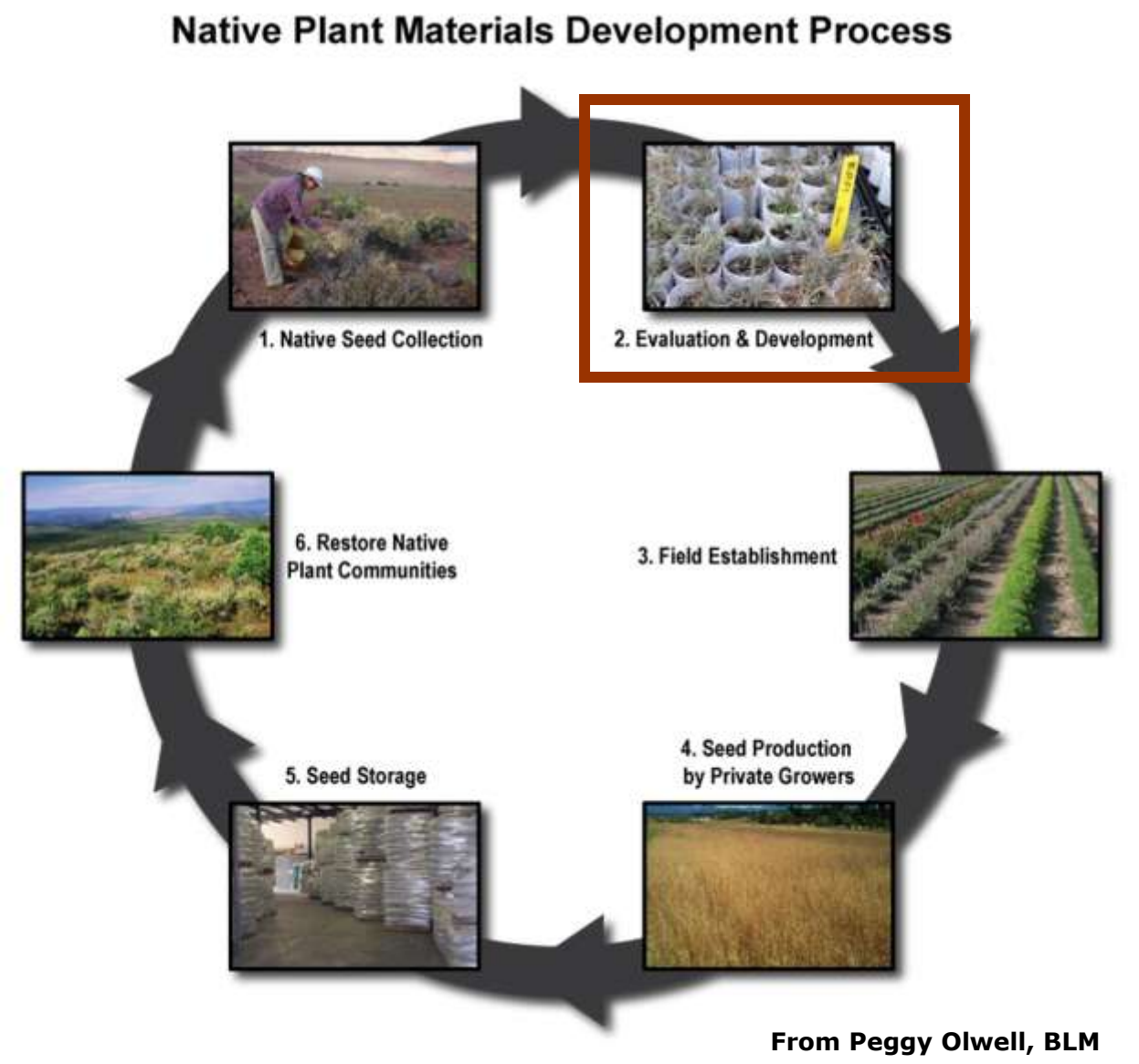
Ecological genetics of *Penstemon* in the Great Basin

Andrea Kramer
Executive Director
Botanic Gardens Conservation International, U.S.

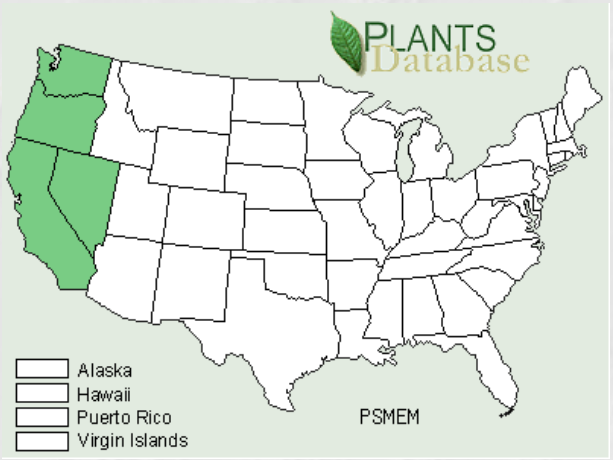
Developing native plant materials



From Peggy Olwell, BLM

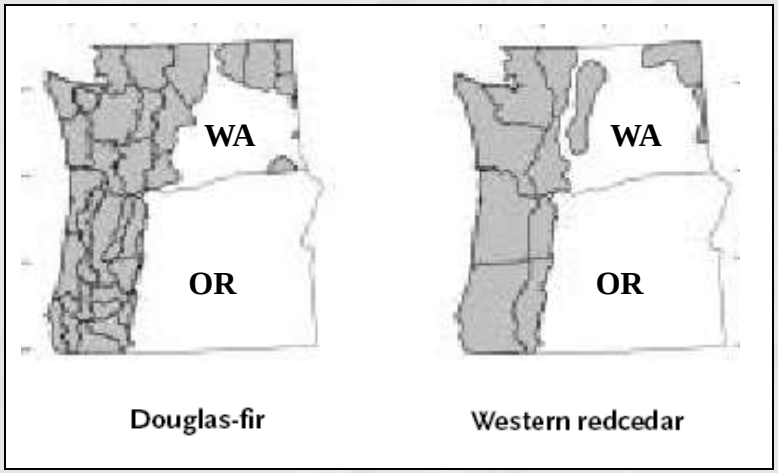
Early common gardens

- Douglas-fir (*Pseudotsuga menziesii*) study plots established by USFS in early 1900's using trees from different sources
- Extreme cold spell 40 years later killed or seriously damaged non-local plants, local plants had only minor damage.



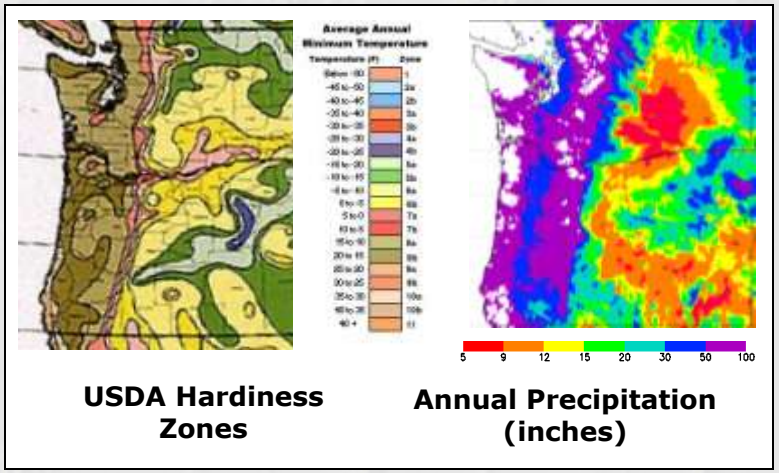
Seed transfer zones

Translating common garden studies to guide movement of seeds



USFS Established Seed Transfer Zones for Two Conifer Species

Taken from Johnson et al. 2004 *Native Plants Journal*



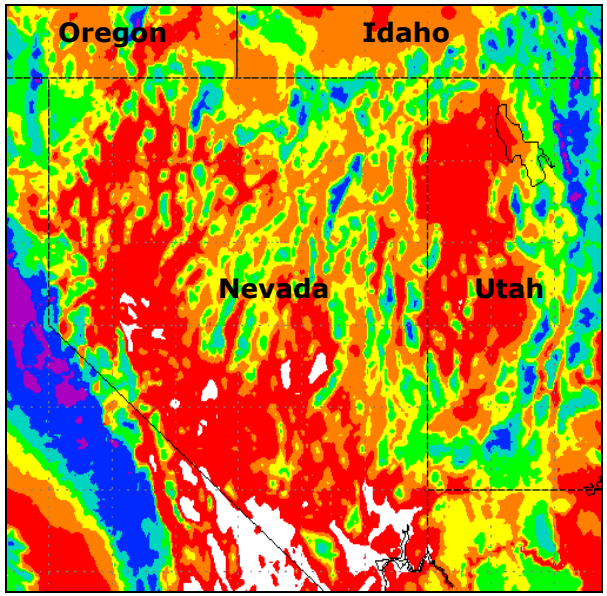
Possible drivers of local adaptation: hardiness zones and annual precipitation

http://www.wrcc.dri.edu/images/pnw.gif

Great Basin Climate

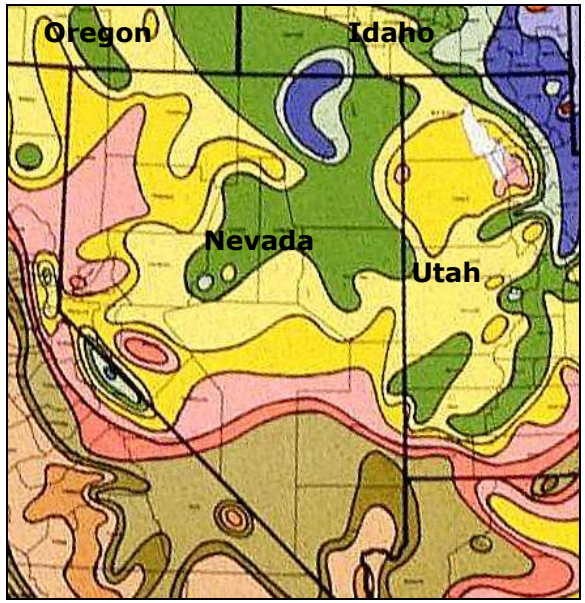
- Climate heterogeneity, many species found throughout the region

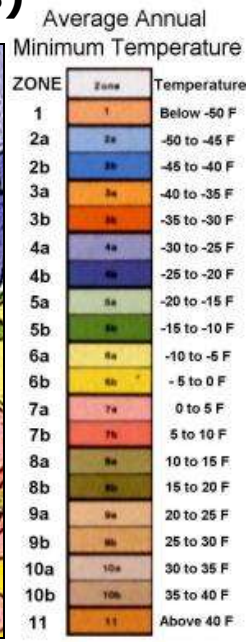
Annual Precipitation in Selected Ranges (inches)



http://www.wrcc.dri.edu/images/gb.gif

Average Minimum Temperature (USDA Hardiness Zones)





http://www.usna.usda.gov/Hardzone/ushzmap.html

Penstemon in the Great Basin

- Largest genus endemic to North America (250+)
- Center of species diversity in Western U.S.
  - Perennial forbs
  - Gravity-dispersed seeds
  - Wide range of insect and bird pollinators

Penstemon deustus var. pedicellatus

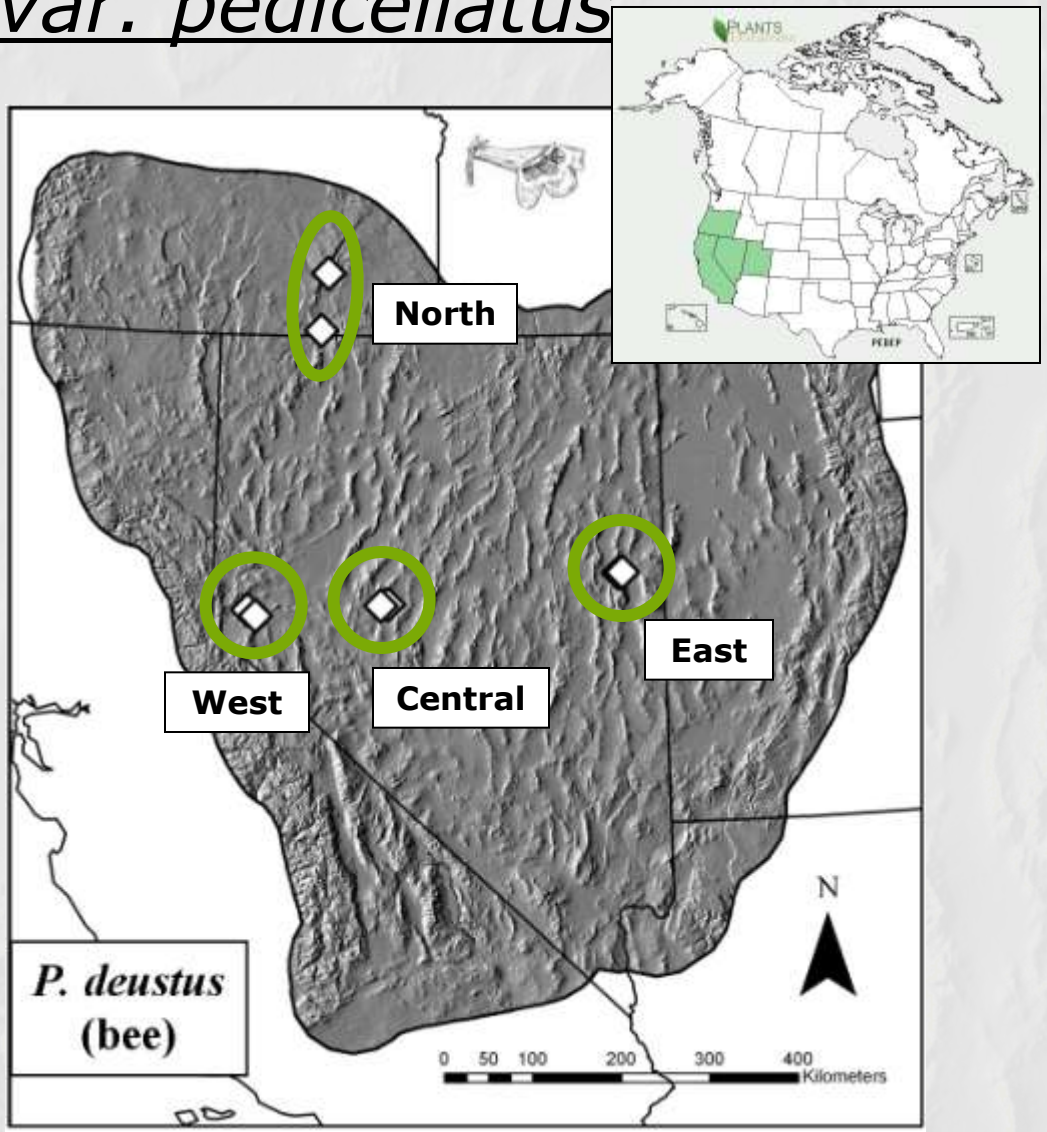
Penstemon pachyphyllus var. congestus

Penstemon rostriflorus

Study species and sites

Penstemon deustus var. pedicellatus

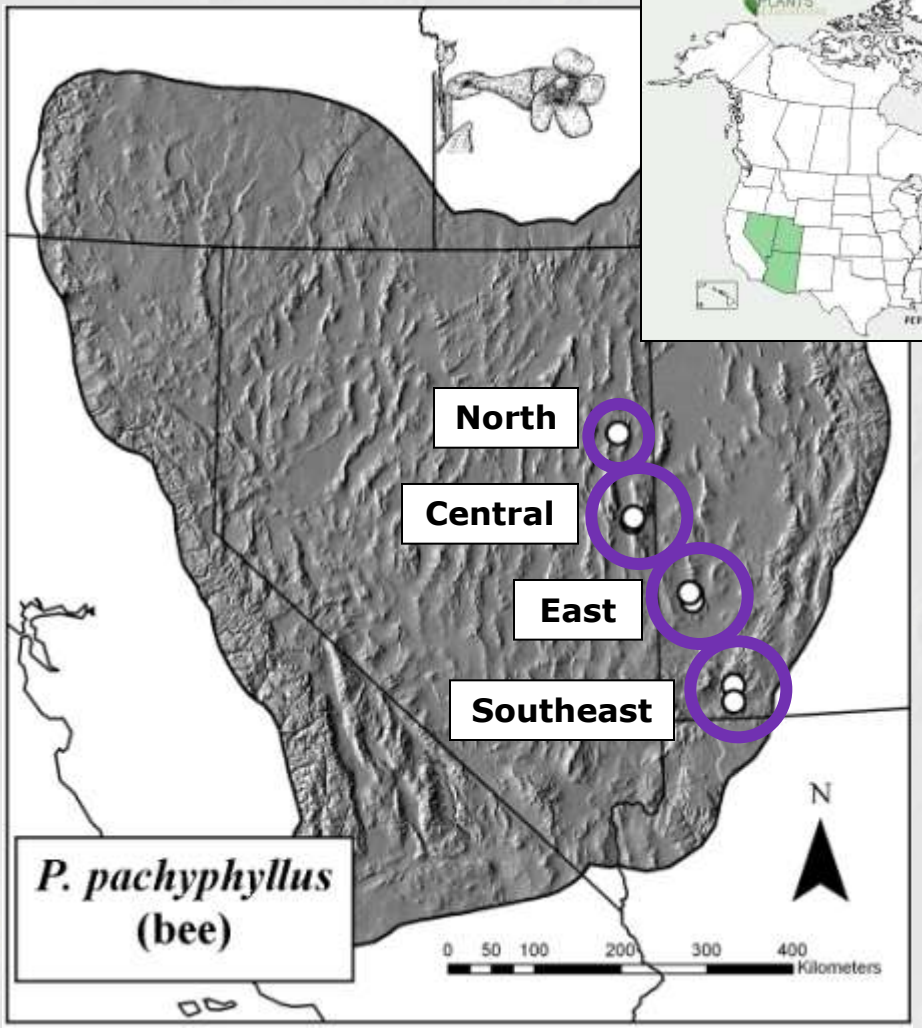
8 populations



Study species and sites

Penstemon pachyphyllus var. congestus

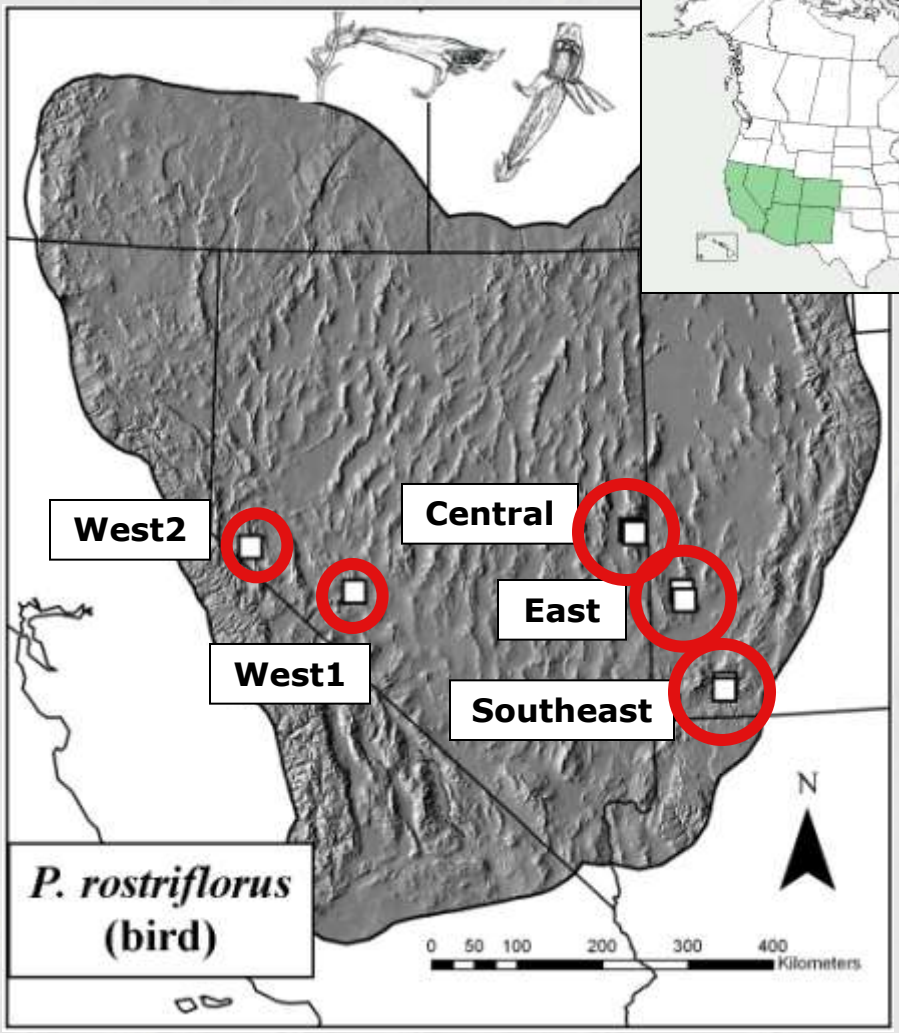
7 populations



Study species and sites

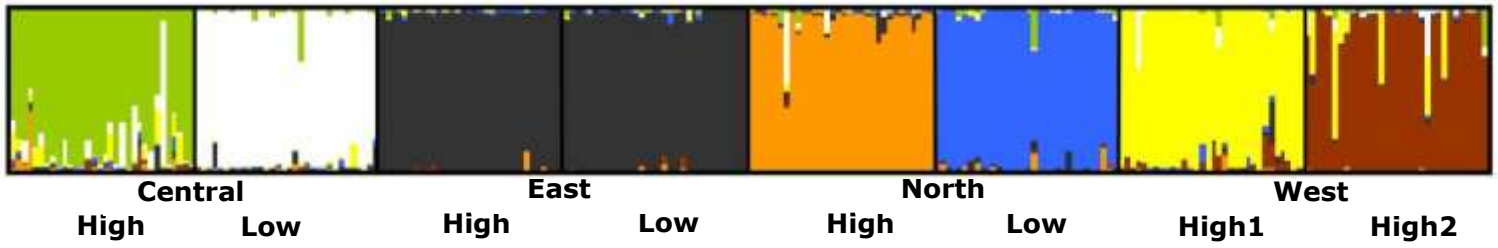
Penstemon rostriflorus

8 populations

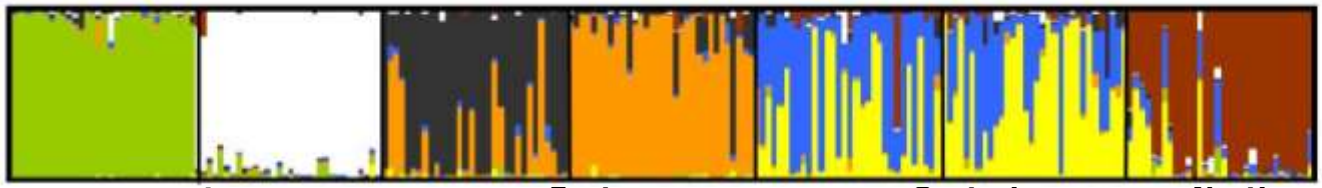


Molecular genetic studies

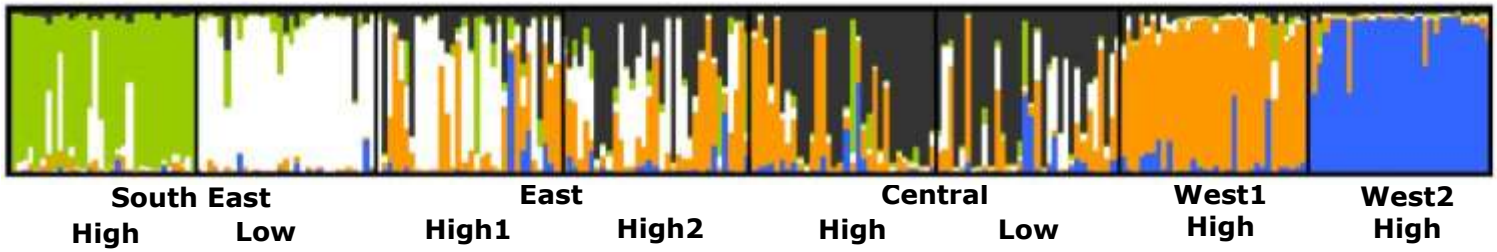
- High genetic diversity in all species (microsatellite markers)
- Different patterns of gene flow by species



P. deustus
K = 7



P. pachyphyllus
K = 7



P. rostriflorus
K = 5

Common garden studies

- Grow plants from many populations in a common environment to identify genetic differences that might be adaptive and important for survival

Common garden studies

- 30 plants per study population, planted in randomized plots and grown for 3 years

Chicago Botanic Garden

Idaho Botanical Garden

Utah Botanical Center

Common garden studies

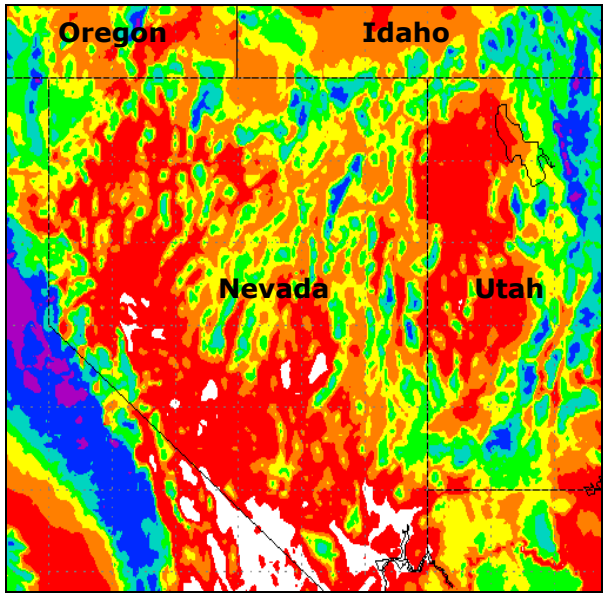
Quantitative traits measured

Growth	Total
	Winter
	Summer
Vegetation structure	Leaf area
	Stem length
	Flower height
	Internode
	Stem diameter
	Dentation
	Peduncle
Flower/Fruit Phenology	% flowers finished
	Number fruit
	Percent flowering
Floral Shape	Corolla length
	Flower opening
	Anther exsertion
Seeds	Days to germination

Common garden studies

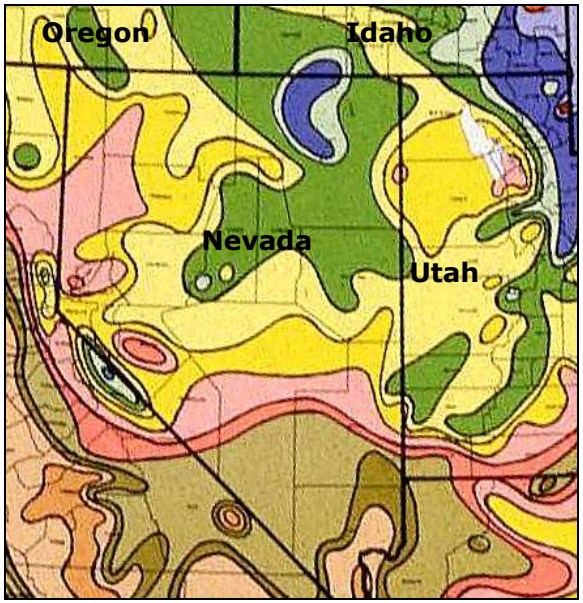
- Climate information gathered

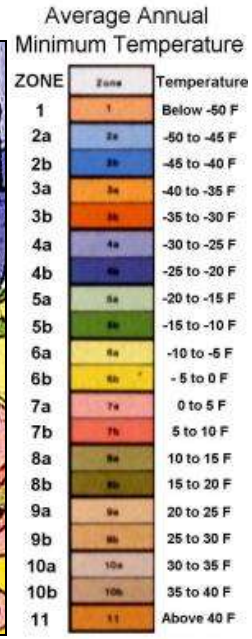
Annual Precipitation in Selected Ranges (inches)



http://www.wrcc.dri.edu/images/gb.gif

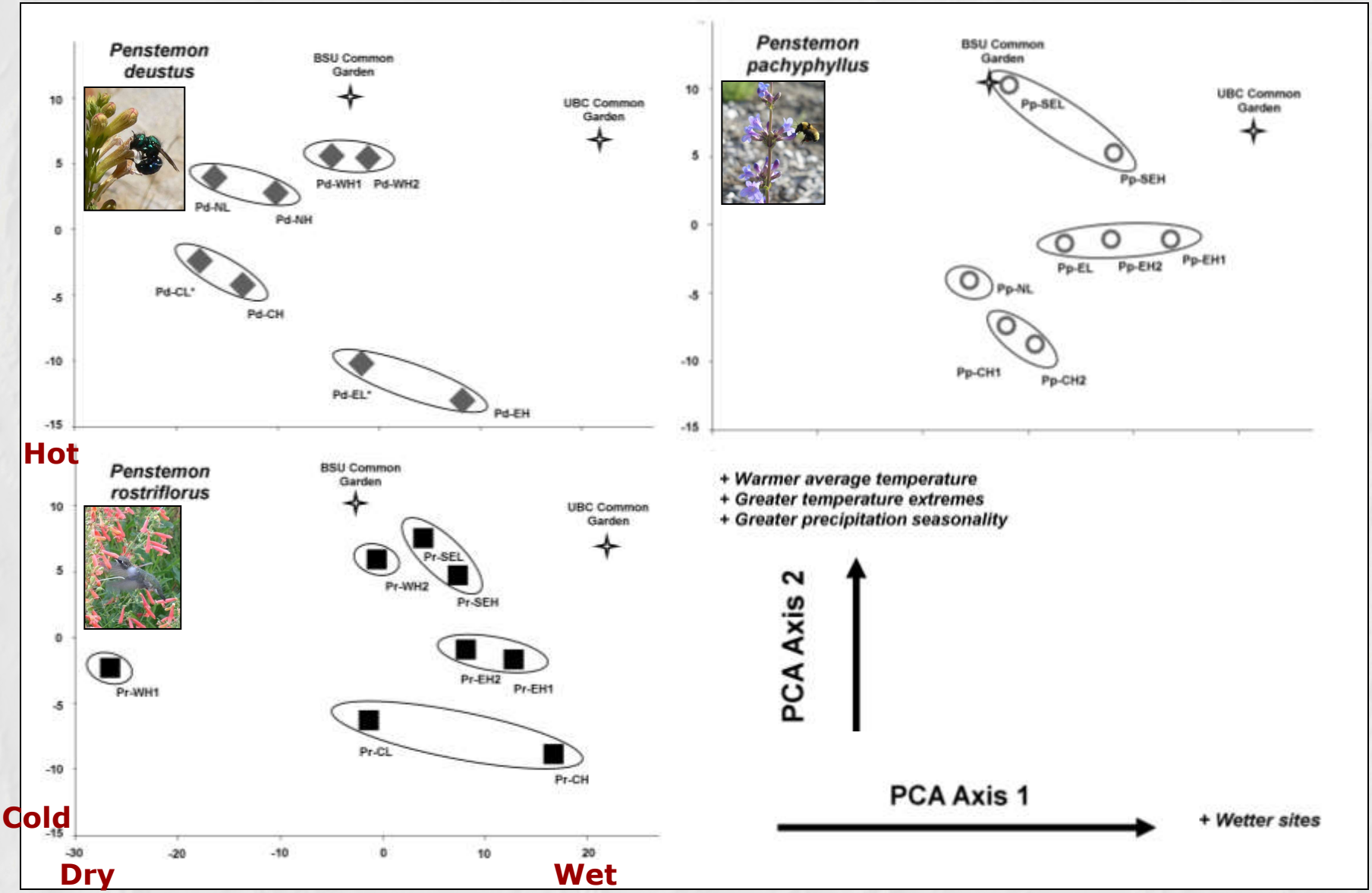
Average annual minimum temperature



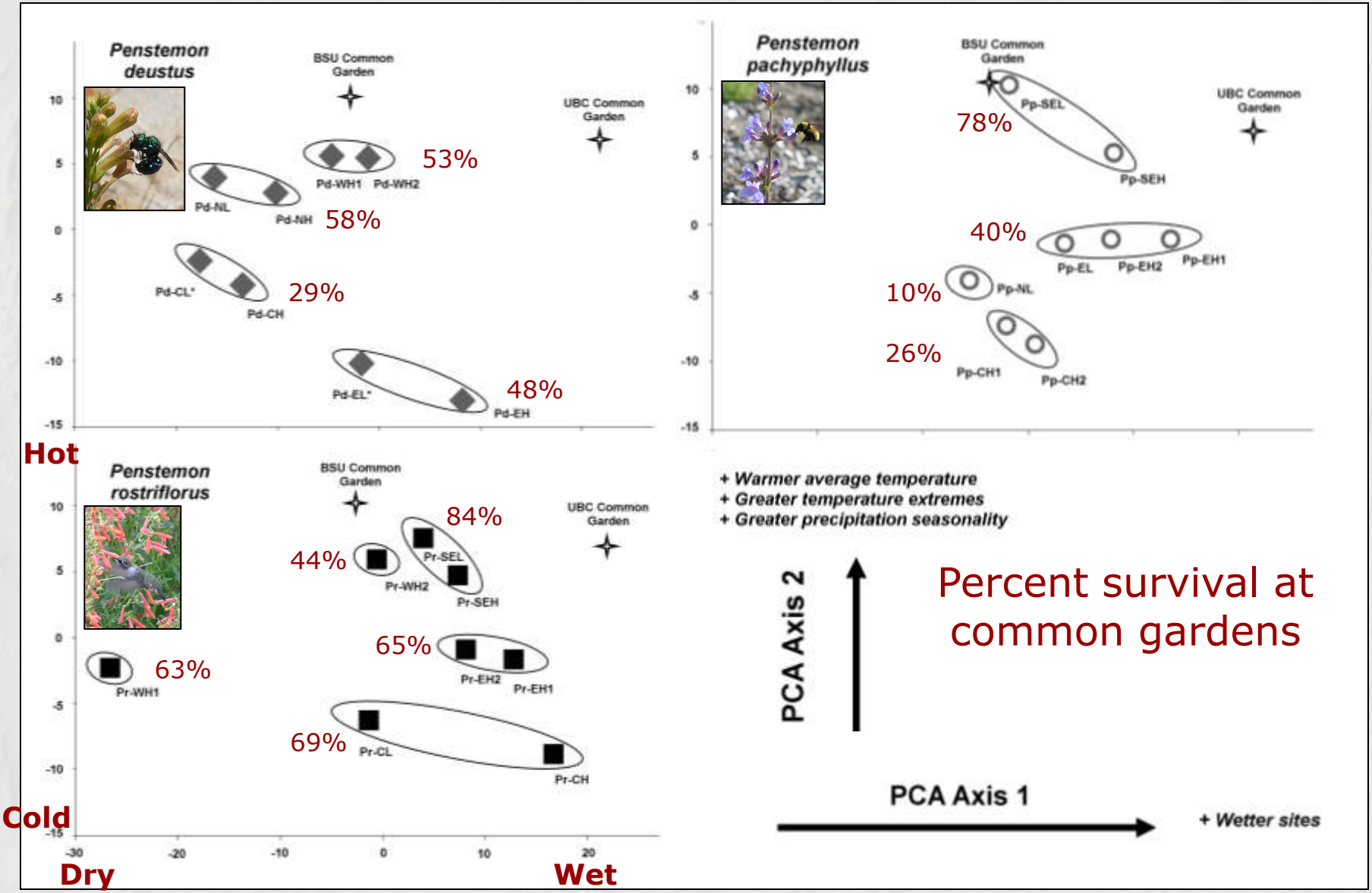


http://www.usna.usda.gov/Hardzone/ushzmap.html

Genetic diversity and local adaptation



Genetic diversity and local adaptation



Common garden studies

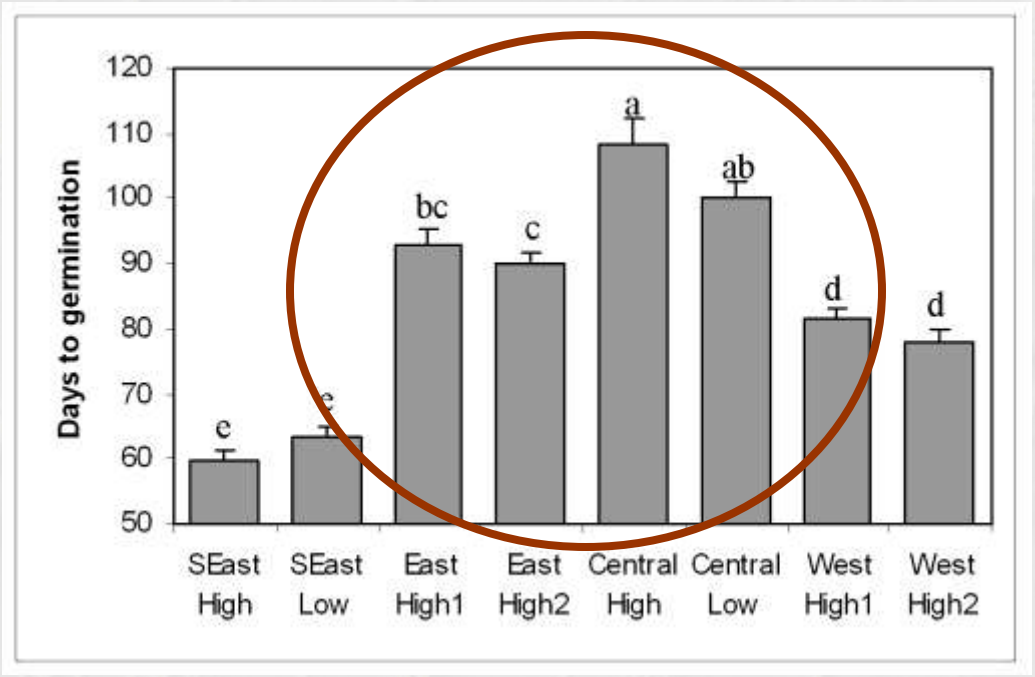
- Significant differences between populations for nearly every test for all three species

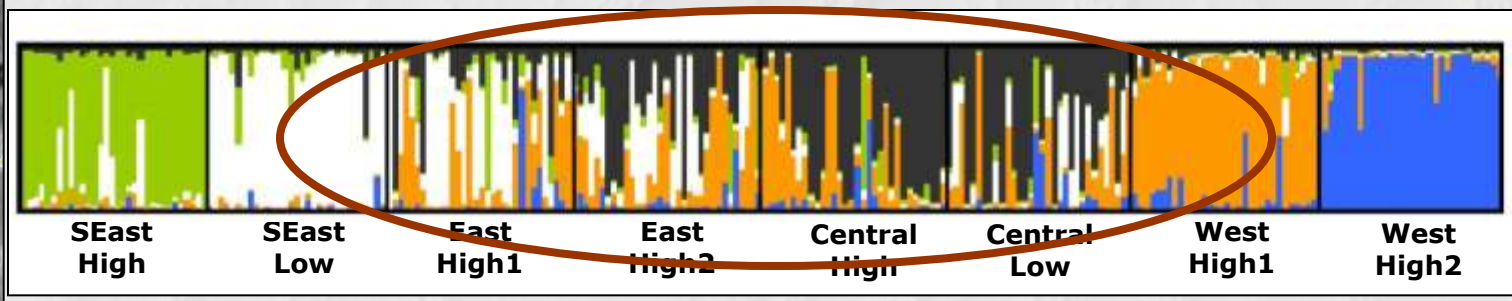
Population	Growth			Vegetation Structure						Flower/fruit phenology		Floral shape			Seeds
	Total	Winter	Summer	Stem length	Leaf area	Flower height	Internode	Stem Dia	Add'l measure[b]	Percent flower	Number fruit	Corolla length	Flower opening	Anther exsertion	Days to germ.
Penstemon deustus															
Pd-CH	10.2 bc		0.22 c	23.2 bc	1.3 bc		1.6 abc		2.9 c	9.6 ab	36.4 a	10.3 a	3.75 ab	1.65 bc	90.4 a
Pd-EH	15.2 bc		0.31 c	22.9 bc	1.6 ab		1.5 bc		2.9 c	12.0 a	36.7 a	9.8 b	3.87 a	1.73 ab	87.1 a
Pd-NH	11.1 bc		0.39 bc	20.9 c	1.2 c		1.4 c		3.7 bc	2.7 cd	24.9 b	10.2 a	3.52 b	1.45 cd	92.3 a
Pd-NL	27.7 a		1.39 a	31.4 a	1.7 a		1.9 a		6.2 a	0.3 d	33.8 ab	10.2 ab	3.95 a	1.88 a	62.3 c
Pd-WH1	17.6 b		0.82 ab	25.5 b	1.4 abc		1.7 ab		5.3 ab	4.3 bc	41.9 a	8.7 c	3.60 b	1.46 d	59.9 c
Pd-WH2	9.20 c		0.34 c	20.9 c	1.6 abc		1.5 bc		5.8 a	5.7 abc	37.0 a	9.0 c	3.58 b	1.45 cd	70.2 b
Penstemon pachyphyllus															
Pp-SEH	0.7 ab	0.11 bc			11.2 a	21.9 ab		4.7 b	0.7 c	0.2 c		15.1 b	6.65 c	1.81 bc	70.4 c
Pp-SEL	0.5 b	0.001 c			9.3 a	26.1 a		5.5 ab	0.4 c	0.1 c		14.3 c	6.75 bc	2.36 a	55.1 d
Pp-EH1	0.6 ab	-0.04 bc			2.2 abc	18.7 ab		6.0 ab	0.6 bc	6.3 b		15.2 bc	7.66 a	1.93 abc	79.8 bc
Pp-EH2	0.8 ab	0.42 abc			2.5 a	23.7 ab		6.7 a	0.6 bc	5.4 b		15.0 bc	7.46 ab	2.36 ab	97.9 ab
Pp-CH1	1.0 a	0.47 a			2.1 ab	20.8 ab		5.4 ab	1.3 ab	13.4 ab		16.2 a	7.91 a	1.94 bc	89.6 ab
Pp-CH2	0.6 ab	0.28 abc			1.6 c	17.3 b		5.2 ab	1.6 a	22.7 a		15.9 ab	7.25 abc	1.58 c	85.6 b
Pp-NL	0.6 ab	0.31 ab			1.7 bc	17.8 b		4.9 b	1.2 ab	11.8 ab		15.5 ab	7.51 a	1.98 abc	99.9 a
Penstemon rostriflorus															
Pr-SEH	127.4 a			69.6 ab	2.8 a	39.4 a		3.3 a	41.7 c	11.4 a	22.3 a	18.7 cd	4.07 bc	7.20 d	59.7 e
Pr-SEL	89.3 abc			58.6 cd	2.8 a	28.2 cd		3.1 ab	71.0 ab	6.7 abc	21.1 ab	19.7 b	4.05 c	7.51 cd	63.2 e
Pr-EH1	57.4 c			60.2 bc	1.2 bc	32.5 bc		2.7 c	71.3 ab	5.0 bc	10.4 c	18.7 cd	3.99 cd	7.97 abc	92.8 bc
Pr-EH2	93.0 abc			71.0 ab	1.3 b	33.7 ab		2.6 c	74.4 ab	4.1 c	11.6 c	18.4 d	3.67 d	7.97 abc	89.9 c
Pr-CH	65.3 bc			49.2 d	1.3 b	27.0 d		2.6 c	82.7 a	4.1 bc	10.8c	19.3 bc	4.23 abc	7.81 bcd	108.2 a
Pr-CL[a]	-			-	-	-		-	-	-	-	-	-	-	100.0 ab
Pr-WH1	103.2 ab			74.4 a	1.3 b	38.5 a		2.9 bc	54.3 bc	8.1 abc	10.0 bc	19.1 bcd	4.44 a	8.64 a	81.6 d
Pr-WH2	77.5 bc			66.4 abc	1.0 c	34.3 ab		2.6 c	26.0 d	9.1 ab	7.1 c	20.8 a	4.42 ab	8.35 ab	78.1 d

ANOVA ($p < 0.001$) and Tukey-Kramer HSD tests ($p < 0.01$)

Common garden studies

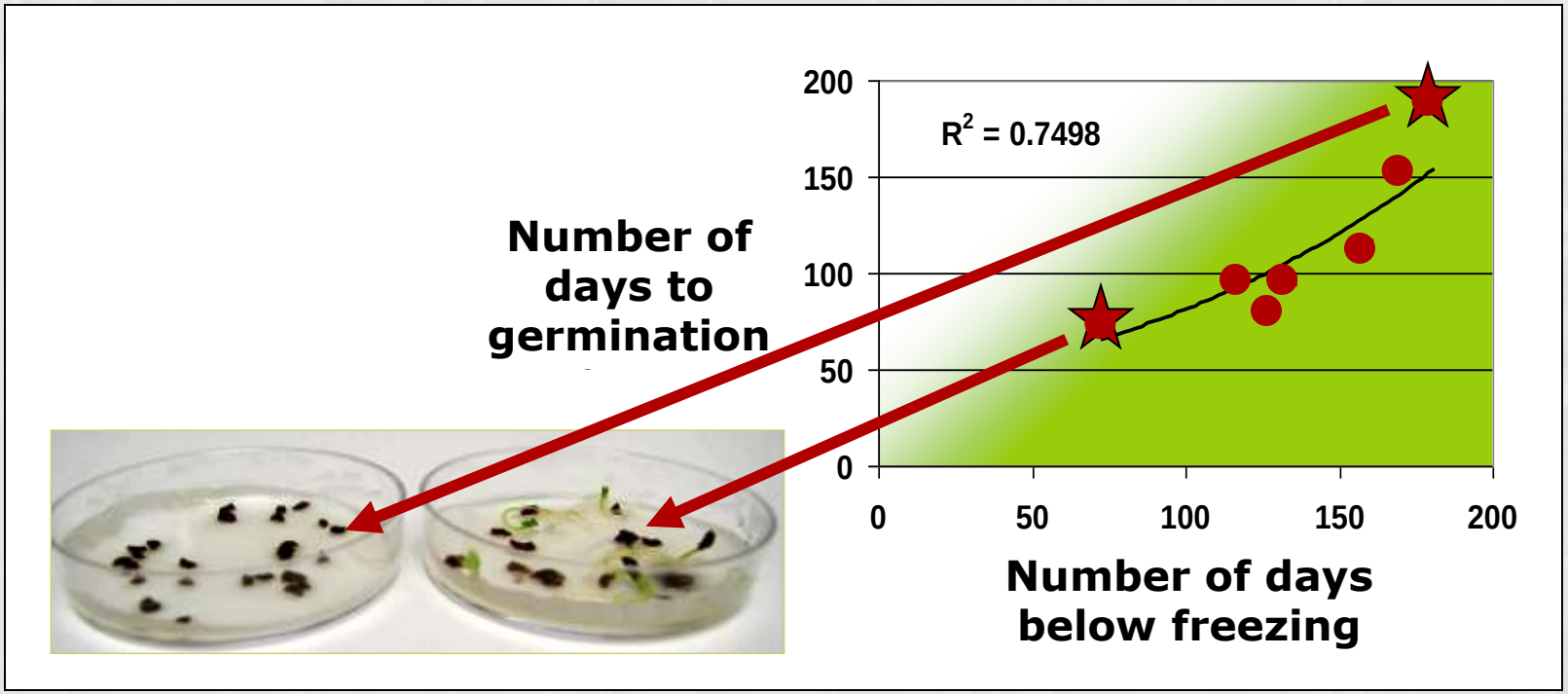
- Seed germination in *P. rostriflorus*





Common garden studies

- Seeds from sites with short winters germinate *faster* than seeds from sites with long winters



- Adaptation to climatic conditions?

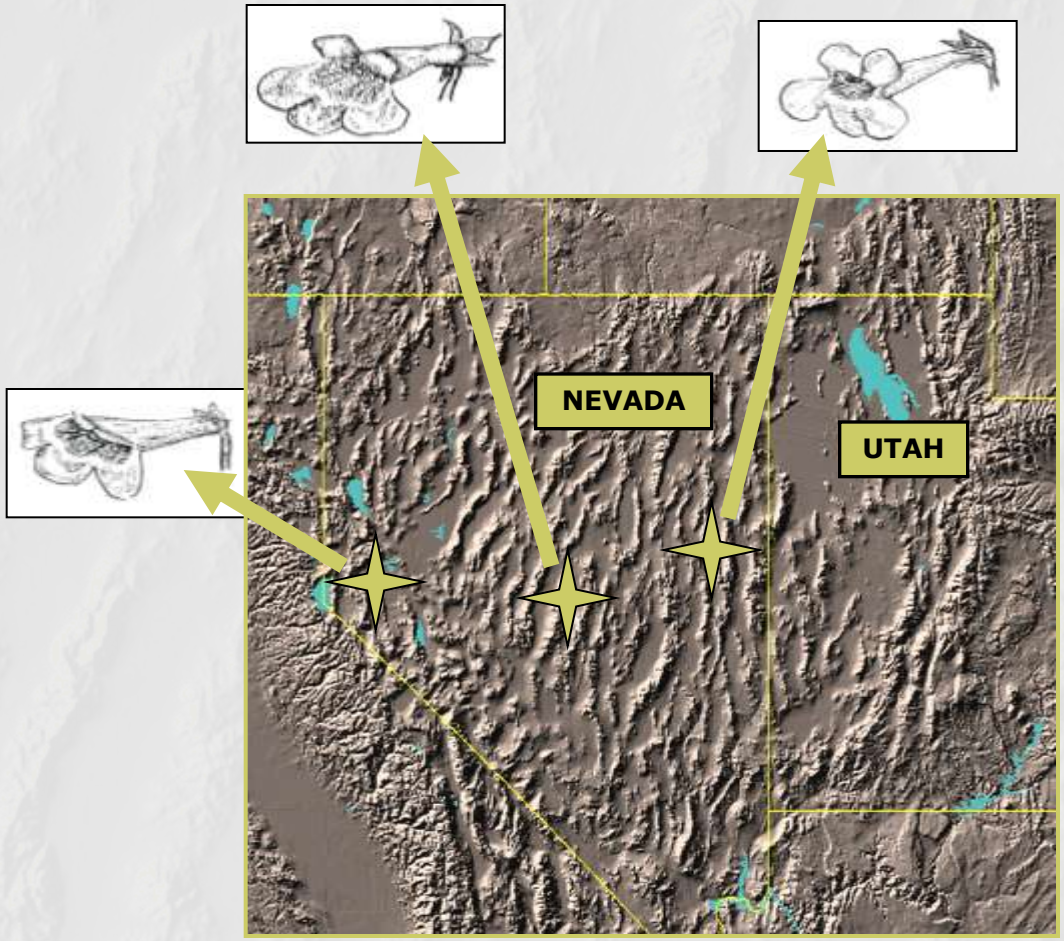
Genetic diversity and local adaptation

Significant genetic diversity by population

	Growth			Vegetation Structure						Flower/fruit phenology		Floral shape			Seeds
Population	Total	Winter	Summer	Stem length	Leaf area	Flower height	Internode	Stem Dia	Add'l measure[b]	Percent flower	Number fruit	Corolla length	Flower opening	Anther exsertion	Days to germ.
Penstemon deustus															
Pd-CH	10.2 bc		0.22 c	23.2 bc	1.3 bc		1.6 abc		2.9 c	9.6 ab	36.4 a	10.3 a	3.75 ab	1.65 bc	90.4 a
Pd-EH	15.2 bc		0.31 c	22.9 bc	1.6 ab		1.5 bc		2.9 c	12.0 a	36.7 a	9.8 b	3.87 a	1.73 ab	87.1 a
Pd-NH	11.1 bc		0.39 bc	20.9 c	1.2 c		1.4 c		3.7 bc	2.7 cd	24.9 b	10.2 a	3.52 b	1.45 cd	92.3 a
Pd-NL	27.7 a		1.39 a	31.4 a	1.7 a		1.9 a		6.2 a	0.3 d	33.8 ab	10.2 ab	3.95 a	1.88 a	62.3 c
Pd-WH1	17.6 b		0.82 ab	25.5 b	1.4 abc		1.7 ab		5.3 ab	4.3 bc	41.9 a	8.7 c	3.60 b	1.46 d	59.9 c
Pd-WH2	9.20 c		0.34 c	20.9 c	1.6 abc		1.5 bc		5.8 a	5.7 abc	37.0 a	9.0 c	3.58 b	1.45 cd	70.2 b
Penstemon pachyphyllus															
Pp-SEH	0.7 ab	0.11 bc			11.2 a	21.9 ab		4.7 b	0.7 c	0.2 c		15.1 b	6.65 c	1.81 bc	70.4 c
Pp-SEL	0.5 b	0.001 c			9.3 a	26.1 a		5.5 ab	0.4 c	0.1 c		14.3 c	6.75 bc	2.36 a	55.1 d
Pp-EH1	0.6 ab	-0.04 bc			2.2 abc	18.7 ab		6.0 ab	0.6 bc	6.3 b		15.2 bc	7.66 a	1.93 abc	79.8 bc
Pp-EH2	0.8 ab	0.42 abc			2.5 a	23.7 ab		6.7 a	0.6 bc	5.4 b		15.0 bc	7.46 ab	2.36 ab	97.9 ab
Pp-CH1	1.0 a	0.47 a			2.1 ab	20.8 ab		5.4 ab	1.3 ab	13.4 ab		16.2 a	7.91 a	1.94 bc	89.6 ab
Pp-CH2	0.6 ab	0.28 abc			1.6 c	17.3 b		5.2 ab	1.6 a	22.7 a		15.9 ab	7.25 abc	1.58 c	85.6 b
Pp-NL	0.6 ab	0.31 ab			1.7 bc	17.8 b		4.9 b	1.2 ab	11.8 ab		15.5 ab	7.51 a	1.98 abc	99.9 a
Penstemon rostriflorus															
Pr-SEH	127.4 a			69.6 ab	2.8 a	39.4 a		3.3 a	41.7 c	11.4 a	22.3 a	18.7 cd	4.07 bc	7.20 d	59.7 e
Pr-SEL	89.3 abc			58.6 cd	2.8 a	28.2 cd		3.1 ab	71.0 ab	6.7 abc	21.1 ab	19.7 b	4.05 c	7.51 cd	63.2 e
Pr-EH1	57.4 c			60.2 bc	1.2 bc	32.5 bc		2.7 c	71.3 ab	5.0 bc	10.4 c	18.7 cd	3.99 cd	7.97 abc	92.8 bc
Pr-EH2	93.0 abc			71.0 ab	1.3 b	33.7 ab		2.6 c	74.4 ab	4.1 c	11.6 c	18.4 d	3.67 d	7.97 abc	89.9 c
Pr-CH	65.3 bc			49.2 d	1.3 b	27.0 d		2.6 c	82.7 a	4.1 bc	10.8c	19.3 bc	4.23 abc	7.81 bcd	108.2 a
Pr-CL[a]	-			-	-	-		-	-	-	-	-	-	-	100.0 ab
Pr-WH1	103.2 ab			74.4 a	1.3 b	38.5 a		2.9 bc	54.3 bc	8.1 abc	10.0 bc	19.1 bcd	4.44 a	8.64 a	81.6 d
Pr-WH2	77.5 bc			66.4 abc	1.0 c	34.3 ab		2.6 c	26.0 d	9.1 ab	7.1 c	20.8 a	4.42 ab	8.35 ab	78.1 d

Adaptation to biological conditions?

- *Penstemon deustus* flower shape differences



Adaptation to biological conditions?

- **Pollinators matter** when choosing seed sources for restoration

Western Nevada: small flowers and small bee visitors

Central Nevada: medium flowers and medium bee visitors

Eastern Nevada: larger flowers and bumblebee visitors

Findings and implications

- Significant genetic diversity in all species
  - Seed bank *many* populations for current, future restoration potential
  - Seed production & restoration practices should ensure genetic diversity is maintained
  - Matching environment of seed source and restoration site is important for
    - short-term restoration success (seed germination)
    - long-term restoration success
- Very different patterns of gene flow and likely adaptation
  - Seed transfer zones will vary by species: Larger seed transfer zones may work for species pollinated by hummingbirds (approximating natural movement of genes)

Implications for restoration

- Controlled crosses to test implications of population divergence on moving & mixing seeds

5 cross treatments

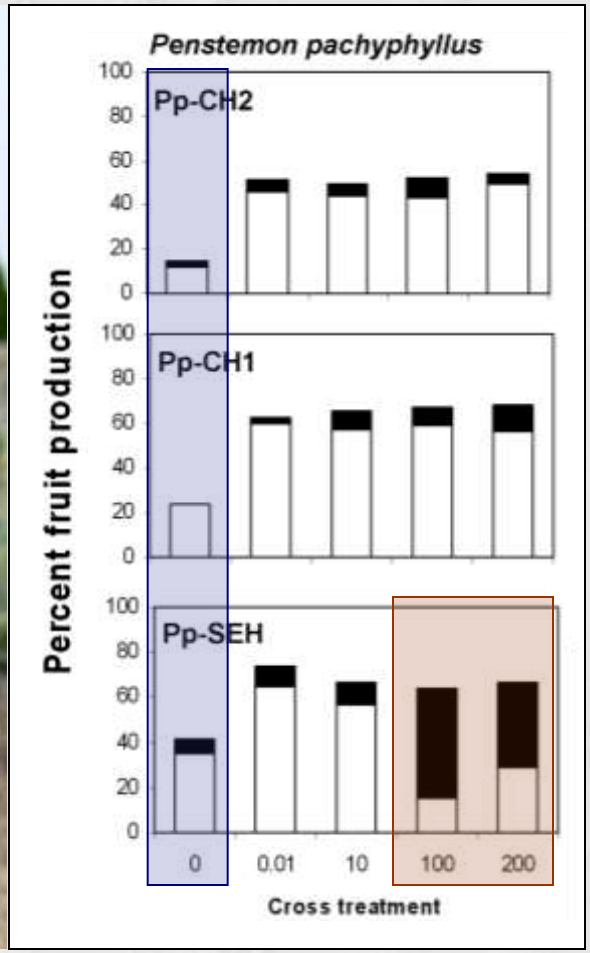
1. Self (0 km)
2. Within population (0.01 km)
3. Within mountain range (10 km)
4. Between mountain ranges (100 km)
5. Distant mountain range (200 km)

- Identification of fitness declines in increasingly distant crosses: inbreeding & outbreeding depression

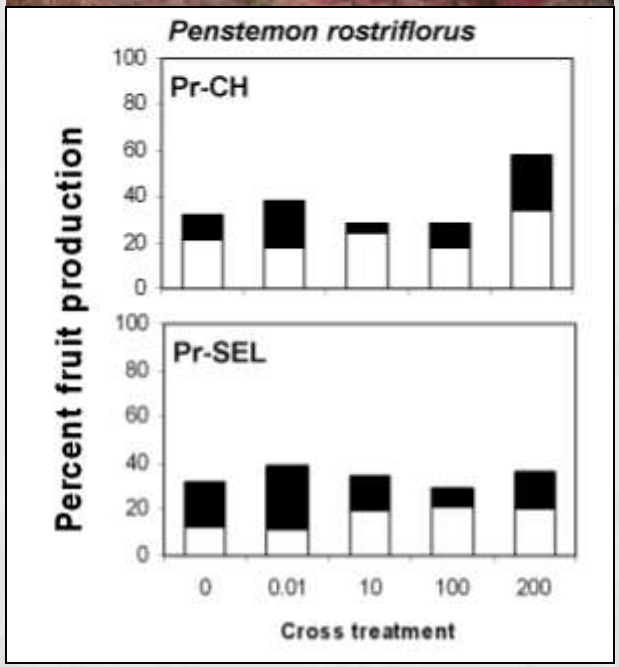
Inbreeding and outbreeding depression

Fruit production as a measure of cross fitness

P. pachyphyllus



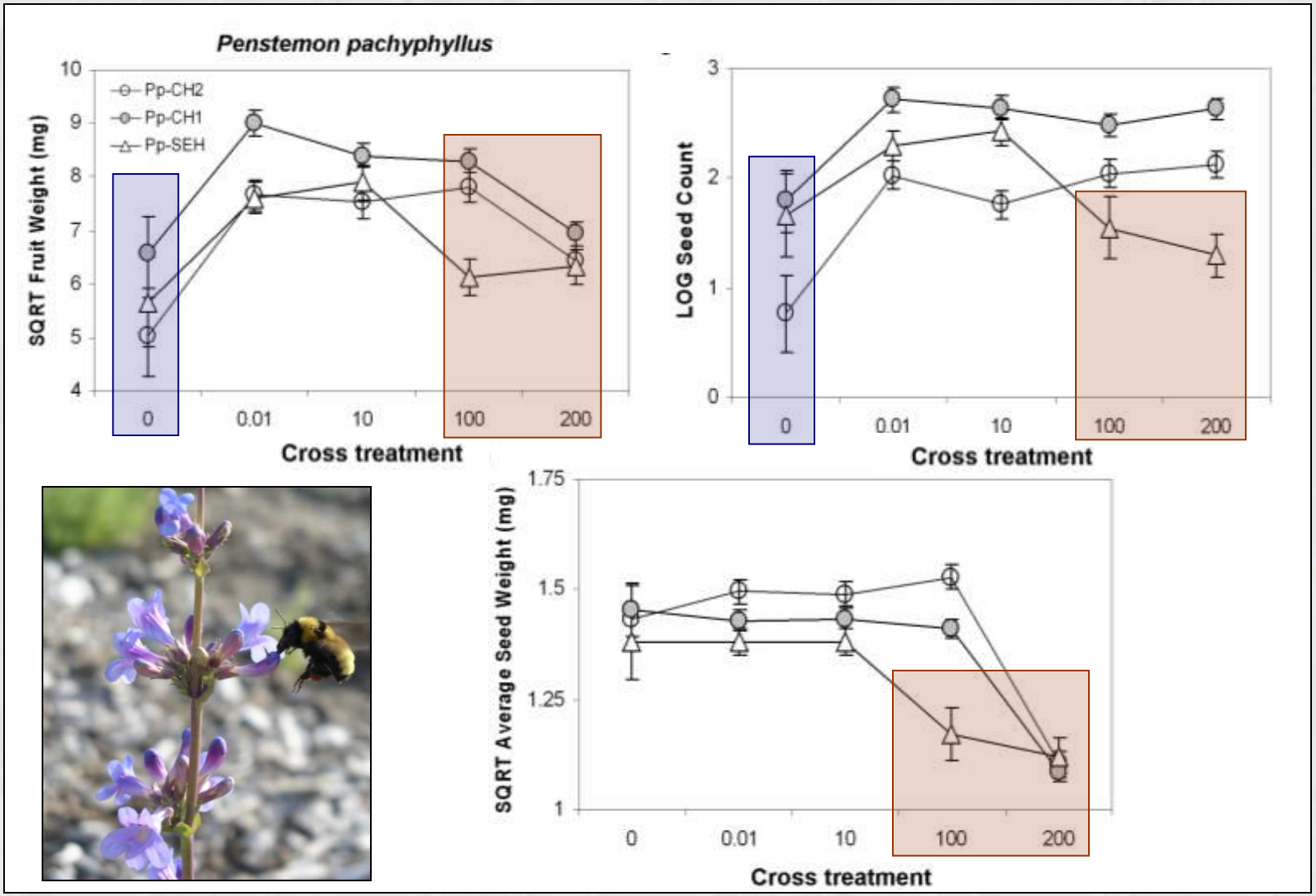
P. rostriflorus



Fruit produced, but contained no seeds

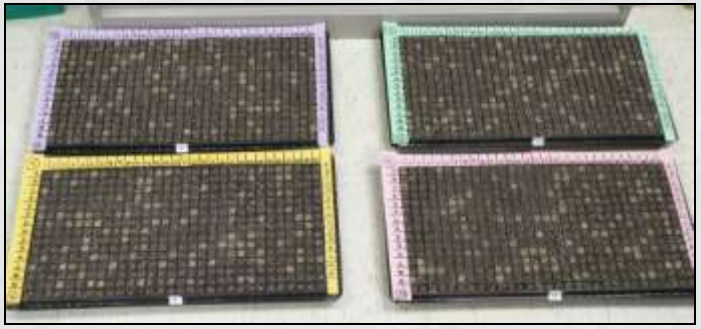
Inbreeding and outbreeding depression

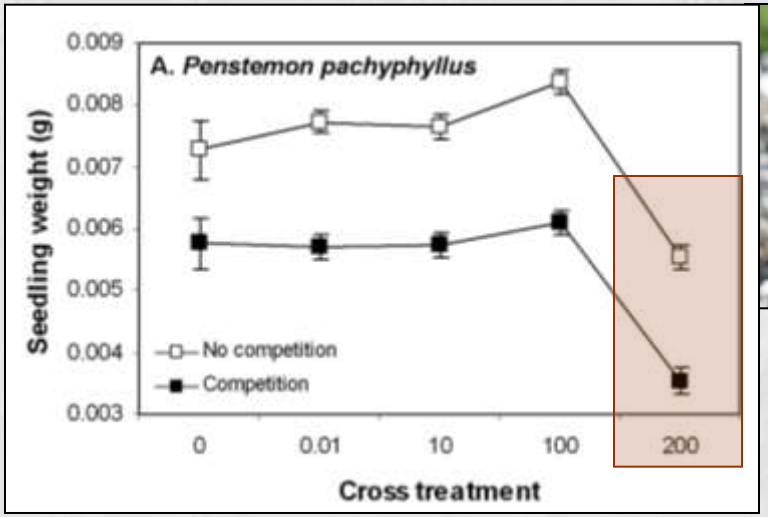
Fruit and seed weight as a measure of fitness

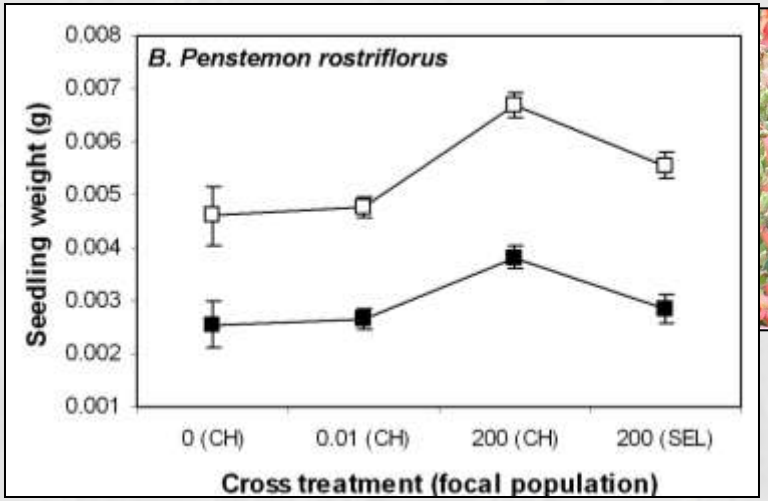


Inbreeding and outbreeding depression

Continued declines in seedling growth with & without cheatgrass





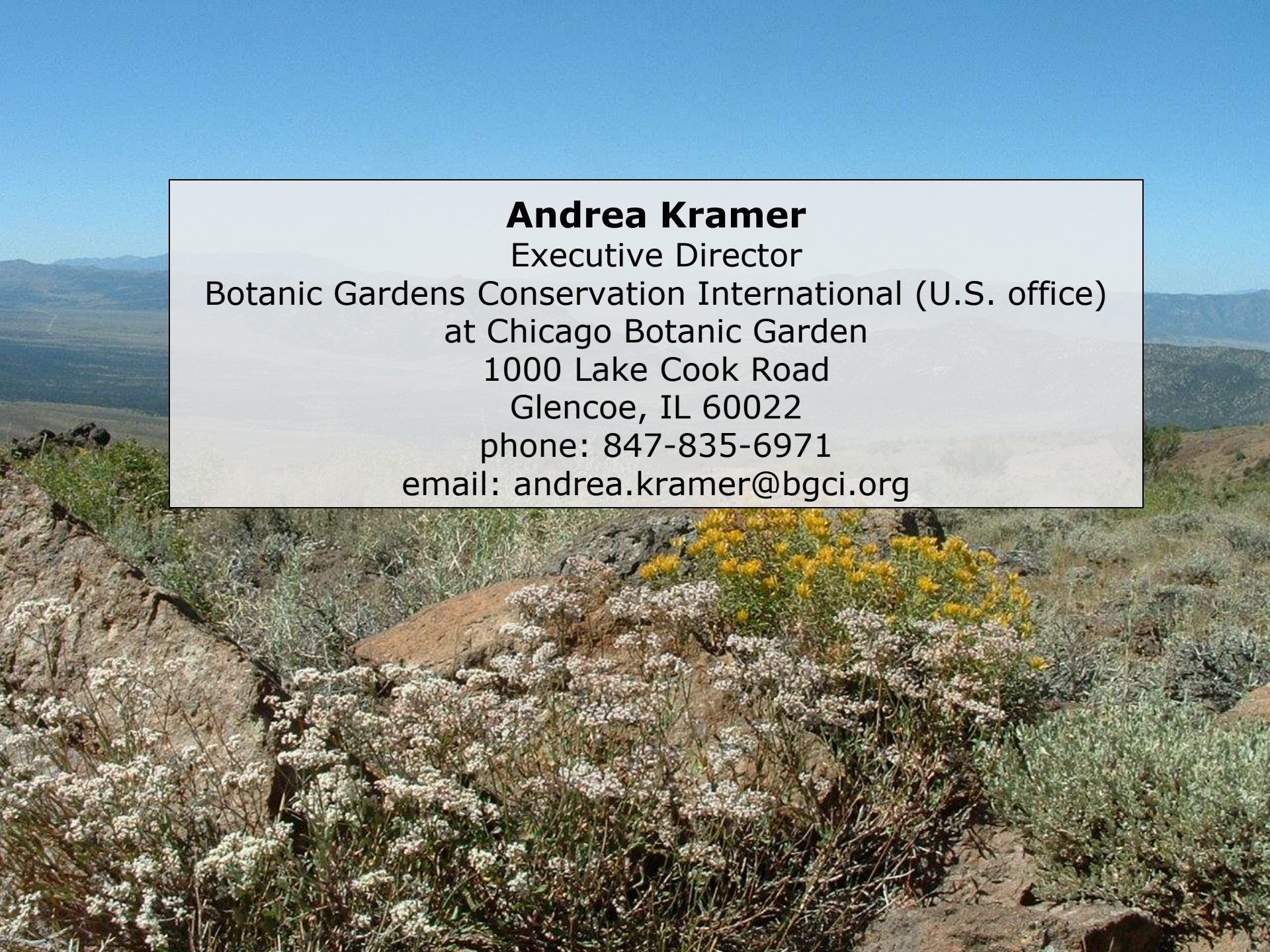


Findings and implications

- Inbreeding depression can significantly lower seed production
  - Avoid narrow genetic diversity in production fields
- Long-distance mixing of genes can significantly decrease population health and regeneration
  - Seed movement may pose less risk to existing populations for hummingbird-pollinated species
  - More research needed
  - Use common gardens as a research opportunity
  - Experimental restoration can inform future practices - make sure long-term monitoring is in place

Acknowledgements

- **Supported by:**
  - Chicago Botanic Garden, Bureau of Land Management, Environmental Protection Agency (STAR fellowship), University of Illinois at Chicago (University fellowship), National Fish and Wildlife Foundation, Center for Invasive Plant Management
- **Thanks to:**
  - Graduate committee members: Mary Ashley, Jeremie Fant, Kay Havens, Hank Howe, Roberta Mason-Gamer
  - Volunteers & students: Brian Kramer, Rebecca Tonietto, Charlie Flower, Oscar Herrera, Jeb Moyer, Bianca Rosenbaum, Marian Hoffher, Krissa Skogen
  - Staff at Chicago Botanic Garden, Utah Botanical Center, Idaho Botanical Garden, Boise State University, Zion and Great Basin National Parks



Andrea Kramer
Executive Director
Botanic Gardens Conservation International (U.S. office)
at Chicago Botanic Garden
1000 Lake Cook Road
Glencoe, IL 60022
phone: 847-835-6971
email: andrea.kramer@bgci.org

Ecological genetics

- The study of genetic variation within and among populations, its relationship with the environment, and its change over time

- Use of multiple tools and techniques to understand how evolutionary processes drive population differentiation
  - Mutation
  - Genetic drift
  - Natural selection
  - Gene flow

Phenotypic plasticity

Comparing differences between common garden sites (Salt Lake City and Boise)

NO PLASTICITY: Flowering time the same regardless of where grown

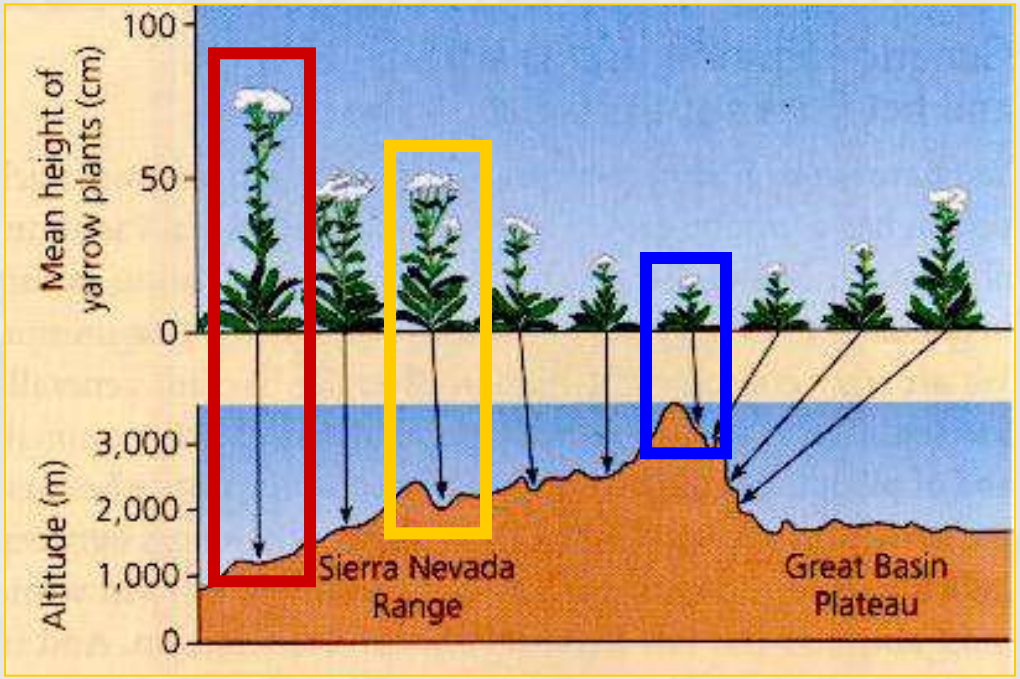
(P. deustus and *P. pachyphyllus)*

LOTS OF PLASTICITY: Flowering time changed significantly depending on where grown

(P. rostriflorus)

Ecological genetics example

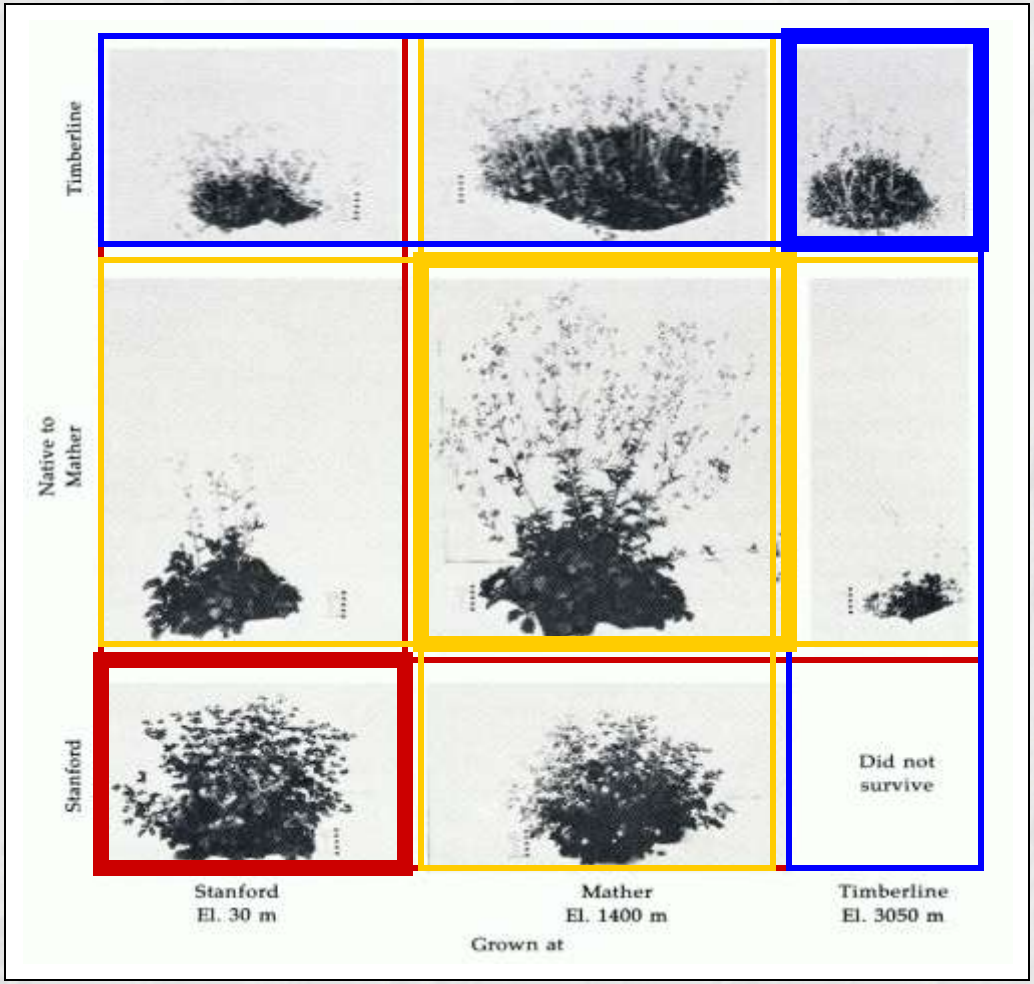
- Ecological genetic research on yarrow plants in the Sierra Nevada mountains
  - Clausen, Keck, and Heisey, 1930's-1950's



Campbell & Reece 2002

Clausen Keck & Heisey

- Key Findings:
  - Differences largely **genetic**
  - Differences due to **local adaptation**
    - local plants outperformed nonlocal plants at each site



Adapted from Figure 3-6 in Terrestrial Plant Ecology (Barbour et al. 1999)