Waking up from a Taxonomist's Nightmare: Progress Towards a Phylogeny of *Boechera* (Brassicaceae).

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Löve and Löve (1976) created the genus in honor of Tyge Böcher, based on chromosome numbers:

Boechera: n=7 Arabis: n=8





Molecular phylogenetic analyses have confirmed Löve & Löve's split of *Boechera* from *Arabis* 

- 110 species, all but one (Boechera falcata) endemic to North America
- 72 sexual diploids, remainder are apomictic triploid hybrids
- Boechera comprises most of the tribe Boechereae, which also includes:
  - Anelsonia
  - Borodinia
  - Cusickiella
  - •Nevada

- Phoenicaulis
- Polyctenium
- Sandbergia



• due in part to the close relationship of the genus to *Arabidopsis*, *Boechera* has become a model system for a wide variety of studies, including:

- apomixis
- evolution of genes & gene families
- local adaptation

- plant/pathogen interactions
- polyploid hybrid speciation

• however, poor understanding of the taxonomy and phylogeny of *Boechera* imposes a constraint on these studies







# Resolving phylogeny of Boechera

present efforts focus on the diploid species

• once the underlying framework of diploid *Boechera* species and their phylogeny is established, the superstructure of hybridization can be laid on top of it



# Methods

• preliminary phylogenetic analyses include 38 of the 72 diploid *Boechera*, and representatives of other Boechereae except *Borodinia* & *Cusickiella* 

• accessions used have data for  $\geq$  seven of:

- two chloroplast loci:
  - trnL-F
  - *trnK-rps*16
- one nuclear ribosomal locus:
  - ITS

•six low-copy nuclear loci:

- alcohol dehydrogenase
- chalcone synthase
- dpa1
- luminidependens
- *nuo*
- pistillata



Methods

• prior to phylogenetic analysis, gaps were coded as characters using simple indel coding of Simmon & Ochoterena (2000) as implemented in SeqState

• including gaps, parsimony-informative characters per locus are as follows:

• trnL-F	113	
• trnK-rps16	73	
• ITS	79	
<ul> <li>alcohol dehydrogenase</li> </ul>	84	
<ul> <li>chalcone synthase</li> </ul>		IO
• dpa1	67	
<ul> <li>luminidependens</li> </ul>	76	
• NU0	24	
• pistillata		14
• plastid	186	
• nuclear	584	
• total	770	

# Methods

- phylogenetic analyses are as follows:
  - heuristic parsimony searches conducted in NONA spawned from WinClada (500 random addition replicates; 20 trees per replicate; swapping to 10001 trees)
  - support is estimated with 1000 jackknife replicates in TNT (courtesy of Willi Hennig Society; JK replicates conducted with "new technology search" including parsimony ratchet, sectorial search, tree drift, and tree-fusing)





Phylogeny produced by the complete data set

non-*Boechera* are yellow to red *Boechera* are cyan to purple

### plastid phylogeny

### nuclear phylogeny





# We'll stick with the complete data set for the moment...

### Boechereae I: Polyctenium + Cusickiella

• Polyctenium: Polyctenium fremontii Polyctenium williamsiae





### Boechereae I: Polyctenium + Cusickiella

• Cusickiella:

Cusickiella douglasii Cusickiella quadricostata





### Boechereae II: Phoenicaulis

#### Phoenicaulis cheiranthoides





# Boechereae II: Phoenicaulis cheiranthoides



# Boechereae III: Sandbergia

#### Sandbergia whitedii

formerly included in *Halimolobos* 





• Nevada: Nevada holmgrenii





• Anelsonia: Anelsonia eurycarpa





• Boechera outliers: 1 Boechera repanda







Boechereae IV: Boechera repanda



### Boechereae IV: eastern North American clade





## Boechereae IV: eastern North American clade: *Boechera laevigata*







### Boechereae IV: eastern North American clade: *Boechera missouriensis*







Boechereae IV: eastern North American clade: Boechera canadensis



### Boechereae V: main Boechera clade



Boechera, main clade: ± 104 spp.
largely allopatric from the eastern N.A. clade

### Boechereae V: main *Boechera* clade



## Boechereae V: main Boechera clade: Boechera davidsonii





Boechereae V: main *Boechera* clade: *Boechera stricta*  Boechereae V: main Boechera clade: Boechera holboellii complex: Boechera retrofracta



### Conclusions

Boechereae consists of 5 lineages:

POLYCTENIUM + CUSICKIELLA PHOENICAULIS SANDBERGIA ANELSONIA, NEVADA, BOECHERA outliers main BOECHERA clade



## Conclusions

- Boechera is not monophyletic, and consists of at least three lineages:
  - Boechera repanda
  - an eastern North American clade of 4 species
  - a western North American clade containing most of the genus



# Future research

- research is ongoing to:

  - increase taxon sampling
    use additional nuclear loci
    reduce missing data



