

Integrating Phylogenomics and Digitized Collections Data to Explore the Processes that Shape the Assembly of Forest Species in the North Temperate Zone

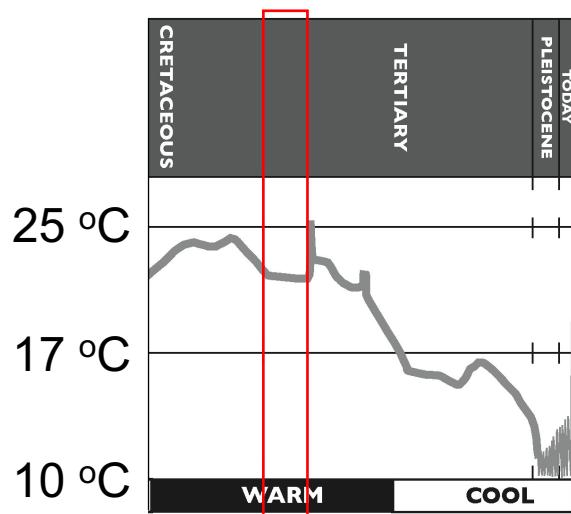
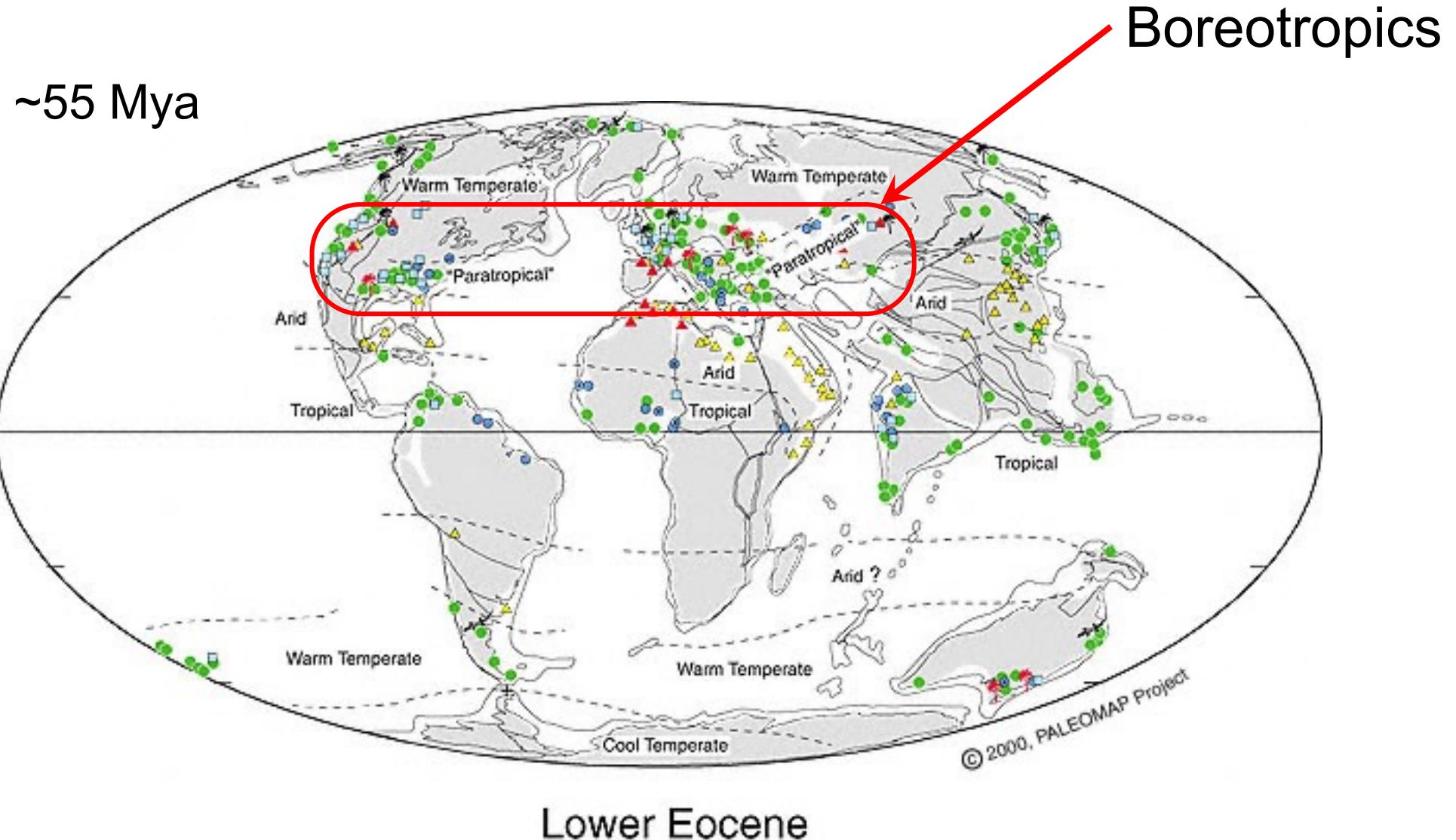


Smithsonian
Institution

Richie Hodel, Alicia Talavera,
Jun Wen

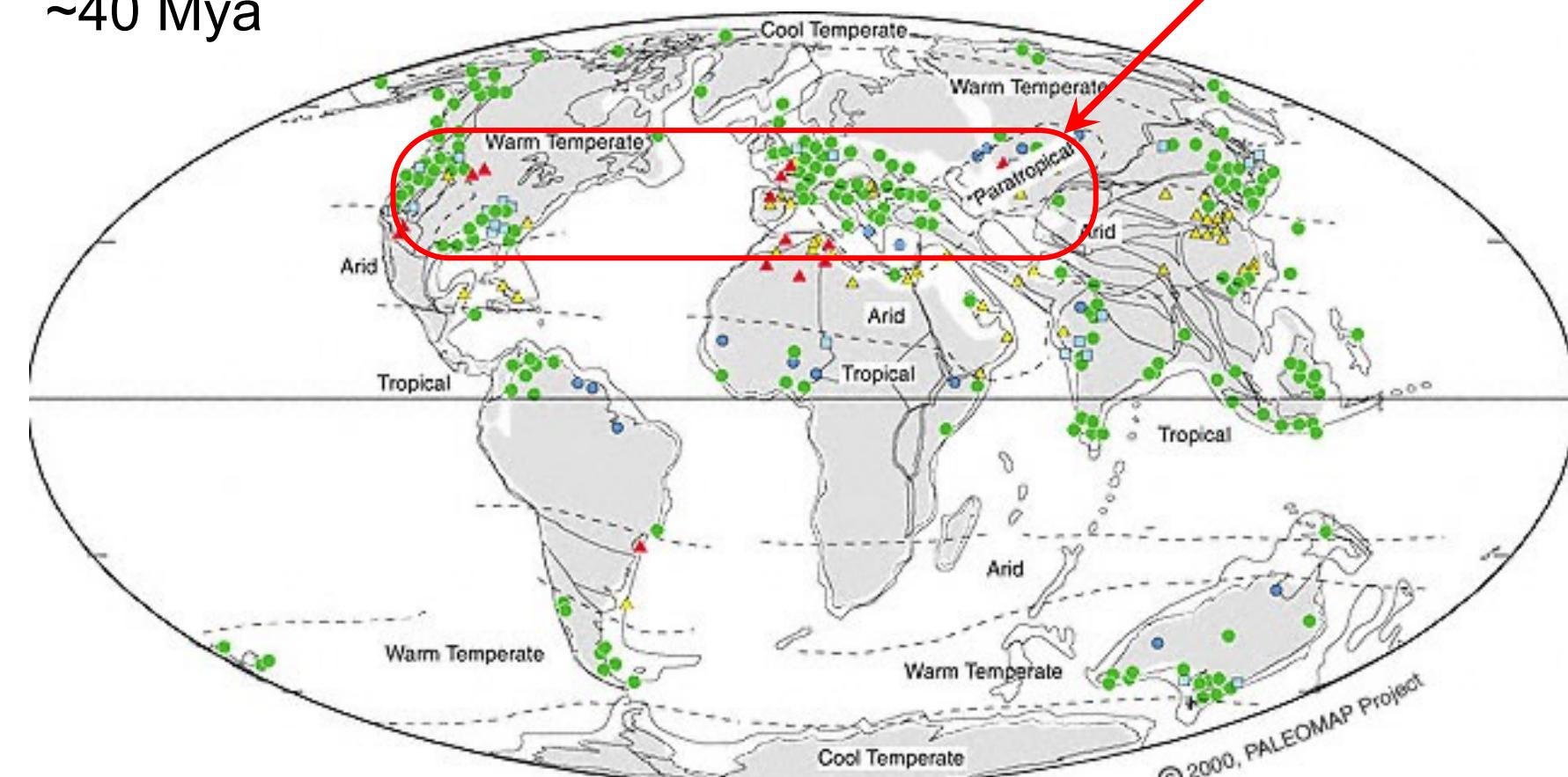
July 22, 2023



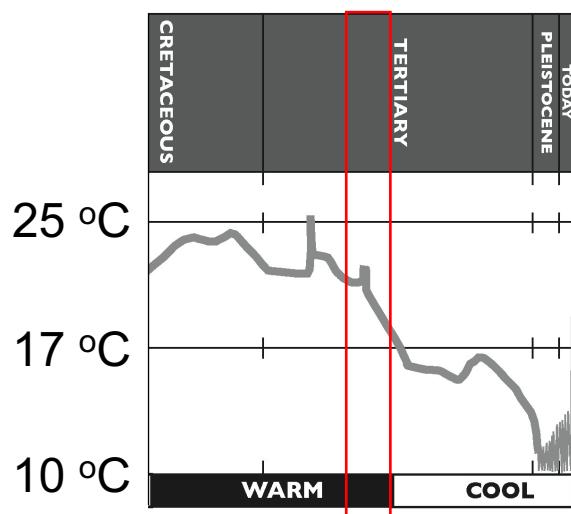


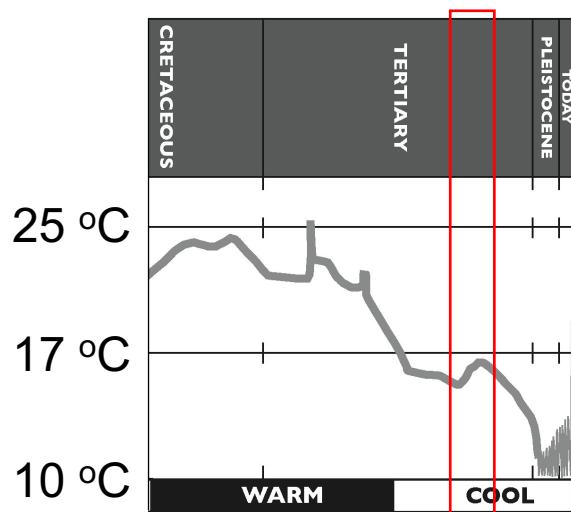
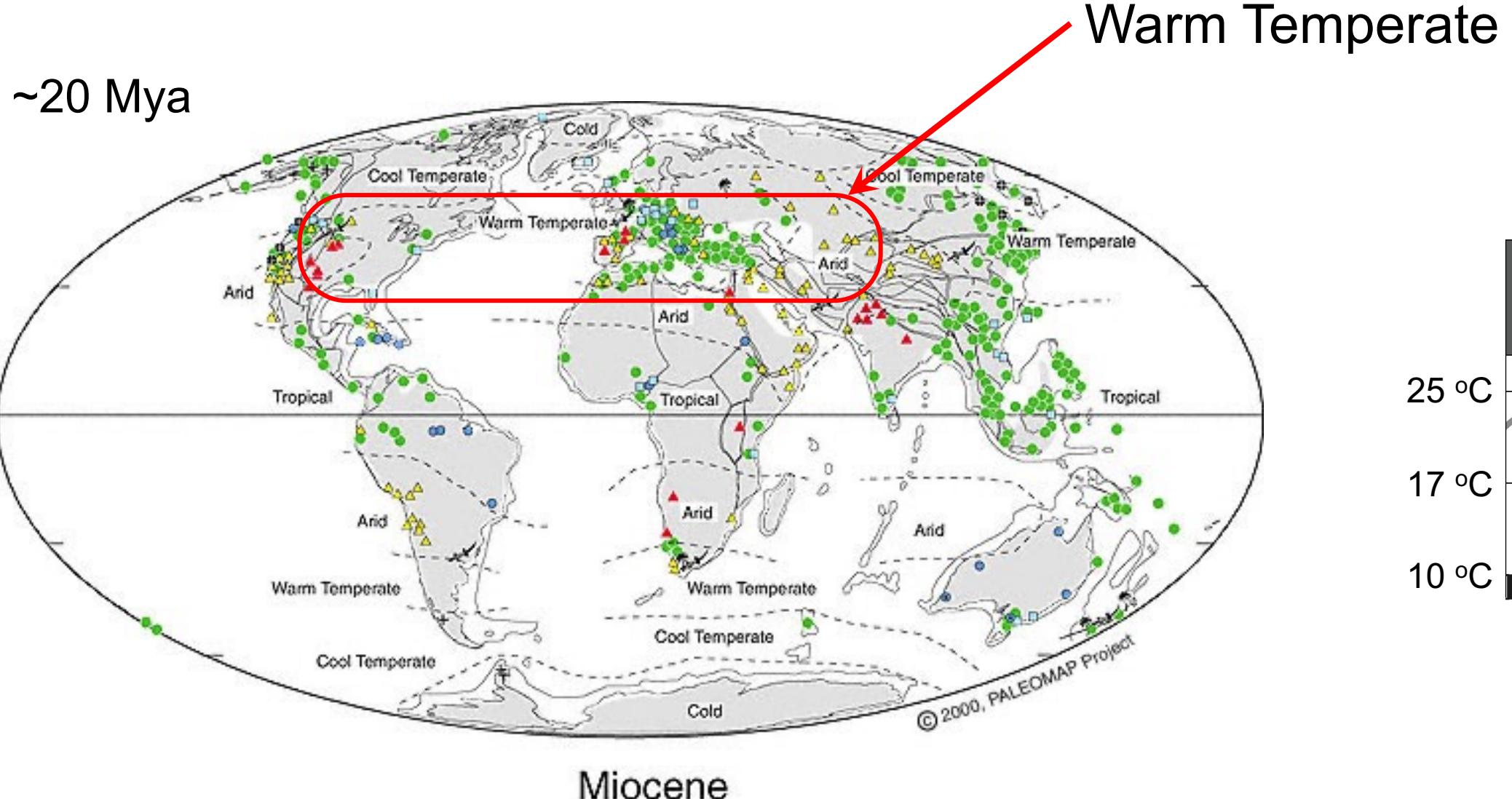
~40 Mya

Boreotropics / Warm Temperate



Middle & Upper Eocene





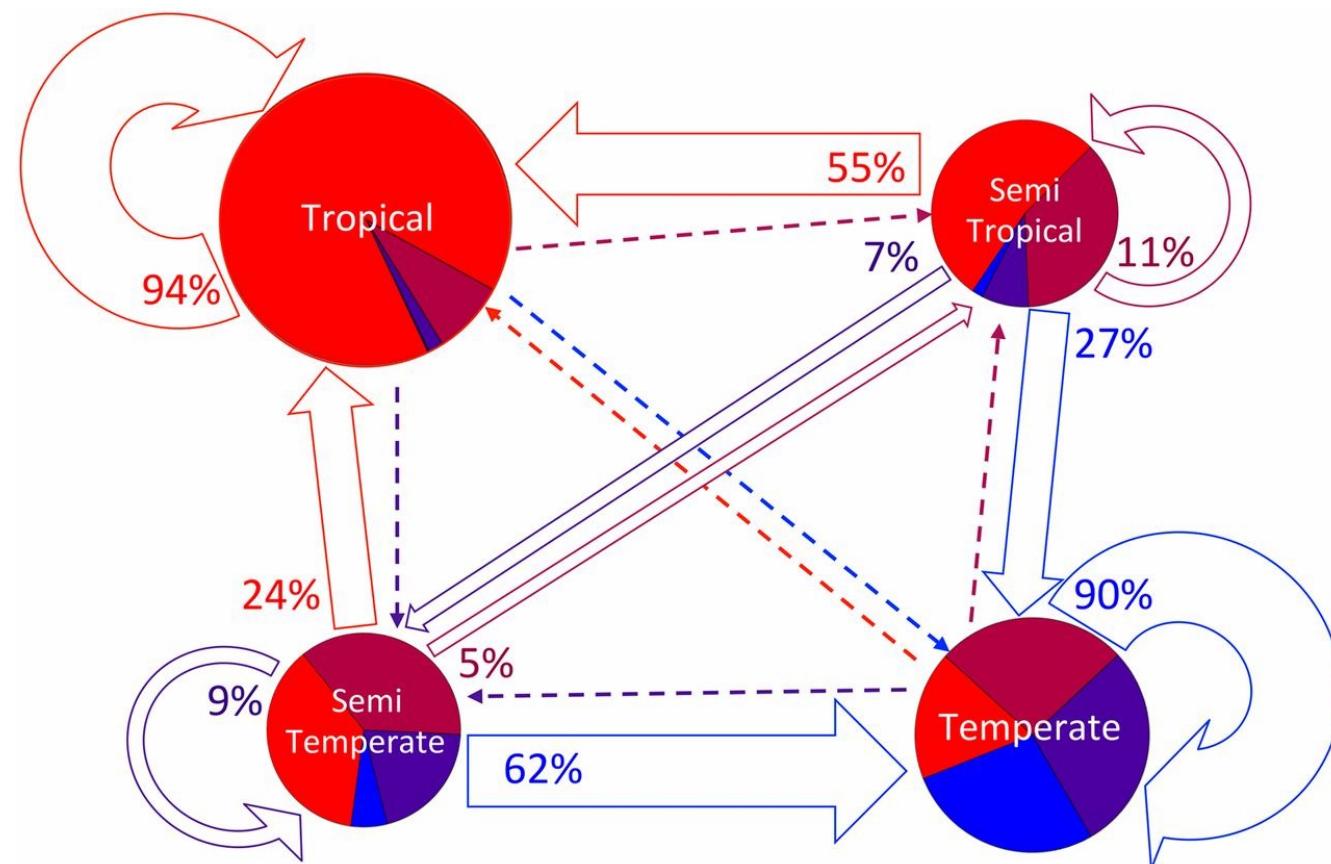
As the climate changes, is it easier for lineages to move or to evolve?

As the climate changes, is it easier for lineages to move or to evolve?

- Early phylogenetic studies revealed that niches were more conserved than expected

In the New World:

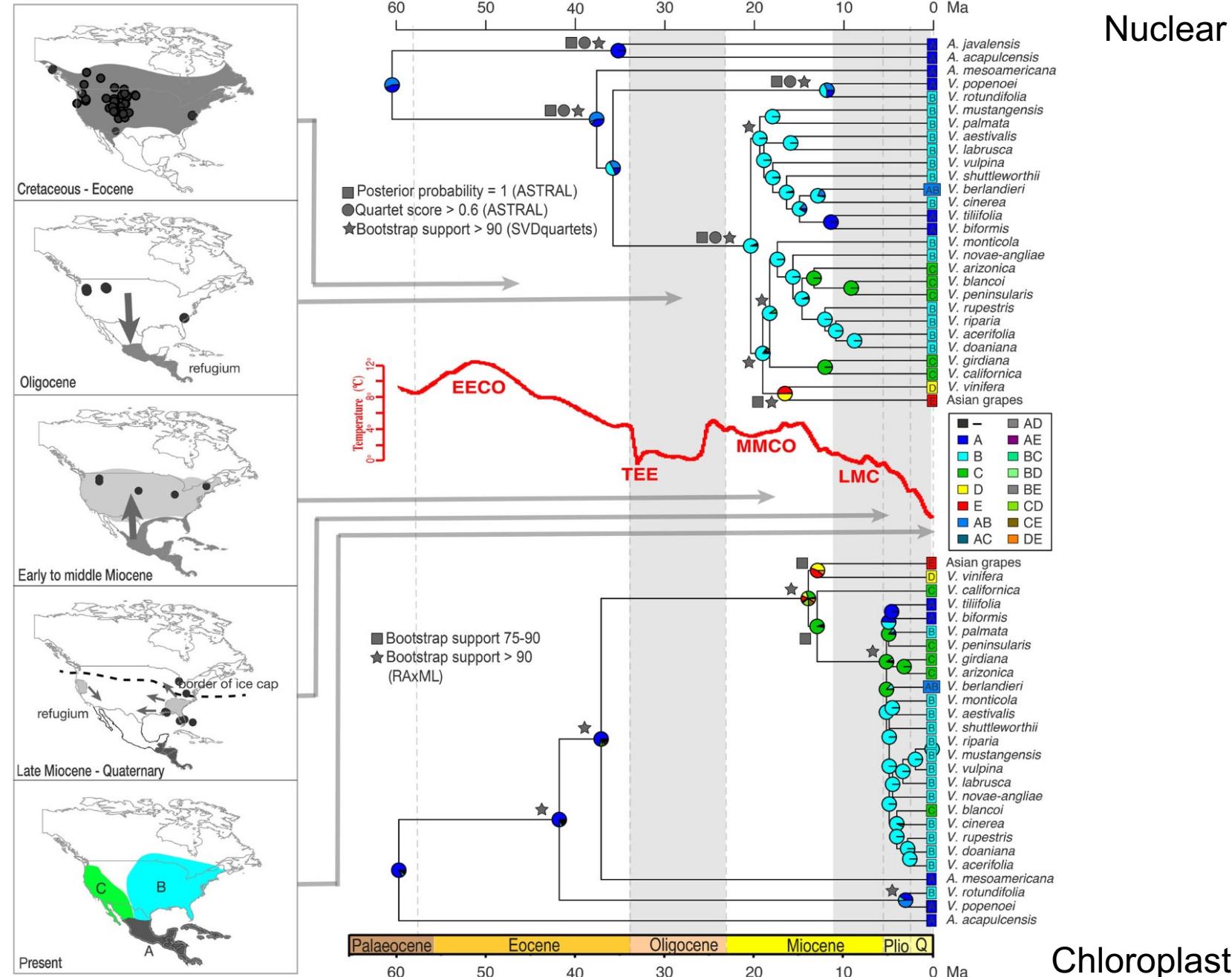
- tropical lineages remained tropical
- temperate lineages remained temperate



- Two prevailing hypotheses:
 - Tropical conservatism hypothesis
 - Taxon pulse hypothesis
- What about the rare lineages that have transitioned from tropical to temperate biomes?
- Two examples:
 - Grapes
 - Cherries

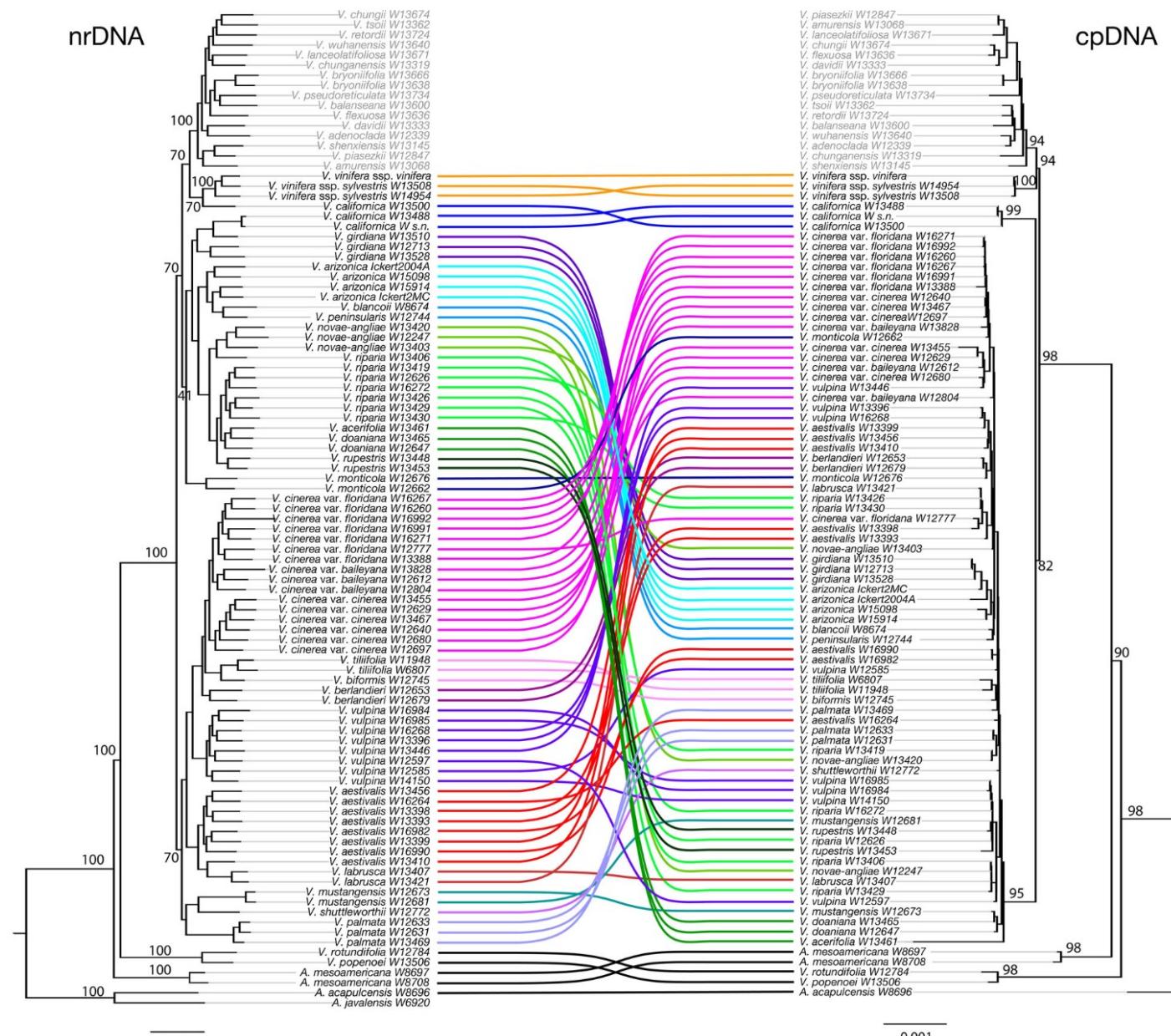
Case study: the grapevine genus (*Vitis*)

- Biogeographic history shaped by changing climatic conditions
- Genomic data:
 - nuclear Hyb-Seq
 - chloroplast genomes



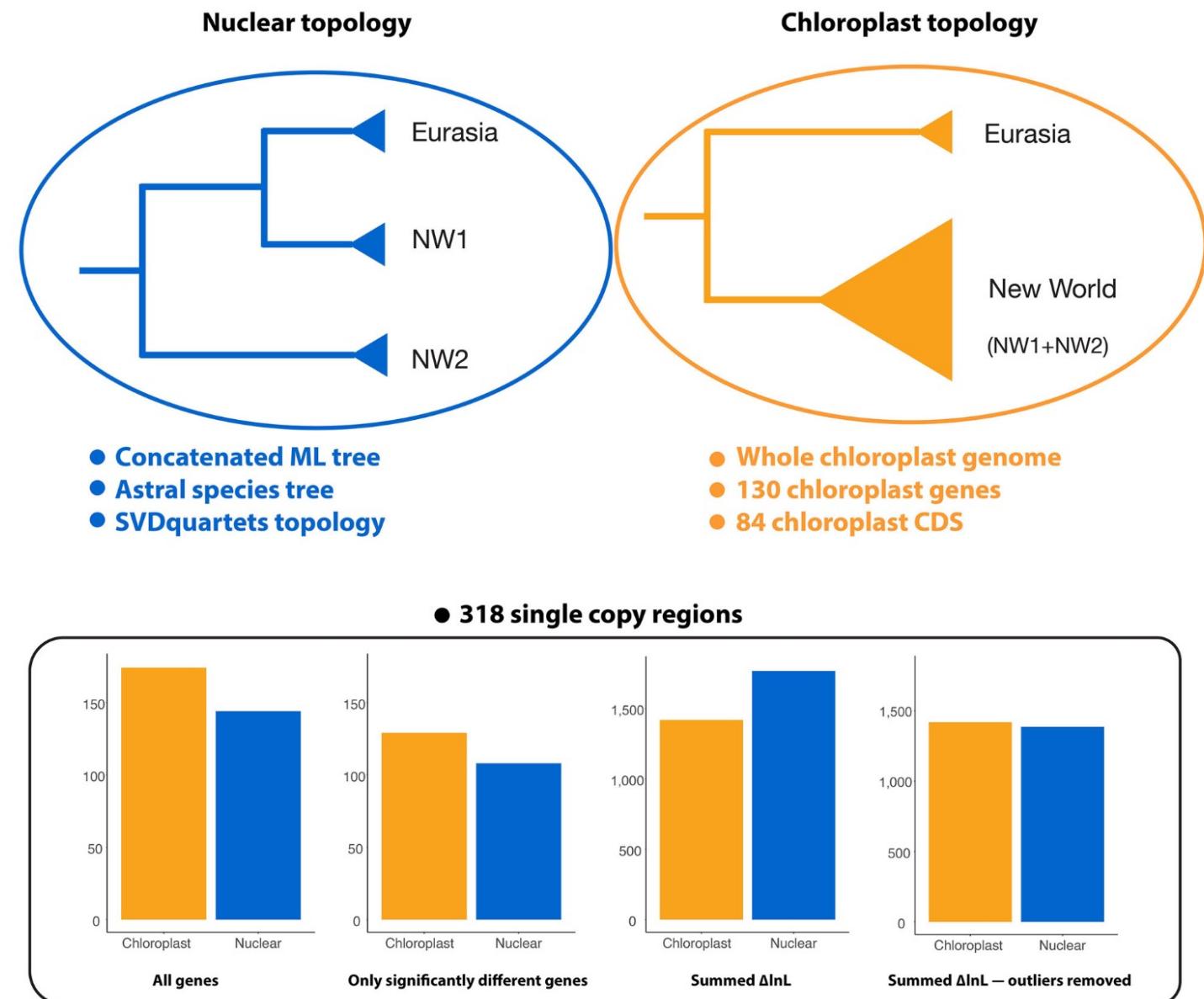
Case study: the grapevine genus (*Vitis*)

- Pervasive cytonuclear discord: an indicator of a history of hybridization
- Different inheritance modes: nuclear vs. chloroplast DNA



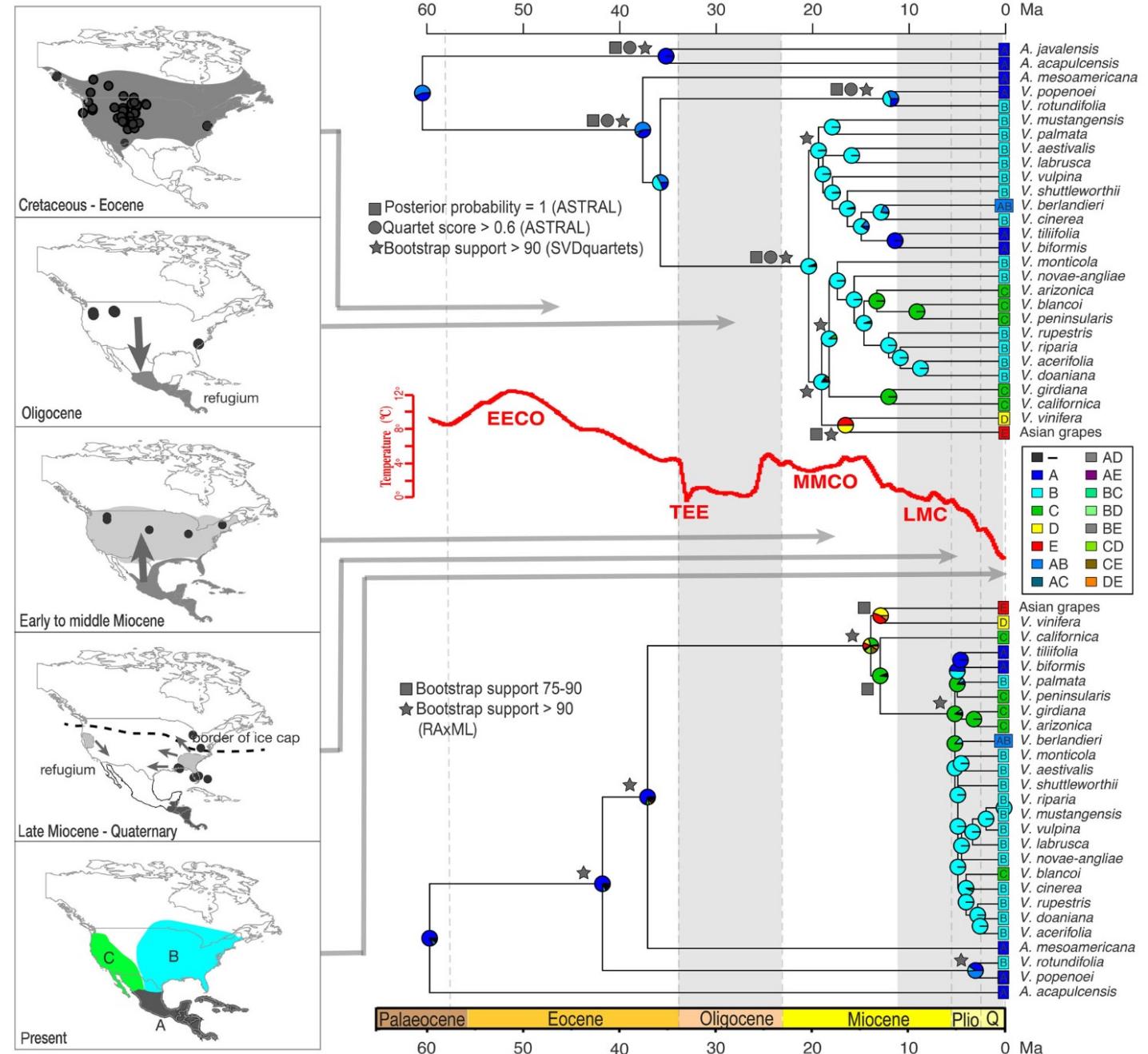
Case study: the grapevine genus (*Vitis*)

- Tests for hybridization confirmed



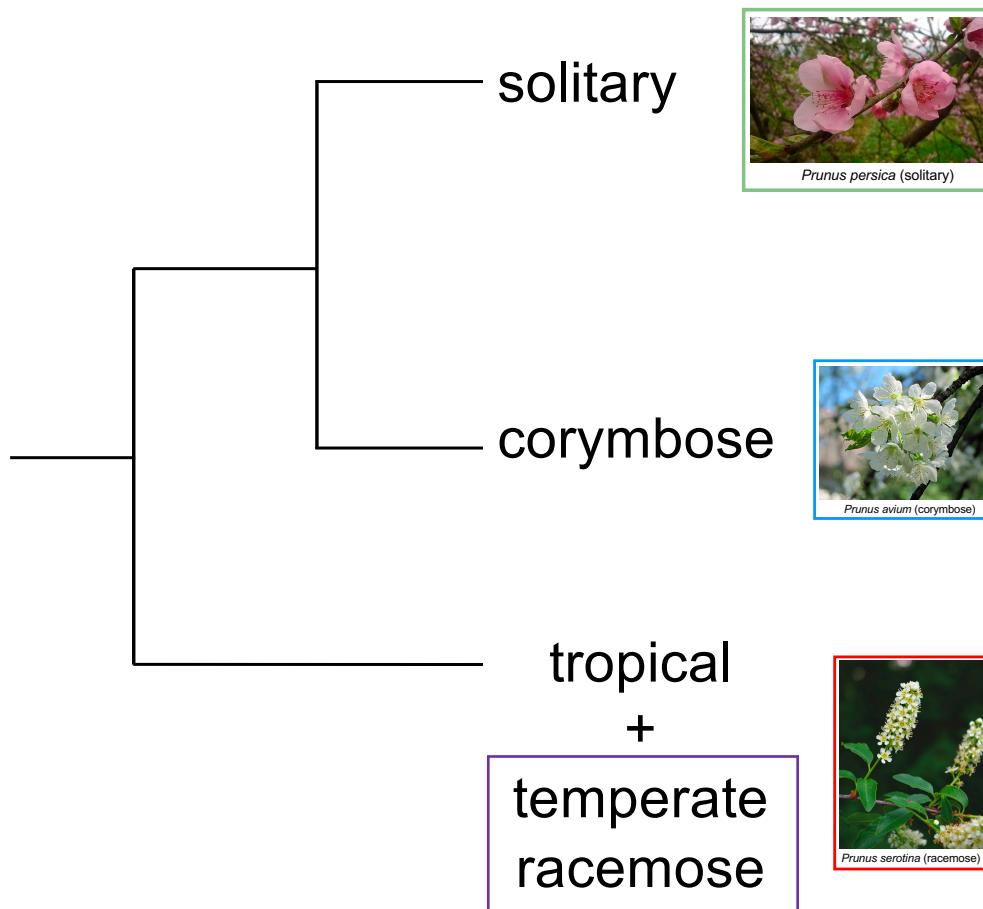
Case study: the grapevine genus (*Vitis*)

- Biogeographic history shaped by changing climatic conditions
- Transitioned from tropical region to temperate regions
- Taxon pulse

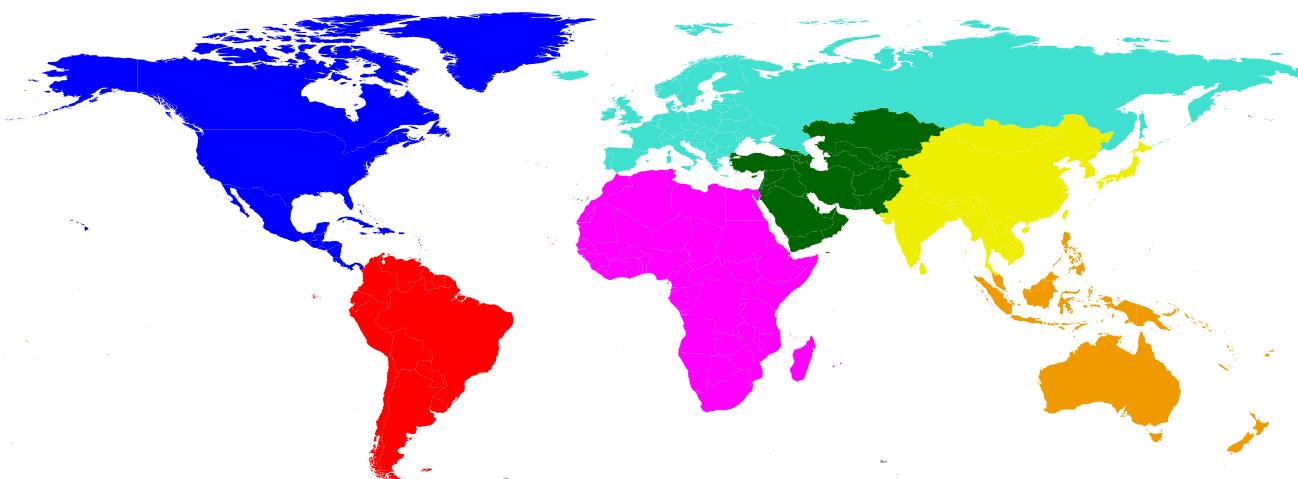


Case study: the cherry genus (*Prunus*)

Chloroplast phylogeny



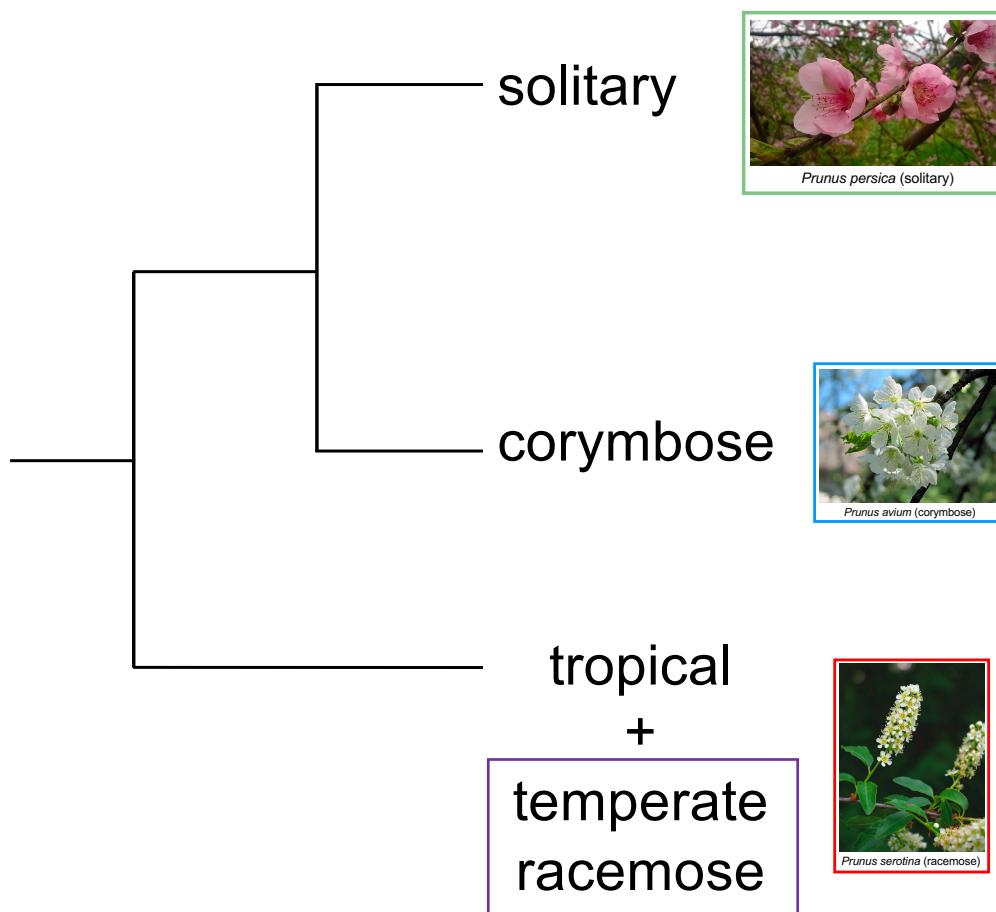
Case study: the cherry genus (*Prunus*)



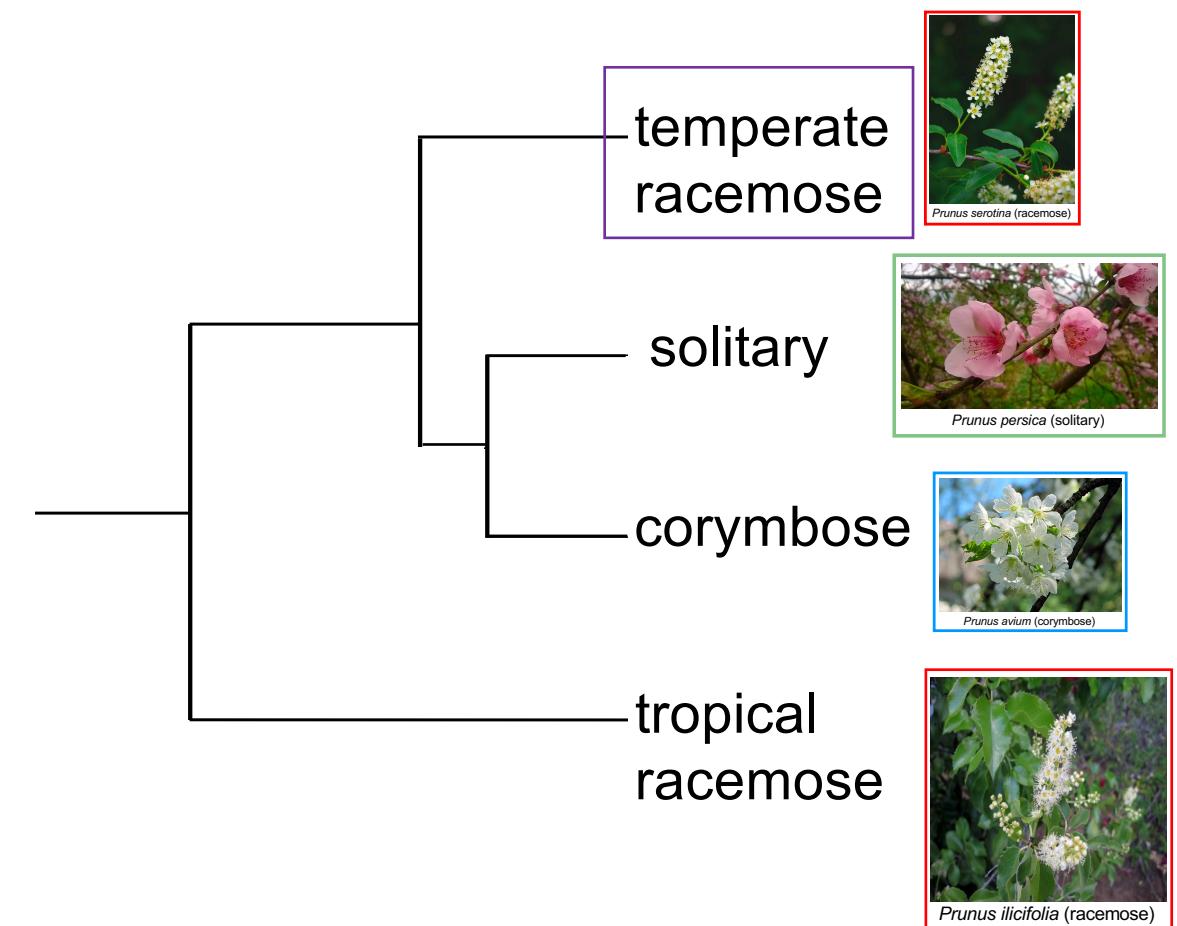
- Not yet studied with phylogenomic data
- Genomic data:
 - nuclear Hyb-Seq
 - chloroplast genomes

Case study: the cherry genus (*Prunus*)

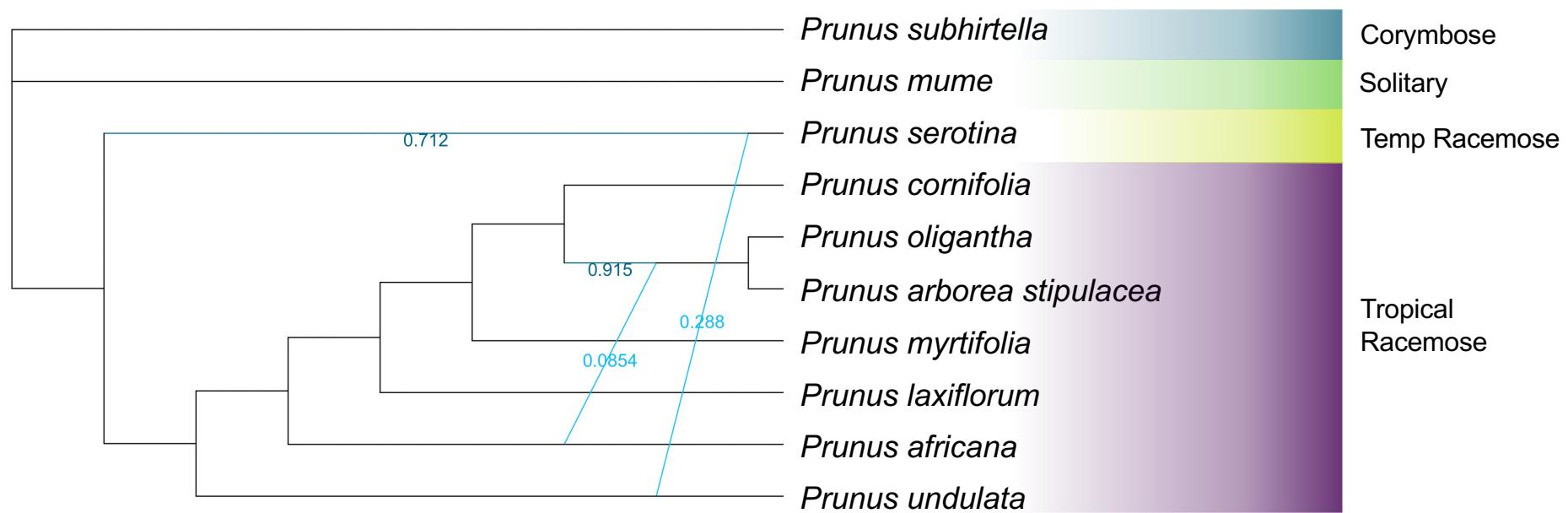
Chloroplast phylogeny



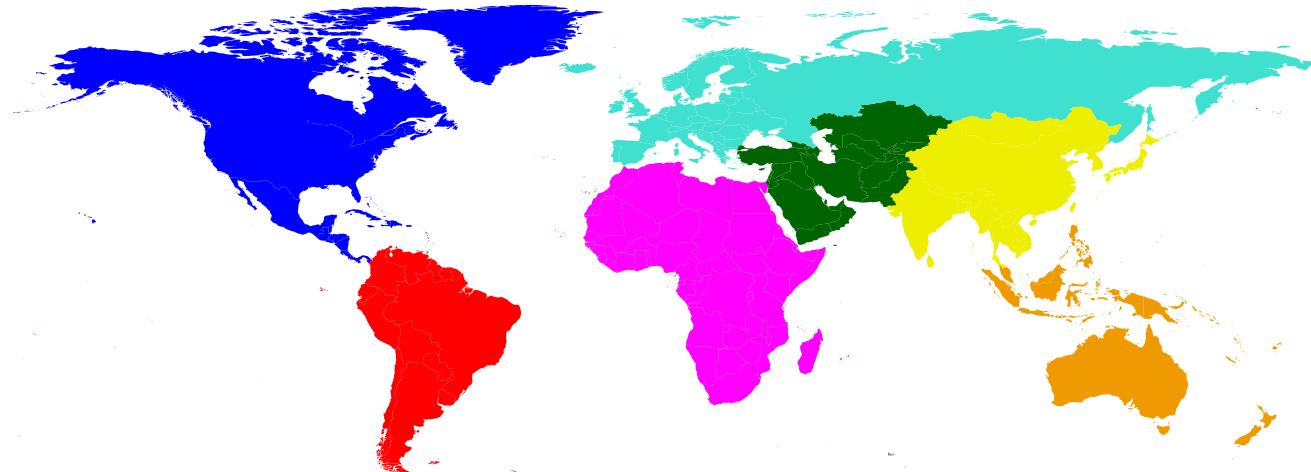
Nuclear phylogeny



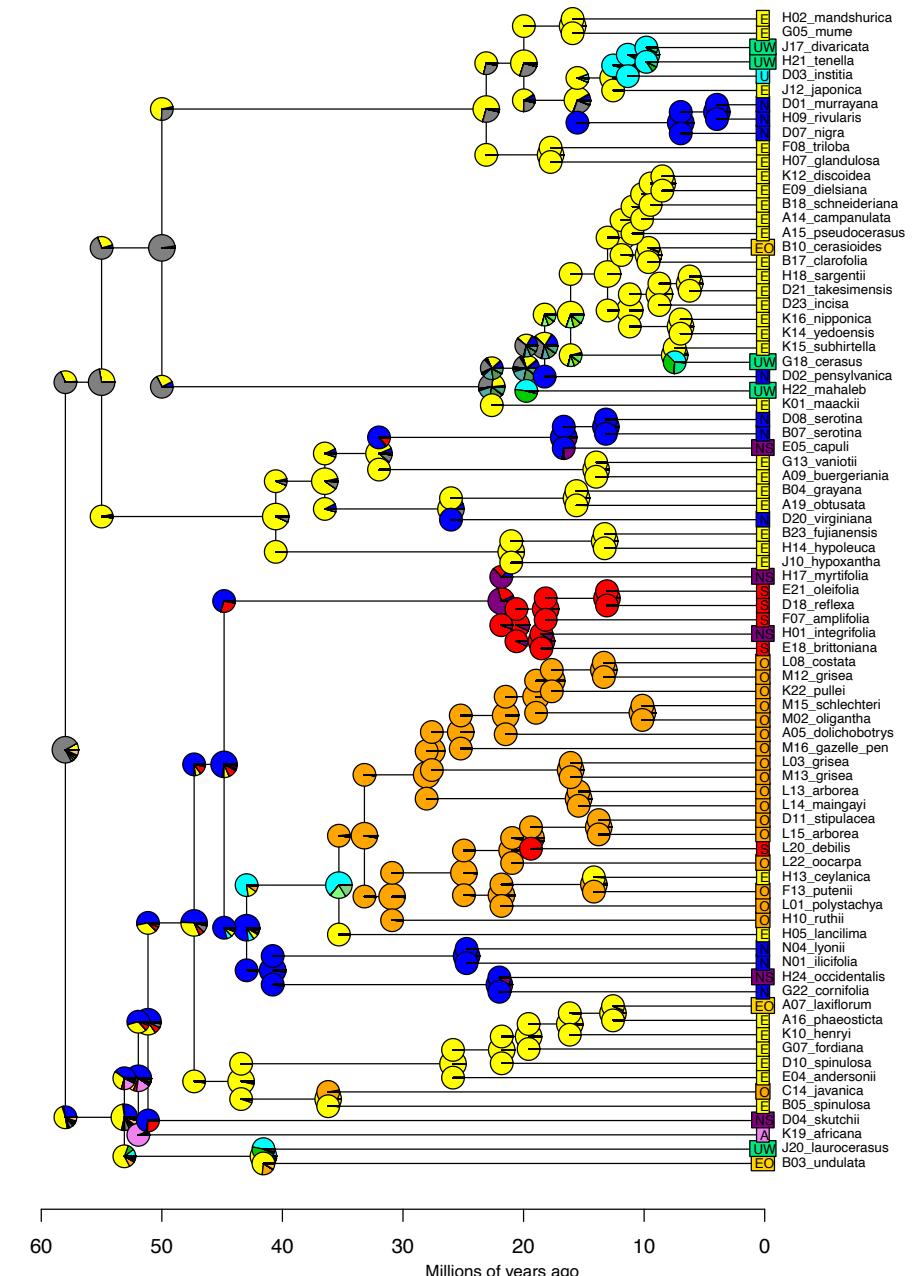
Case study: the cherry genus (*Prunus*)



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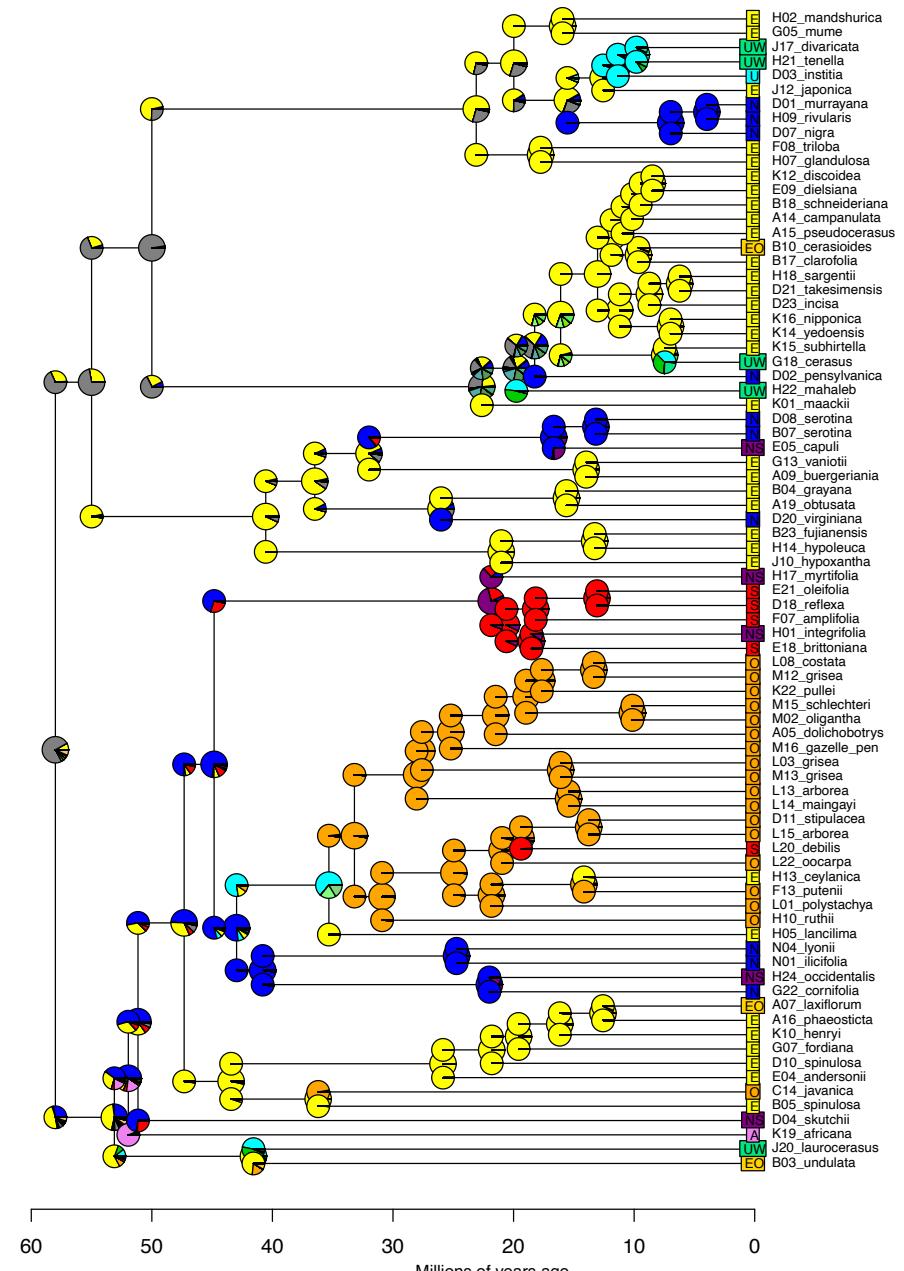
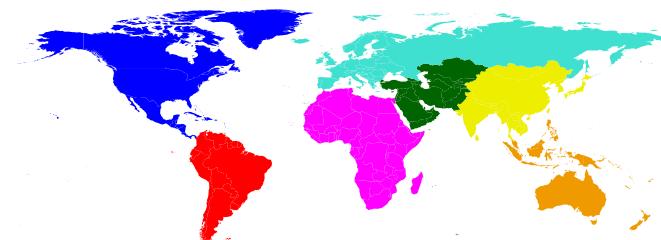


- Biogeographic history shaped by changing climatic conditions
- Genomic data:
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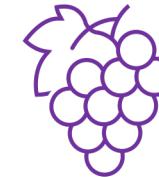


Case study: the cherry genus (*Prunus*)

- Transitioned from tropical to temperate regions, but maintained diversity in tropics
- History of hybridization
- Mix of TCH/Taxon pulse? New hypothesis?

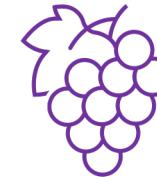


Comparison of grape and cherry genera



hybridization	✓	✓
moved to temperate region	✓	✓
subsequent low tropical diversity	✓	
retained high tropical diversity		✓

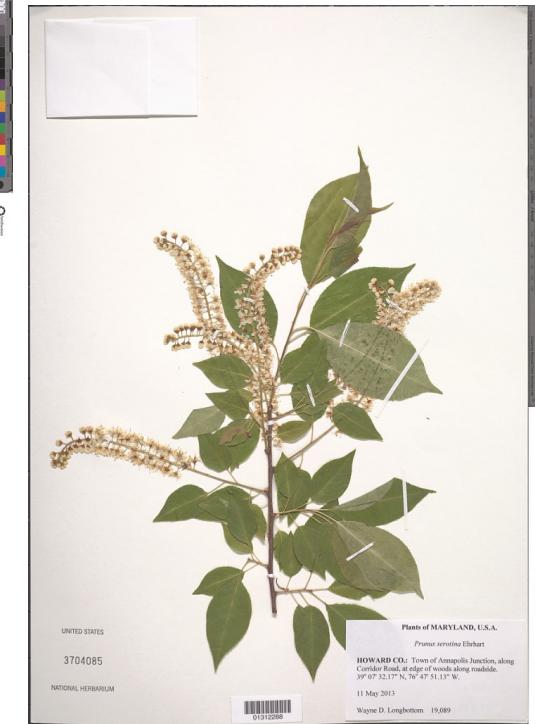
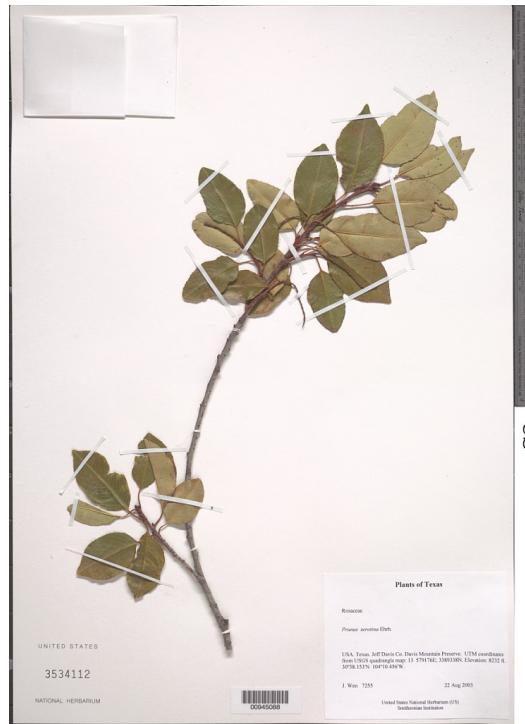
Comparison of grape and cherry genera



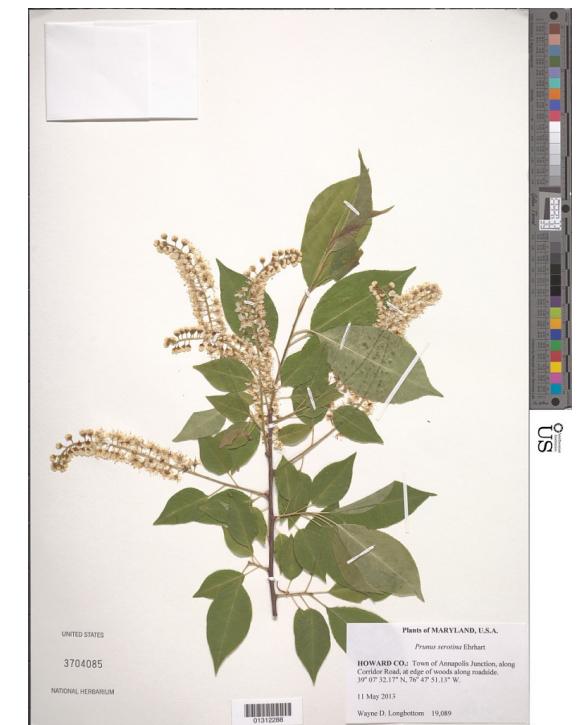
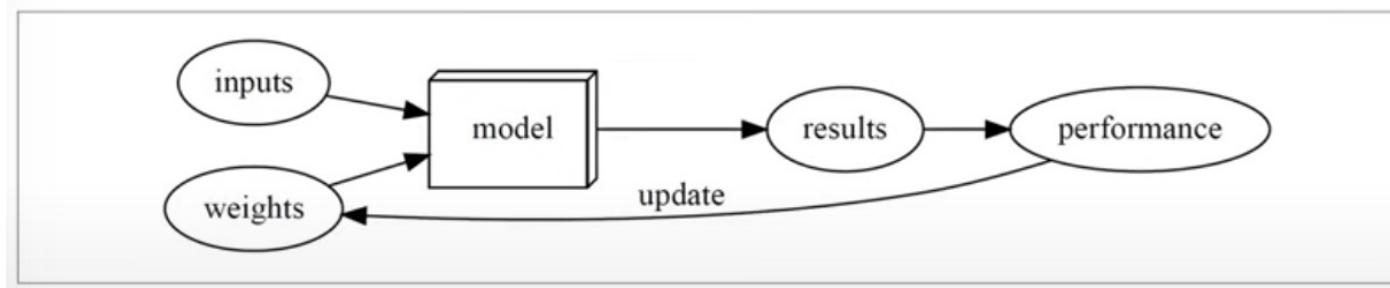
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moved to temperate region	✓	✓
subsequent low tropical diversity	✓	
retained high tropical diversity		✓

We know about the genetic and environmental conditions that enabled these two lineages to diversify successfully – but what morphological features accompanied these transitions?

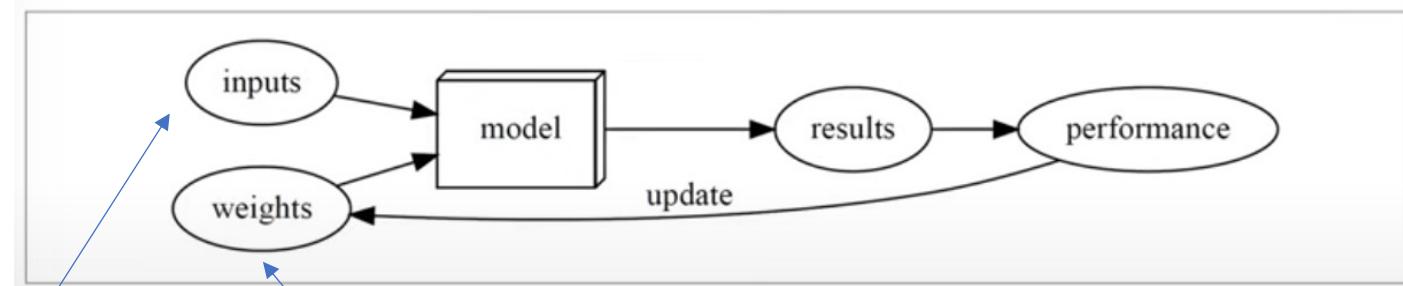
Digitized collections as a source of phenotypic data: Deep learning with herbarium specimens



Deep Learning with Herbarium Specimens



Deep Learning with Herbarium Specimens

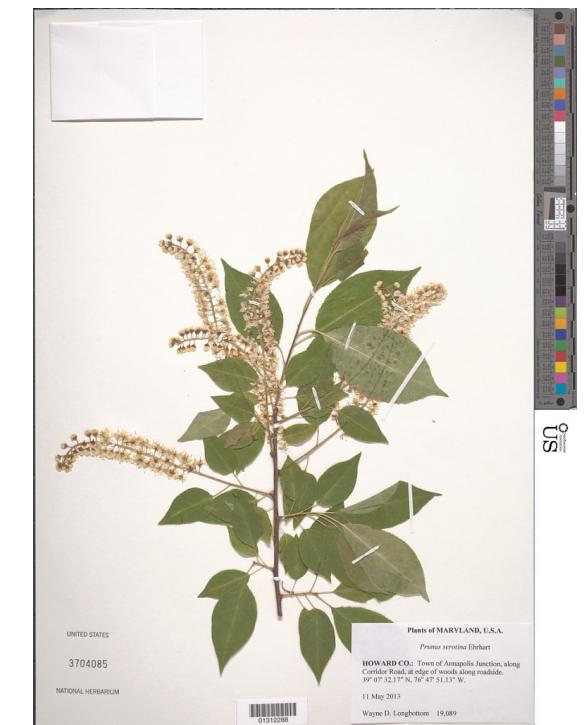


data

parameters

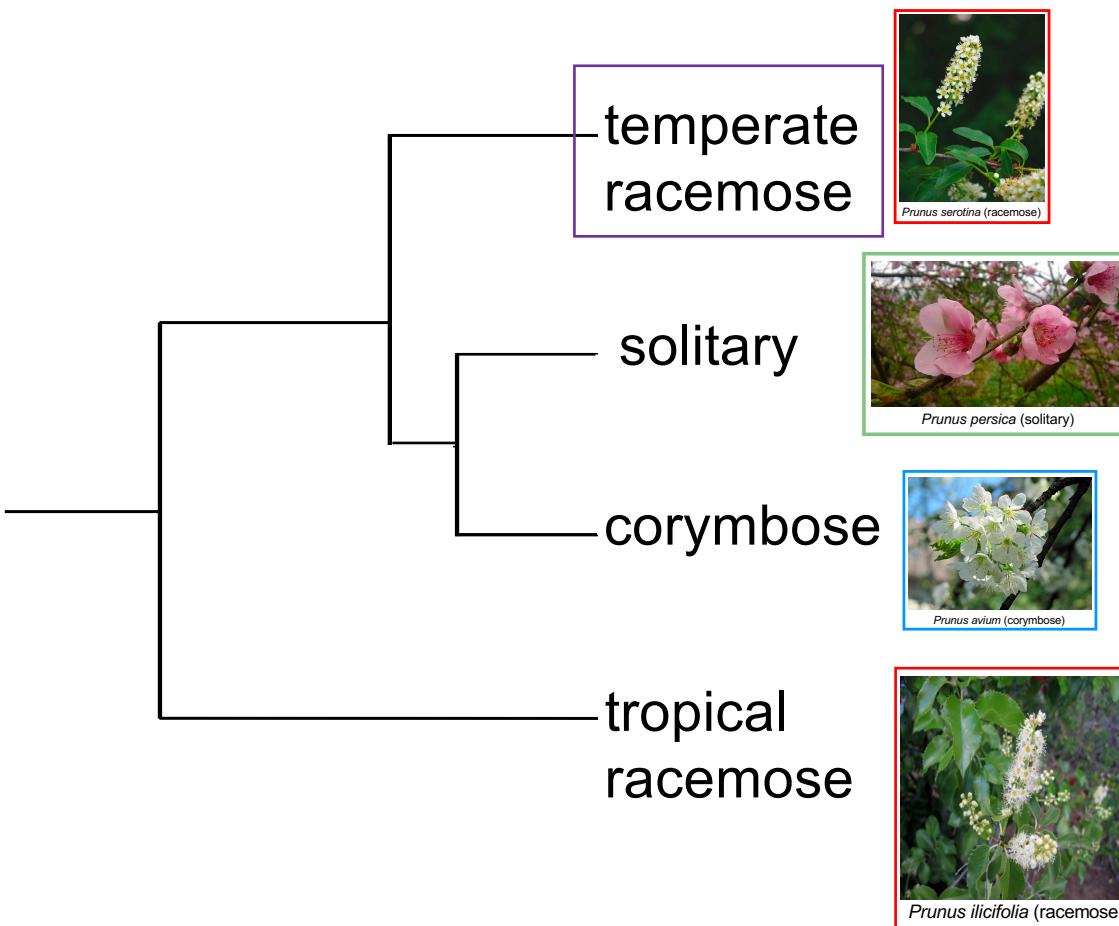
labeled

**High
Throughput
Phenotyping**

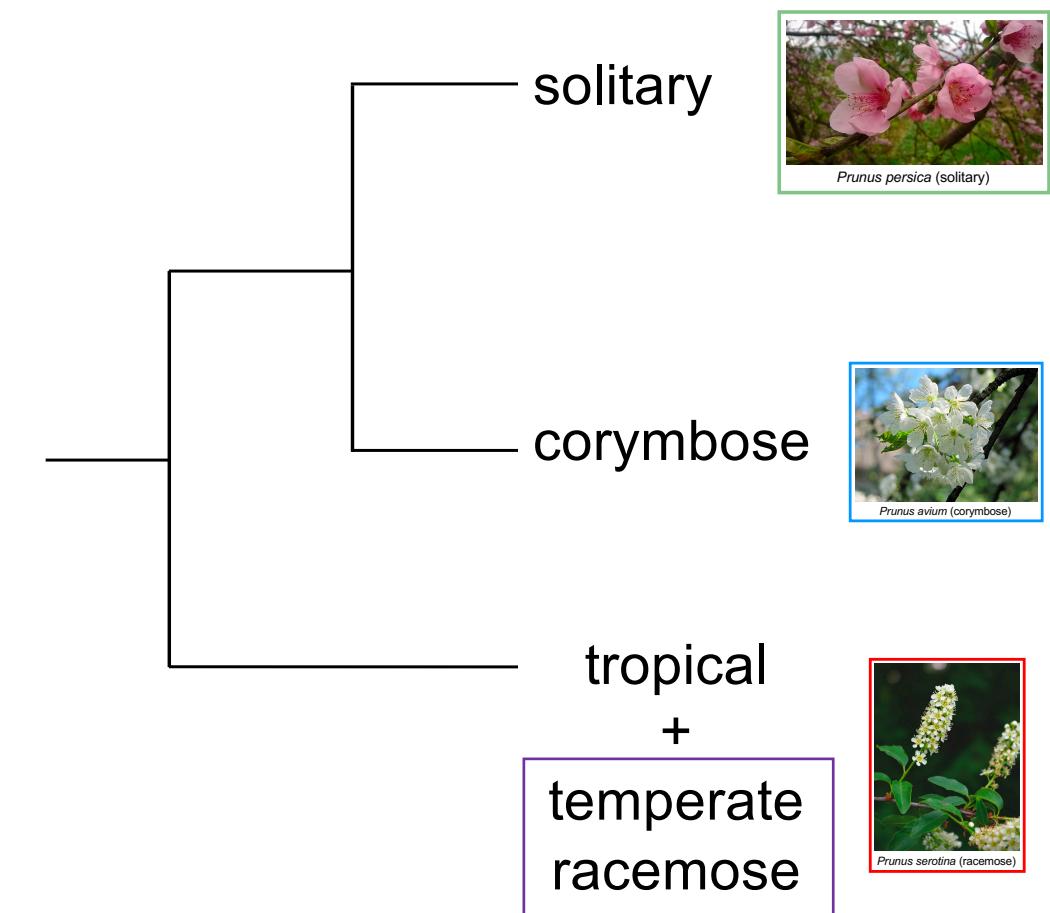


Example: Morphological signatures of ancient hybridization in *Prunus*

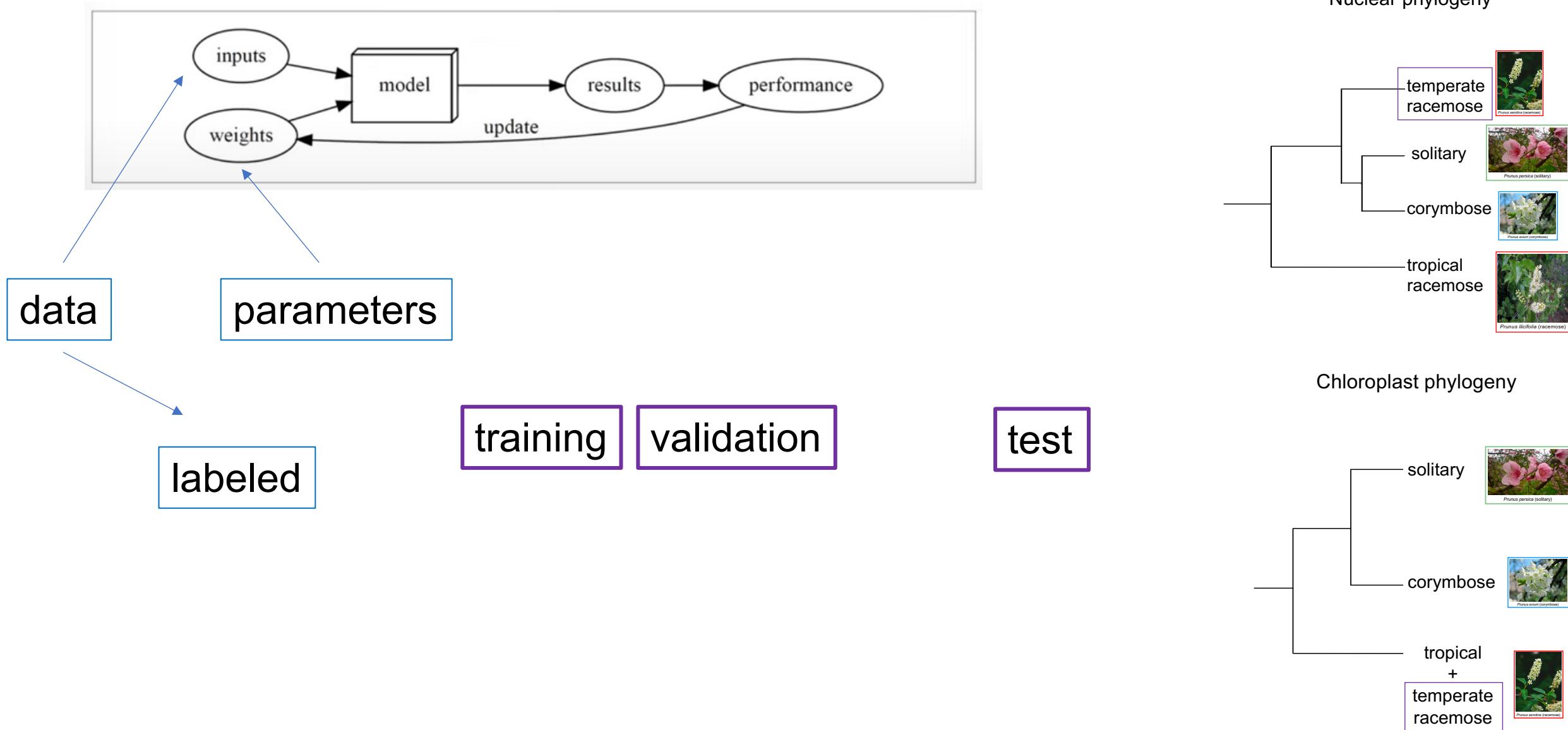
Nuclear phylogeny



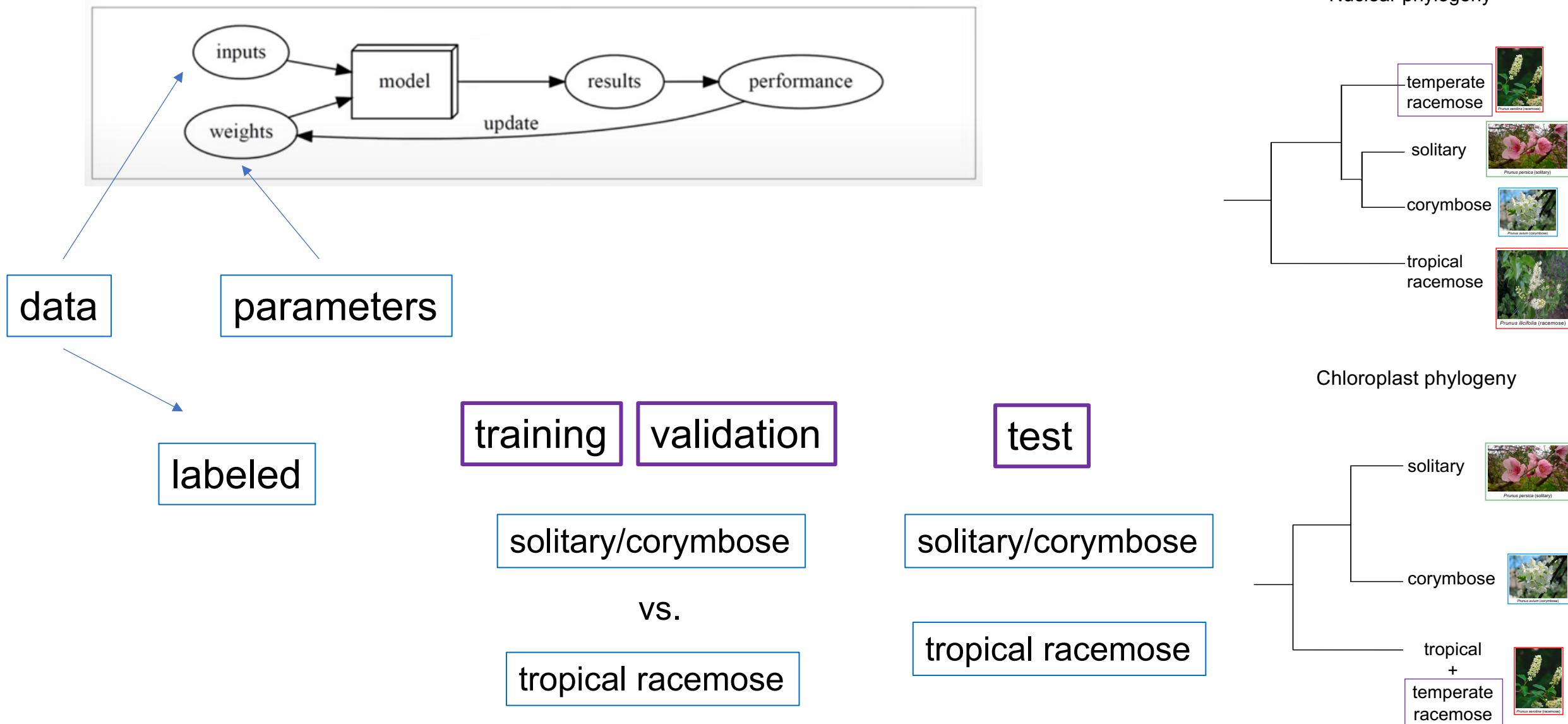
Chloroplast phylogeny



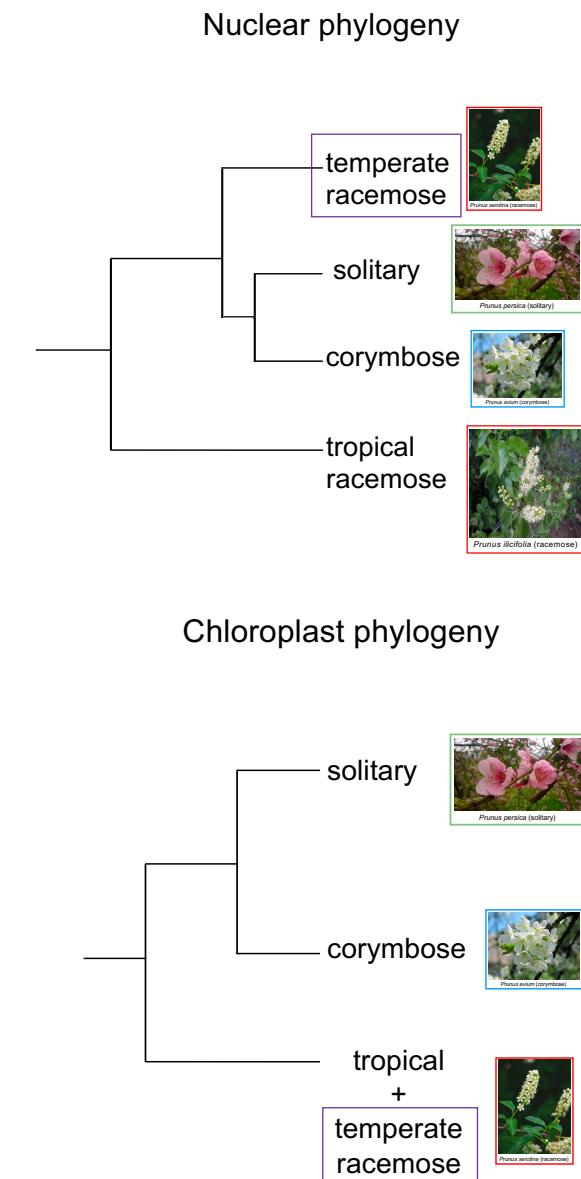
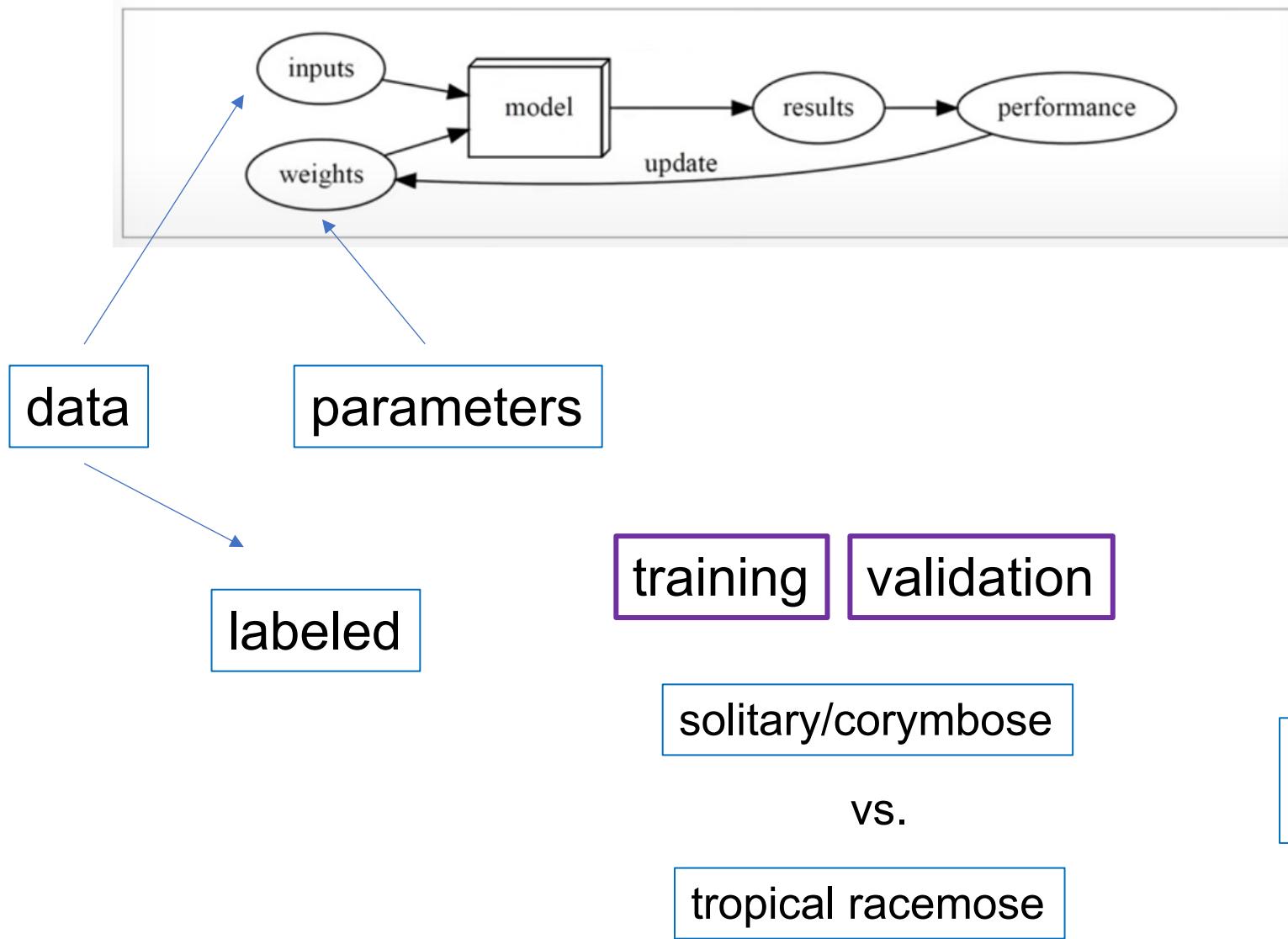
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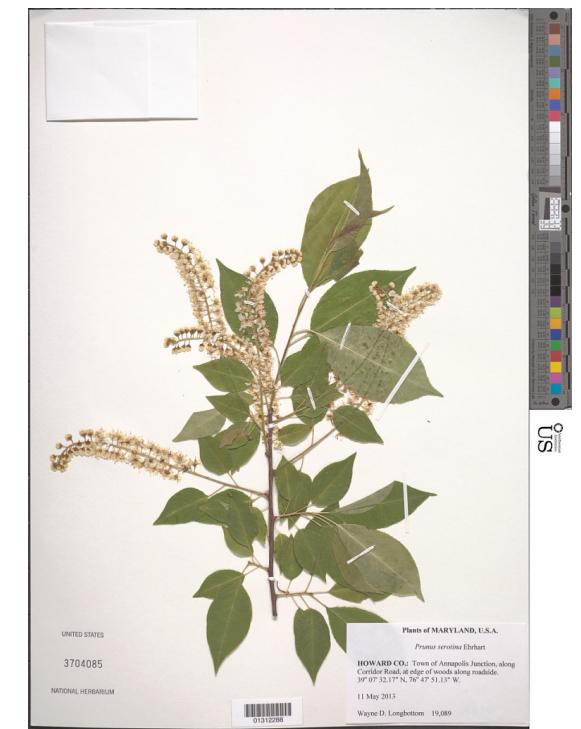
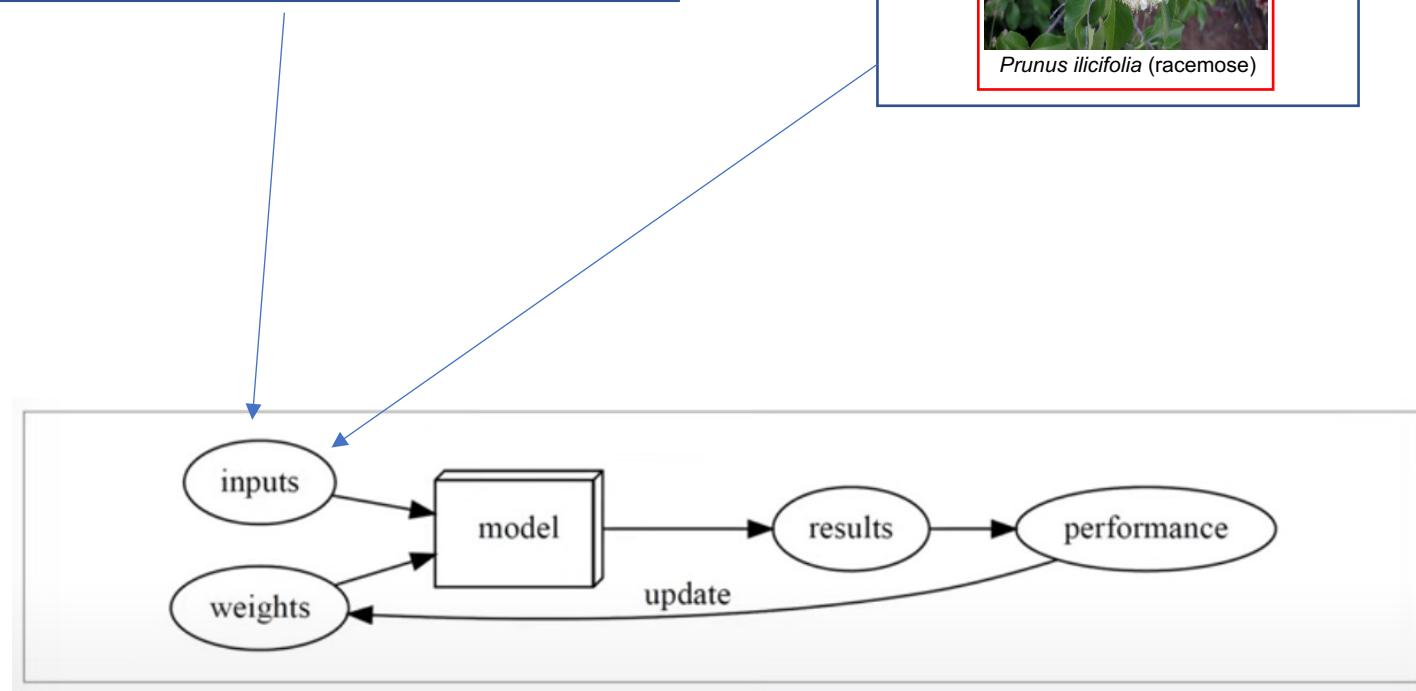
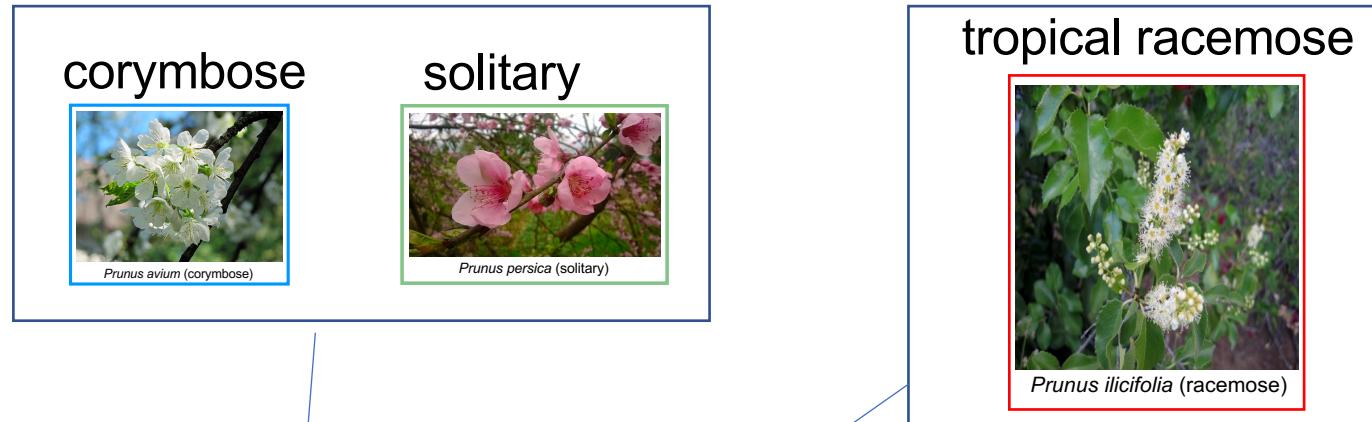
Deep Learning with Herbarium Specimens



Deep Learning with Herbarium Specimens



10,240 herbarium specimens



Test data controls indicate the model has strong predictive power – unseen images

tropical racemose



Prunus ilicifolia (racemose)

corymbose



Prunus avium (corymbose)

solitary



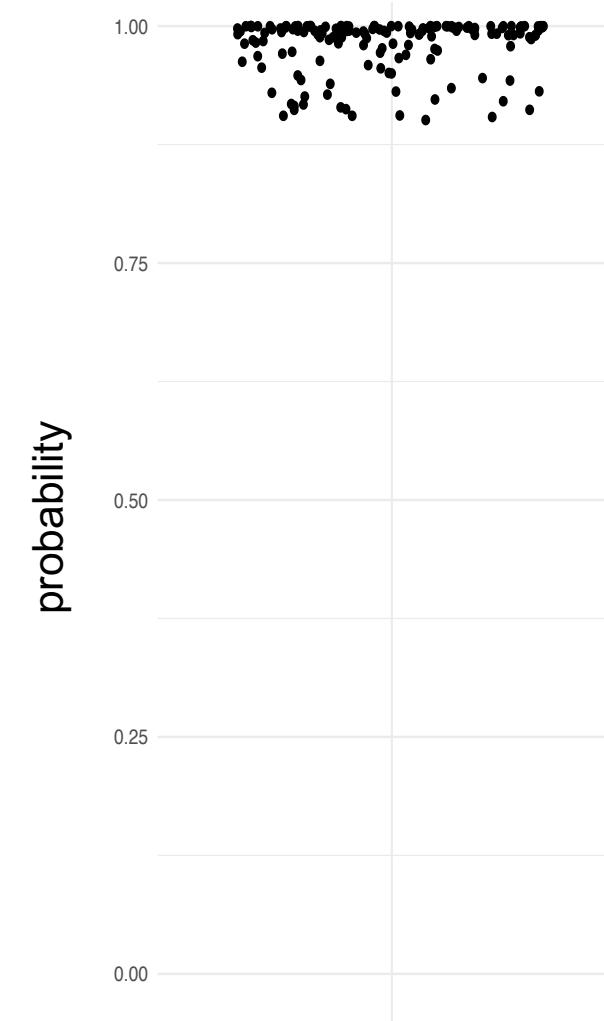
Prunus persica (solitary)

Test data controls indicate the model has strong predictive power – unseen images

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corymbose



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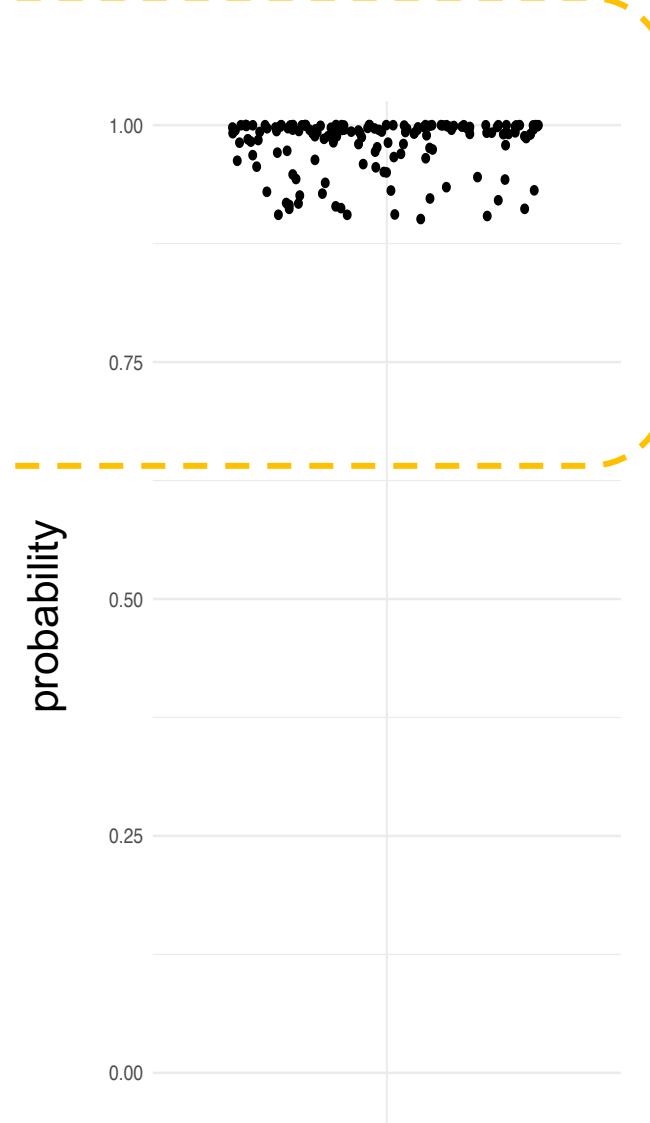
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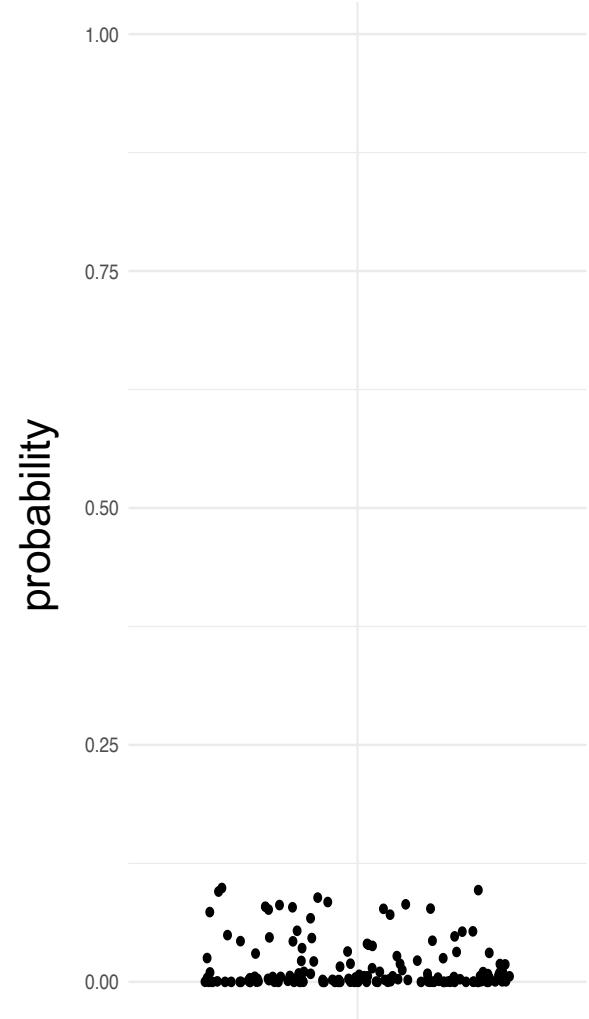
tropical racemose



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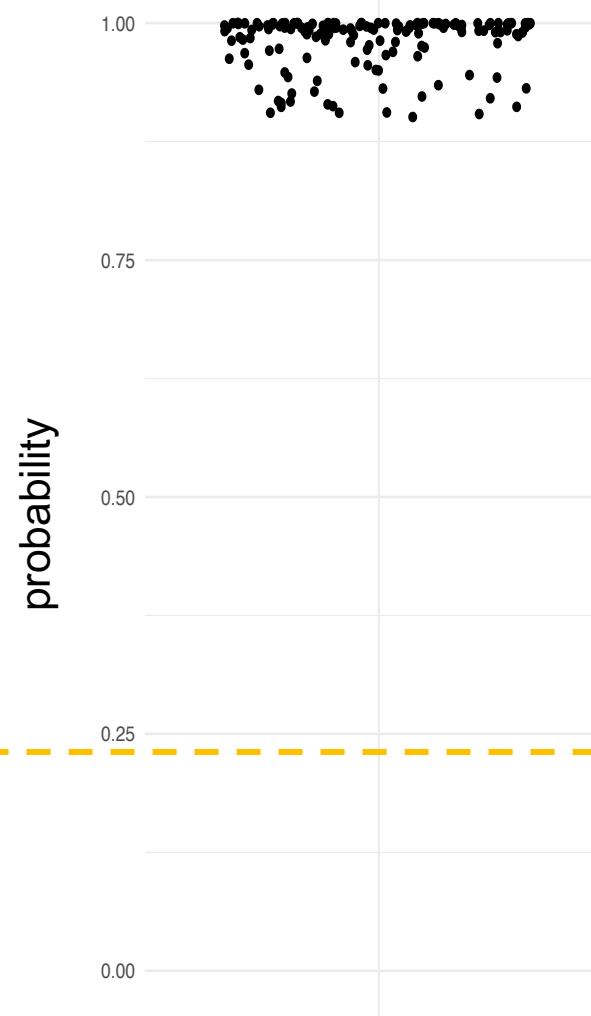


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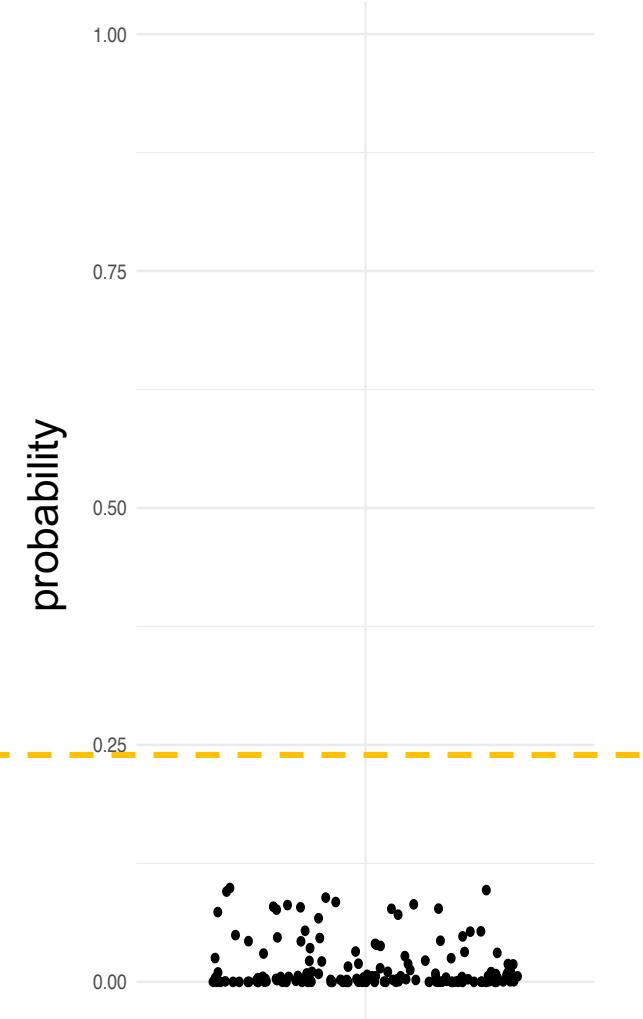


Prunus avium (corymbose)

solitary



Prunus persica (solitary)



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tropical racemose



Prunus ilicifolia (racemose)

corymbose



Prunus avium (corymbose)

solitary



Prunus persica (solitary)

Phylogenetic hypothesis: temperate racemose evenly classified in each morphogroup

tropical racemose



Prunus ilicifolia (racemose)



temperate racemose



Prunus serotina (racemose)

corymbose

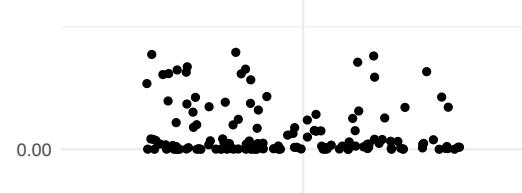


Prunus avium (corymbose)

solitary



Prunus persica (solitary)



Phylogenetic hypothesis: temperate racemose evenly classified in each morphogroup

tropical racemose



Prunus ilicifolia (racemose)



$N = 606$ predicted tropical
racemose

temperate racemose



Prunus serotina (racemose)

corymbose

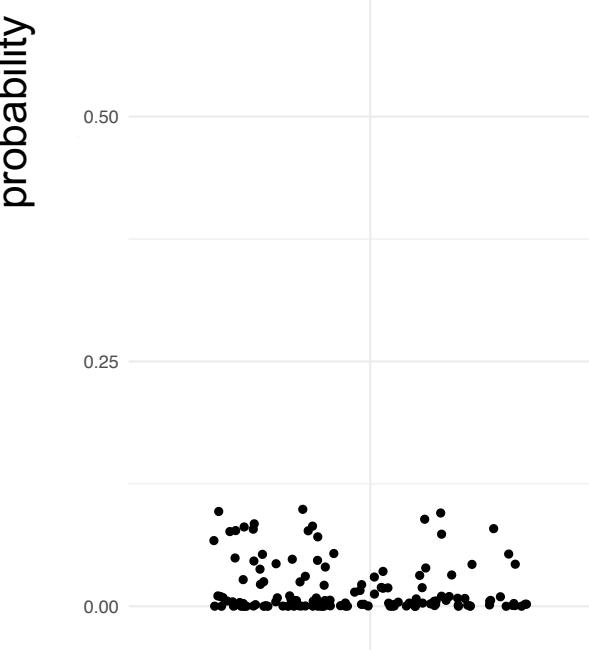


Prunus avium (corymbose)

solitary



Prunus persica (solitary)



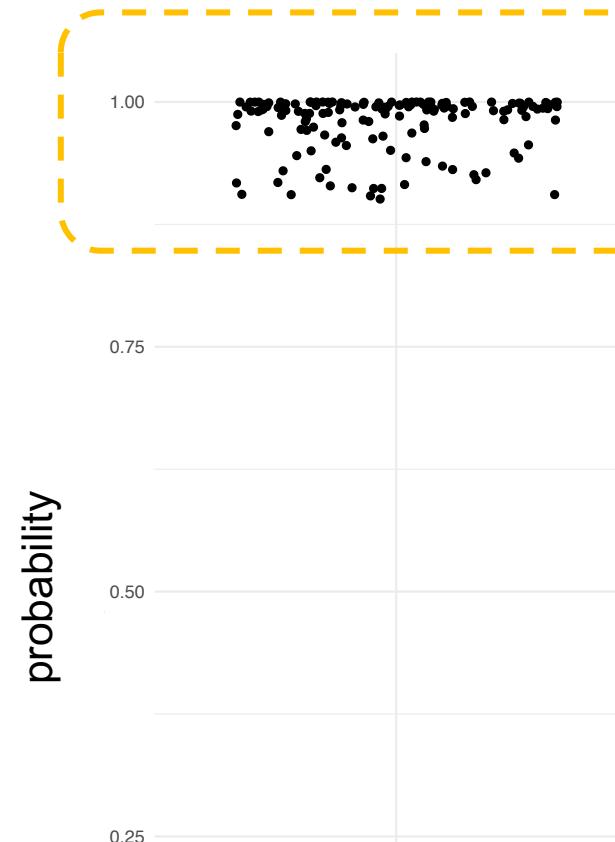
$N = 607$ predicted solitary
or corymbose

Phylogenetic hypothesis: temperate racemose evenly classified in each morphogroup

tropical racemose



Prunus ilicifolia (racemose)



$N = 606$ predicted tropical
racemose

temperate racemose



Prunus serotina (racemose)

corymbose

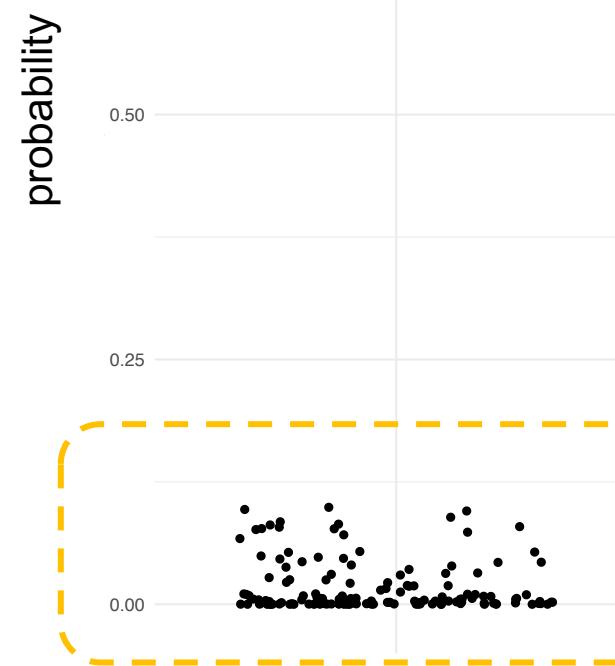


Prunus avium (corymbose)

solitary



Prunus persica (solitary)

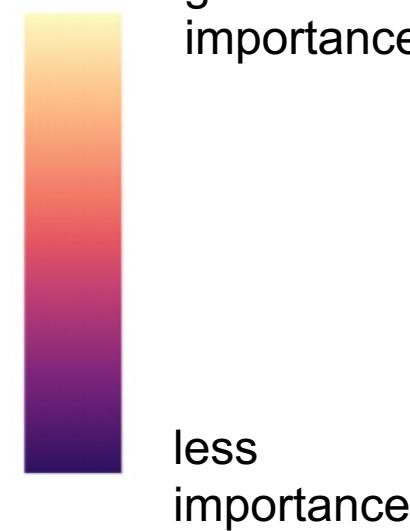


$N = 607$ predicted solitary
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What sources of morphological variation are important for classifying temperate racemose species?

What sources of morphological variation are important for classifying temperate racemose species?

Pixels



What sources of morphological variation are important for classifying temperate racemose species?

Classified 'tropical racemose'



Pixels



greater
importance

less
importance

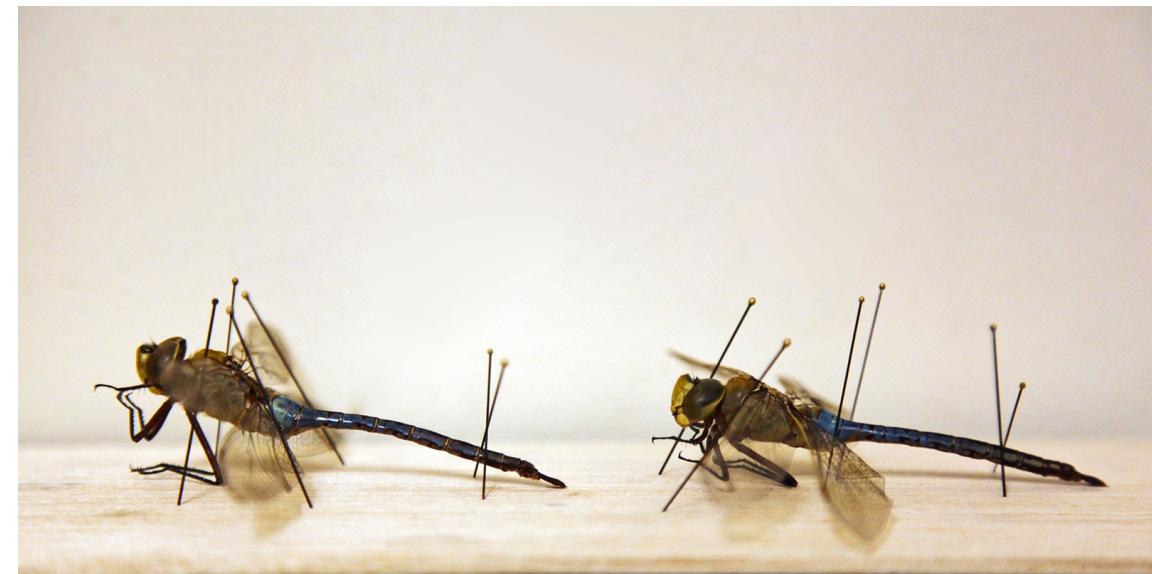
Classified 'corymbose / solitary'



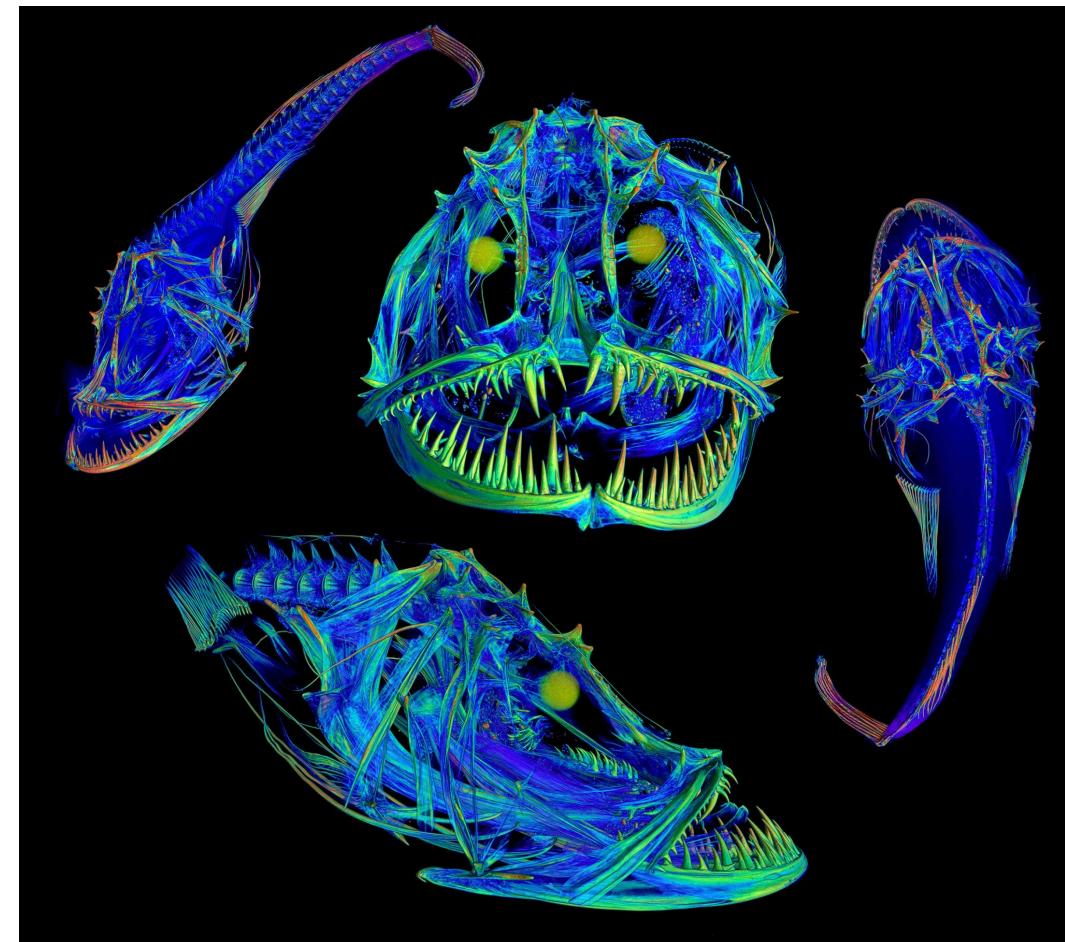
Morphological data

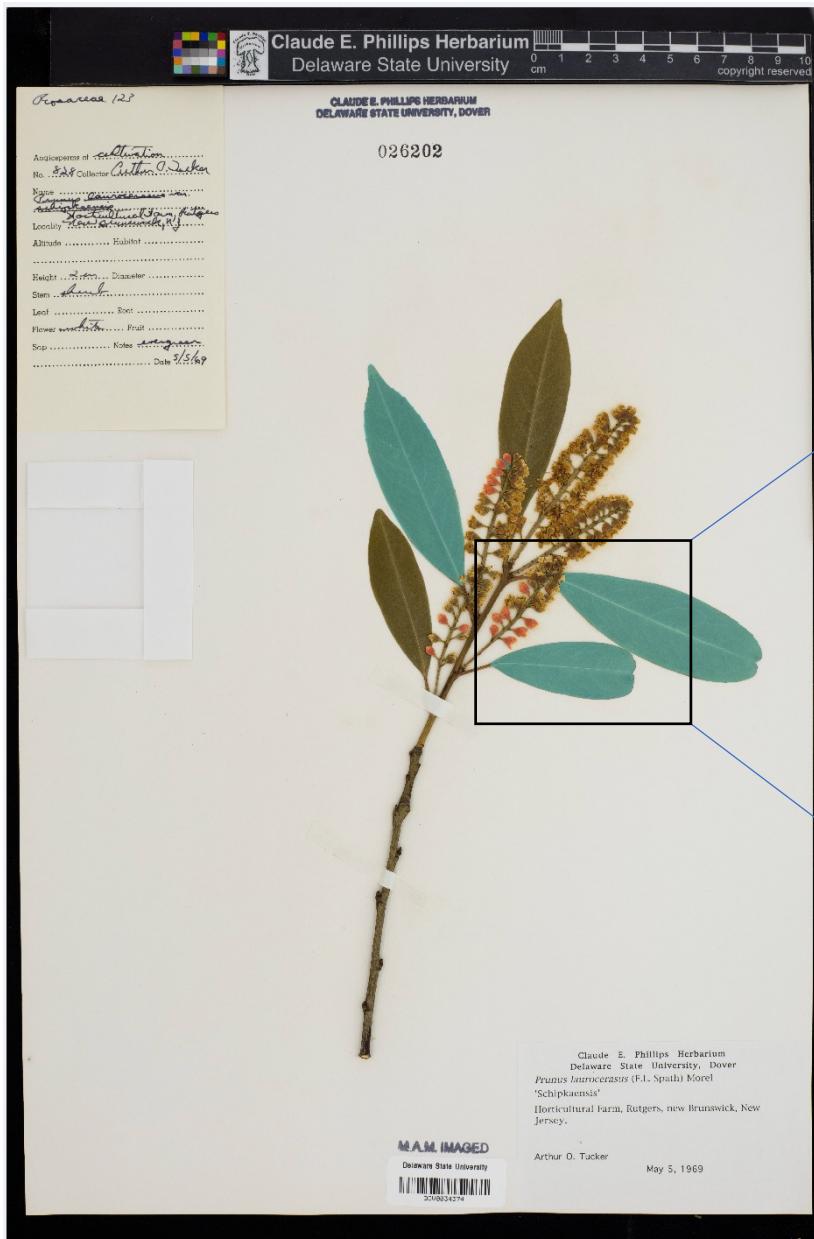
- High-throughput specimen phenotyping identifies signals of ancient hybridization
- Even when not targeting specific traits
- One of many possible applications of machine learning with specimen data -- tool to be applied creatively

Can be readily applied to many digitized specimens



Can be readily applied to many digitized specimens



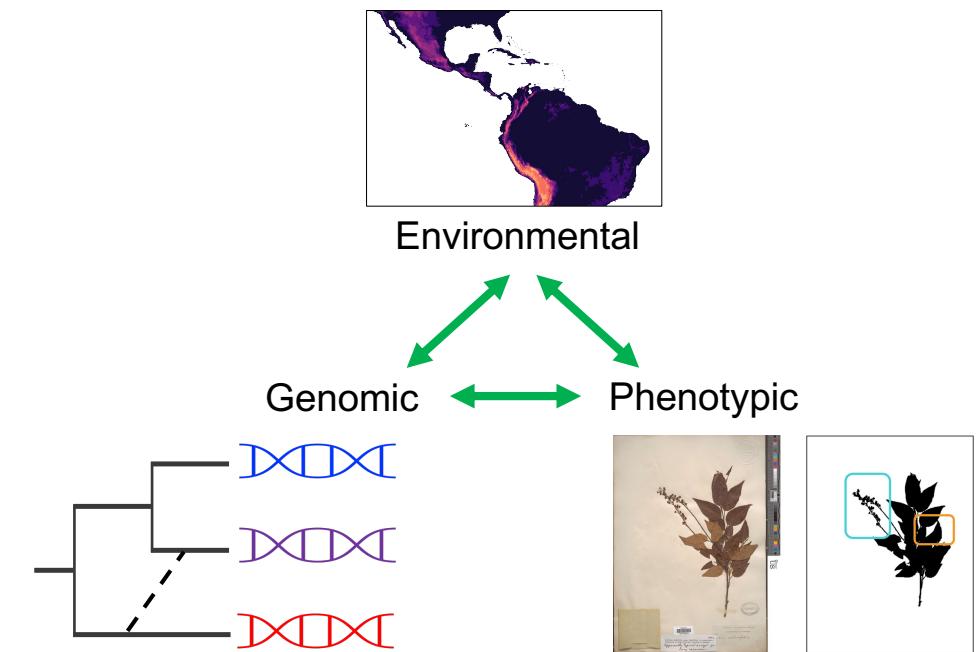


Target Specific Characters



Our understanding of North temperate forest evolution

- Many species explained by tropical conservatism hypothesis, but some are not
- Grapes: taxon pulse
- Cherries: new hypothesis needed?



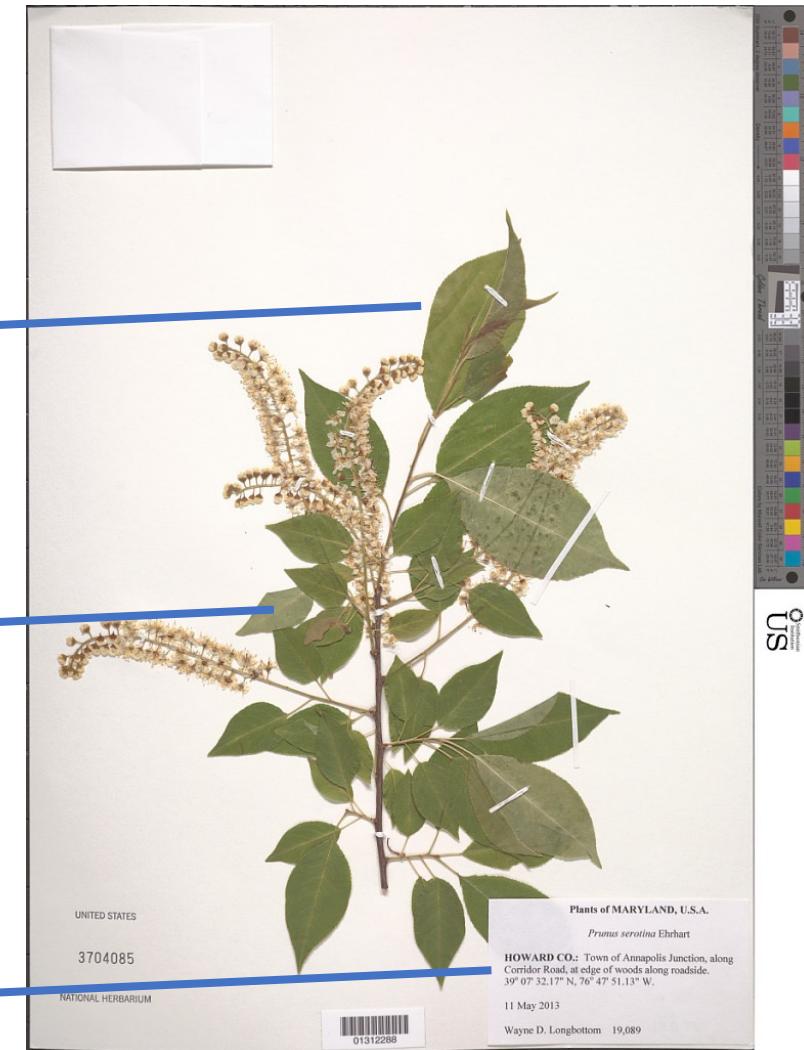
Studying museum specimens: different data types

Further investigation needed!

Genetic

Phenotypic

Environmental



Acknowledgments



Jun Wen



Alicia Talavera



Smithsonian
National Museum of Natural History



- Sundre Winslow
- Liz Zimmer
- Rebecca Dikow
- Zelong Nie
- Gabe Johnson
- Greg Stull
- Mike Trizna
- Alex White

Questions?

