Genetic variation & local climate adaptation in grassland species:

Implications for seed sourcing

April Goebl Ph.D. – Denver Botanic Gardens

National Conference on Ecosystem Restoration

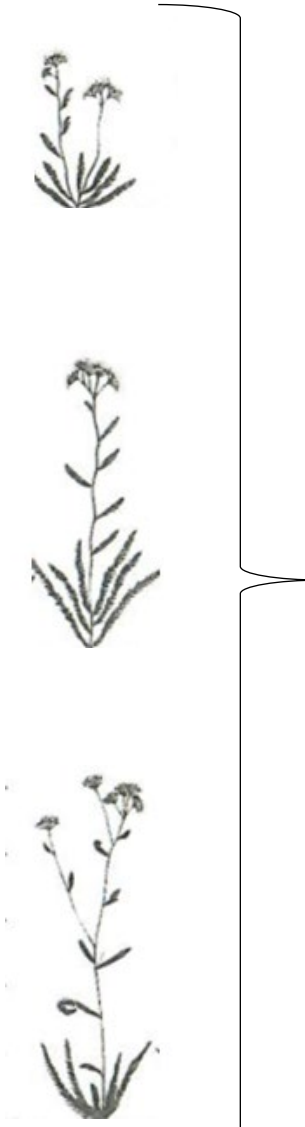
April 16th, 2024

Denver Botanic Gardens - Chatfield Farms

Research on seed sourcing for grassland restoration

Evolution & within-species diversity mean not all seed is genetically appropriate

wikimedia.org



Adapted from: https://www.crimrxiv.com/pub/jaq5x0b3/release/1

Neutral evolutionary forces
e.g. genetic drift

Non-neutral evolutionary forces
e.g. natural selection (local adaptation)

BLM Seeds of Success conserves natural genetic diversity

SEEDS OF SUCCESS

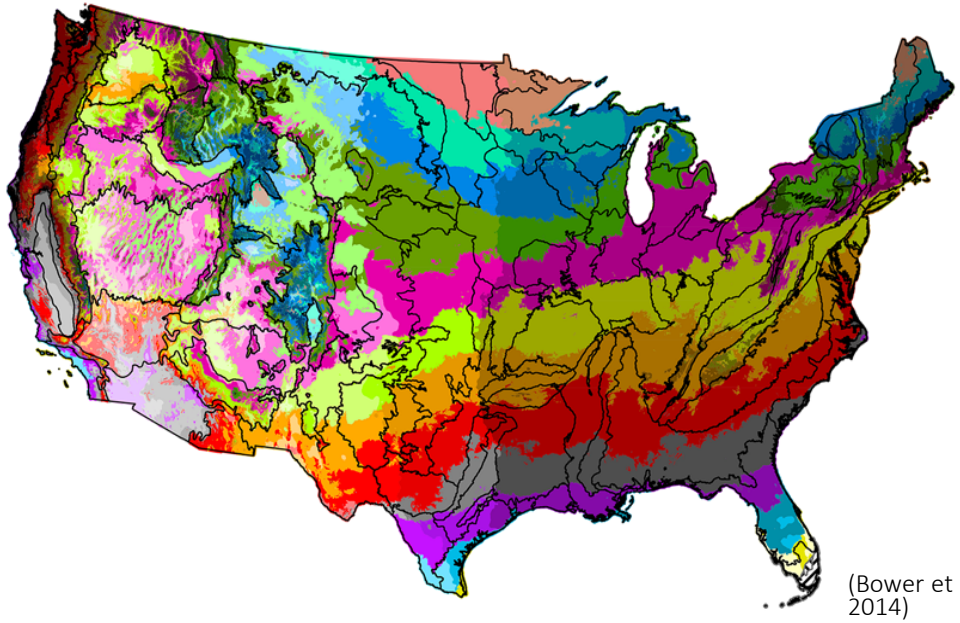
Source: BLM.gov

Natural genetic diversity is a benefit & a challenge

SOS Collections 2001-2022

Source: BLM.gov

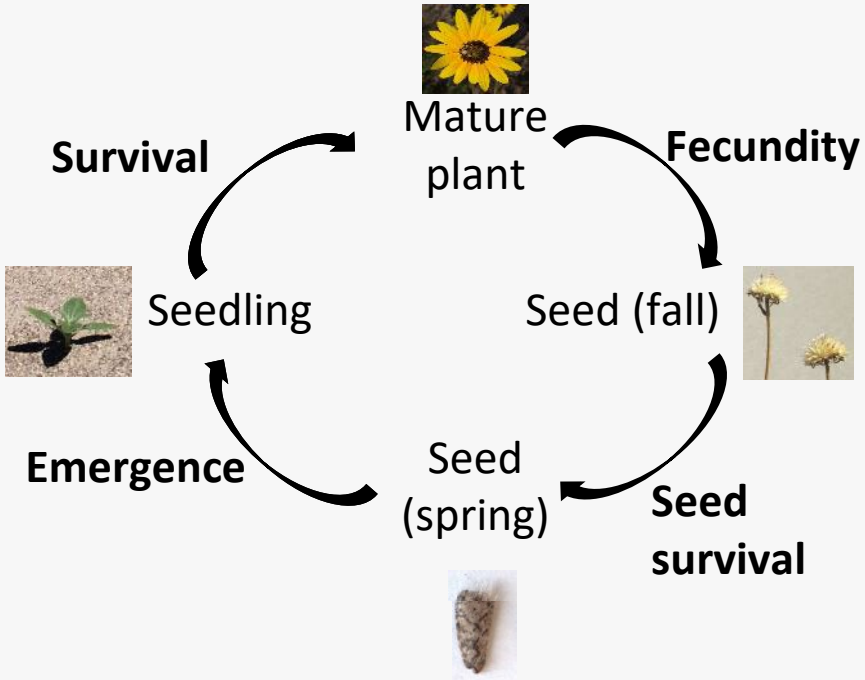
Provisional Seed Zones



(Bower et al. 2014)

Research framework

What traits are critical for restoration success?

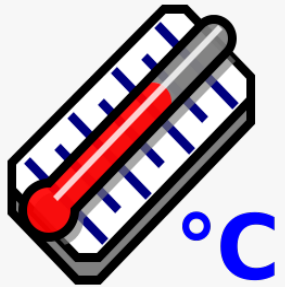


Are these traits locally adapted?

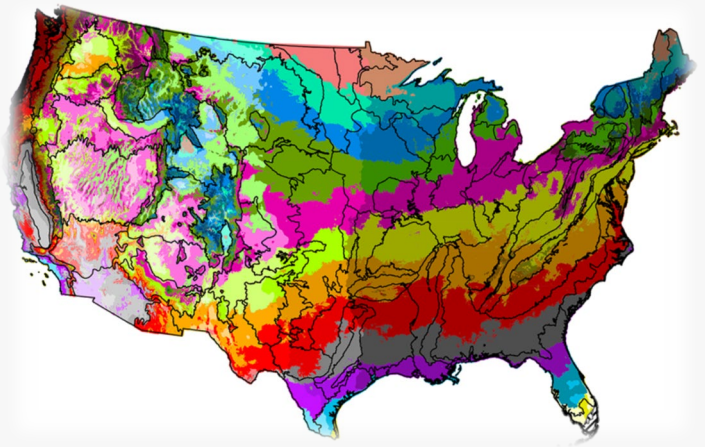
No

Yes

To what?



Source by matching, mixing, maximizing?



Talk outline

1. Local adaptation to climate in blue grama and rabbitbrush

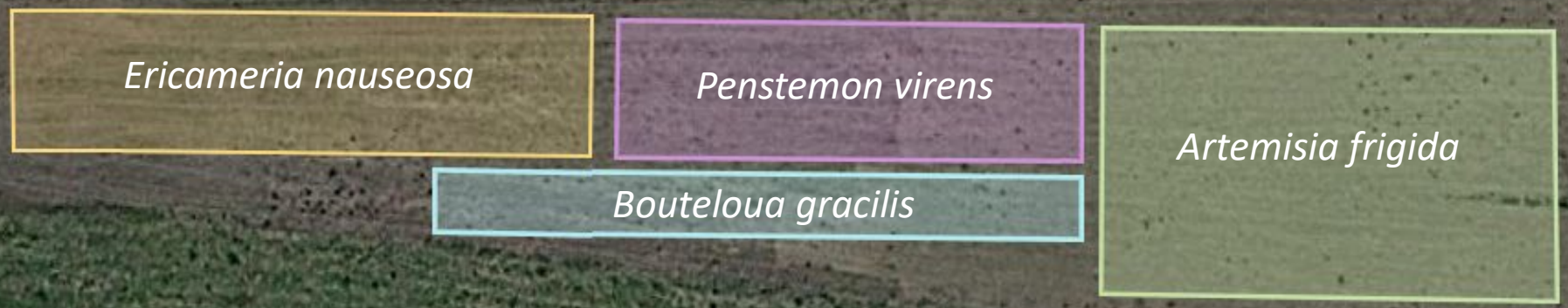
2. Warming experiment with Front Range penstemon

3. Population genomic study of fringed sage

METHODS

Species	Sample size	Populations
Artemisia frigida (fringed sage)	2183	11
Ericameria nauseosa (rubber rabbitbrush)	1124	20
Penstemon virens (Front Range penstemon)	1106	6
Bouteloua gracilis (blue grama)	1135	21

Data collection
phenology, survival, size, reproduction, leaf traits



Germination in greenhouse

METHODS

Transplant to field

Bouteloua gracilis
(blue grama)

Ericameria nauseosa
(rubber rabbitbrush)

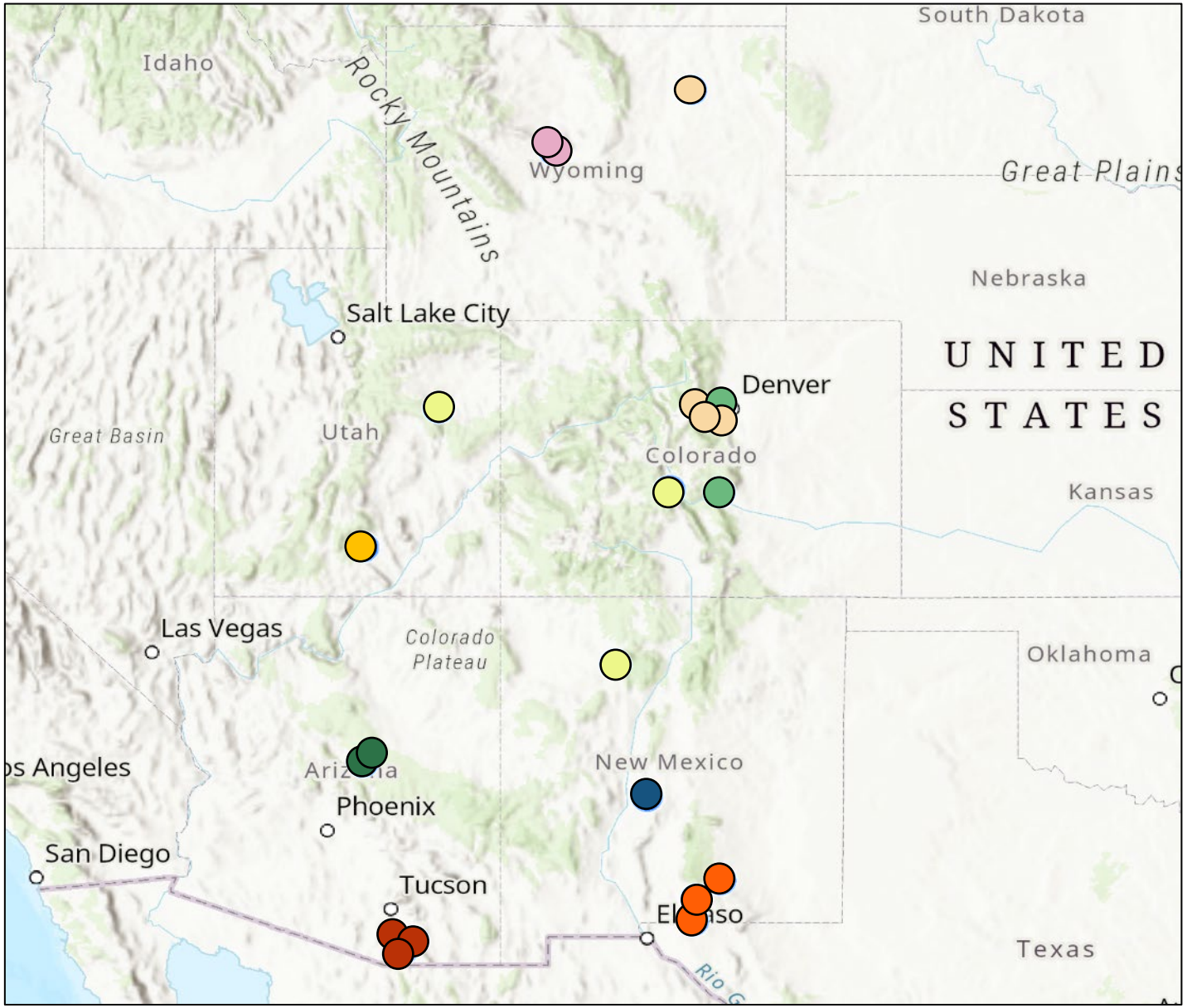
Bouteloua gracilis
(blue grama)

Ericameria nauseosa
(Rubber rabbitbrush)

Are these species locally adapted to climate?

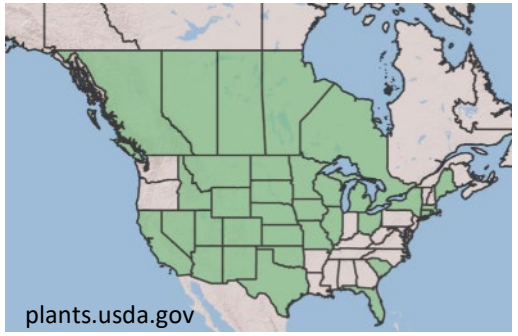
Bouteloua gracilis (blue grama)

Sample size: 1135
Populations: 21



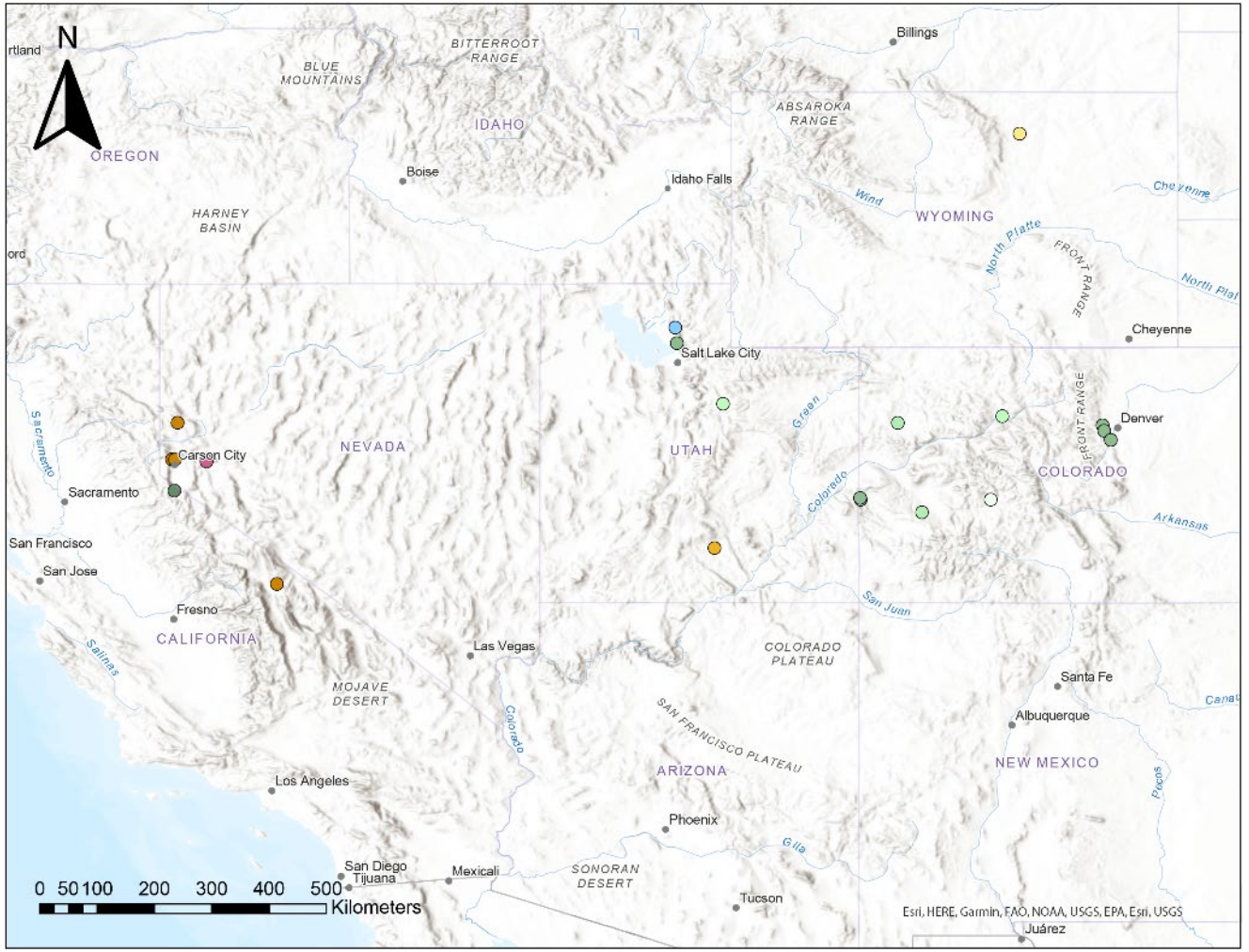
- semi-humid, cool
- semi-humid, warm
- semi-humid, v.warm
- semi-arid, cool
- semi-arid, warm
- semi-arid, v.warm
- semi-arid, hot
- semi-arid, v.hot
- arid, cold

(9 seed zones)



Ericameria nauseosa (rubber rabbitbrush)

Sample size: 1124
Populations: 20

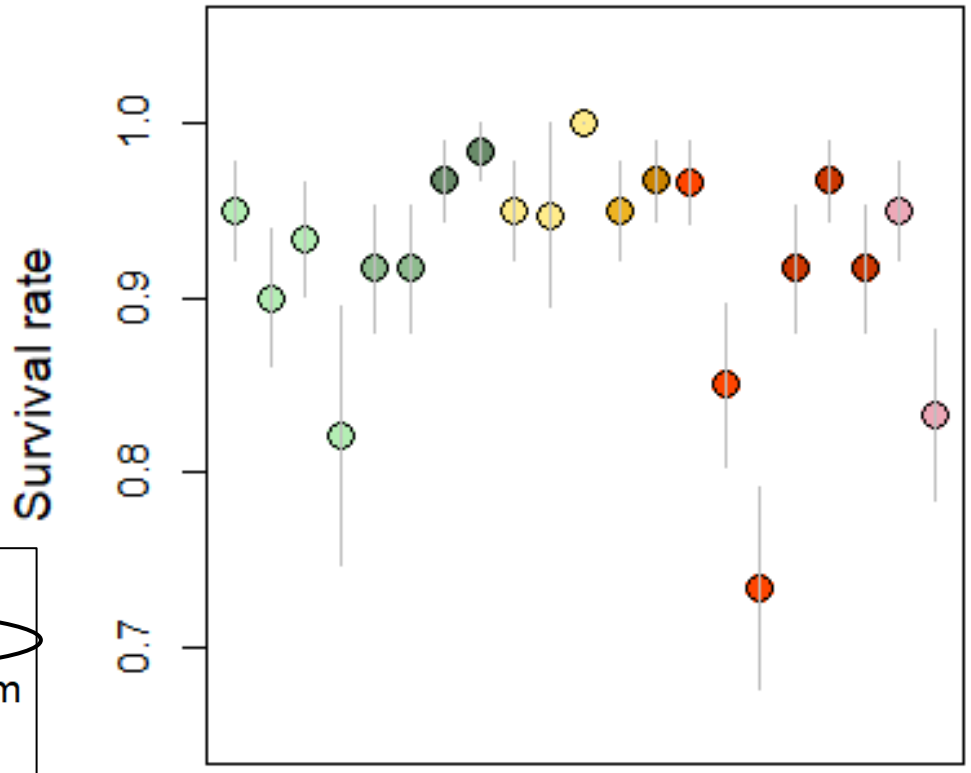


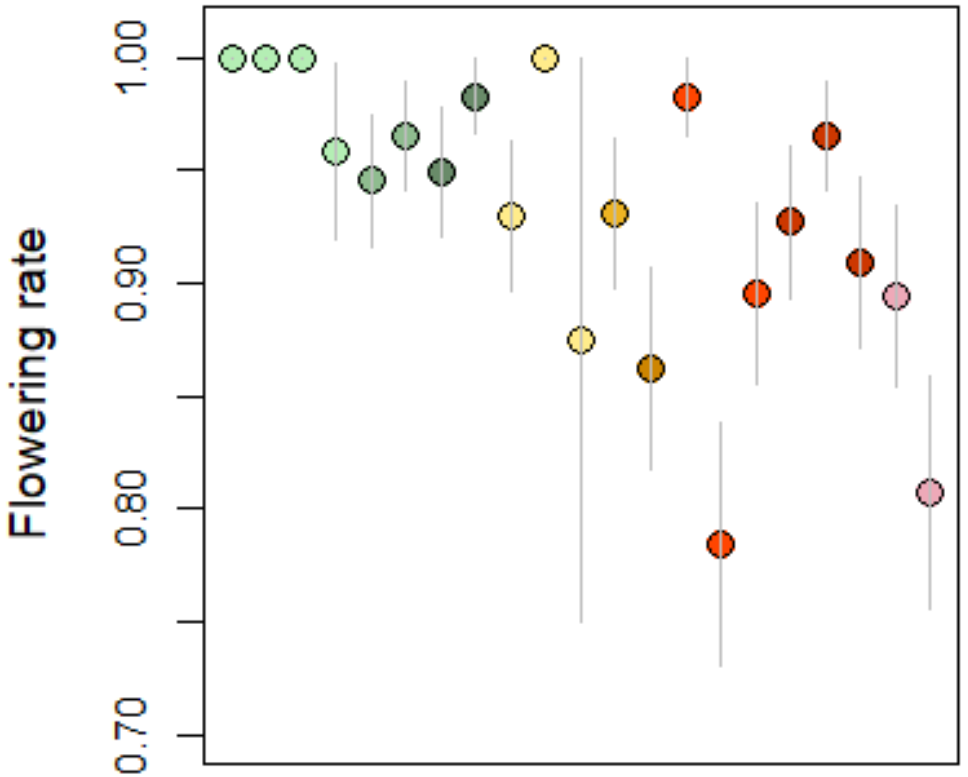
- humid, warm
- semi-humid, v.cold
- semi-humid, cold
- semi-humid, cool
- semi-humid, warm
- semi-humid, v.warm
- semi-arid, cool
- semi-arid, warm
- semi-arid, v.warm
- arid, v.warm

(10 seed zones)

plants.usda.gov/home/plant

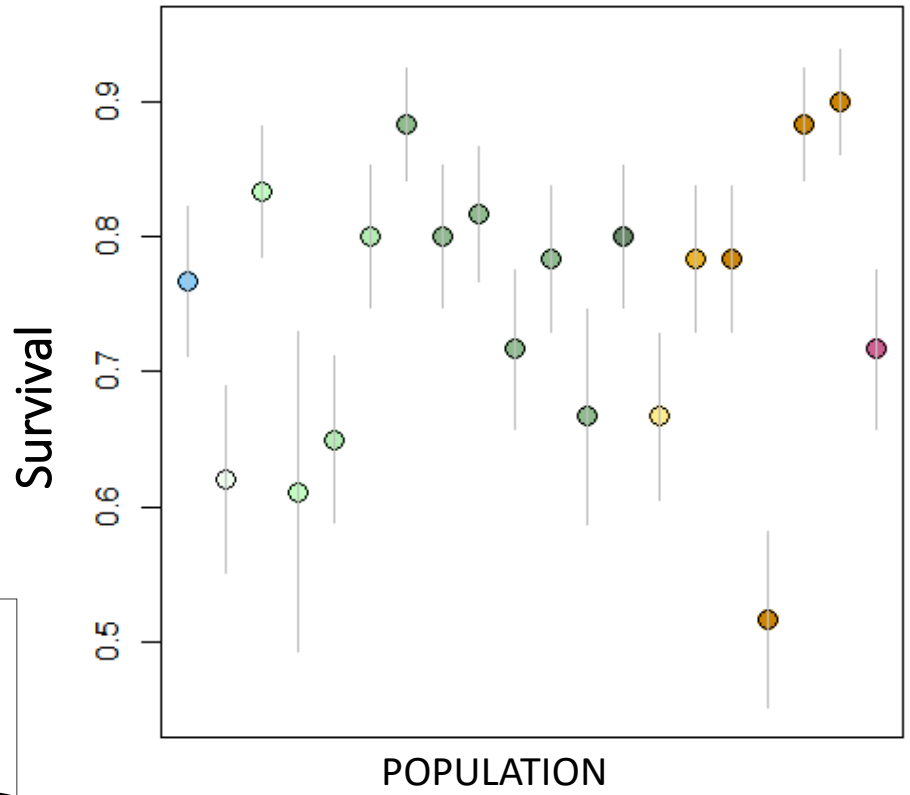
High survival & flowering rates

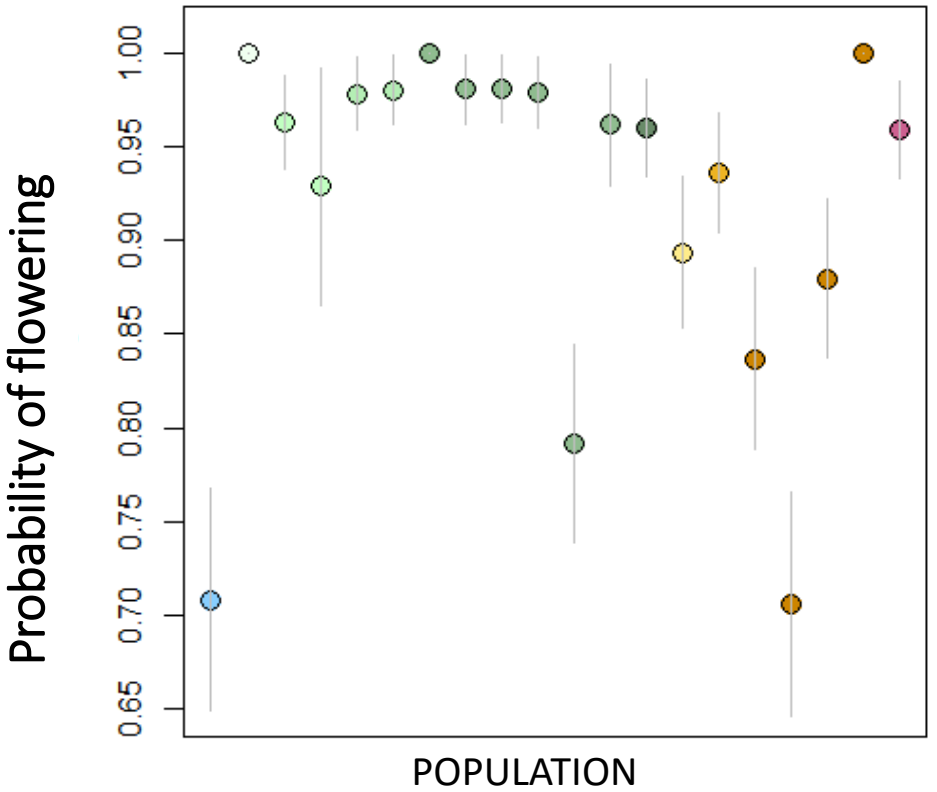




- semi-humid, cool
- semi-humid, warm
- semi-humid, v.warm
- semi-arid, cool
- semi-arid, warm
- semi-arid, v.warm
- semi-arid, hot
- semi-arid, v.hot
- arid, cold

Relatively high survival & flowering rates



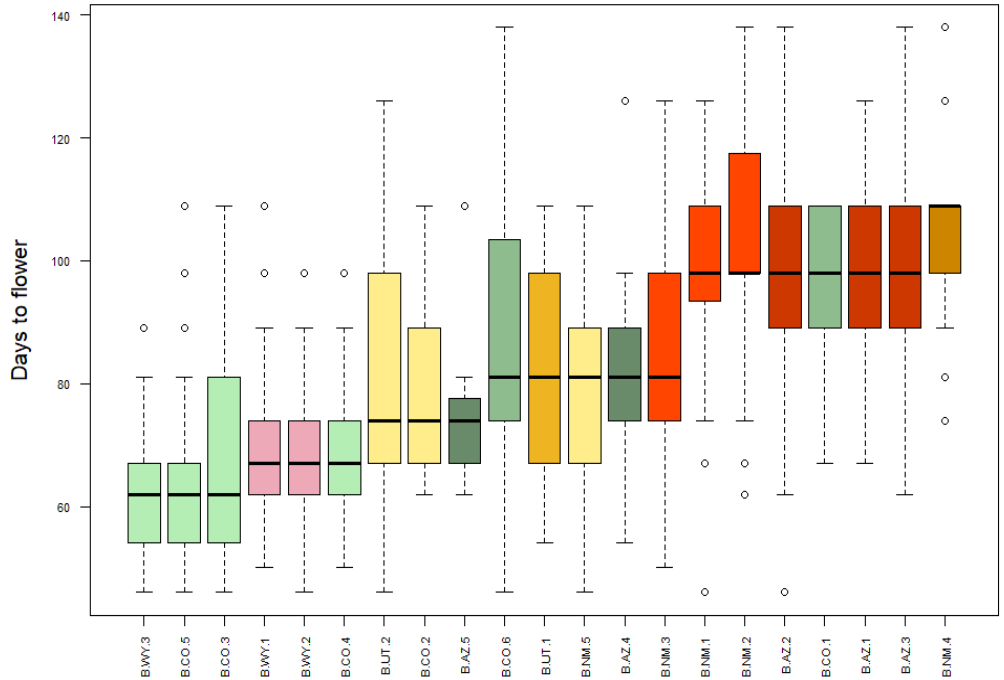


- humid, warm
- semi-humid, v.cold
- semi-humid, cool
- semi-humid, cool
- semi-humid, warm
- semi-humid, v.warm
- semi-arid, cool
- semi-arid, warm
- semi-arid, v.warm
- arid, v.warm

RESULTS - *B. gracilis*

- semi-humid, cool
- semi-humid, warm
- semi-humid, v.warm
- semi-arid, cool
- semi-arid, warm
- semi-arid, v.warm
- semi-arid, hot
- semi-arid, v.hot
- arid, cold

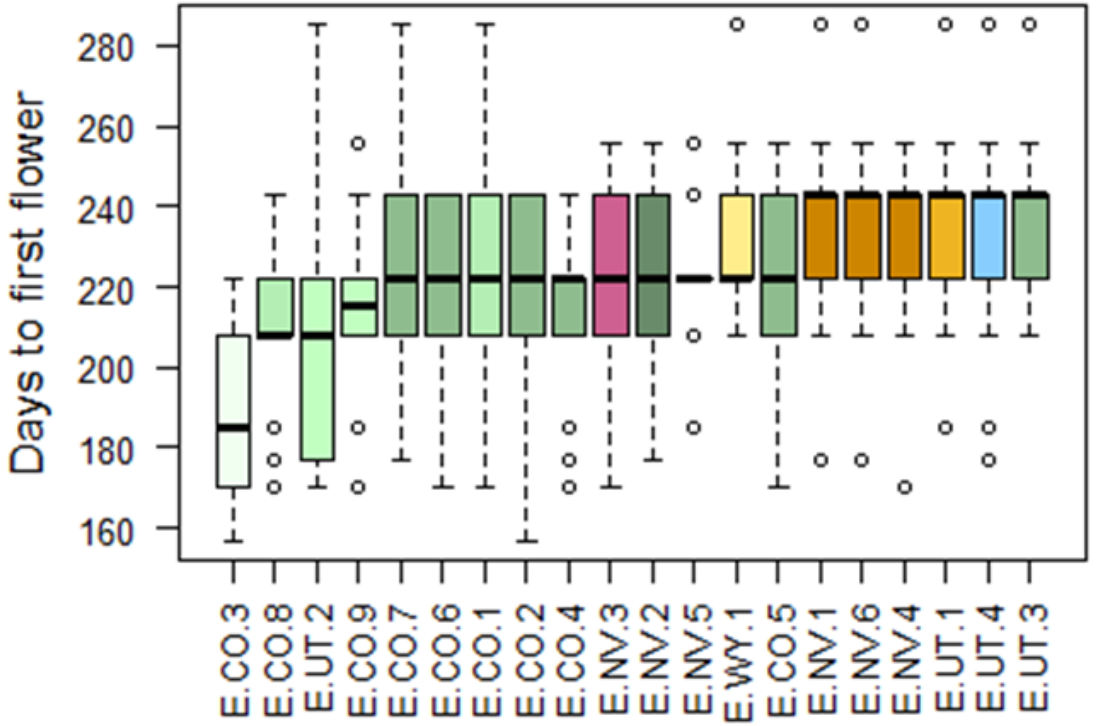
FLOWERING PHENOLOGY



RESULTS – *E. nauseosa*

- humid, warm
- semi-humid, v.cold
- semi-humid, cold
- semi-humid, cool
- semi-humid, warm
- semi-humid, v.warm
- semi-arid, cool
- semi-arid, warm
- semi-arid, v.warm
- arid, v.warm

FLOWERING PHENOLOGY

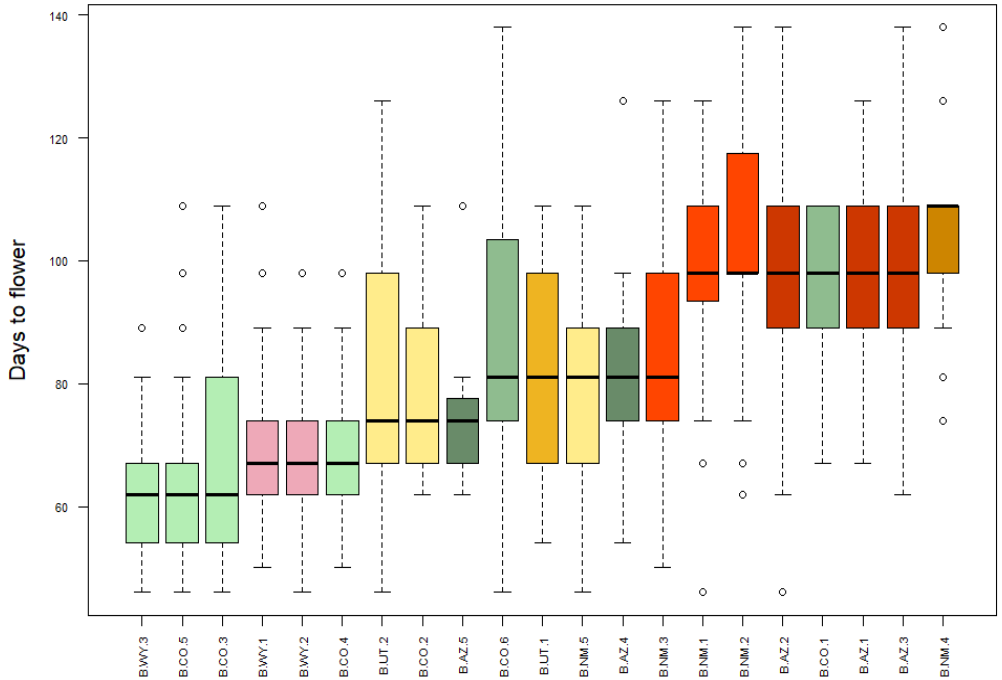


RESULTS - B. gracilis

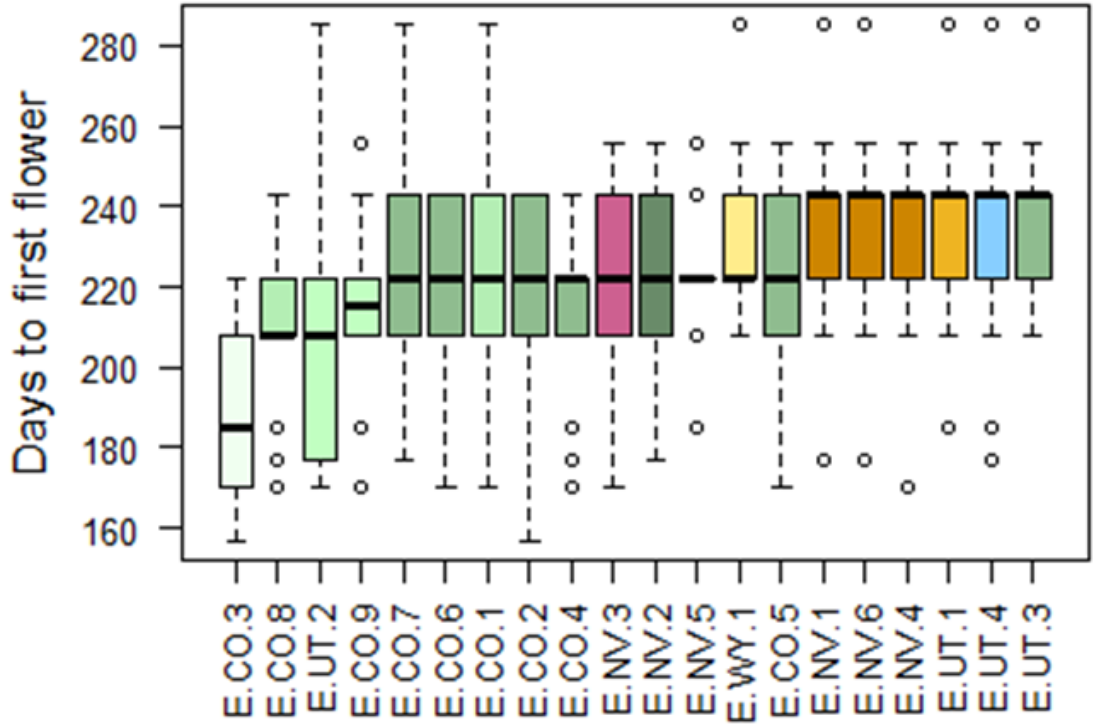
RESULTS – E. nauseosa

Timing of flowering can vary widely between populations

FLOWERING PHENOLOGY



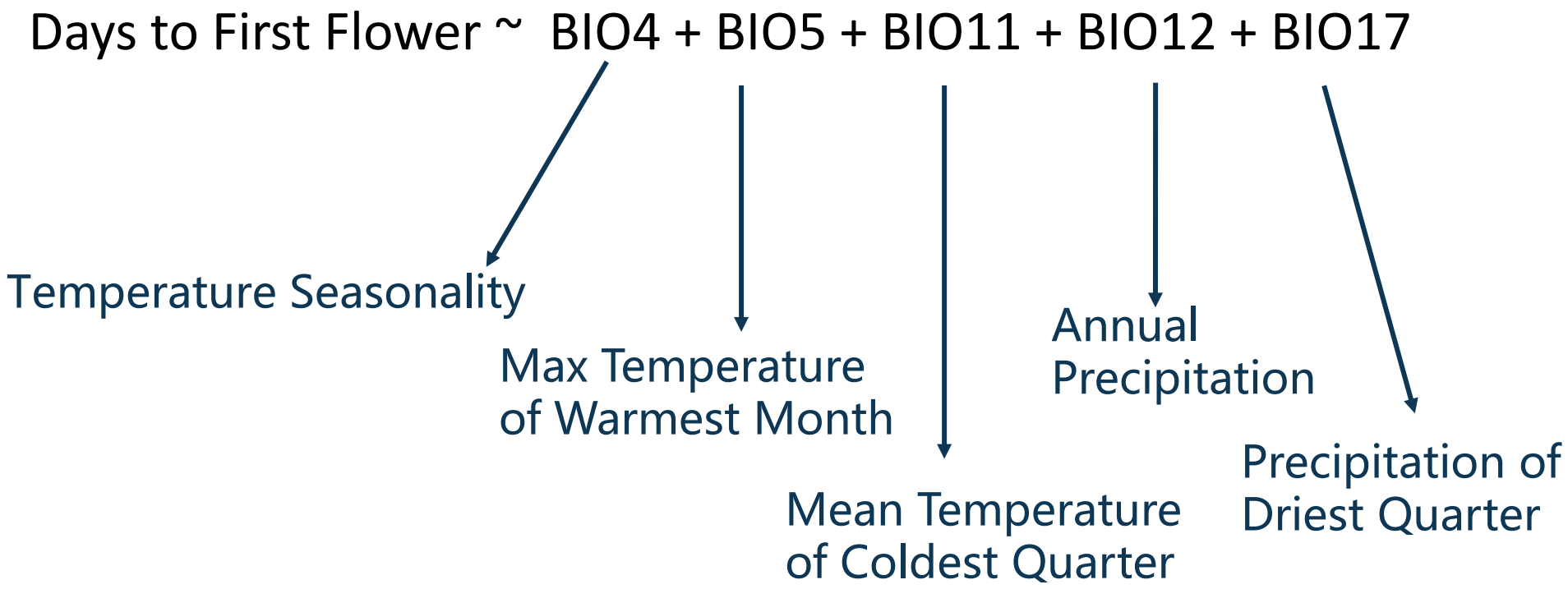
FLOWERING PHENOLOGY



Bioclimatic variables

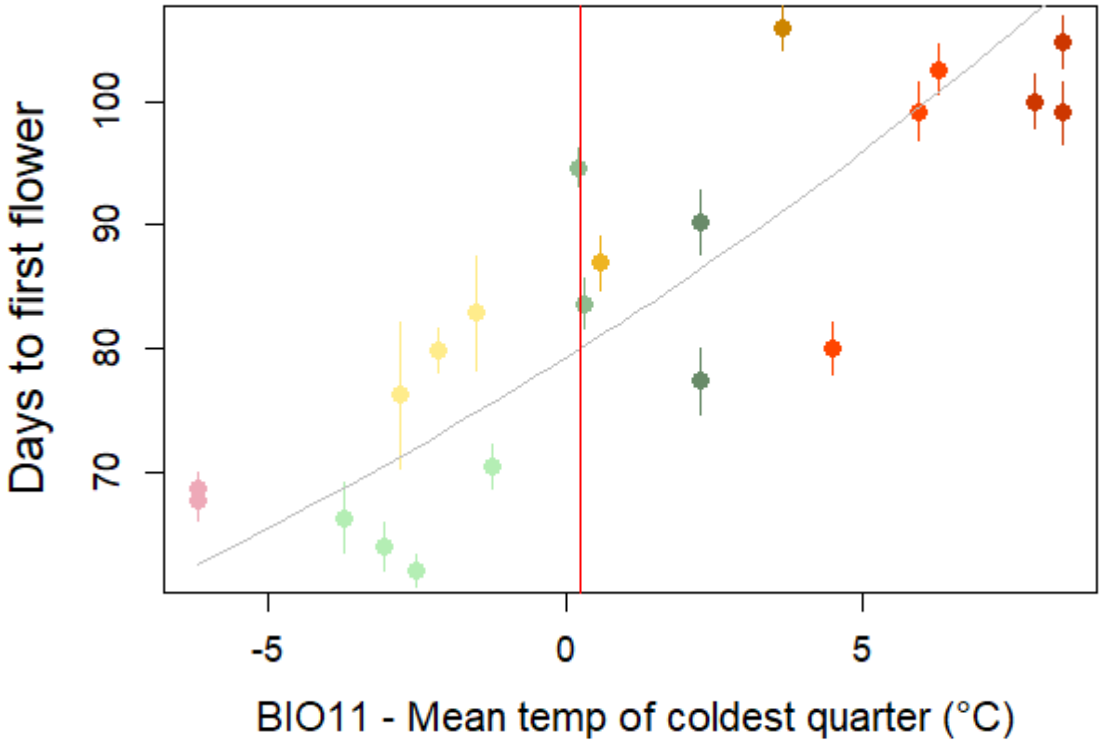
BIO1 = Annual Mean Temperature
BIO2 = Mean Diurnal Range
BIO3 = Isothermality
BIO4 = Temperature Seasonality
BIO5 = Max Temperature of Warmest Month
BIO6 = Min Temperature of Coldest Month
BIO7 = Temperature Annual Range
BIO8 = Mean Temperature of Wettest Quarter
BIO9 = Mean Temperature of Driest Quarter
BIO10 = Mean Temperature of Warmest Quarter
BIO11 = Mean Temperature of Coldest Quarter
BIO12 = Annual Precipitation
BIO13 = Precipitation of Wettest Month
BIO14 = Precipitation of Driest Month
BIO15 = Precipitation Seasonality
BIO16 = Precipitation of Wettest Quarter
BIO17 = Precipitation of Driest Quarter
BIO18 = Precipitation of Warmest Quarter
BIO19 = Precipitation of Coldest Quarter

Example regression model of trait against bioclim variables



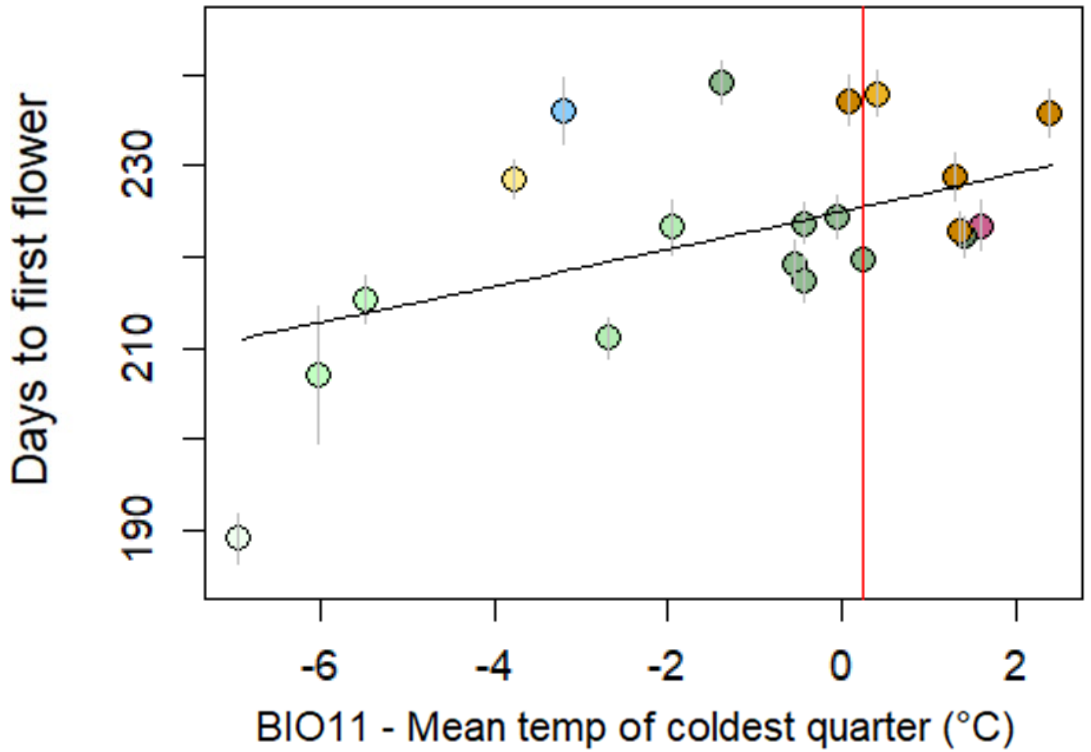
RESULTS - B. gracilis

- semi-humid, cool
- semi-humid, warm
- semi-humid, v.warm
- semi-arid, cool
- semi-arid, warm
- semi-arid, v.warm
- semi-arid, hot
- semi-arid, v.hot
- arid, cold



RESULTS – E. nauseosa

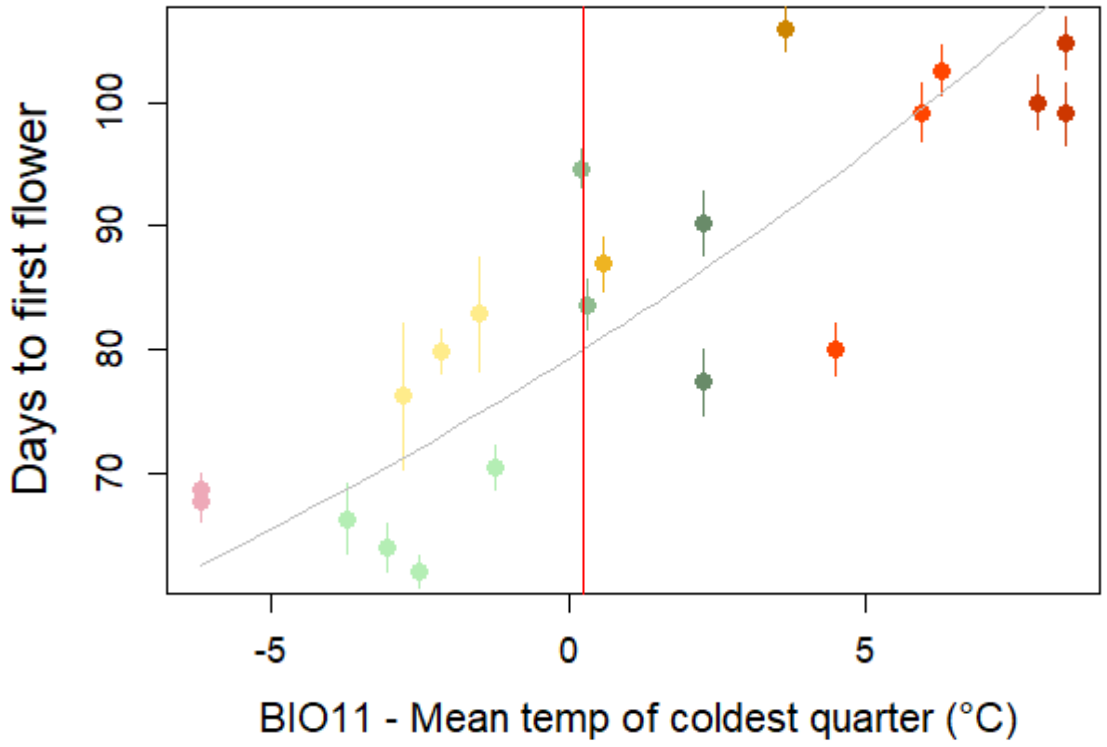
- humid, warm
- semi-humid, v.cold
- semi-humid, cold
- semi-humid, cool
- semi-humid, warm
- semi-humid, v.warm
- semi-arid, cool
- semi-arid, warm
- semi-arid, v.warm
- arid, v.warm

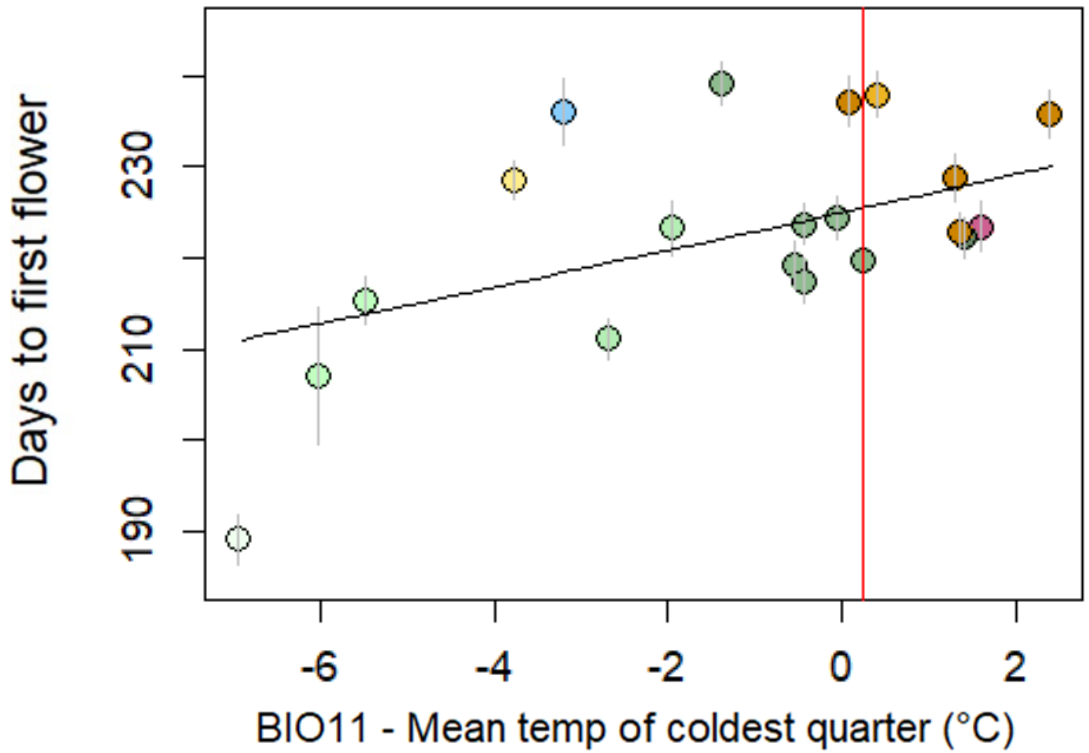


RESULTS - *B. gracilis*

RESULTS – *E. nauseosa*

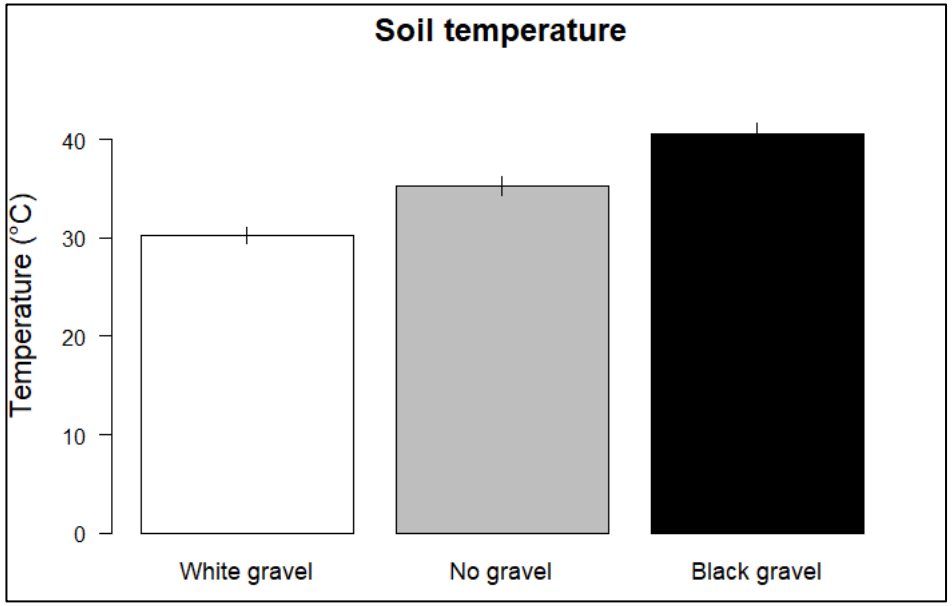
Plants adapted to mild winters flower later





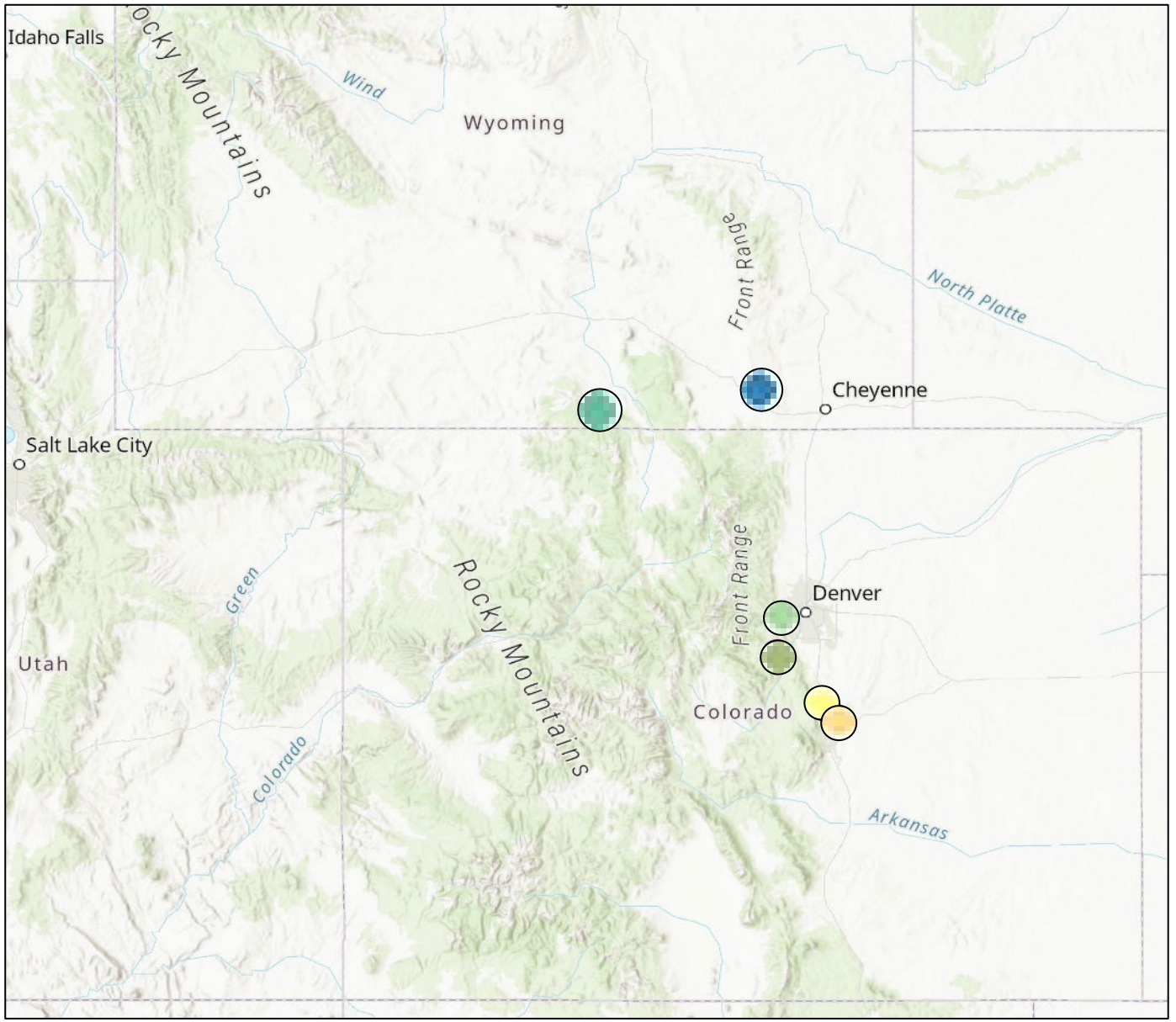
Penstemon virens (Front Range penstemon)

How does penstemon respond to warming?



Penstemon virens (Front Range penstemon)

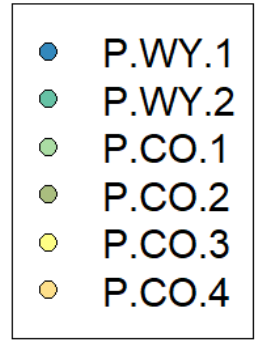
Sample size: 1106
Populations: 6



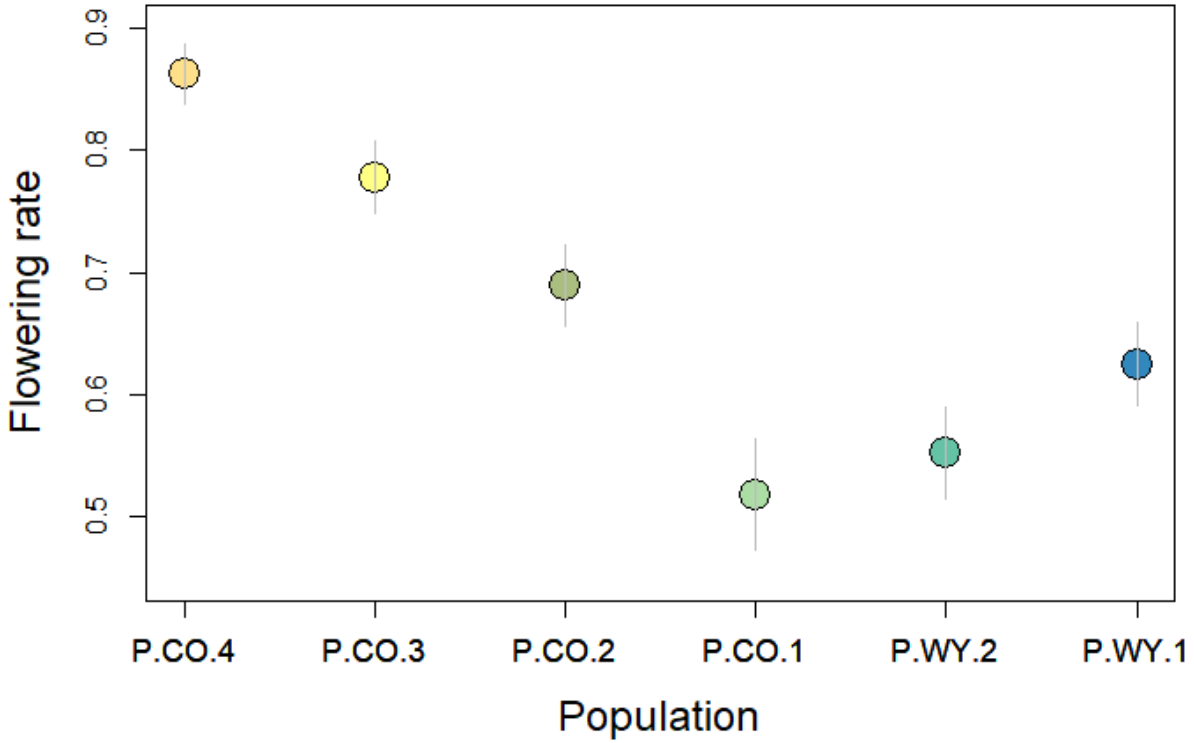
P.WY.1
P.WY.2
P.CO.1
P.CO.2
P.CO.3
P.CO.4

plants.usda.gov/home/plantProfile?symbol=PEVI3

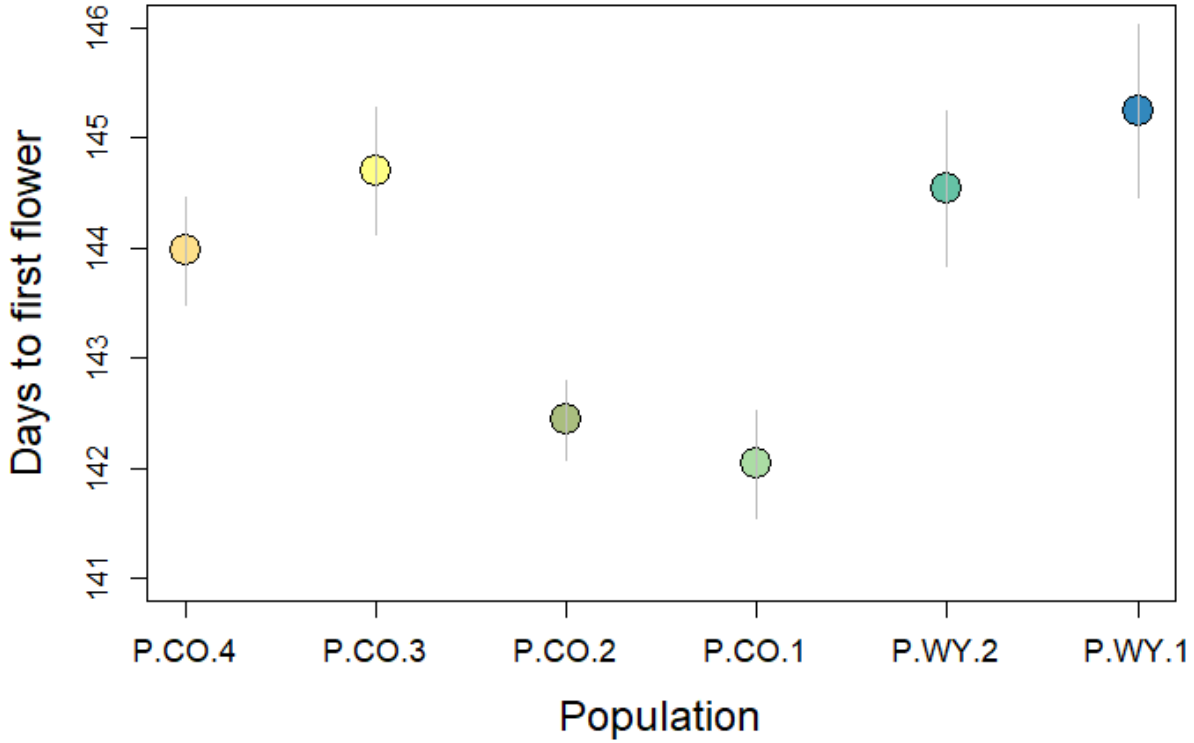
RESULTS – P. virens

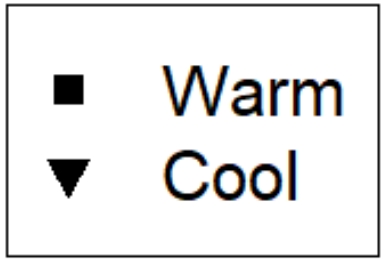


Flowering rates differ between populations

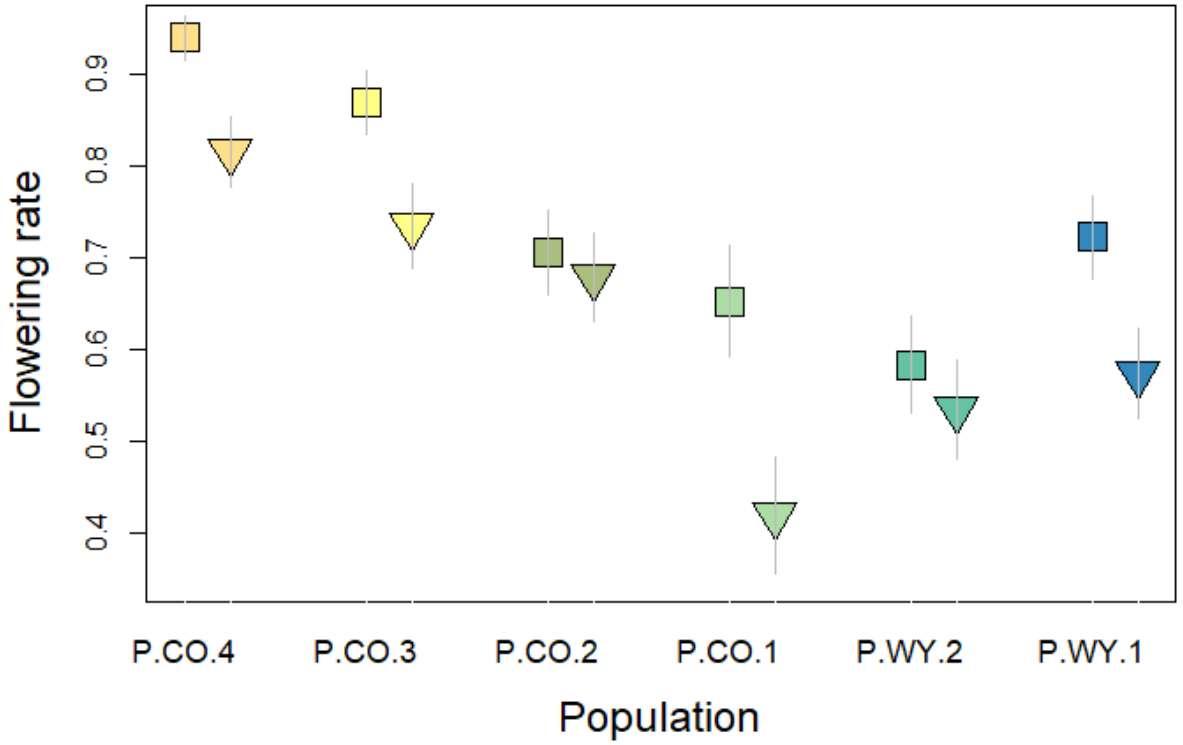


Timing of flowering similar between populations

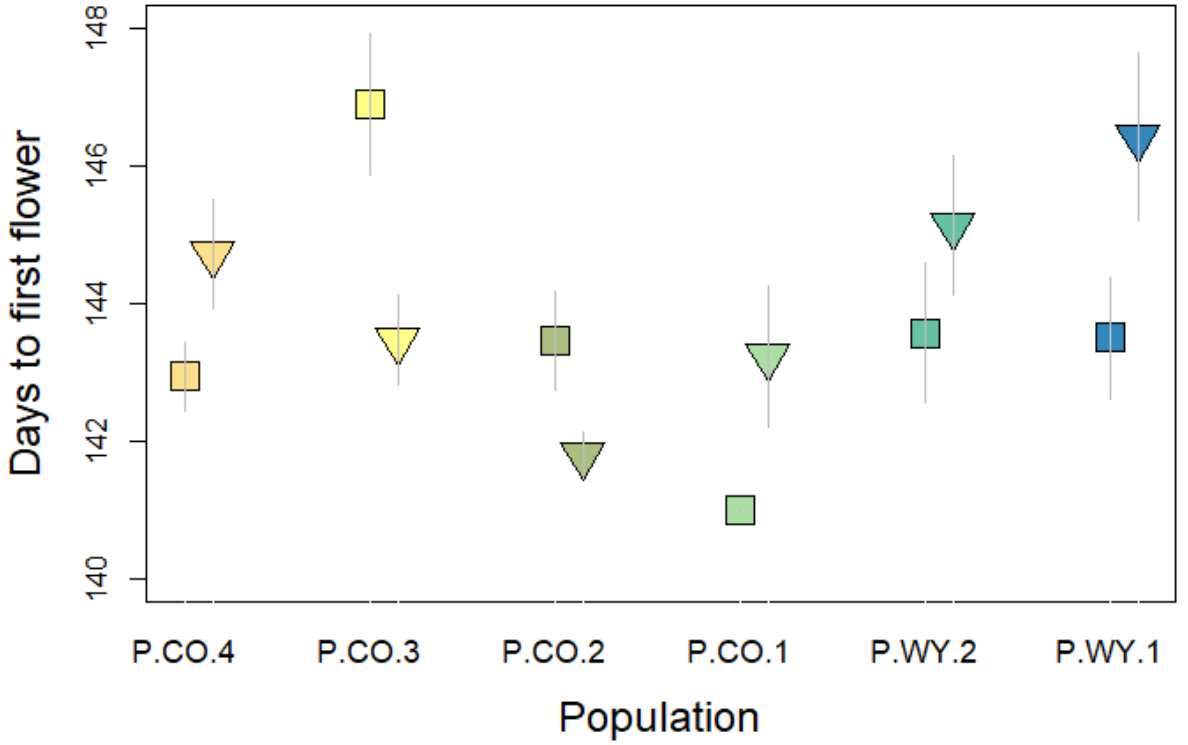




Warming resulted in higher flowering rates



Warming resulted in earlier flowering in most populations

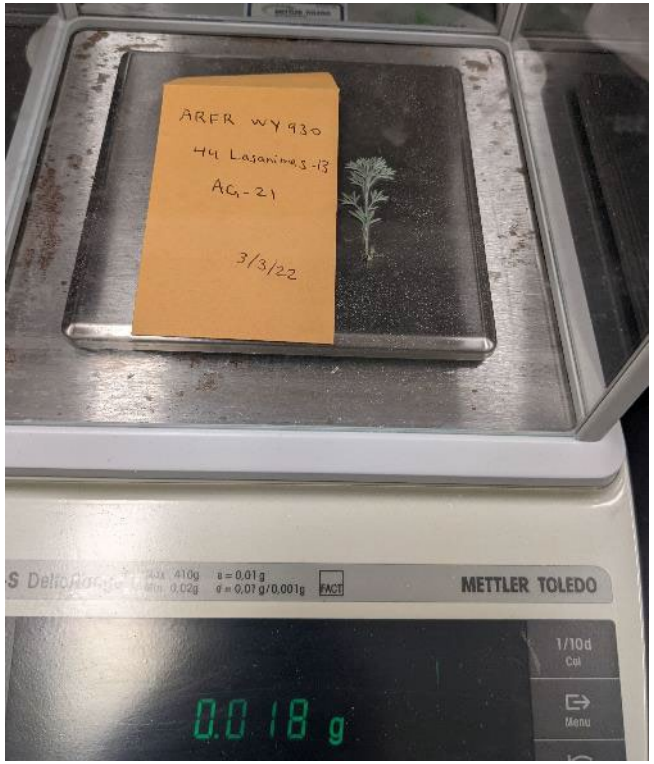


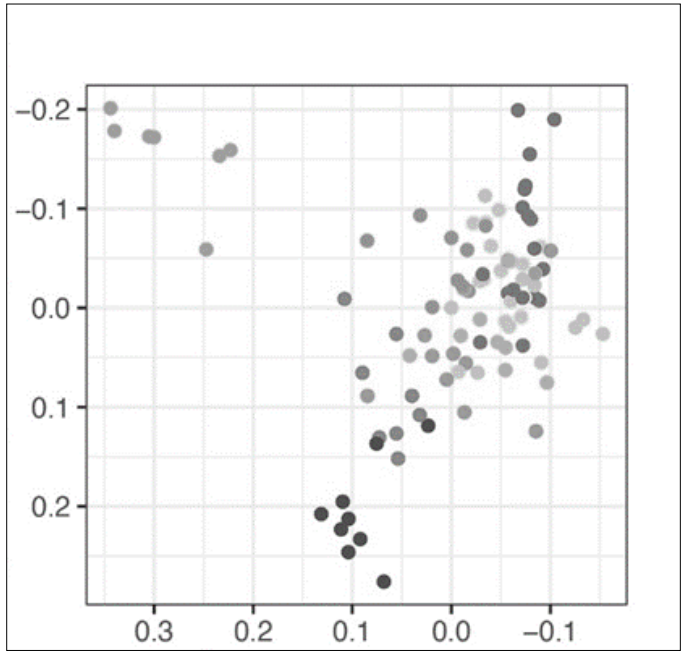
Penstemon virens

Next steps: germination & emergence field experiment to look at warming during early life stages

Artemisia frigida (fringed sage)

Artemisia frigida – Population genomics

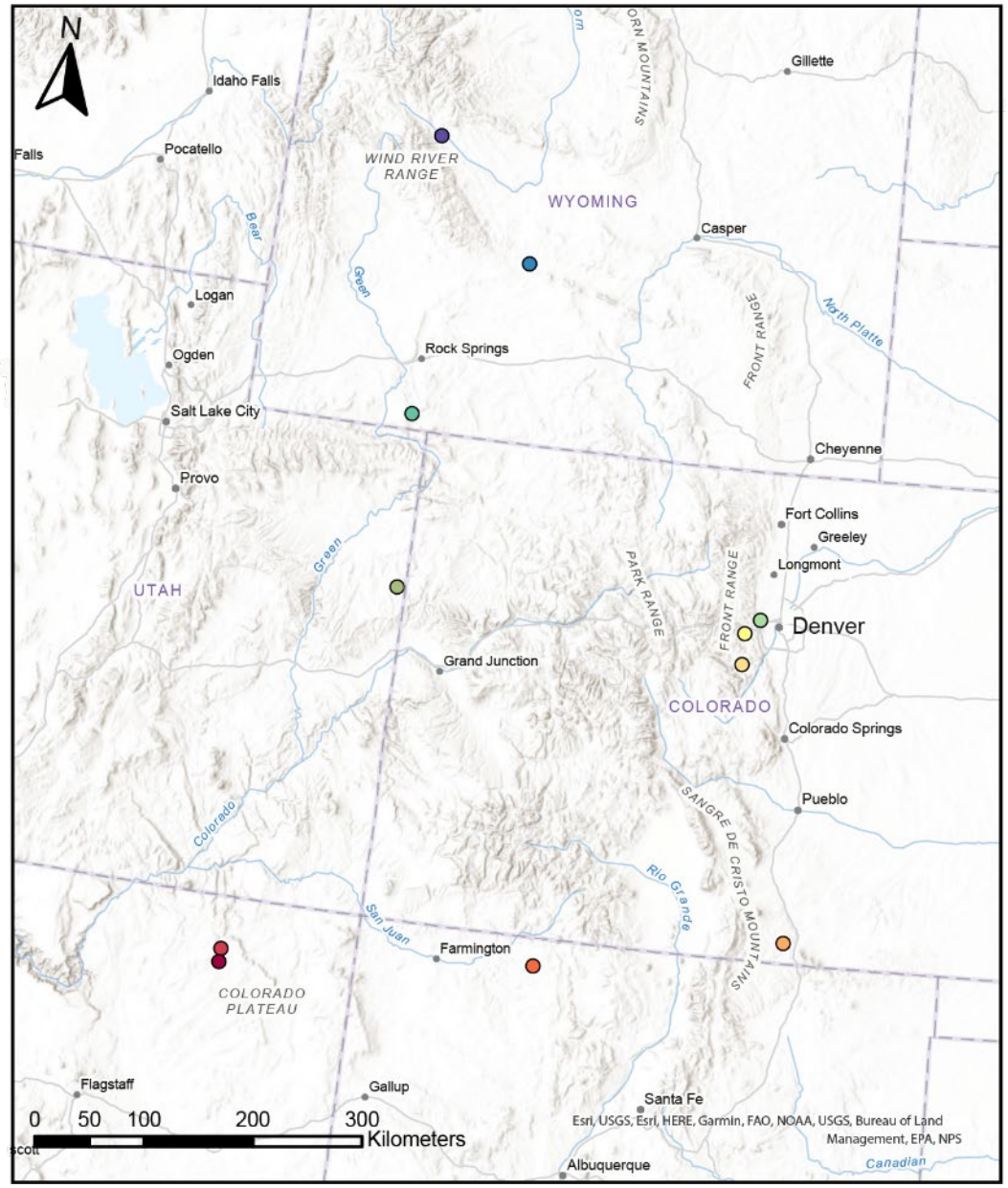




- Do seed sources differ genetically?
- Can we identify adaptive genetic variation in key traits?

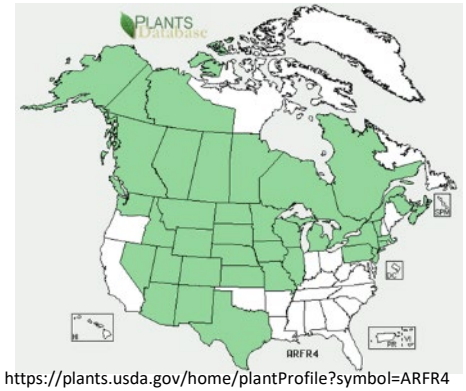
Artemisia frigida (fringed sage)

Sample size: 2183
Populations: 11



- ARFR-WY050-49-FREMONT-12
- ARFR-WY050-151-FREMONT-16
- ARFR-WY040-71-10
- ARFR-CO932-294-11
- ARFR-UT080-109-UINTAH-12
- ARFR-CO932-316-JEFFERSON-12
- ARFR-CO932-314-JEFFERSON-12
- ARFR-WY930-44-LASANIMAS-13
- ARFR-NM930N-66-11
- ARFR-AZ930-422-NAVAJO-18
- ARFR-AZ930-423-NAVAJO-18

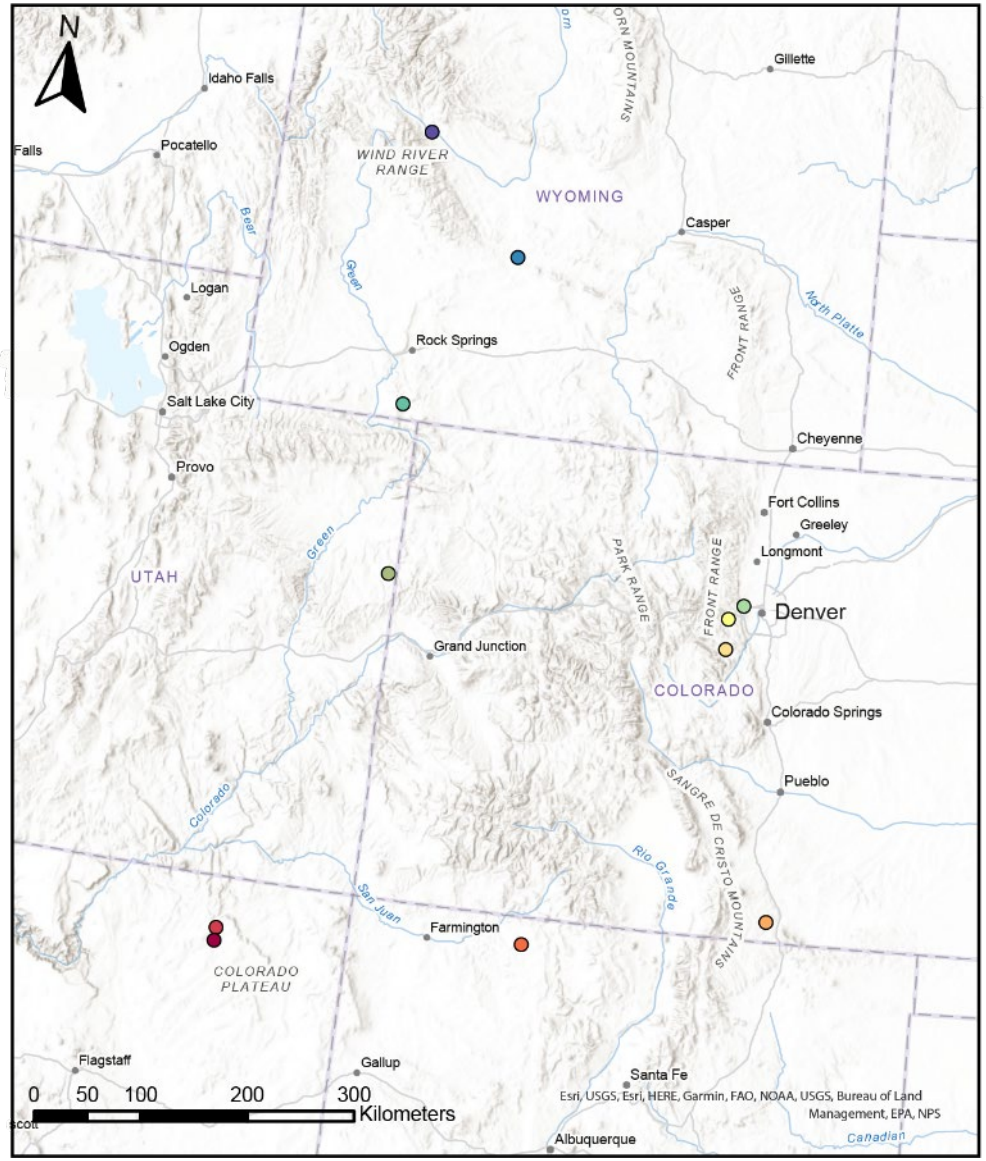
(6 seed zones)

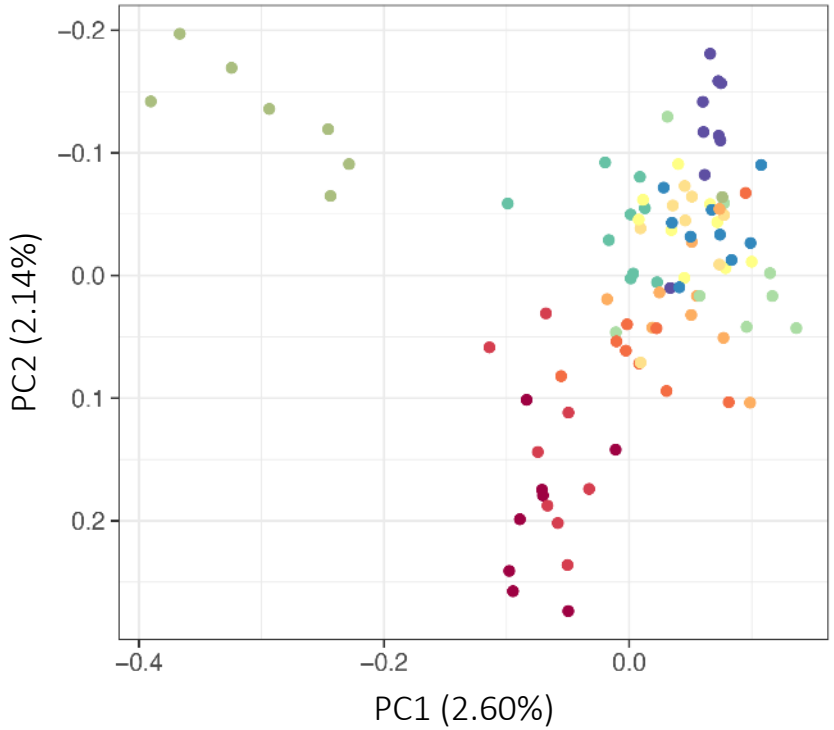


https://plants.usda.gov/home/plantProfile?symbol=ARFR4

RESULTS – *A. frigida*

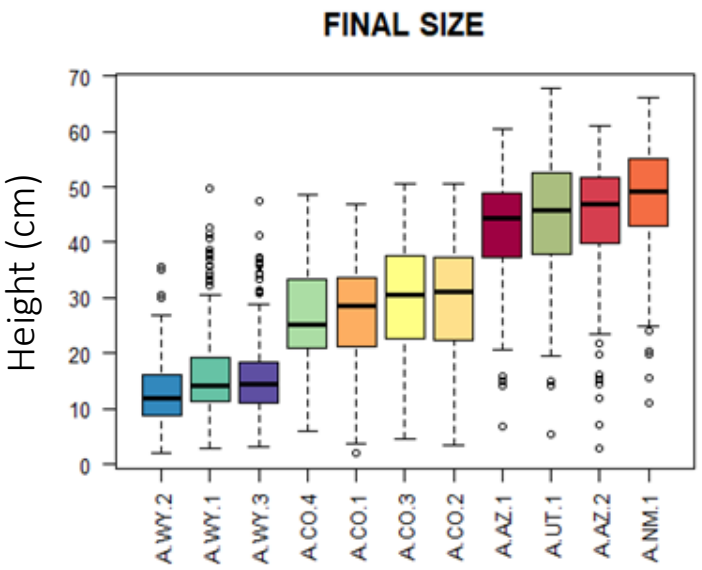
Alyson Emery



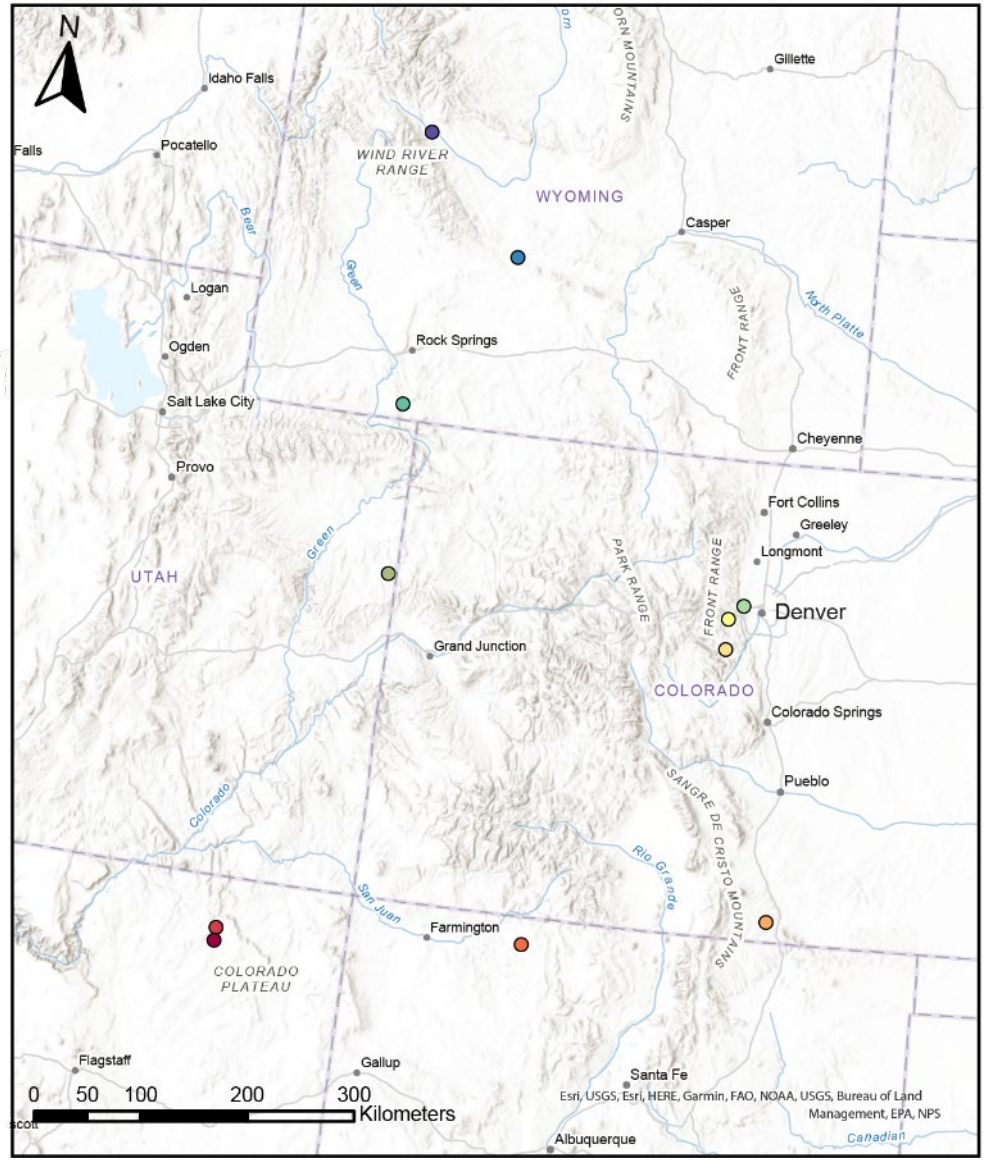


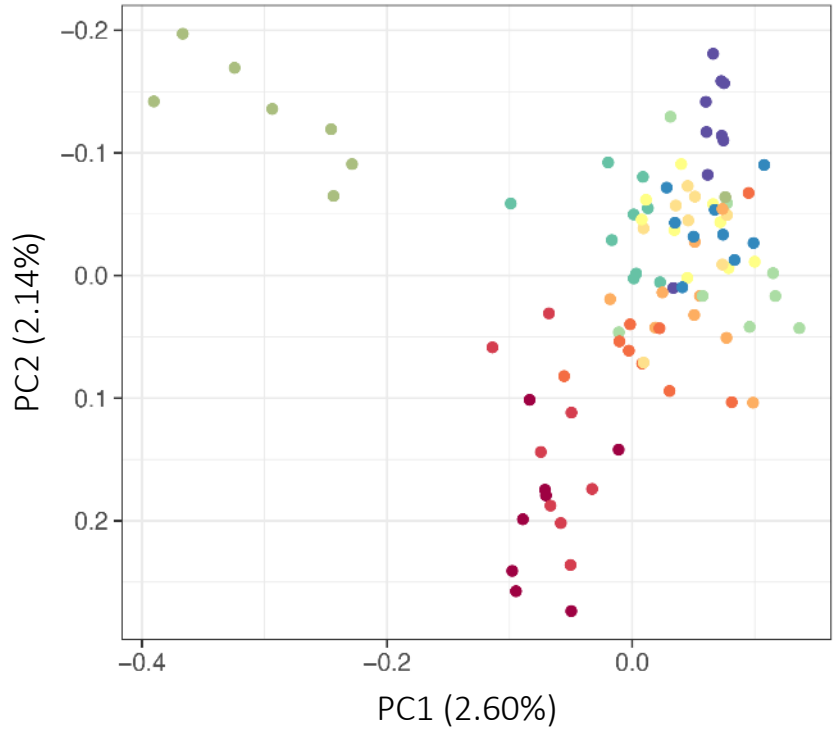
RESULTS – *A. frigida*

Alyson Emery



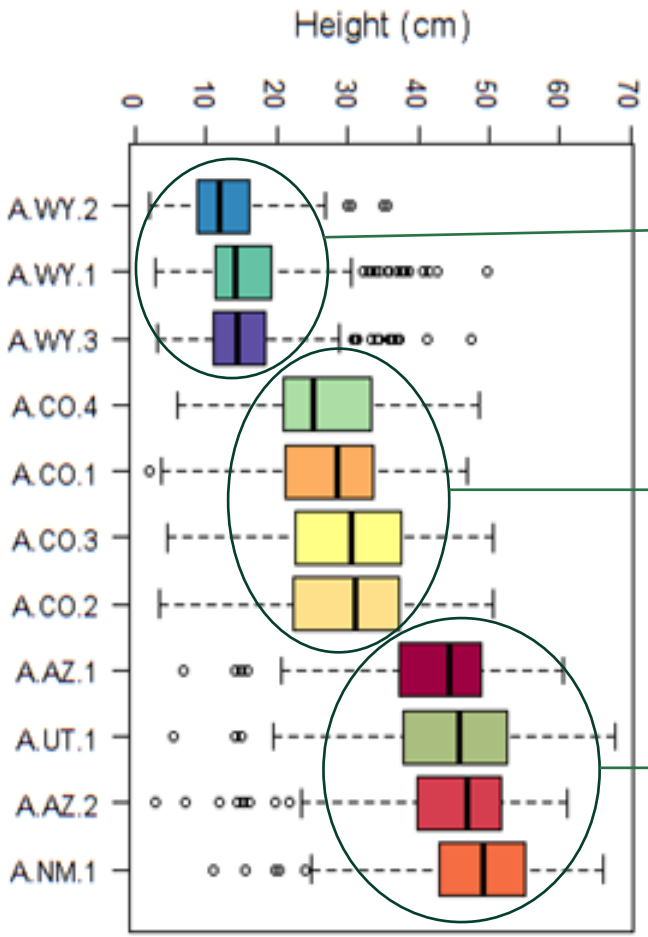
Population
- ARFR–WY050–49–FREMONT–12
- ARFR–WY050–151–FREMONT–16
- ARFR–WY040–71–10
- ARFR–CO932–294–11
- ARFR–UT080–109–UINTAH–12
- ARFR–CO932–316–JEFFERSON–12
- ARFR–CO932–314–JEFFERSON–12
- ARFR–WY930–44–LASANIMAS–13
- ARFR–NM930N–66–11
- ARFR–AZ930–422–NAVAJO–18
- ARFR–AZ930–423–NAVAJO–18

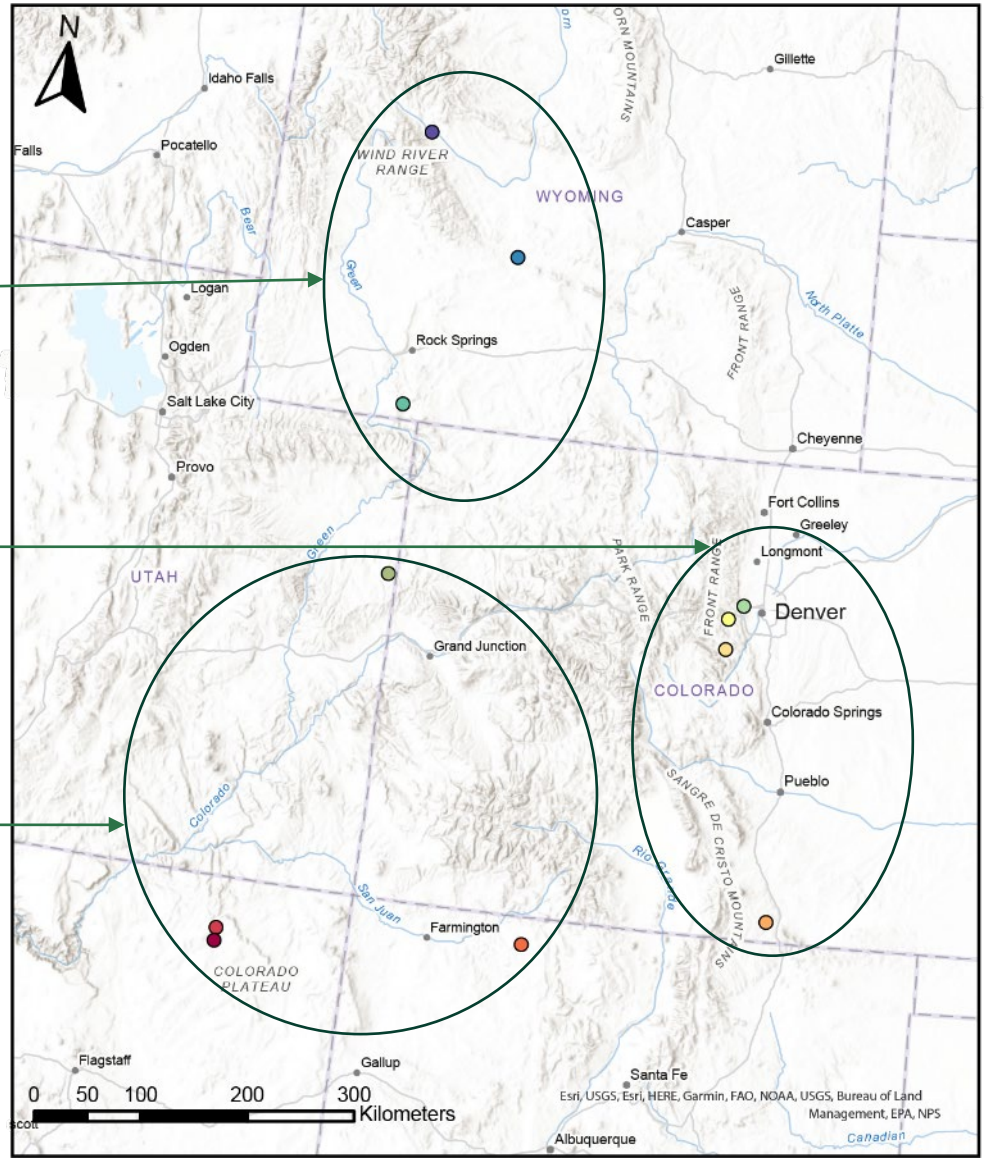


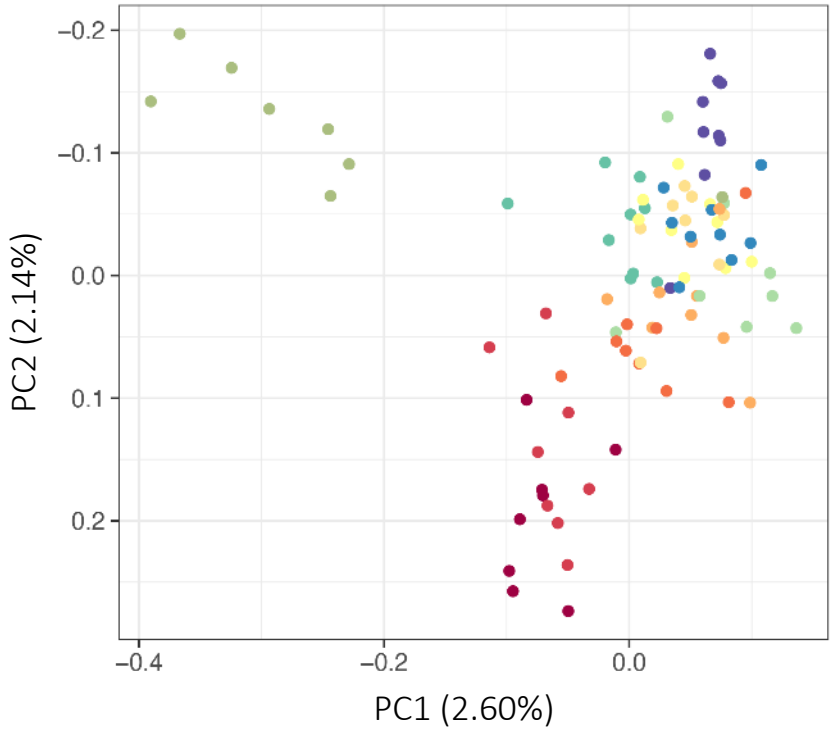


Plant size & SNPs map onto source location

Alyson Emery







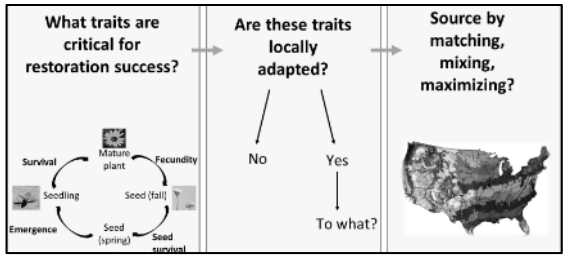
Summary

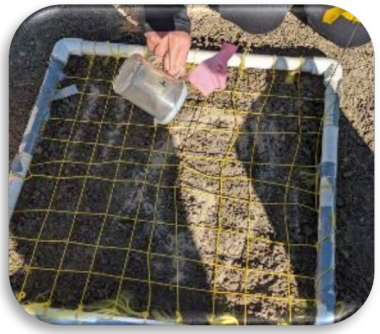
1. Blue grama & Rubber rabbitbrush
   - Trait variation between populations
   - Phenology has high between population variation and low within population variation
   - Phenology correlates with winter temperature

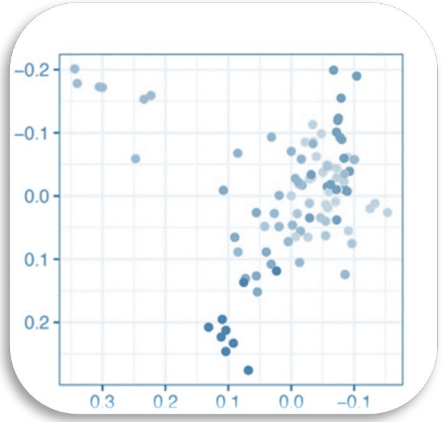
2. Front Range penstemon flowering responds to warming

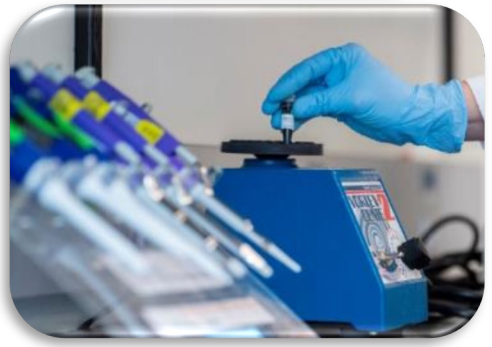
3. Fringed sage shows variation in plant size and SNPs that maps onto geographic source site location

Next Steps









Data from additional traits & life stages

DNA sequence data of common garden plants

Test local adaptation hypotheses

Acknowledgments

Land acknowledgment
This research was conducted on land of the Núu-agha-tʉvʉ-pʉ̱ (Ute), Tséstho'e (Cheyenne)

- Larry Vickerman
- Brooke Palmer
- Mike Bone
- Emily McAuley
- Erik Geyer
- Christina Alba
- Dan Doak
- Nolan Kane
- Rebecca Hufft
- SNPsaurus
- Laura Green
- Tiffany Gentry
- Michelle Williams
- Adriana Jacobi
- Theresa Melhem
- Michelle Deprenger-Levin
- Jacob Stanley
- Alyson Emery
- Erica Larson
- Gardens Research & Conservation Dept

Contact: april.goebl@botanicgardens.org