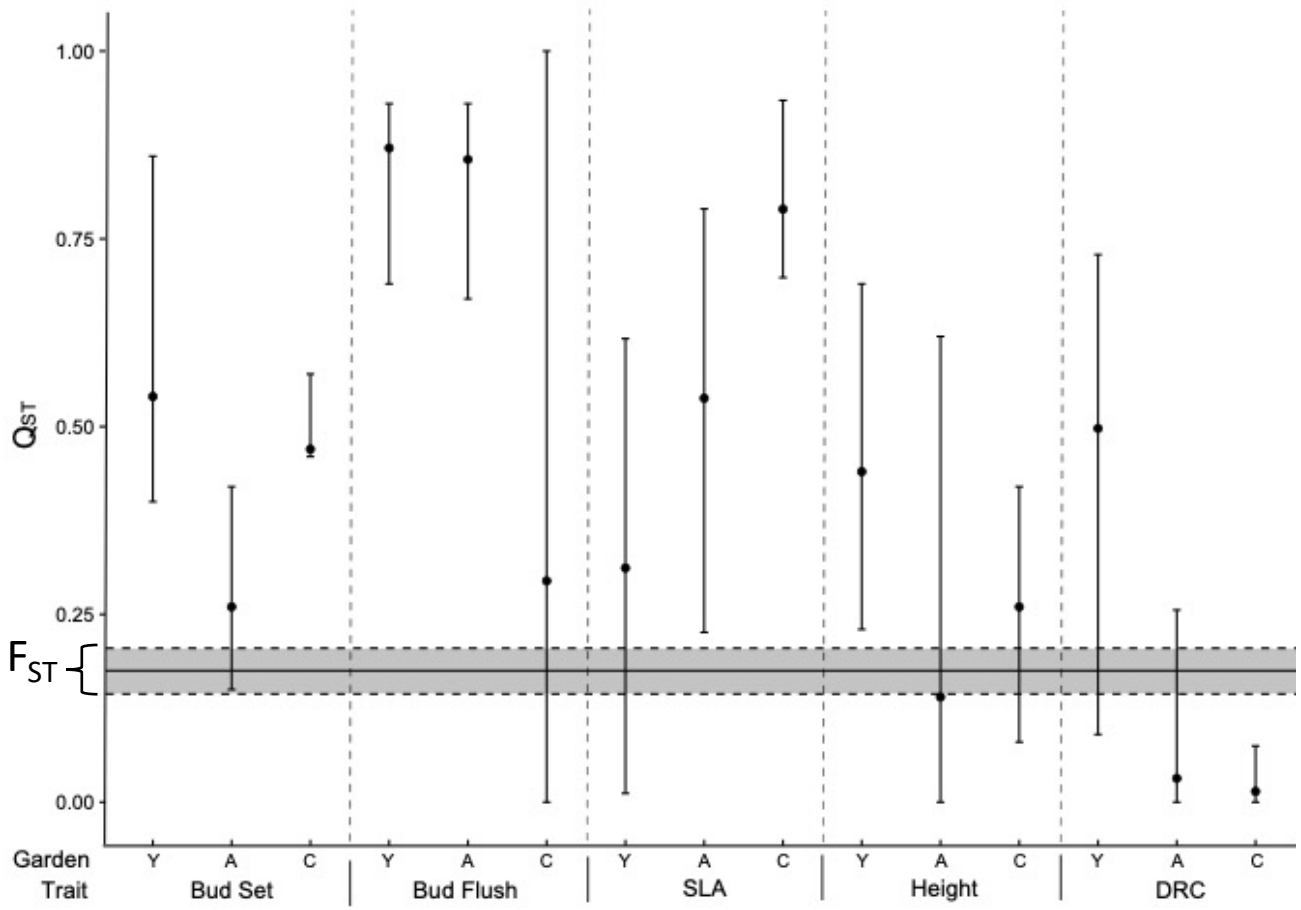


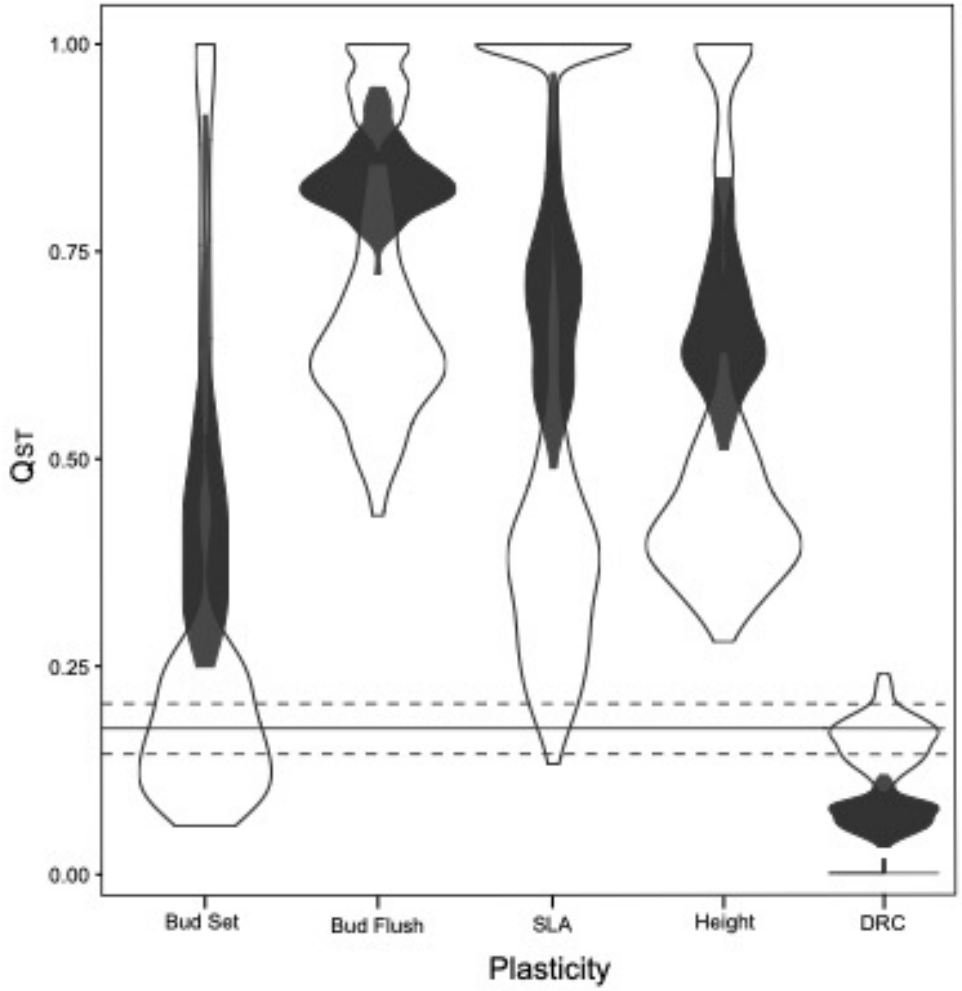




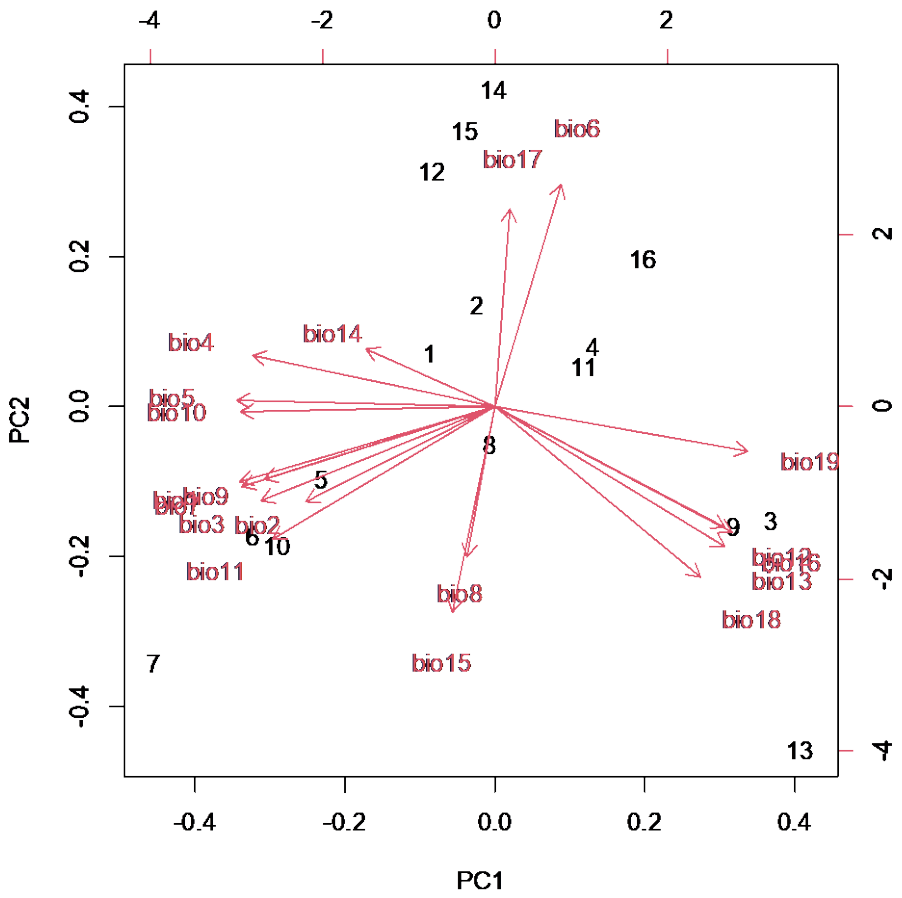
More evidence of selection:

Q_{ST}-F_{ST} comparisons show evidence for selection by climate means on traits and trait plasticity





Cooper *et al.* 2022 Mol. Ecol.



1. BCE
2. CAF
3. CCR-COL
4. CCU
5. CLF
6. JLA
7. KKH
8. KWF
9. LBW-BIL
10. MRN
11. NRV
12. PSA
13. SCT
14. TSE
15. TSZ
16. WHY