Phenotypic variation in *Lupinus polyphyllus* (Fabaceae)

Emma Bergh[1,2], Claudia Ciotir[1,3], Allison Miller[1,3,4]

[1] Missouri Botanical Garden
[2] Oberlin College
[3] The Land Institute
[4] Saint Louis University

Developing Perennial Agriculture

- Sustainable agriculture system: **perennial polycultures**
  - Mimics a natural system
  - Less soil loss than annual monocultures
  - More efficient at using resources
- Herbaceous perennial grain crops rarely domesticated
- The Land Institute in Salina, KS is working to domesticate such perennial species
- 3 families: Asteraceae, Fabaceae, Poaceae

Images: https://landinstitute.org

De novo domestication

- Breeding crops requires variation in morphological traits
  - Variation must have a genetic basis
  - First step: understand the range of natural phenotypes

- Ongoing work focuses on **legumes**, which are important food sources and also contributors of nitrogen to the soil.

Several legume species of domestic-ation interest

http://www.tropicos.org/projectwebportal.aspx?pagename=Fabaceae&projectid=80

Lupinus (Fabaceae)

- Both perennial and annual species
- Some annuals already domesticated
- Nitrogen-fixing
- However: toxic seeds (can be procesed out)

Lupinus polyphyllus Lindl.

- Perennial, native to western North America, have been introduced elsewhere.
- Variable morphologically
  - Distinctive large leaves with many leaflets
- Efforts to domesticate already underway in Scandinavia and Russia (Kurlovich 2002)
  - Toxicity can be bred out, sweet mutants developed

Lupinus polyphyllus main questions

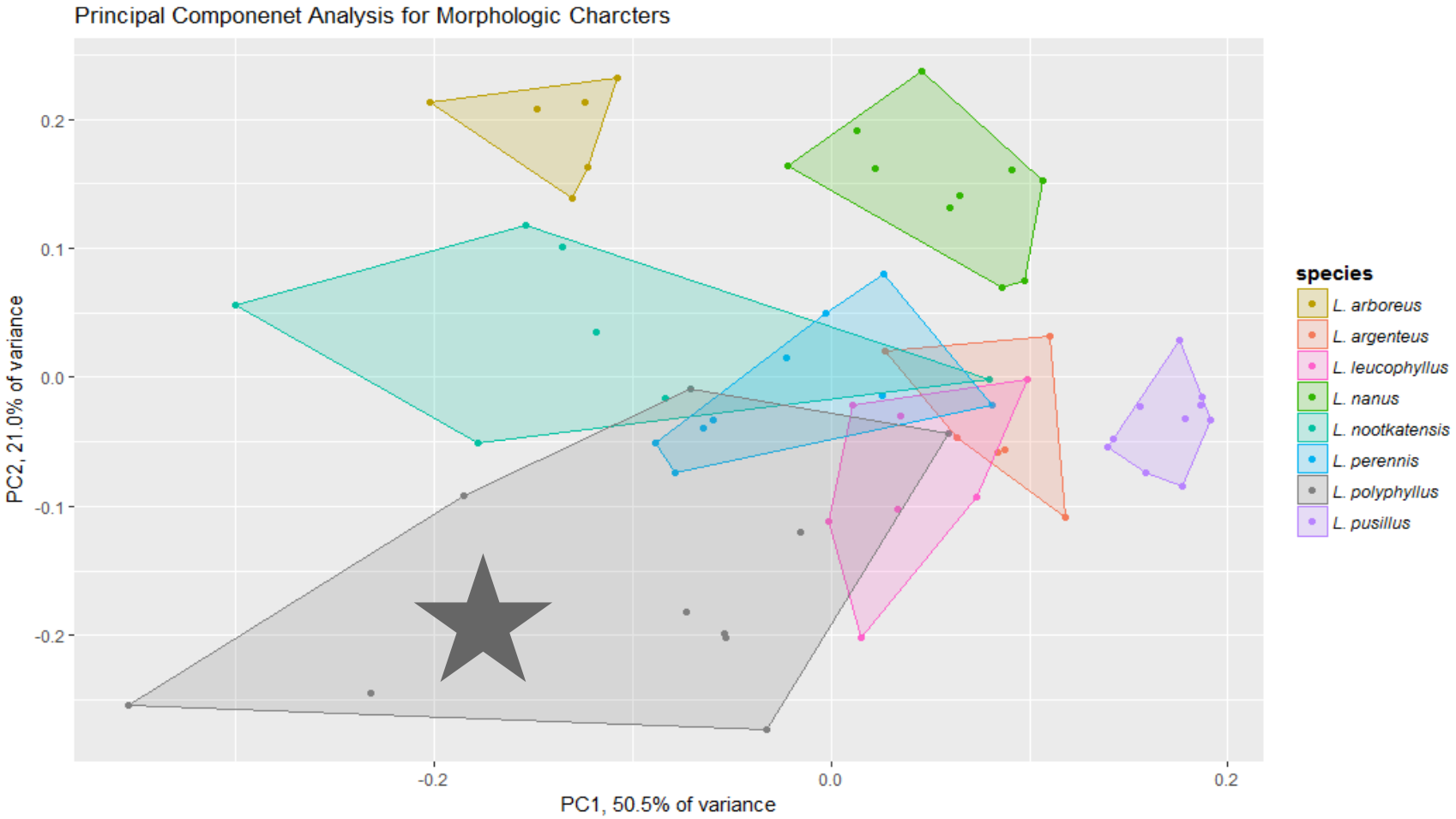
1. What is the extent of morphological variation in *L. polyphyllus*?
2. Does morphological variation differ based on co-occurrence with other *Lupinus*?
3. How does morphological variation correlate with climatic variation?
4. Is there any evidence for trade-offs between reproductive and vegetative traits?

Herbarium data collection

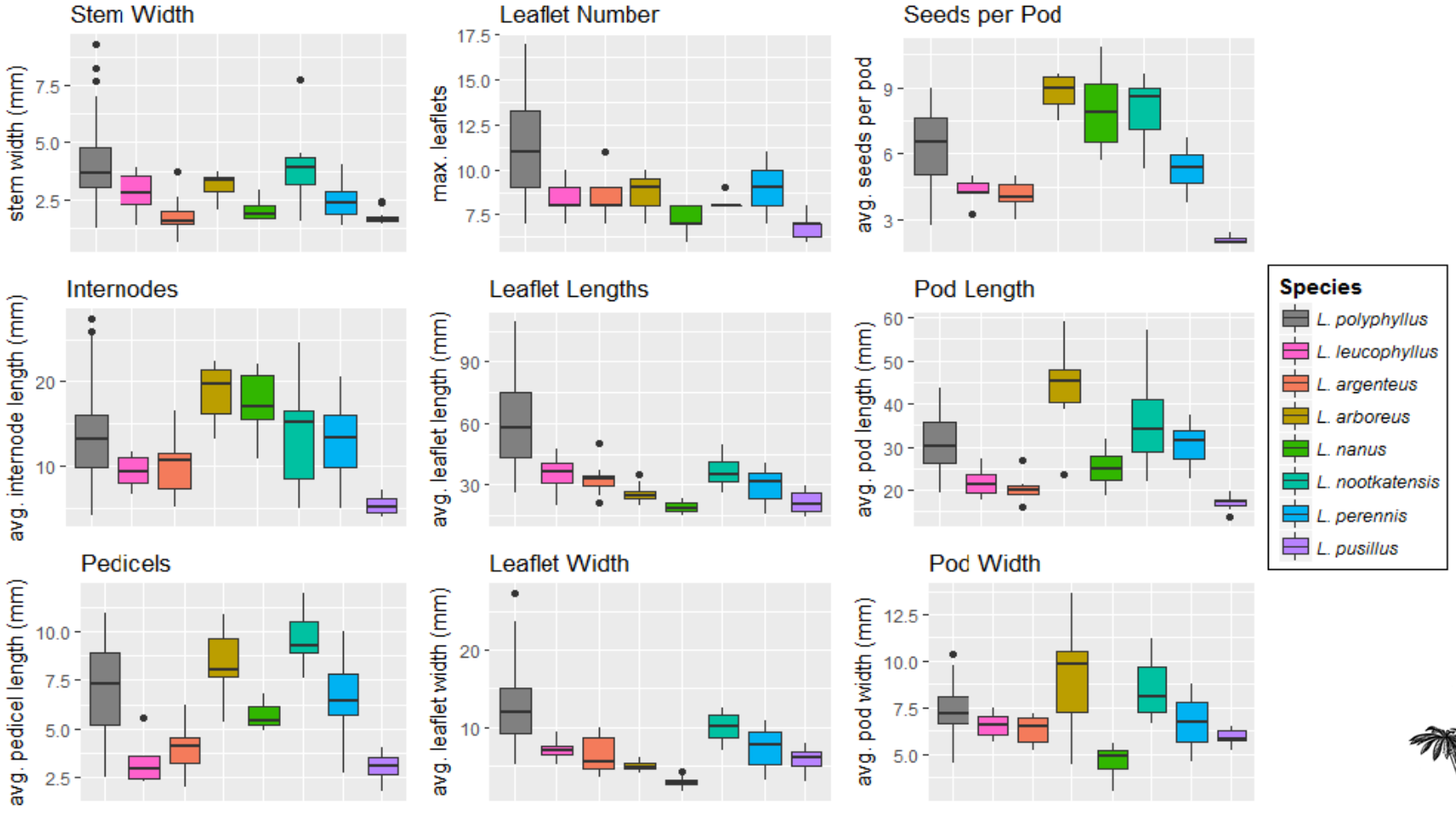
Reproductive traits	Vegetative traits	Specimen information
• Seeds per pod (5) • Pod length / width (5) • Inflorescence length • Internode length (5) • Pedicel length (3)	• Stem width • Leaflets per leaf (5) • Leaflet length / width (5) • Leaflet shape • Leaf pubescence	• MOBOT Accession number • Date collected • Location collected • Elevation • Most updated label classification

Examiend at *L. polyphyllus* (77 specimens total) plus several other *Lupinus* species (9-20 specimens each).

1. What is the extent of morphological variation in *L. polyphyllus*?



1. What is the extent of morphological variation in *L. polyphyllus*?



Lupinus polyphyllus main questions

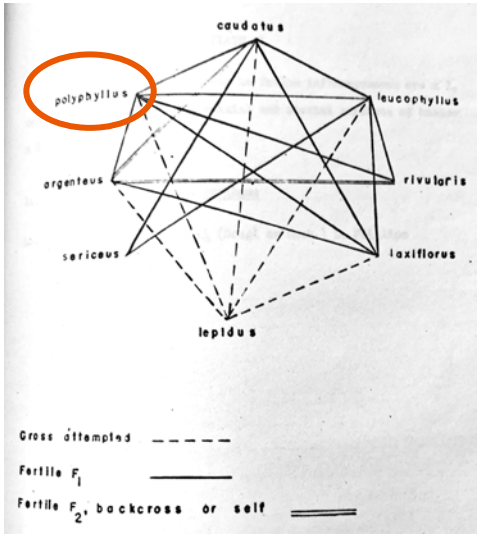
1. What is the extent of morphological variation in *L. polyphyllus*?
2. **Does morphological variation differ based on co-occurrence with other *Lupinus*?**
3. How does morphological variation correlate with climatic variation?
4. Is there any evidence for trade-offs between reproductive and vegetative traits?

Hypothesis: In areas of sympatry, vegetative and reproductive traits will be intermediate to both parental phenotypes whereas in allopatric areas, traits will be distinct.

2. Does morphological variation differ based on co-occurrence with other *Lupinus*?

Possible explanations:

- Hybridization
- Convergent evolution
- Phenotypic plasticity



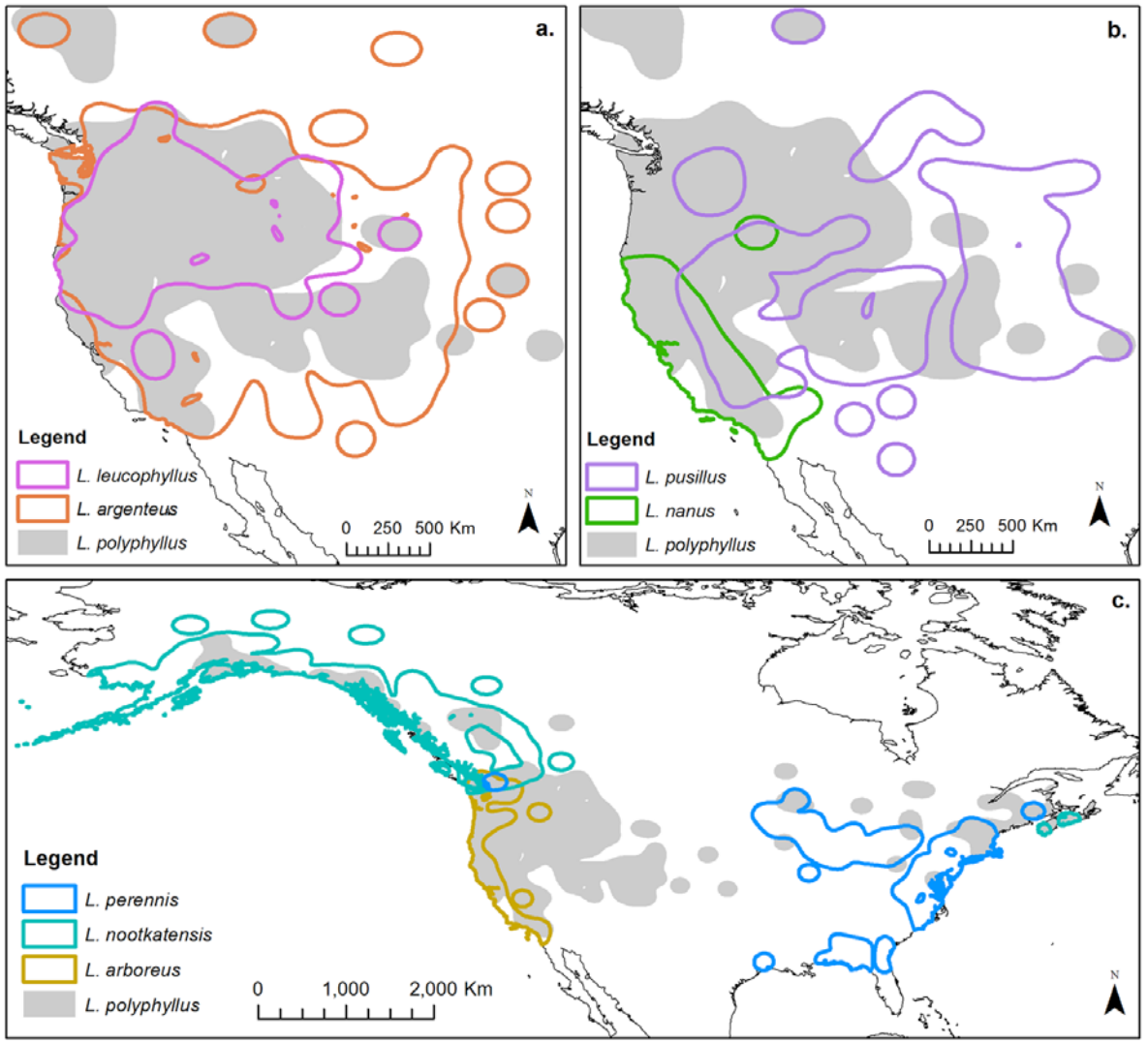
Phillips 1954: attempted crosses as part of a genus revision

Ornamental Russell lupin, developed in 1920s, thought to be a cross between *L. polyphyllus*, *L. arboreus* and *L. nootkatensis*.

2. Does morphological variation differ based on co-occurrence with other *Lupinus*?

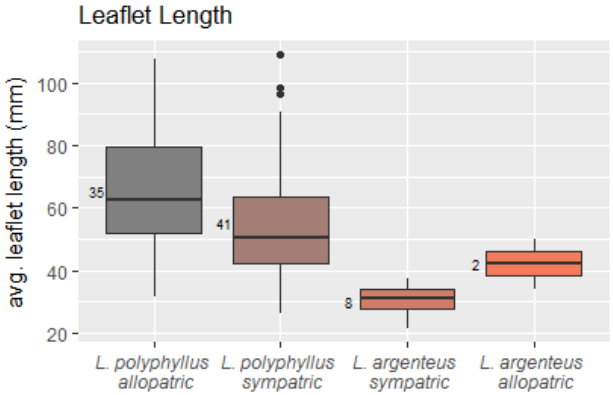
There are 100+ species of North American *Lupinus*

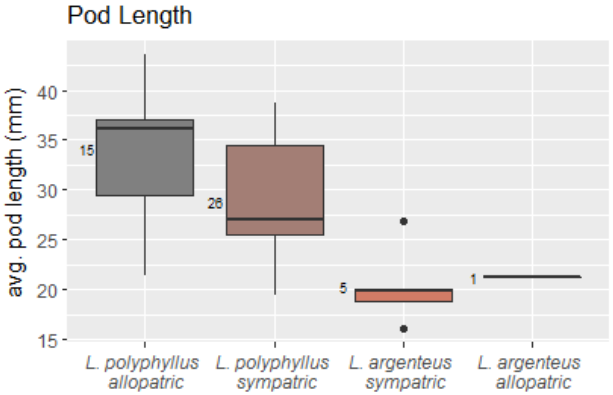
- Criteria for selection:
  - Co-occurring with *L. polyphyllus*
  - Previous record of interspecific hybridization with *L. polyphyllus*
- Taxa selected:
  - Perennial taxa (5)
  - Annual taxa (2)
  - Phylogenetic distances range from ~1.0 mya to ~9.0 mya (Drummond et al. 2012)

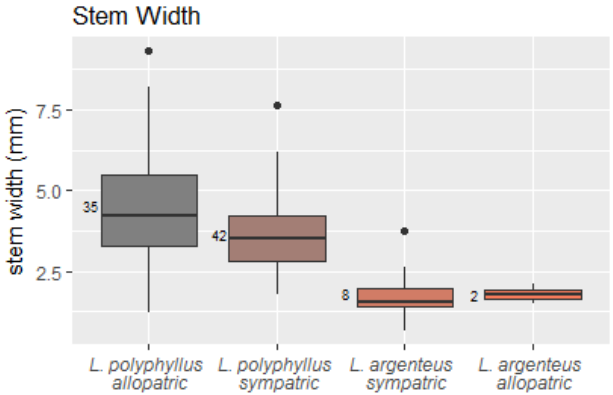


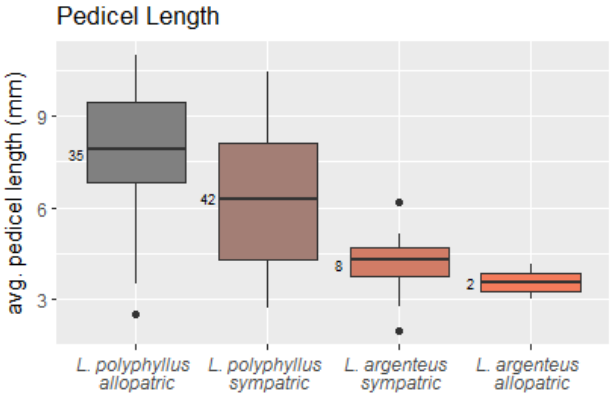
Some traits of *L. polyphyllus* appear intermediate in areas of sympatry with *L. argenteus*

- Could be due to hybridization, convergent evolution or phenotypic plasticity.
- Need genetic data to know more.
- Elevation possibly skewing results. *L. arboreus* only lives at high elevations.



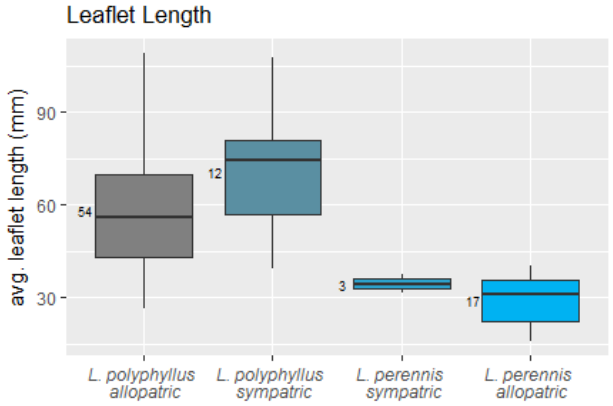


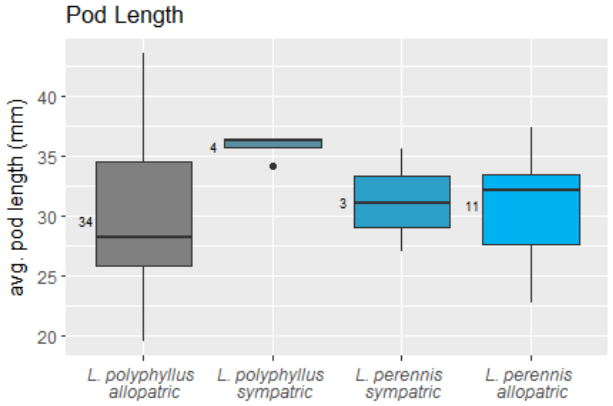


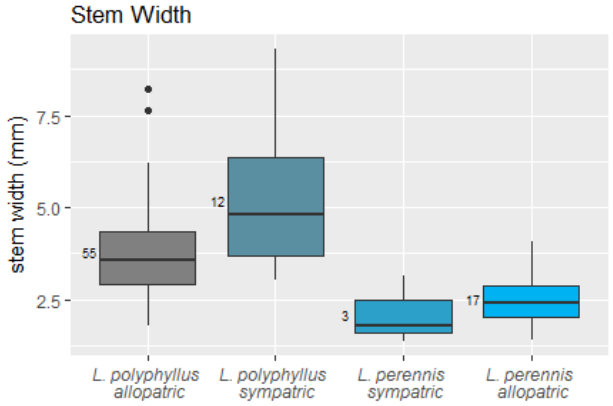


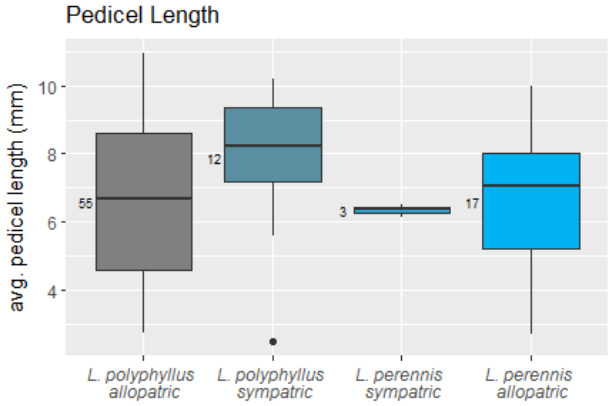
Some traits of *L. polyphyllus* appear divergent in areas of sympatry with *L. perennis*

- Could be due to **character displacement**
- All these traits display an increase in values, so could be due to better growth in invasive regions.









Results:	Life history (Drummond et al. 2012)	Aprx. date divergence from *L. polyphyllus* (Drummond et al. 2012)	*Lupinus polyphyllus* is more similar to taxon in sympatry	*Lupinus polyphyllus* is less similar to taxon in sympatry
L. arboreus	perennial	~ 2.5 mya	X	X
L. argenteus	perennial	~ 1.4 mya	X	
L. leucophyllus	perennial	~ 1.0 mya		
L. nanus	annual	~ 3.9 mya		X
L. nootkatensis	perennial	~ 4.2 mya	X	
L. perennis	perennial	~ 4.2 mya		X
L. pusillus	annual	~ 9.0 mya	X	X

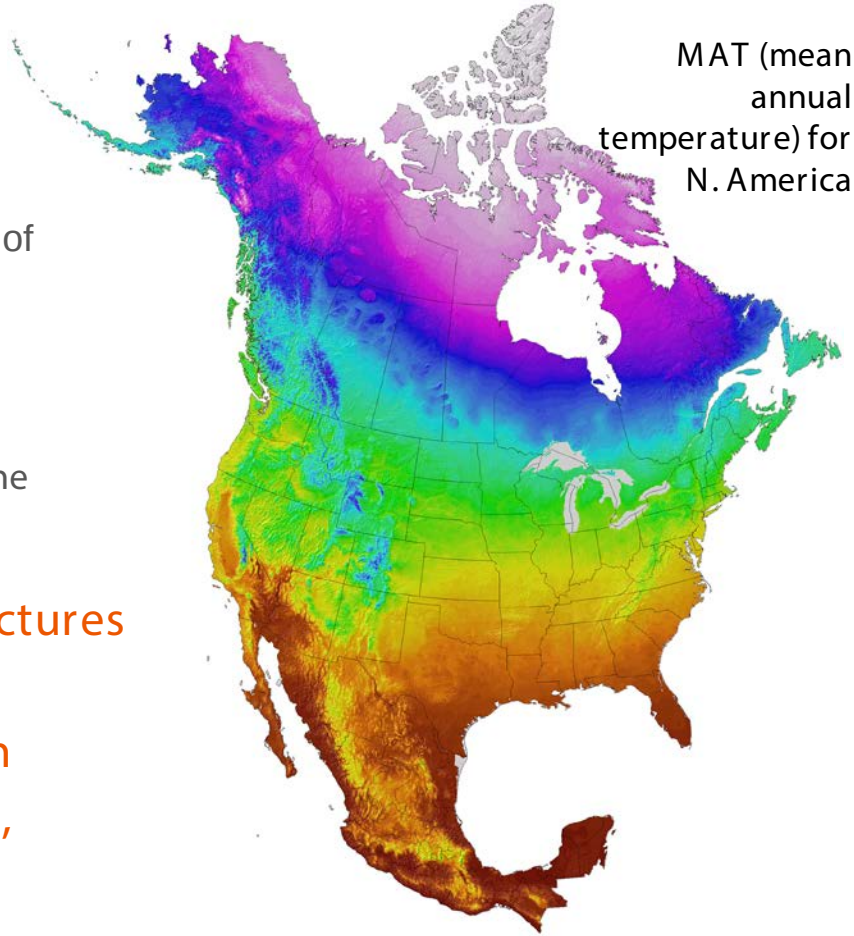
Lupinus polyphyllus main questions

1. What is the extent of morphological variation in *L. polyphyllus*?
2. Does morphological variation differ based on co-occurrence with other *Lupinus*?
3. **How does morphological variation correlate with climatic variation?**
4. Is there any evidence for trade-offs between reproductive and vegetative traits?

Climate and morphology

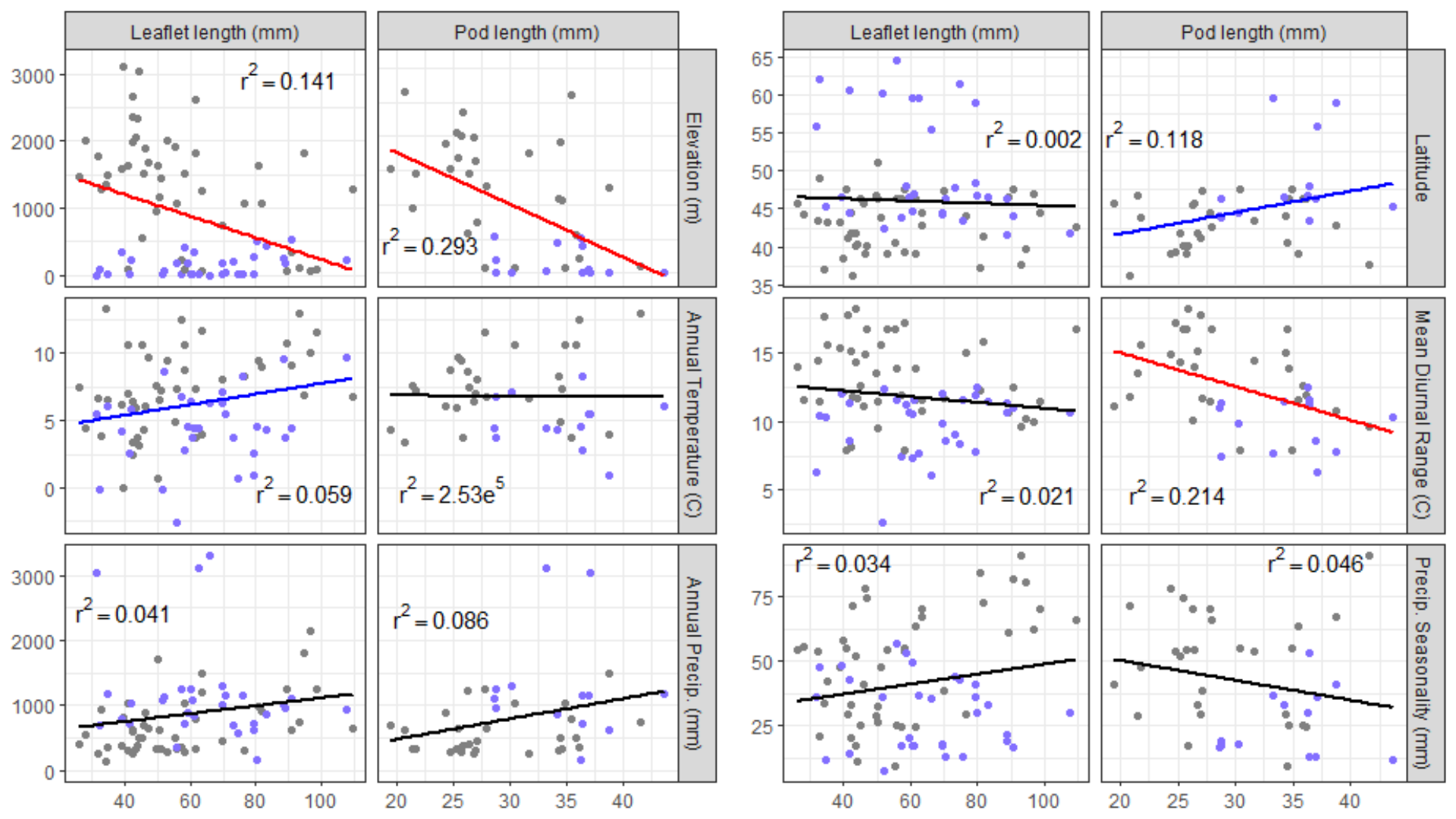
- *Lupinus polyphyllus* grows successfully in a wide range of conditions.
- For each *L. polyphyllus* specimen, **BioClim** data for the coordinate was downloaded.
- Correlations were looked at for one vegetative and one reproductive trait

Hypothesis: Vegetative and reproductive structures in *L. polyphyllus* are correlated with climatic conditions. I predict that sizes will be smaller in stressful environments such as high elevations, temperature extremes and little rainfall.



MAT (mean annual temperature) for N. America

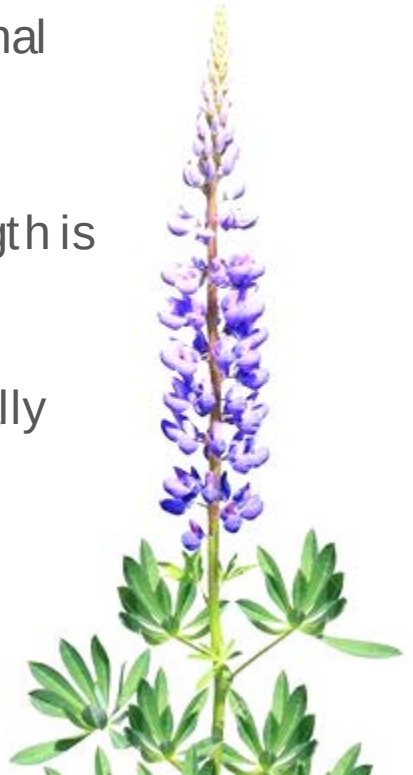
https://adaptwest.databasin.org/pages/adaptwest-


Leaflet length (mm)
Pod length (mm)
Leaflet length (mm)
Pod length (mm)
Elevation (m)
Latitude
Annual Temperature (C)
Mean Diurnal Range (C)
Annual Precip. (mm)
Precip. Seasonality (mm)
r2 = 0.141
r2 = 0.293
r2 = 0.002
r2 = 0.118
r2 = 0.059
r2 = 2.53e5
r2 = 0.021
r2 = 0.214
r2 = 0.041
r2 = 0.086
r2 = 0.034
r2 = 0.046
3000
2000
1000
0
65
60
55
50
45
40
35
10
5
0
15
10
5
3000
2000
1000
0
75
50
25
40
60
80
100
20
25
30
35
40

Climate results

- Pod length is negatively correlated with elevation and mean diurnal range. Pod length is positively correlated with latitude.
  - Diurnal range = range of temperatures in a day
- Leaflet length is negatively correlated with elevation. Leaflet length is positively correlated with mean annual temperature.

- Further work investigating these significant correlations, especially **common garden experiments** to determine if changes are due to phenotypic plasticity or fixed genetic changes.



Lupinus polyphyllus main questions

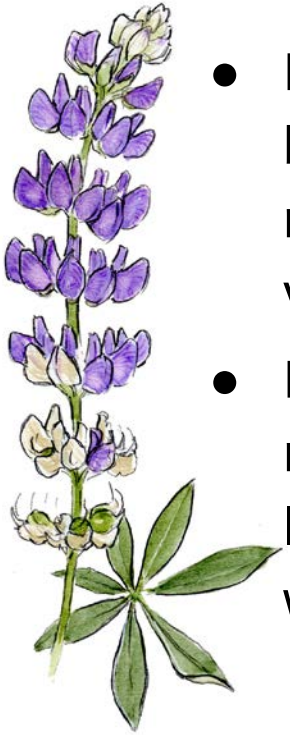
1. What is the extent of morphological variation in *L. polyphyllus*?
2. Does morphological variation differ based on co-occurrence with other *Lupinus*?
3. How does morphological variation correlate with climatic variation?
4. **Is there any evidence for trade-offs between reproductive and vegetative traits?**

Trade-offs?

One theory as to why perennial herbaceous crops have not yet been developed is that there are significant trade-offs between reproductive output and vegetative growth, so breeders cannot select for both long lifespans and high yield (Van Tassel et al. 2010).

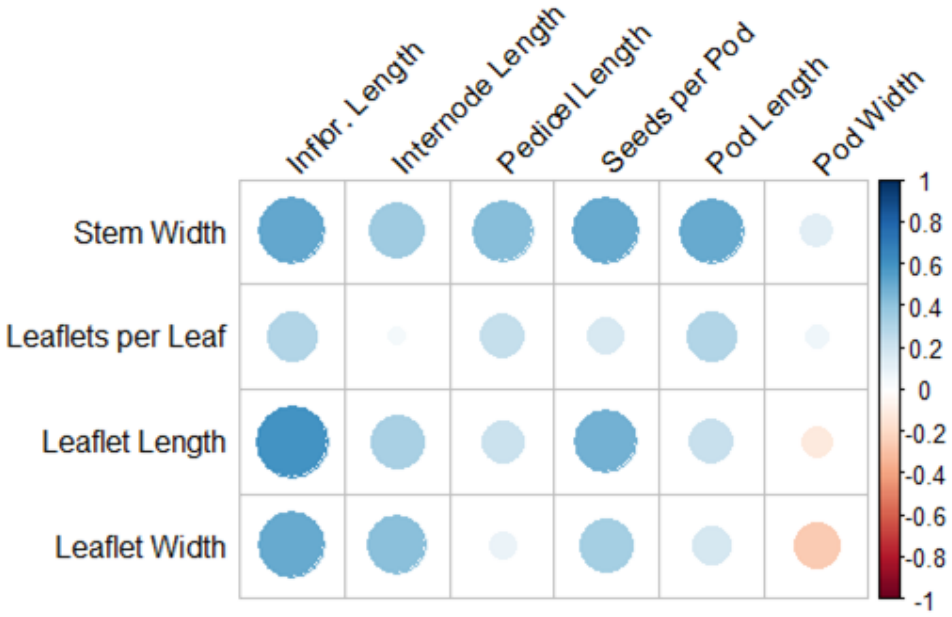
Hypothesis: *Lupinus polyphyllus* will exhibit trade-offs (negative correlations) between vegetative and reproductive traits and these relationships will be similar in other perennial *Lupinus* species.

Trade-offs in *Lupinus polyphyllus:* not found



- Positive correlations between most reproductive traits and vegetative traits
- Pod width shows a weak negative relationship to leaflet length and leaflet width.

Correlation plot of *Lupinus polyphyllus* tradeoffs, n=77

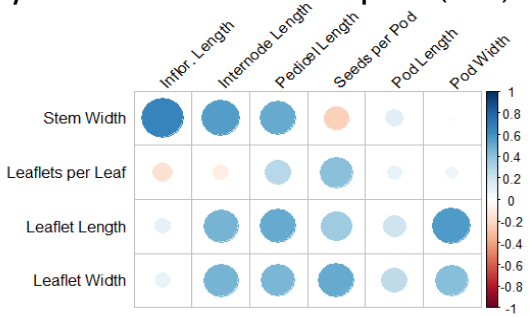


Trade-offs in other perennial *Lupinus*

Lupinus polyphyllus may be an outlier. Why are there no tradeoffs between leaf size and reproductive output in this species?

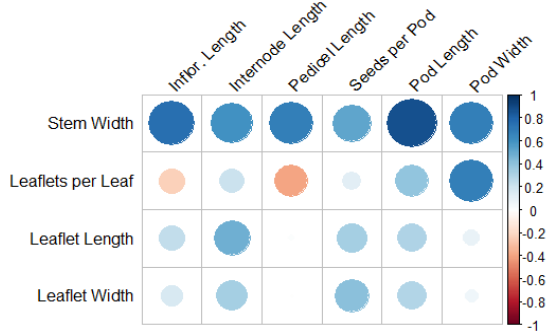
- Positive correlation between stem width and reproductive traits
- But otherwise: different trade-offs in each species

L. perennis correlation plot (n=20)

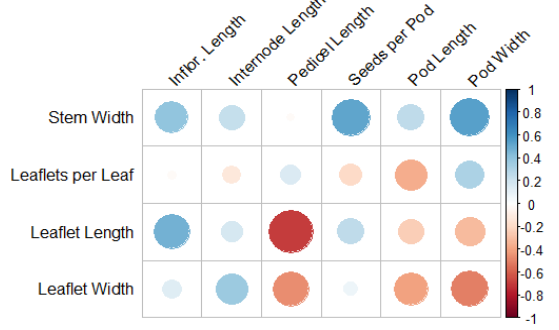


L. arboreus correlation plot (n=11)

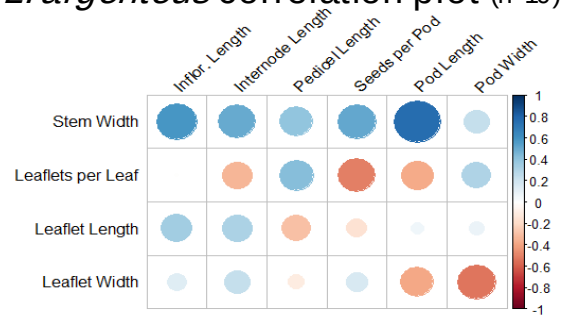
L. nootkatensis correlation plot (n=10)



L. leucophyllus correlation plot (n=9)

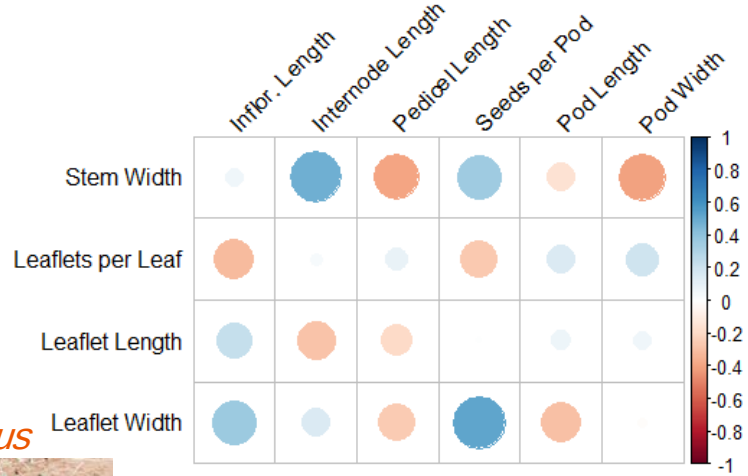


L. argenteus correlation plot (n=10)

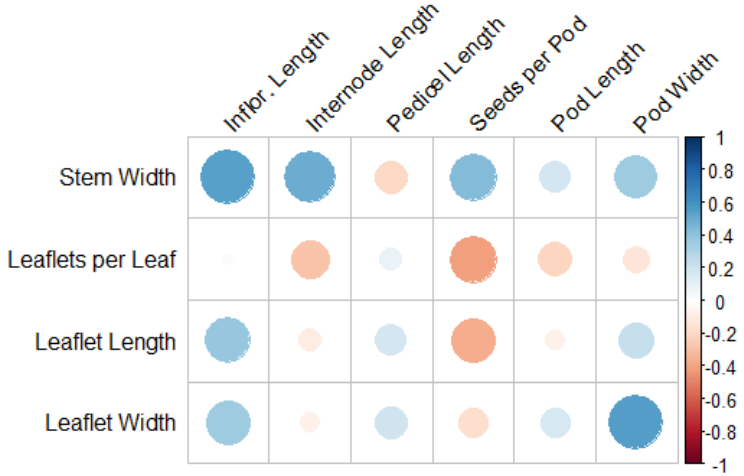


Trade-offs in annual *Lupinus*

L. pusillus correlation plot (n=10)



L. nanus correlation plot (n=10)



L. pusillus

- Multiple tradeoffs, but no clear trends
- Issues with sample size? (10 per species)

https://cals.arizona.edu/herbarium/content/legumes-arizona-images

Lupinus polyphyllus main questions

1. What is the extent of morphological variation in *L. polyphyllus*? Wide range of phenotypes, especially in its large and highly variable leaves.
2. Does morphological variation differ based on co-occurrence with other *Lupinus*? Yes. Traits displayed significant shifts both towards and away from the means of co-occurring species.
3. How does morphological variation correlate with climatic variation? Significant correlations for elevation, mean annual temperature, latitude and mean diurnal range.
4. Is there any evidence for trade-offs between reproductive and vegetative traits? Only slightly between pod width & leaflet size.

Thank you!

Aknowledgements:

Miller Lab: Laura Klein, Sterling Herron, Summer Sherrod

NSF REU program & Missouri Botanical Garden

Literature cited:

Drummond C. S., R. J. Eastwood, S. T. S. Miotto, and C. E. Hughes. 2012. Multiple Continental Radiations and Correlates of Diversification in Lupinus (Leguminosae): Testing for Key Innovation with Incomplete Taxon Sampling. Systematic Biology 61:443-460.

Dunn D. B. 1966. The lupines of Canada and Alaska. Research Branch, Canada Department of Agriculture, Canada.

Isely D. 1998. Native and naturalized Leguminosae (Fabaceae) of the United States. Brigham Young Univ, Provo, Utah.

Jackson W. 1980. New Roots for Agriculture. University of Nebraska Press, Lincoln and London.

Kurlovich B. B. S. 2002. Lupins: Geography, Classification, Genetic Resources and Breeding. Publishing House "Intan", St. Petersburg

Phillips L. L. 1954. A revision of the genus *Lupinus* in northwestern North America, A Taxonomic Study. University of Washington,.

Van Tassel D. L., L. R. DeHaan, and T. S. Cox. 2010. Missing domesticated plant forms: can artificial selection fill the gap? Evolutionary applications 3:434.

Lupinus drawings / clip art:

https://johnmuirlaws.com/wp-content/uploads/2011/06/Lupinus-polyphyllus.jpg

https://etc.usf.edu/clipart/82500/82524/82524_lupinus_3_lg.gif

http://www.fotor.com/fotor.test/75e875efaa514d52a6ec6927aa2abd52/75e875efaa514d52a6ec6927aa2abd52_p_400.png

https://openclipart.org/detail/230044/sabines-lupine