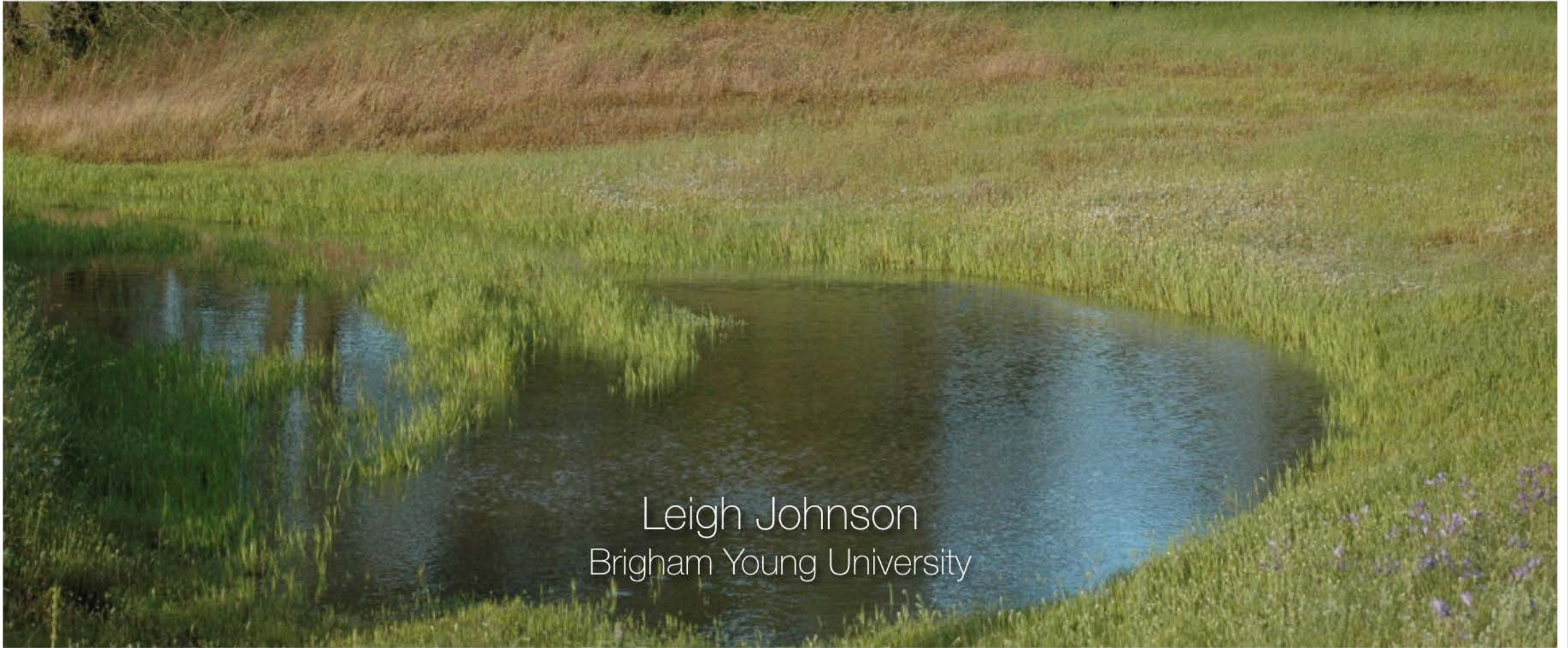




Vernal pool Navarretia and their near relatives: what we know and what we have yet to learn about relationships & genetic structure



Leigh Johnson
Brigham Young University



Navarretia Ruiz & Pav.

- 47 species; annual, mostly spinescent
- Western North Am. (46), South Am. (1)
 - 43 in California; 34 only in California
 - 3 federally listed taxa
 - Vernal pool & serpentine endemism
- Putatively divergent (bifurcating) evolution among diploid species





Navarretia Ruiz & Pav.

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 - 43 in California; 34 only in California
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 - Vernal pool & serpentine endemism
- Putatively divergent (bifurcating) evolution among diploid species

Sect. *Navarretia*: 14 species + 7 subspecies

- Early diverging species in marginal habitats + “core vernal pool clade”





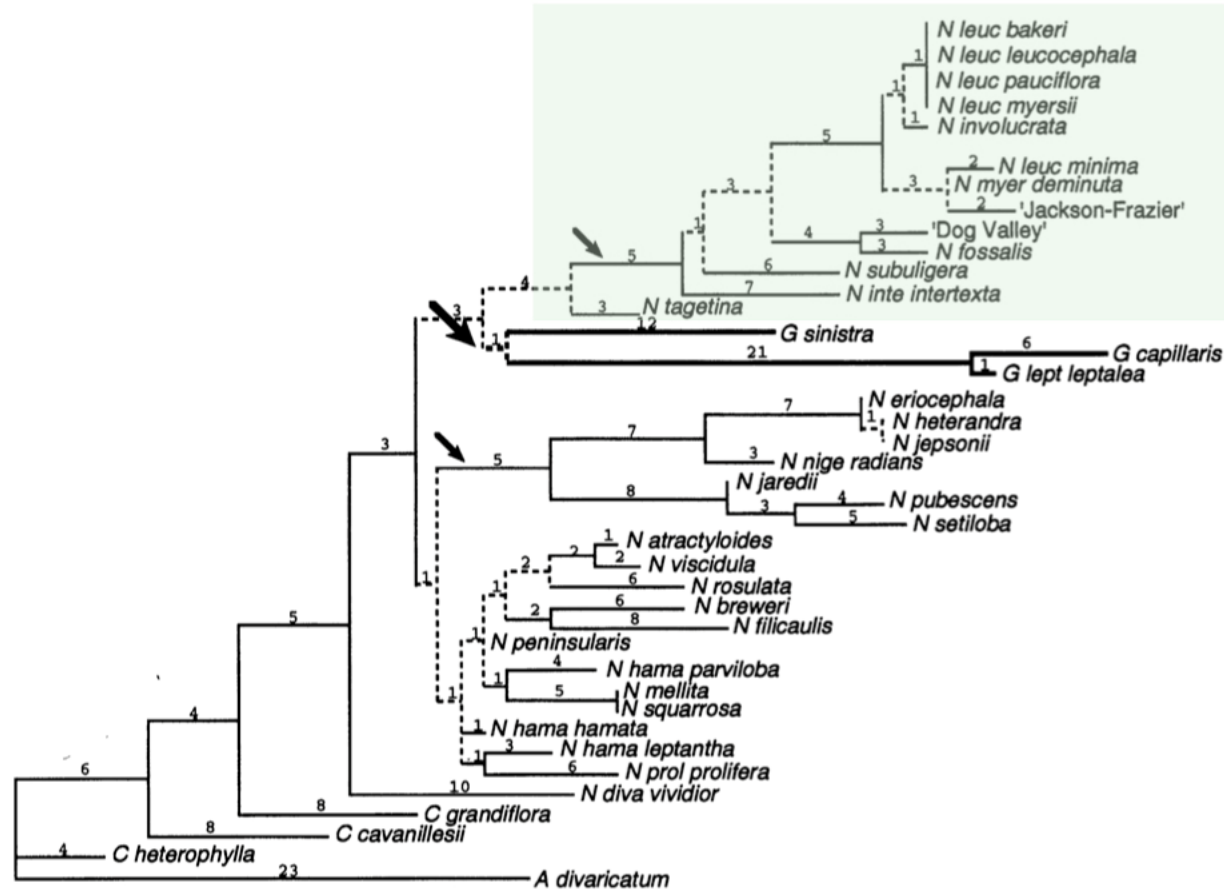
Evolution of Vernal Pool Species

- Vicariance vs. dispersal ?
- Gene flow vs. genetic isolation ?
- Correlated specializations ?
- Adaptations or stochastic fixation ?
- Is morphological differentiation a consequence of small founding populations?
- Federal/State listing/delisting?
- Taxon boundaries & evolutionary significant units?

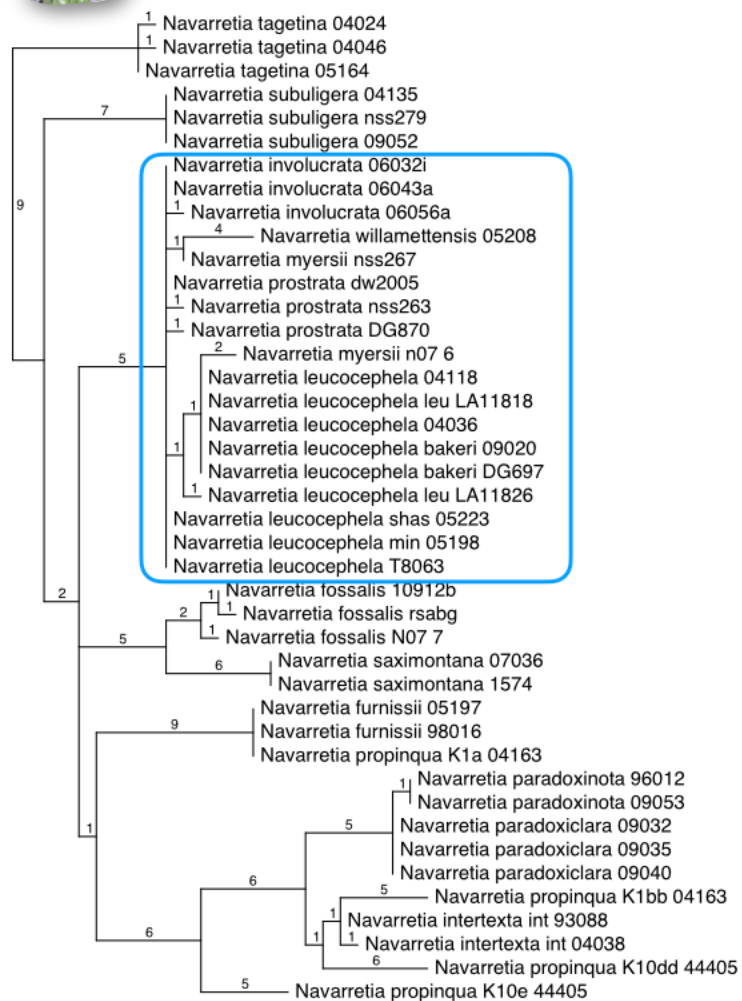




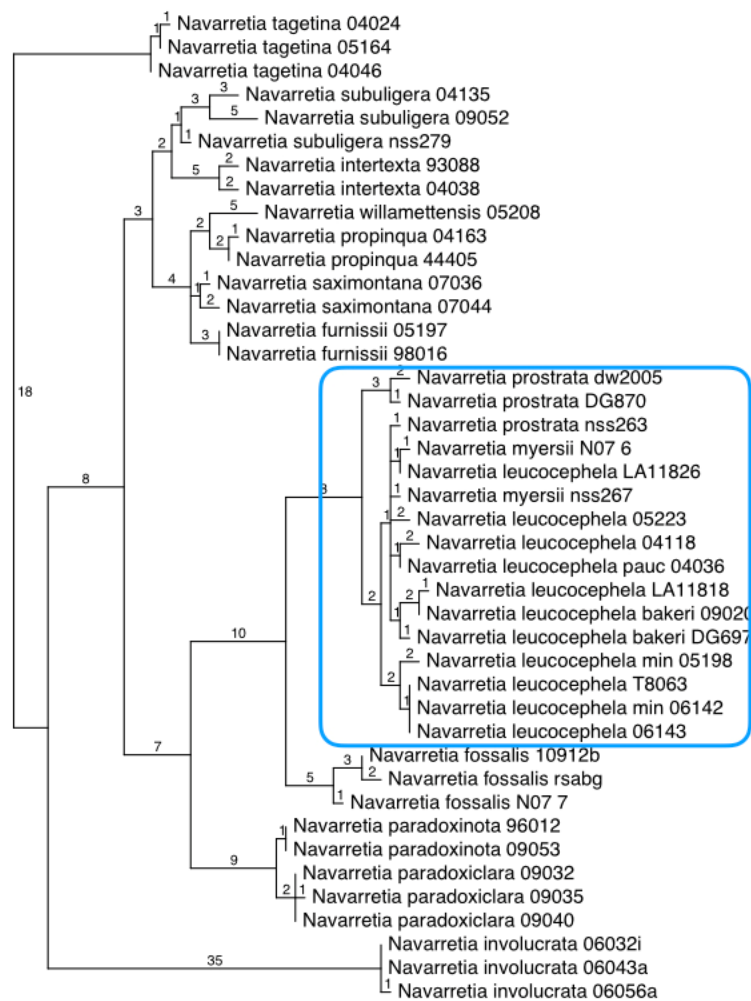
Navarretia section Navarretia



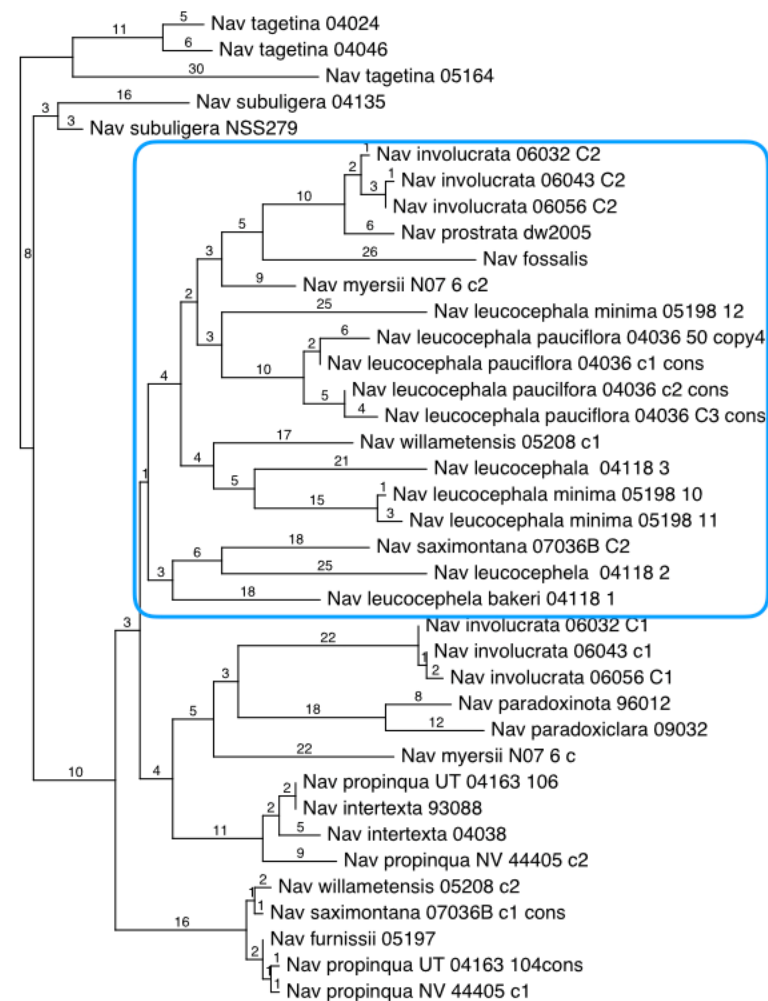
- Spencer & Porter (1996) - Morphology & ITS-based relationships
- Spencer & Rieseberg (1998) - Adaptive evolution



nuITS



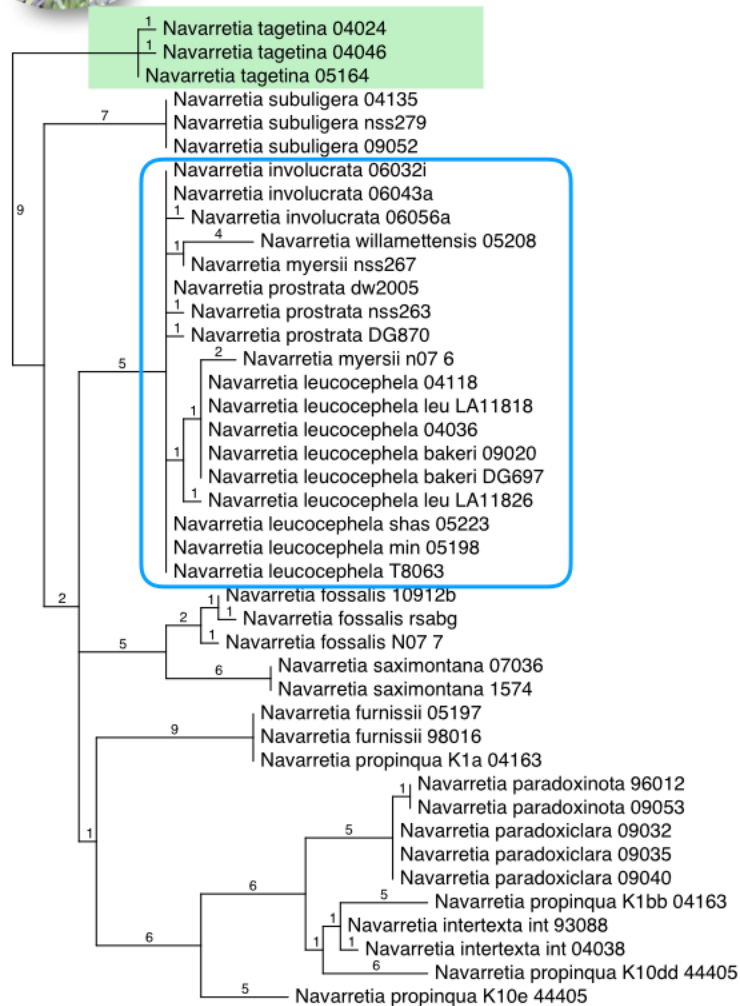
cpDNA



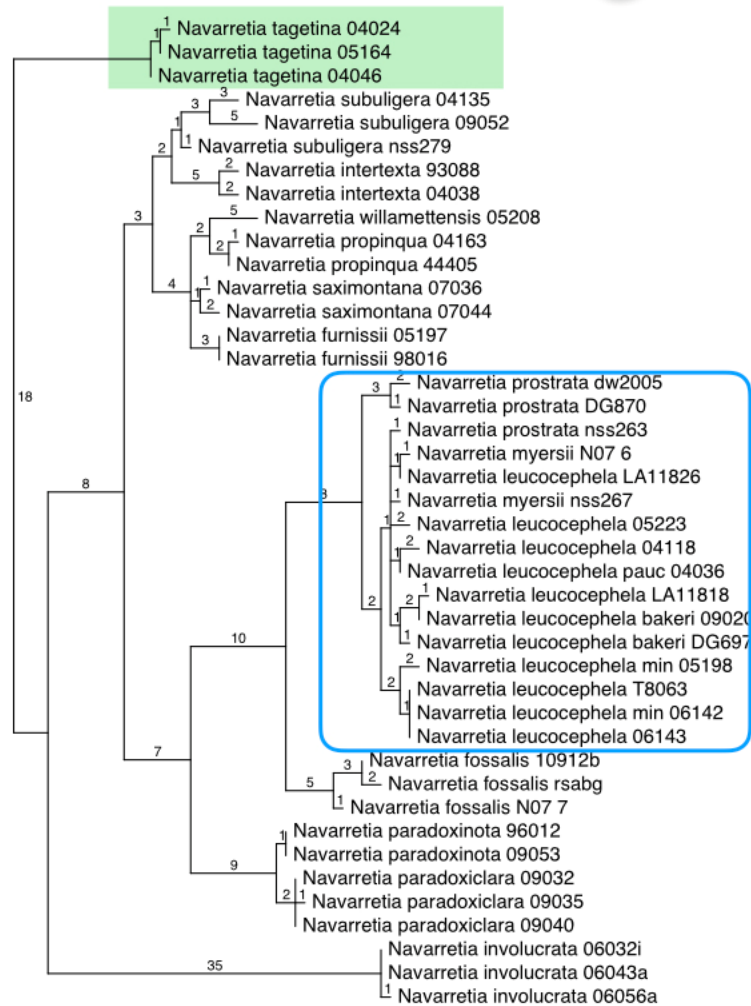
nuPistillata



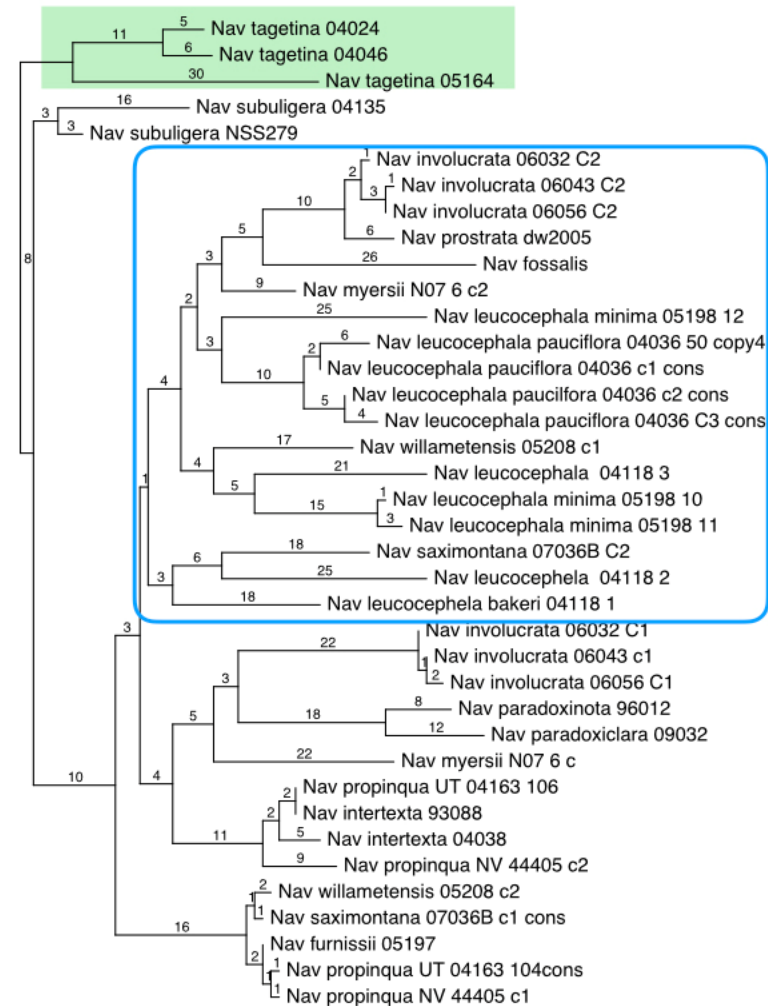
Navarretia tagetina



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cpDNA



nuPistillata



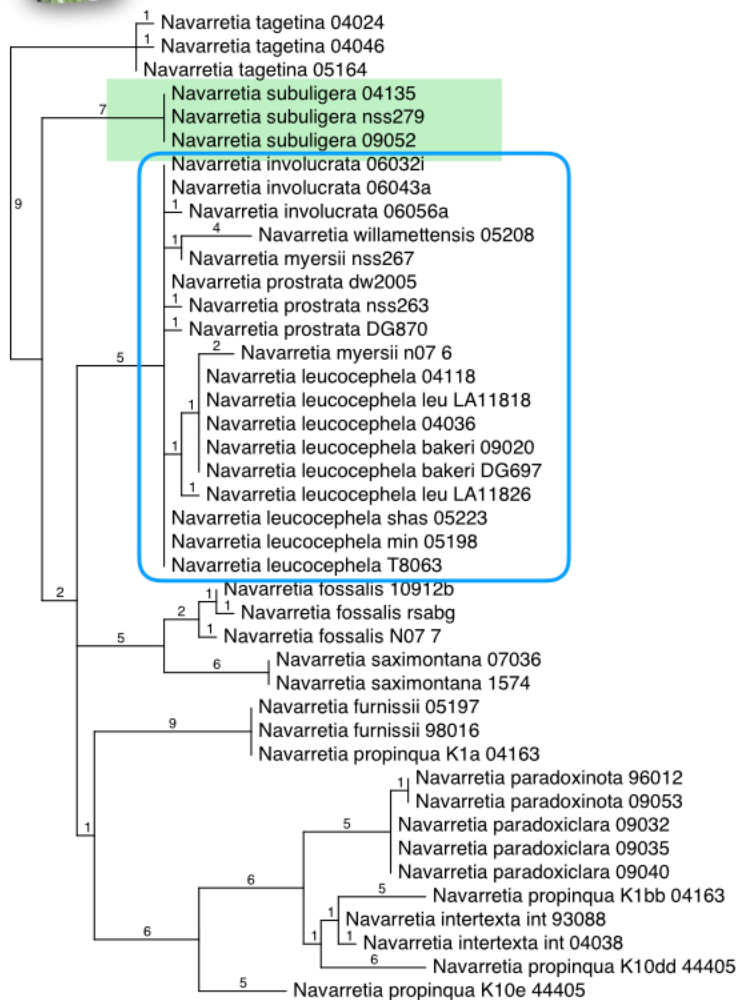
Navarretia tagetina

- Sister to rest of section *Navarretia*
 - 3 stigmatic lobes
 - Upright habit
 - Yellow pollen
 - White to blue corollas
 - Many lobes on bracts
- Shallow depressions, margins of areas with longer inundation

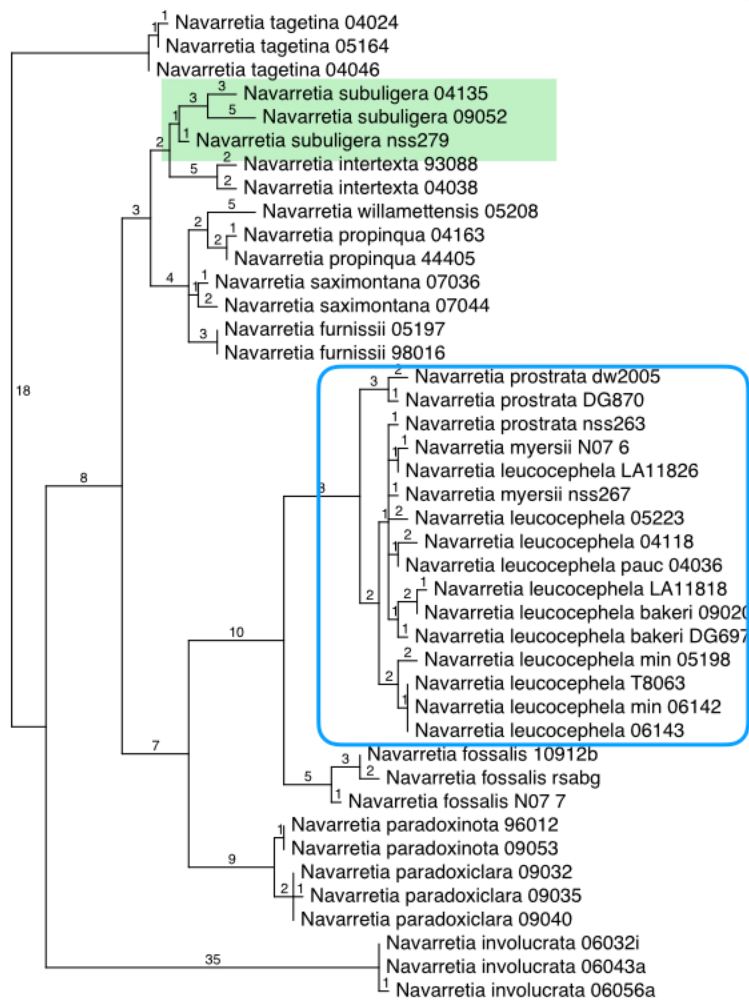




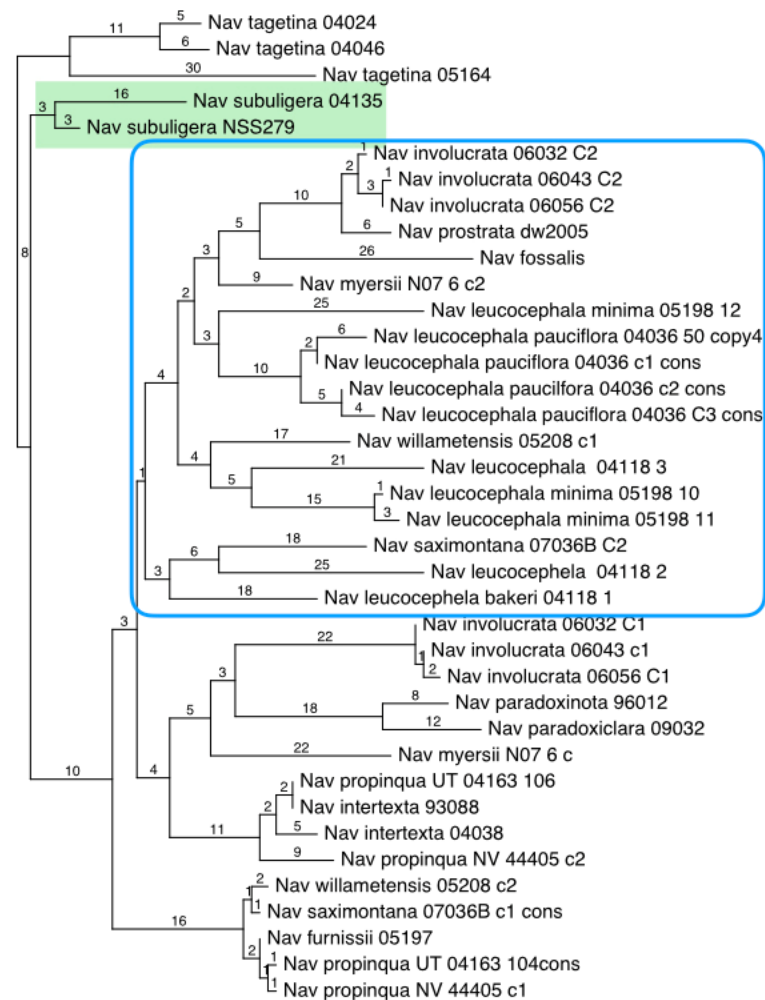
Navarretia subuligera



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nuPistillata



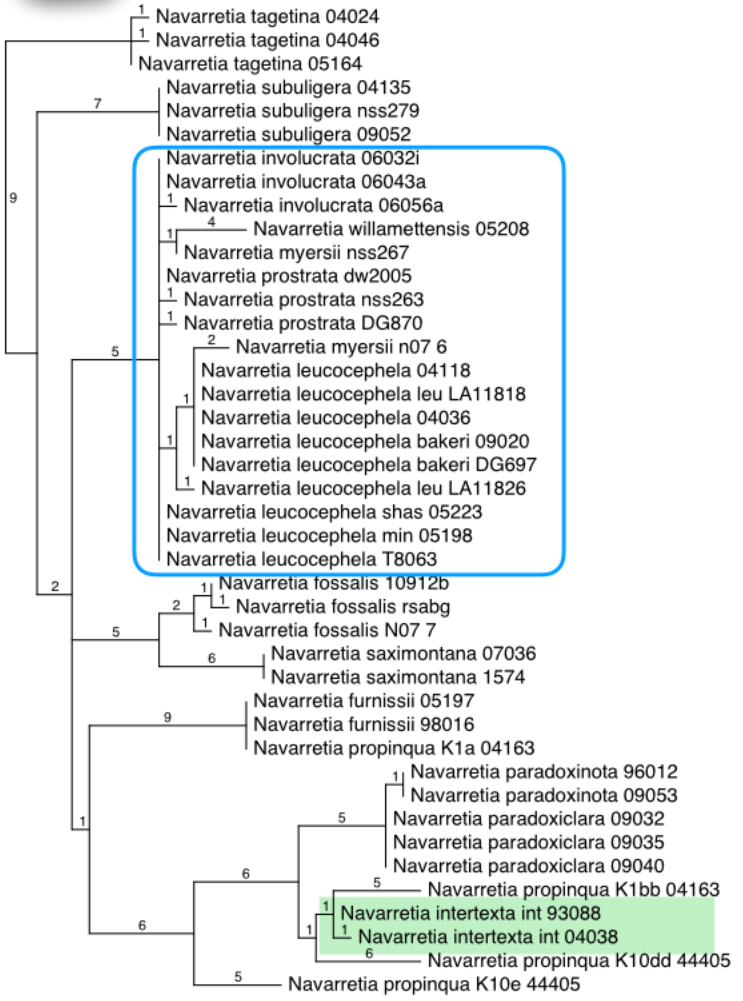
Navarretia subuligera

- Sister to rest of section *Navarretia* exclusive of *N. tagetina*; possible introgression (cpDNA)
- 3 stigmatic lobes
- Upright habit
- Yellow pollen
- White corollas
- Unlobed calyces
- Not very hairy
- Shallow depressions, streamlets, margins of areas with longer inundation

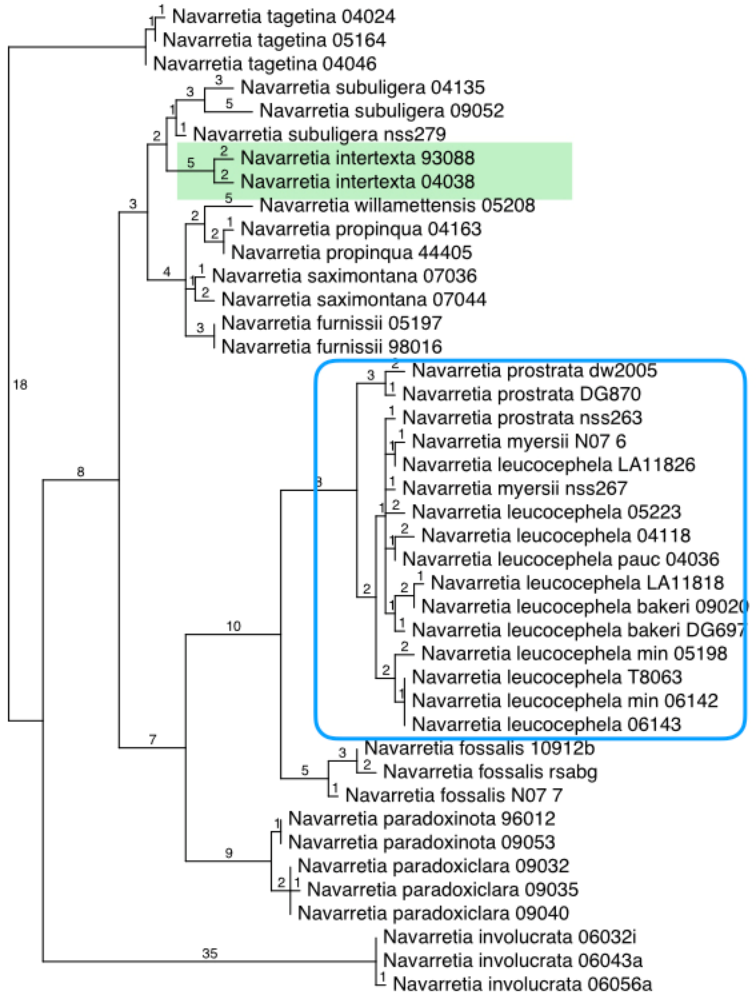




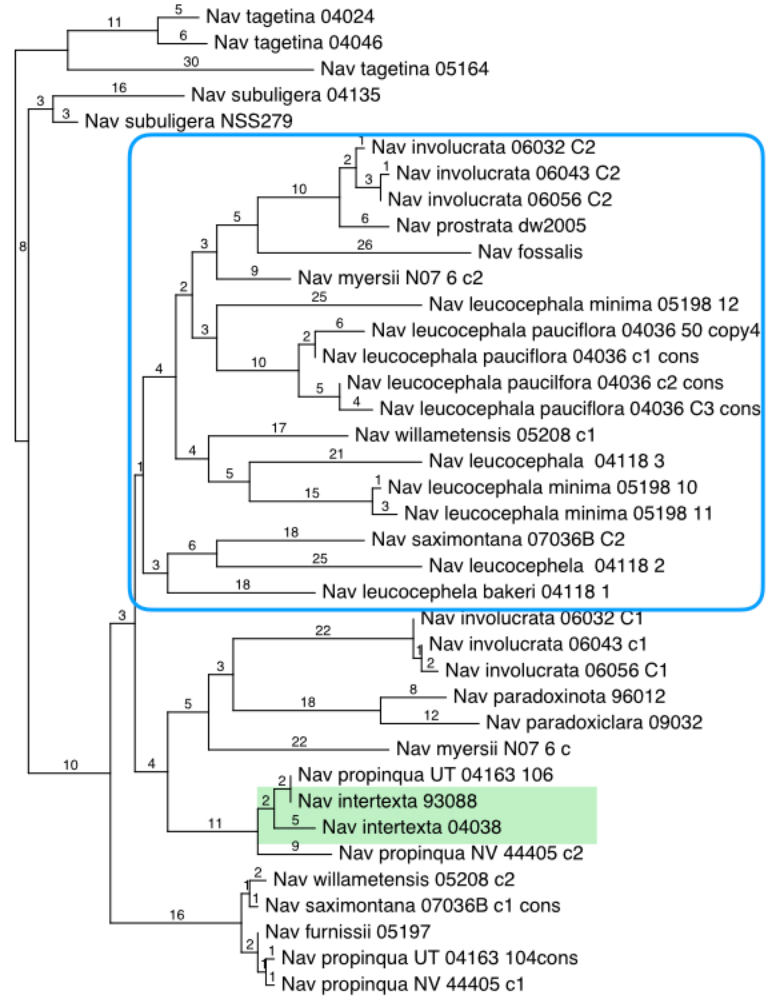
Navarretia intertexta



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nuPistillata



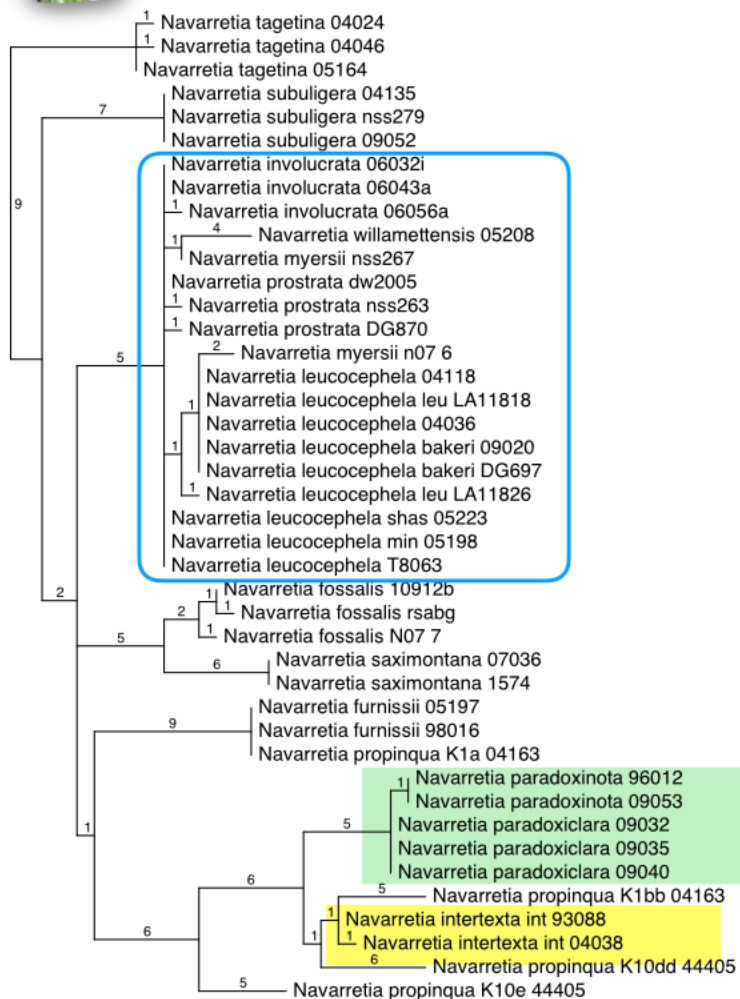
Navarretia intertexta

- Not part of the VP clade
- 2 stigmatic lobes
- Upright habit
- Yellow pollen; stamens exerted beyond corolla lobes
- White to blue corollas
- 3-pronged bracts
- hairy
- Shallow depressions, streamlets, margins of areas with longer inundation; widespread W. N. Am.

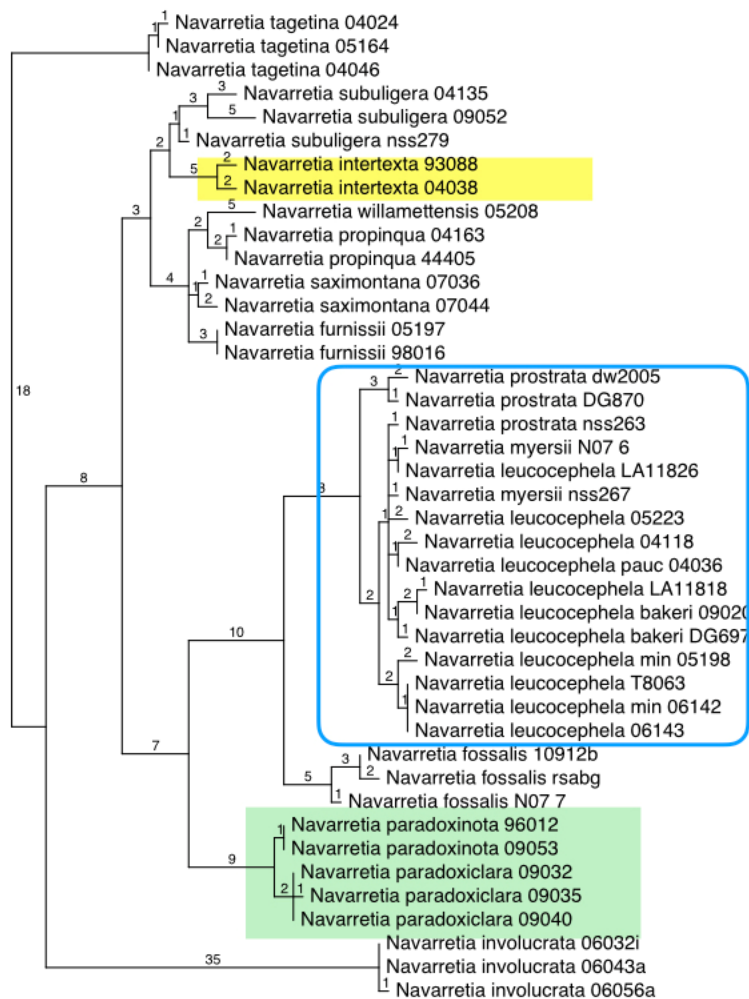




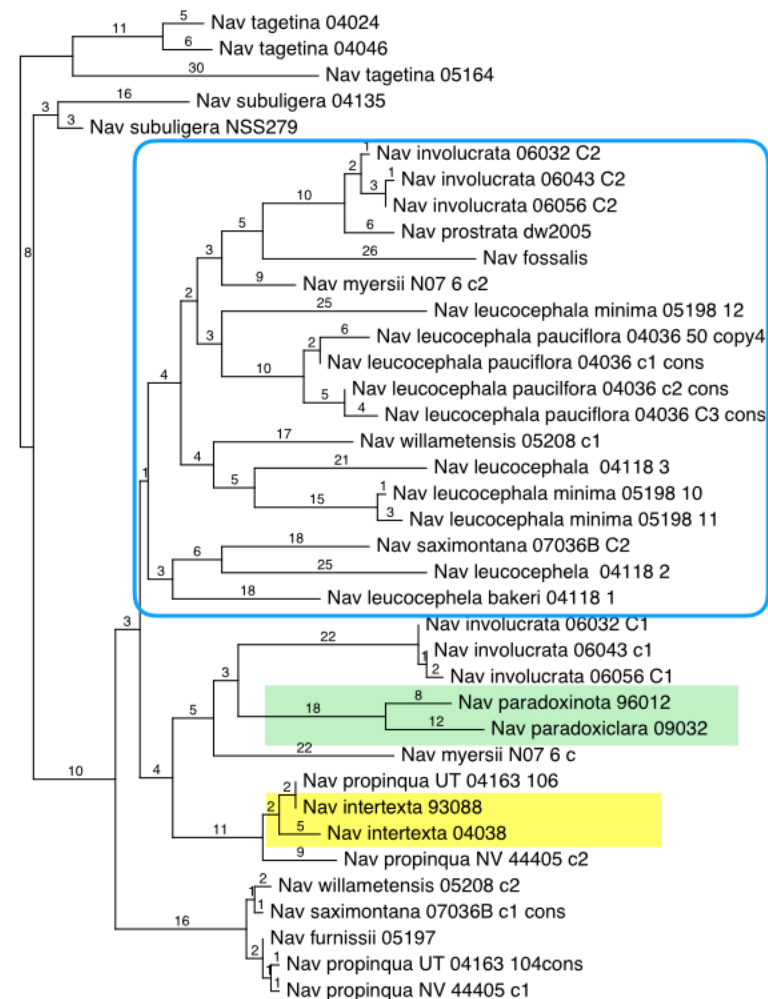
N. paradoxinota & *N. paradoxiclara*



nuITS



cpDNA

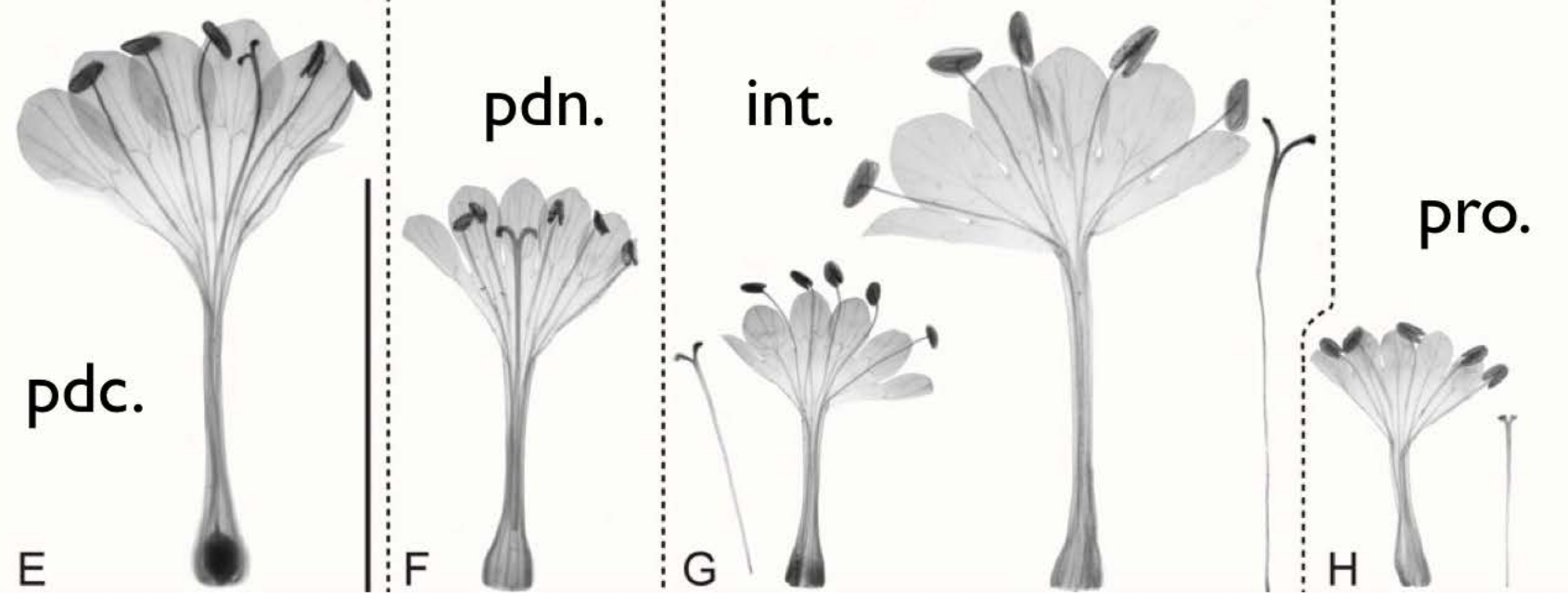


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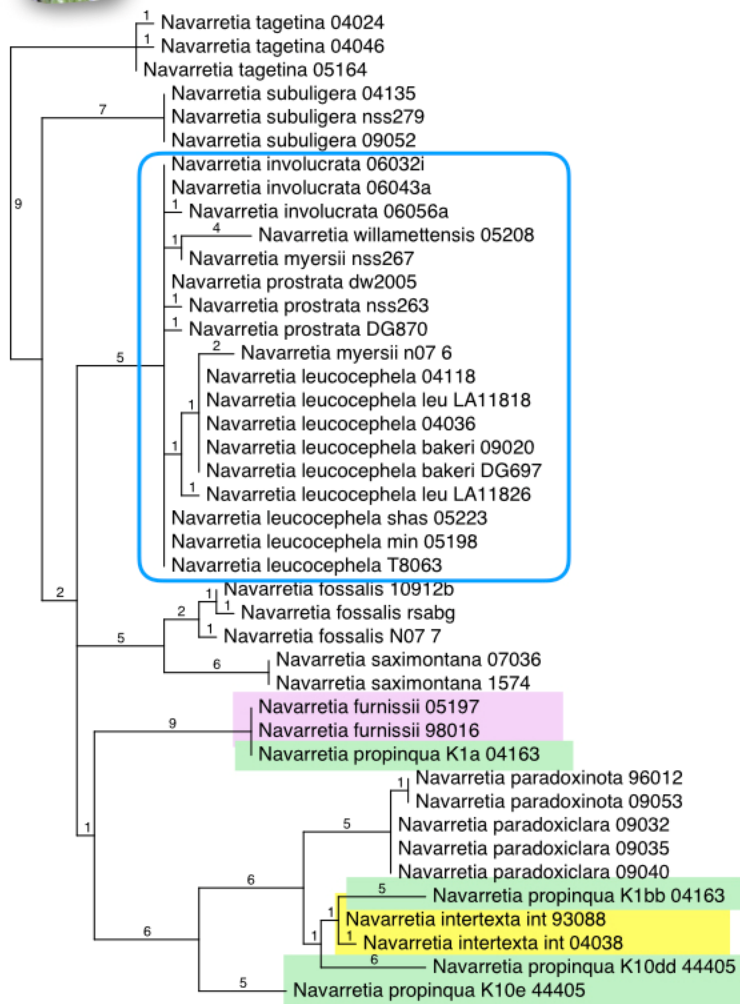
N. paradoxinota & *N. paradoxiclara*

- Morphologically similar to *N. intertexta*, but genetically distinct
- 2 stigmatic lobes
- Upright habit
- Yellow pollen; stamens exerted less than corolla tips
- White to blue corollas (*paradoxinota* white only)
- Affiliated with serpentine influenced soils

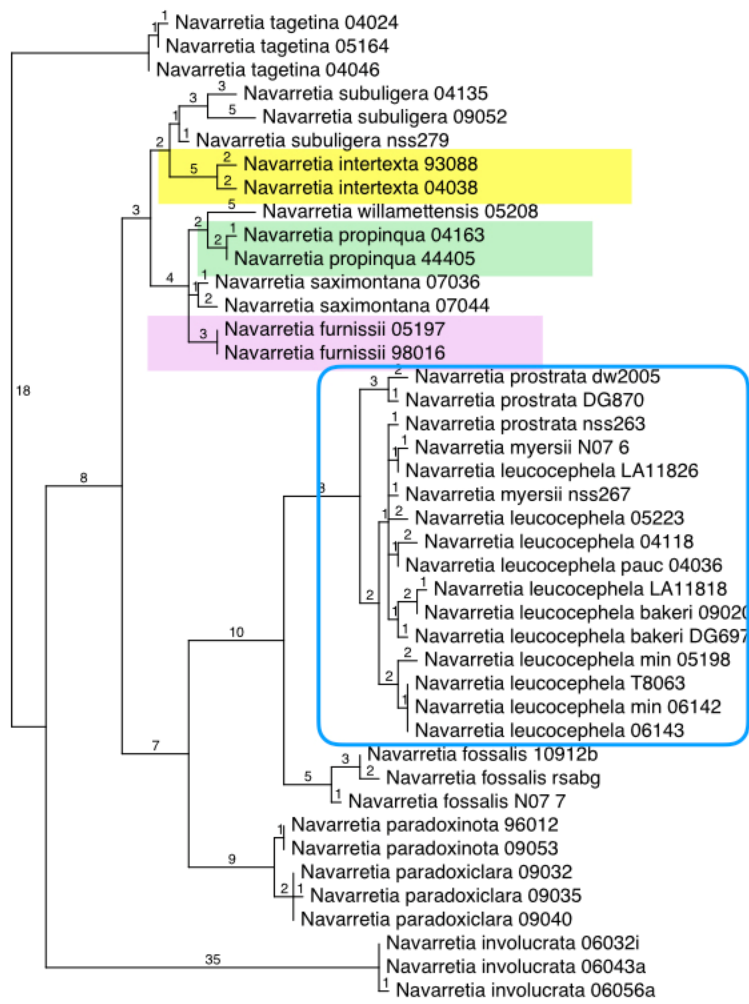




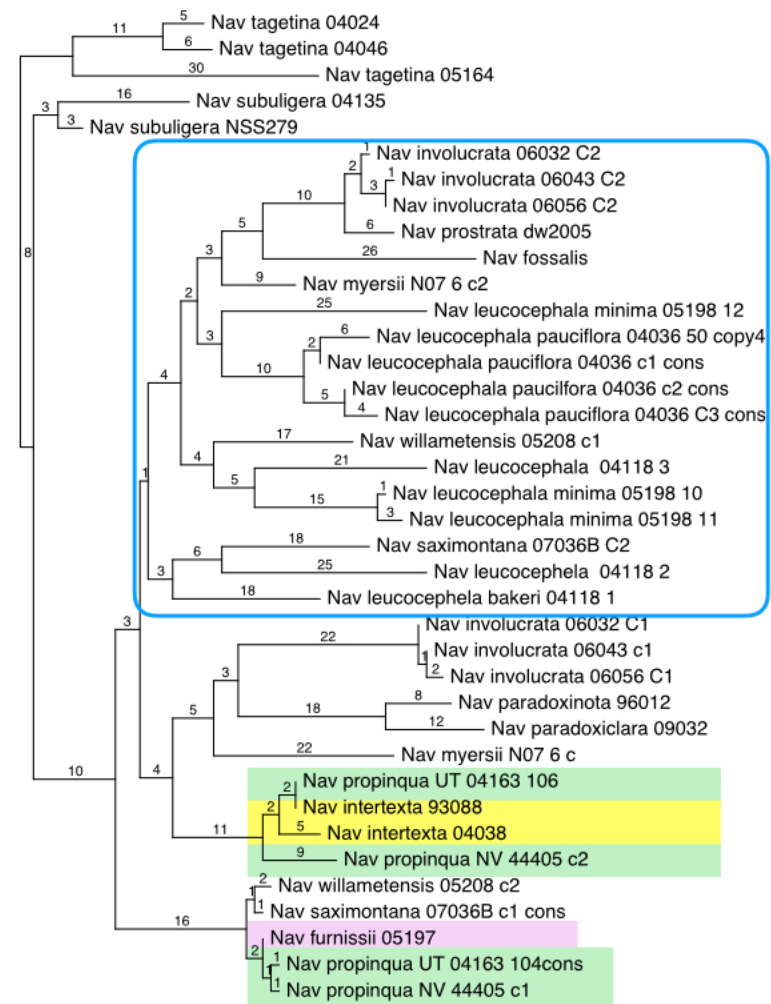
Navarretia propinqua



nuITS



cpDNA



nuPistillata



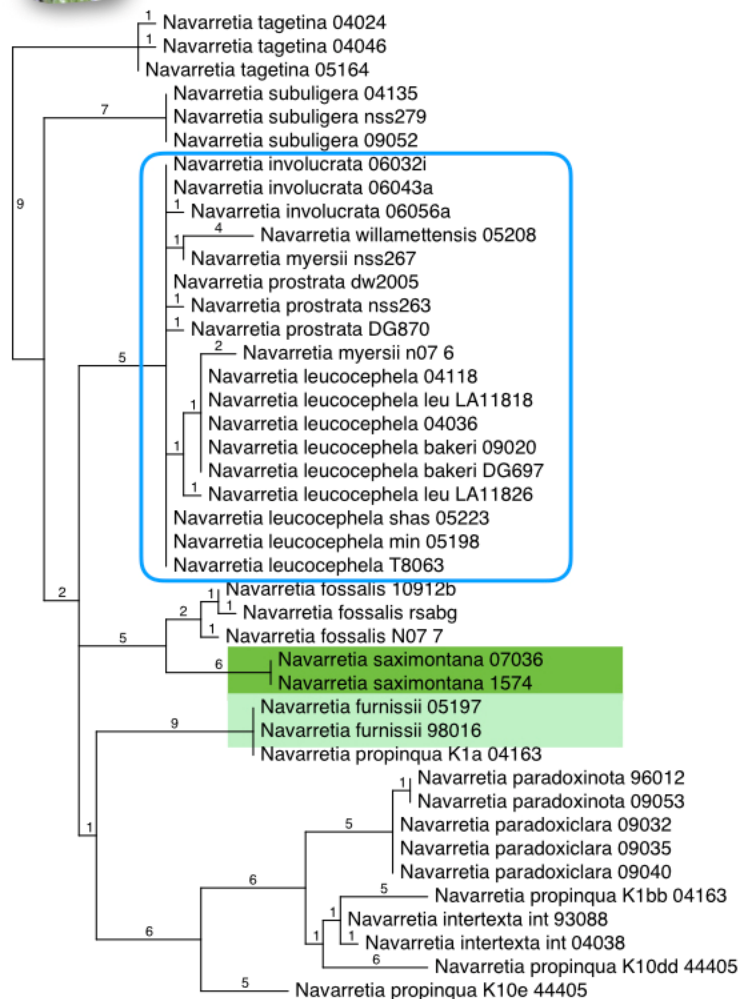
Navarretia propinqua

- Morphologically similar to *N. intertexta*, but smaller. deeper blue-green
- 2 stigmatic lobes
- spreading habit
- Yellow pollen; stamens exerted to corolla tips
- White to blue corollas
- Allopolyploid with *N. intertexta* generally the father and *N. furnissii* the mother (reversed in Arizona, some *N. California* populations).

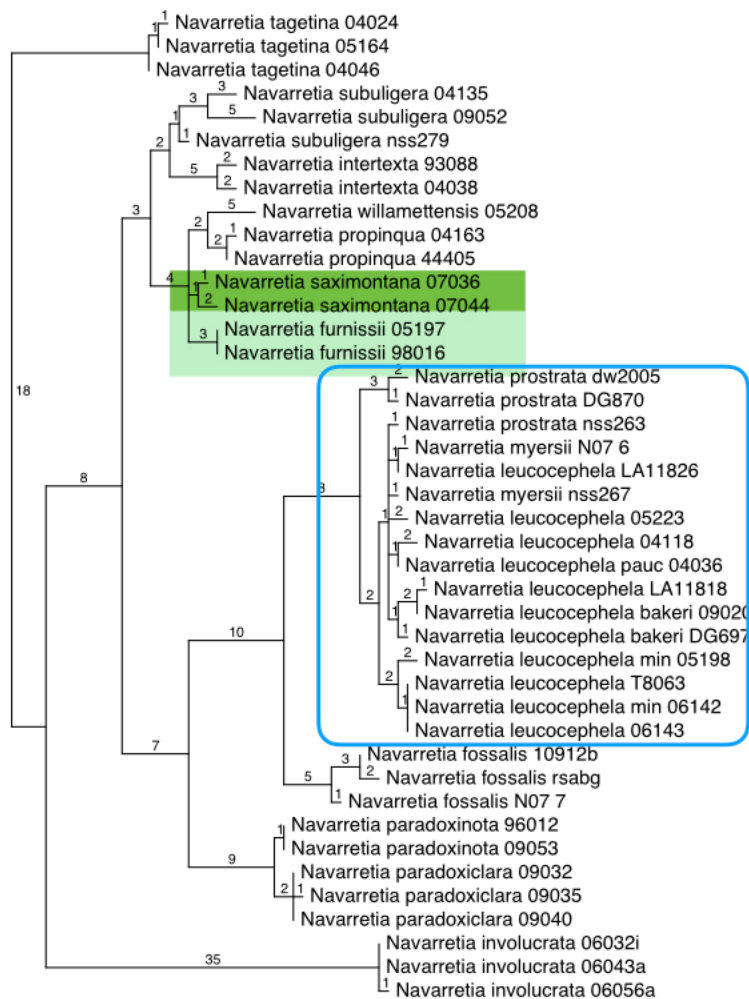




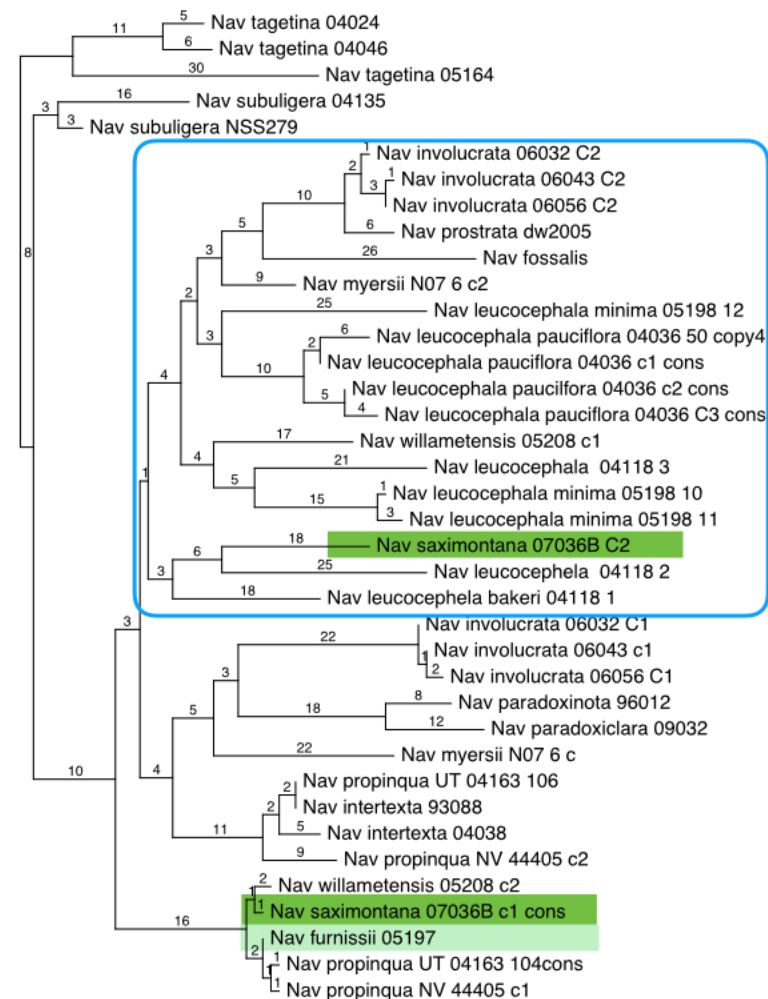
N. furnissii & *N. saximontana*



nuITS



cpDNA



nuPistillata

N. furnissii



- Morphologically similar to *N. propinqua*, but smaller, yellow green in comparison
- 2 stigmatic lobes
- spreading habit
- Yellow pollen; anthers in throat
- White (to blue) corollas, 4 mm long
- 2 calyx lobes usually 3-pronged
- Diploid species of Rocky Mtns; depressions, rivlets, disturbed areas



N. saximontana



- Morphologically similar to *N. propinqua*, but smaller, yellow green in comparison
- 2 stigmatic lobes
- spreading habit
- Yellow pollen; anthers in throat
- White to blue corollas, 5mm long
- All calyx lobes generally entire
- Tetraploid species of Rocky Mtns; depressions, ephemeral pool margins





N. saximontana

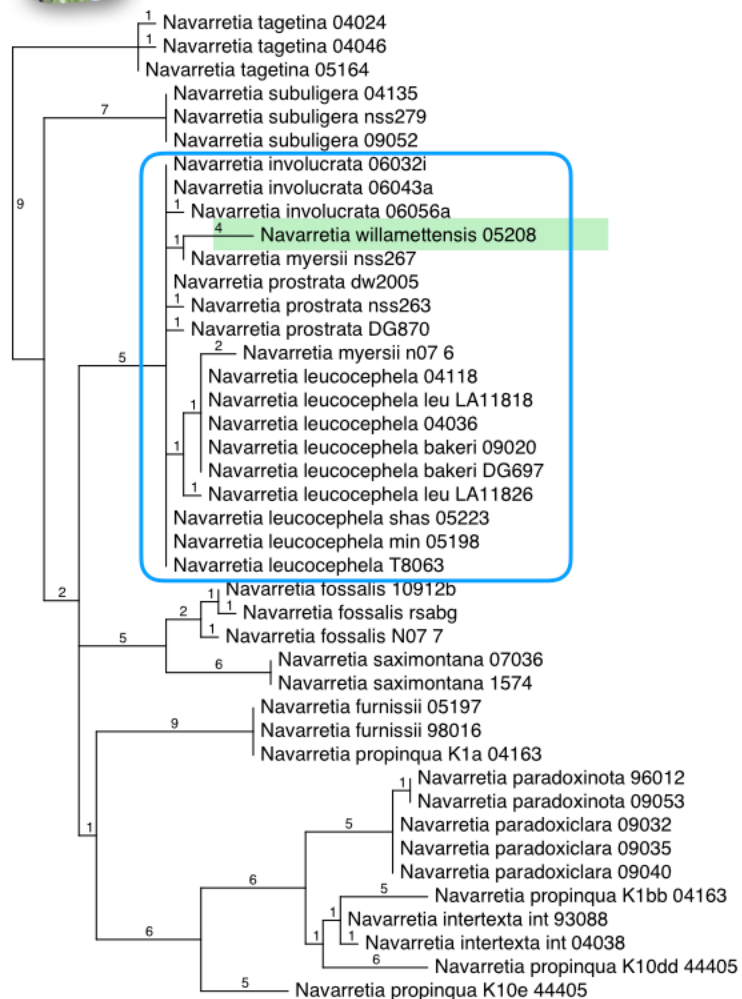
- Morphologically similar to *N. propinqua*, but smaller, yellow green in comparison
- 2 stigmatic lobes
- spreading habit
- Yellow pollen; anthers in throat
- White to blue corollas, 5mm long
- All calyx lobes generally entire
- Tetraploid species of Rocky Mtns; depressions, ephemeral pool margins



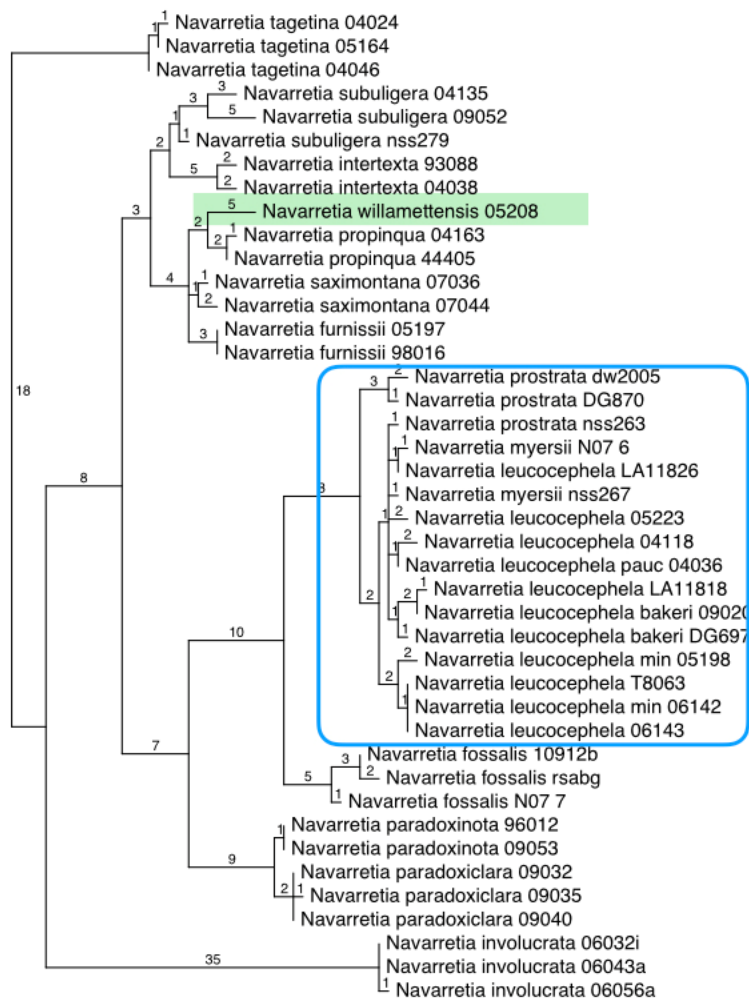
Stoneman Lake, Ariz.



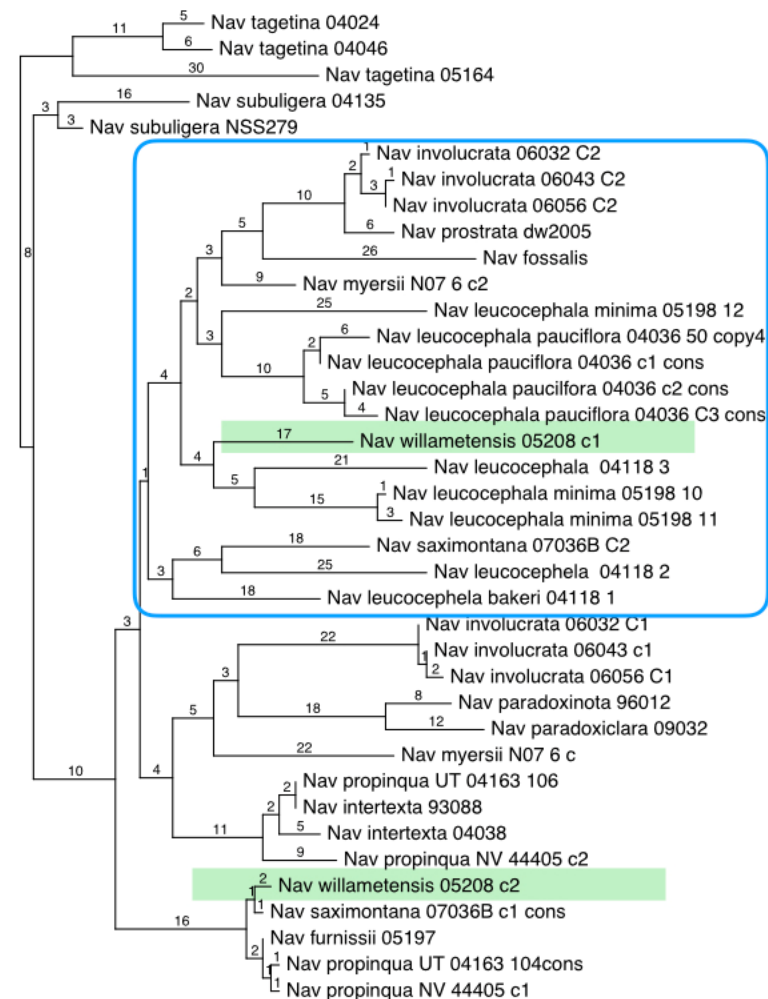
Navarretia willamettensis



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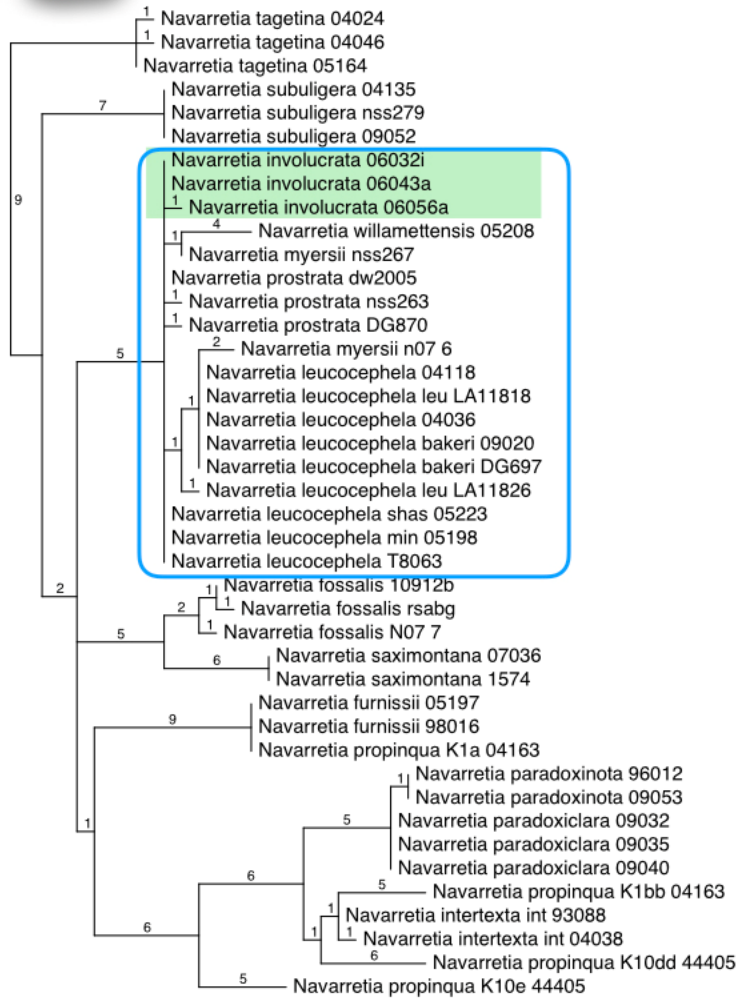
Navarretia willamettensis

- Morphologically similar to *N. intertexta*
- 2 stigmatic lobes
- Upright habit
- Cream pollen; anthers to mid corolla lobes
- Light blue to white corollas
- Allotetraploid ? possibly between *N. furnissii* and *N. leucocephala* ssp. *minima*? very localized in Oregon

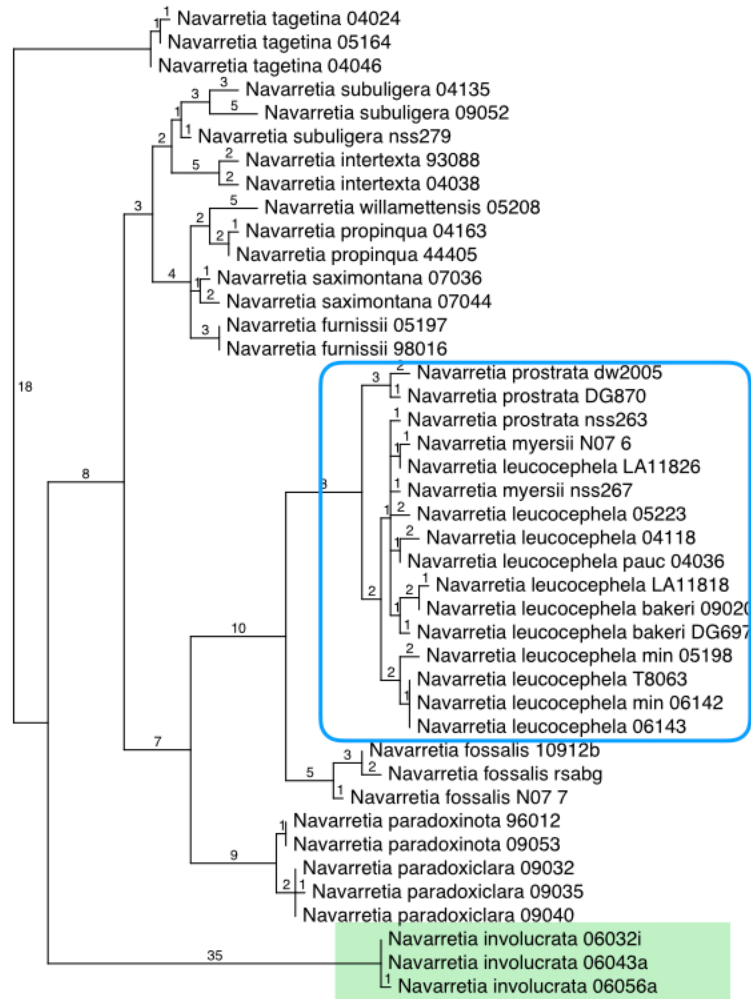




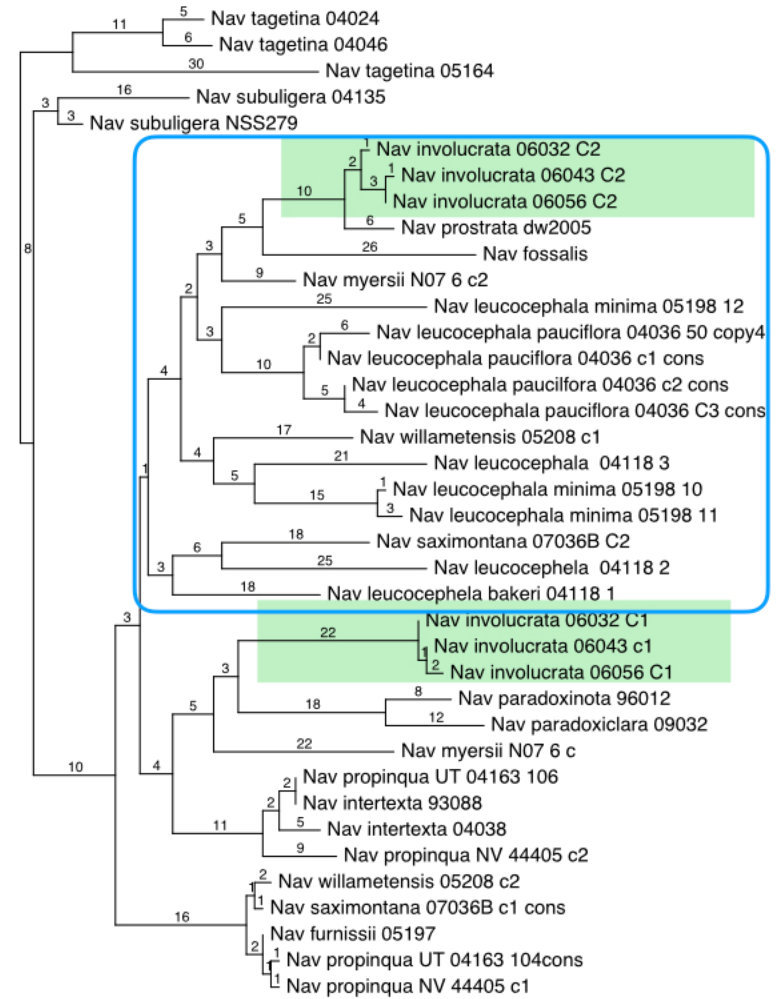
Navarretia involucrata



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cpDNA



nuPistillata



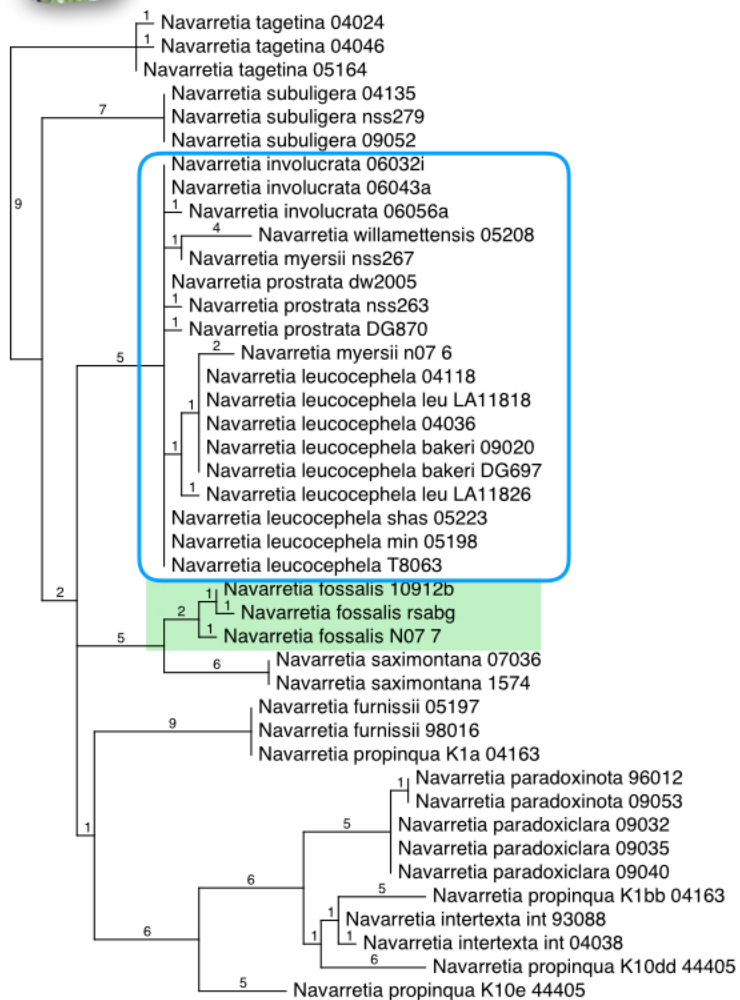
Navarretia involuocrata

- Distinct element occupying vernal pools and marginal habitats in Chile & Argentina
- 2 stigmatic lobes
- Spreading habit
- Cream pollen; anthers at orifice
- Light blue to white corollas; sometimes unusual numbers of parts
- Allotetraploid with something near *N. prostrata* and ?? as parents

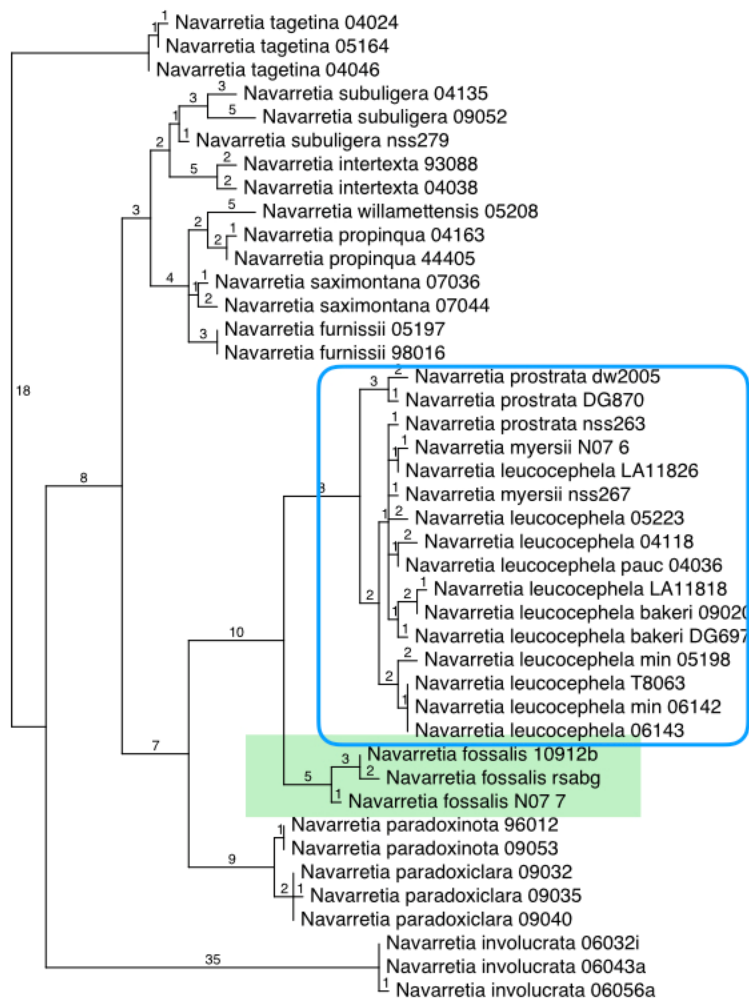




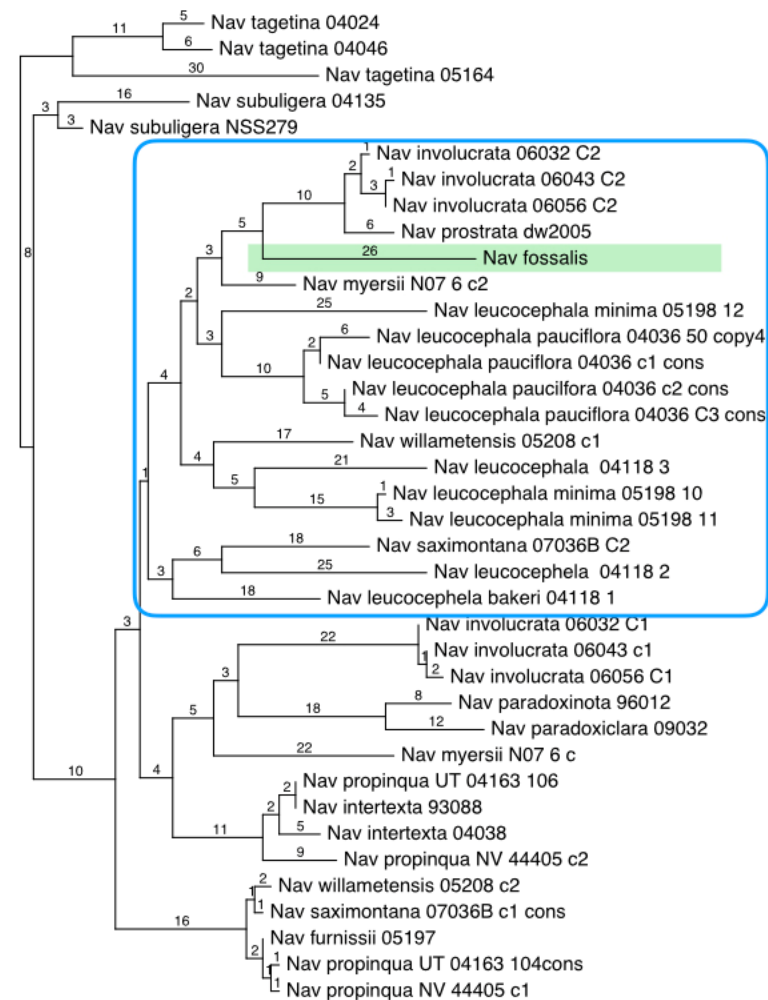
Navarretia fossilis



nuITS



cpDNA



nuPistillata



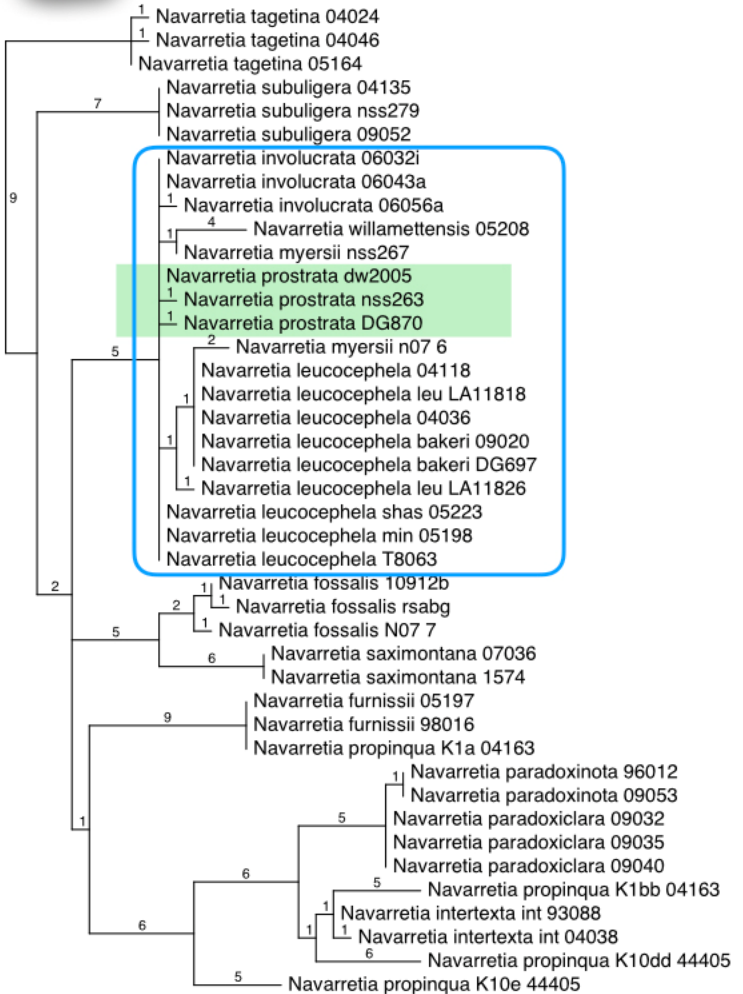
Navarretia fossalis

- Closely related to vernal pool clade, possibly hybrid origin or introgression?
- 2 stigmatic lobes
- spreading habit
- Cream pollen; anthers slightly exserted
- Light blue to white corollas; lobes tapering

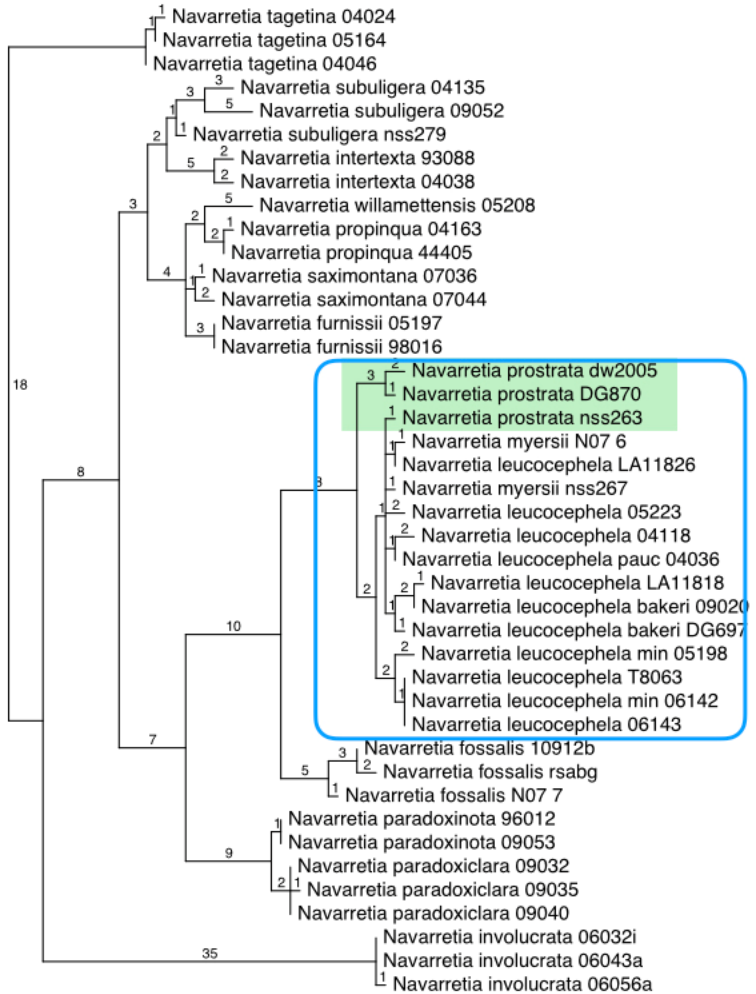




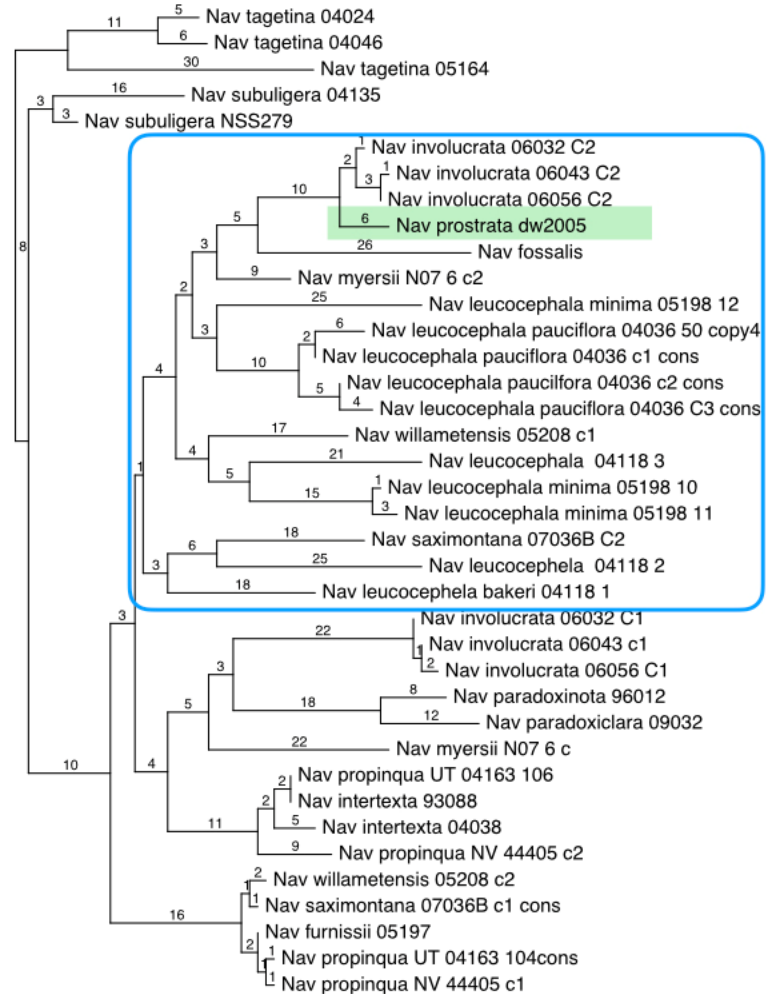
Navarretia prostrata



nuITS



cpDNA



nuPistillata



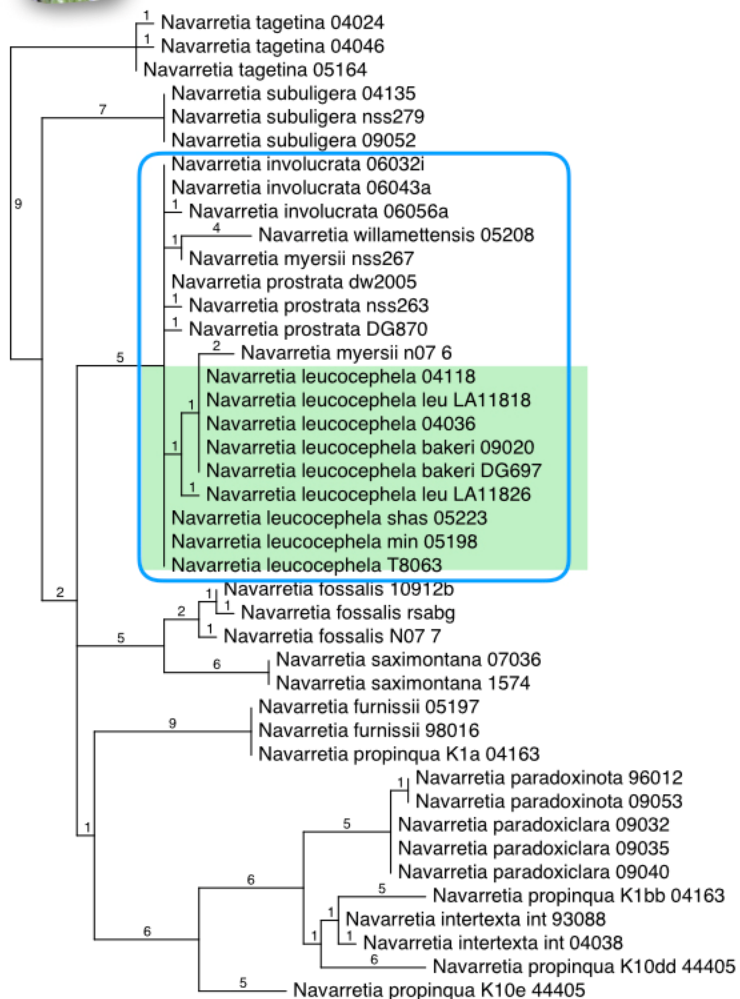
Navarretia prostrata

- Part of the vernal pool clade
- 2 stigmatic lobes
- Spreading, flat, prostrate habit; broad strap-like leaves
- Cream pollen; anthers well exserted
- Light blue to white corollas; lobes tapering

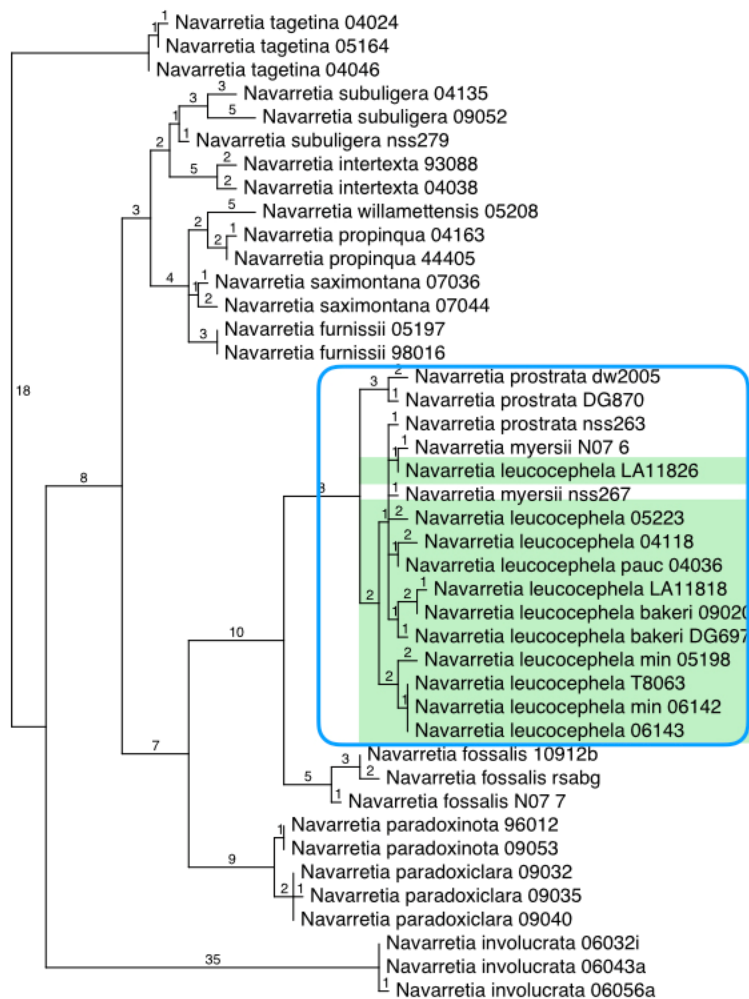




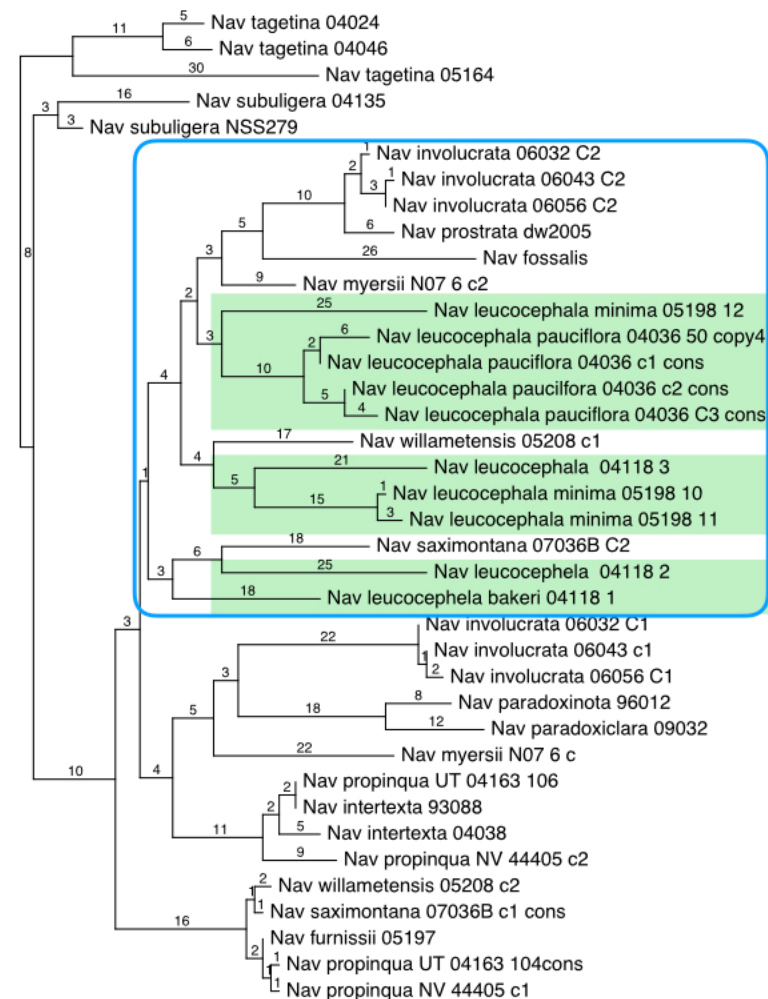
Navarretia leucocephala



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nuPistillata



N. leucocephala ssp. *leucocephala*

- Part of the vernal pool clade; six subspecies
- 2 stigmatic lobes
- Spreading to upright-
Pollen cream to white;
anthers attached near
sinus or in throat
- Light blue to white
corollas; lobes linear or
tapering





N. leucocephala ssp. *bakeri*

- Part of the vernal pool clade; six subspecies
- 2 stigmatic lobes
- Spreading to upright-
Pollen cream to white;
anthers attached near
sinus or in throat
- Light blue to white
corollas; lobes linear or
tapering





N. leucocephala ssp. *pauciflora*

- Part of the vernal pool clade; six subspecies
- 2 stigmatic lobes
- Spreading to upright-
Pollen cream to white; anthers attached near sinus or in throat
- Light blue to white corollas; lobes linear or tapering





N. leucocephala ssp. *minima*

- Part of the vernal pool clade; six subspecies
- 2 stigmatic lobes
- Spreading to upright-
Pollen cream to white;
anthers attached near
sinus or in throat
- Light blue to white
corollas; lobes linear or
tapering





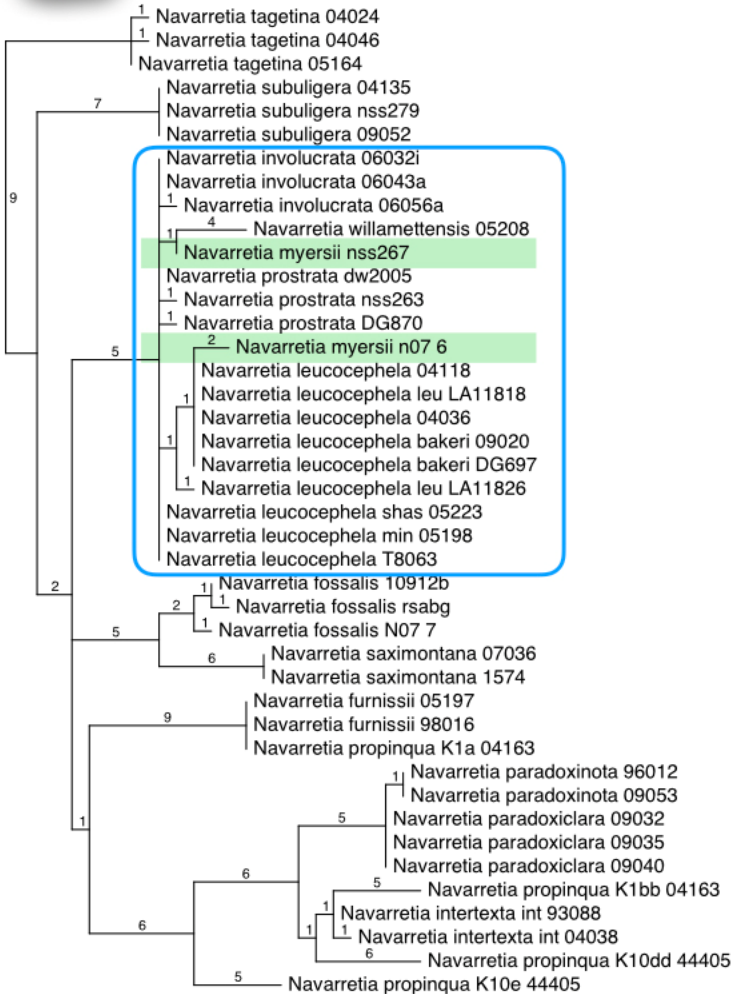
Navarretia leucocephala

Species boundaries? All
diploid? Intergradation/
hybridization?

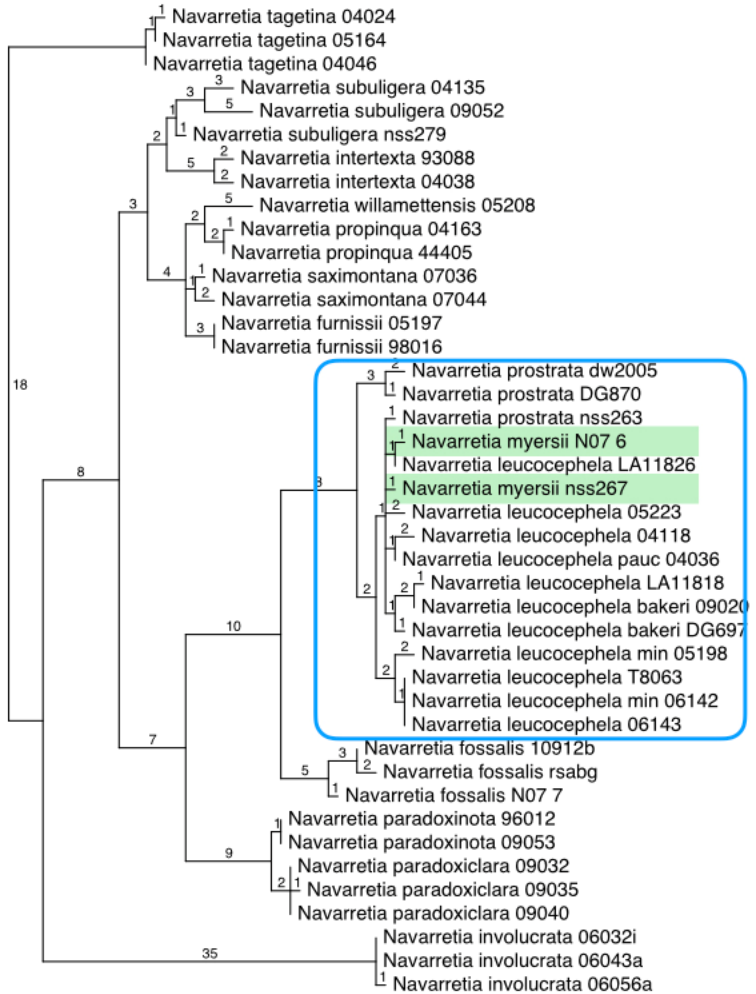




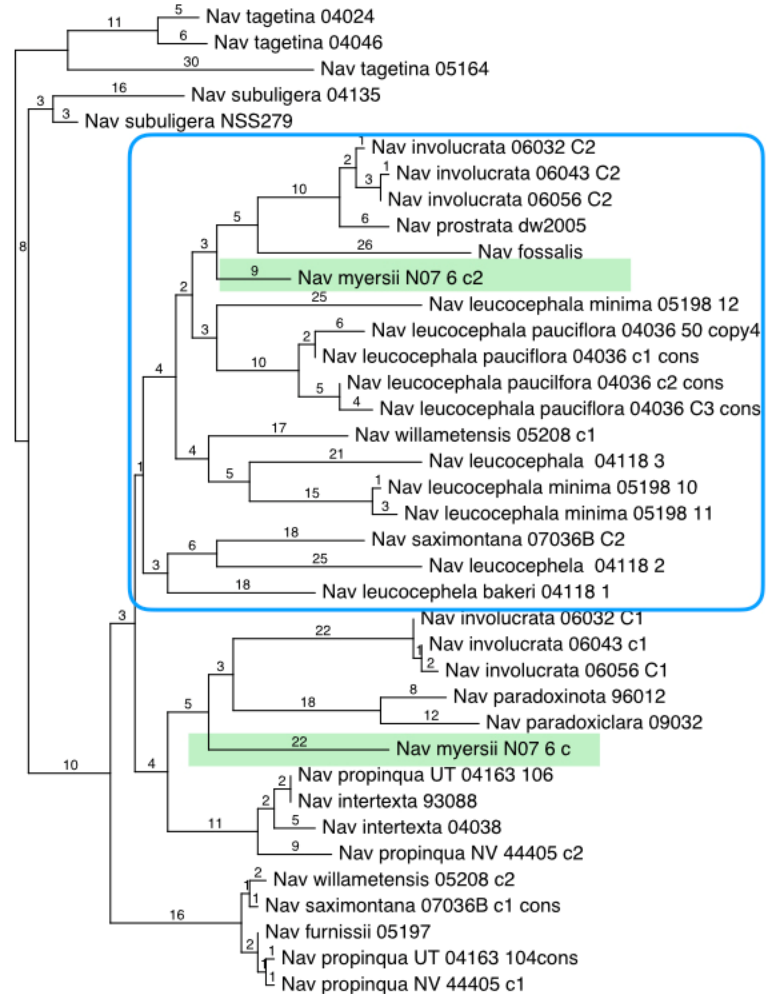
Navarretia myersii



nuITS



cpDNA



nuPistillata



Navarretia myersii

- Part of the vernal pool clade; six subspecies
- 2 stigmatic lobes
- Spreading
- Pollen cream to white
- Light blue to white corollas; lobes tapering; tubes elongated (+/-)
- Flowers on a common receptacle (true head)

Intergradation/
hybridization with *N.*
leucocephala?





other species to consider

N. cotulifolia...





Identification tools

- 18. Plant generally not glandular, stem hairs generally recurved or reflexed; fruit translucent, at least below middle, dehiscent when wetted, at base
- 19. Inner bracts concave-expanded at base; corolla lobes ovate
 - 20. Bract tips with few to several fine spines; corolla lobes with 3 veins entering base; stigmas 3
 - 21. Calyx hairs fine, obscure; calyx lobes entire *N. subuligera*
 - 21' Calyx coarsely appressed-hairy; calyx lobes toothed *N. tagetina*
 - 20' Bract tips with 3 spreading, needle-like lobes; corolla lobes with 1 vein entering base; stigmas 2
 - 22. Plant generally mounding, dense, multiple heads in close proximity; corolla 4.5–6.5 mm; filaments 1–2.5 mm, anthers ± equalling corolla lobes *N. propinqua*
 - 22' Plant erect, open, multiple heads well separated; corolla 6–13.5 mm; filaments 1.5–4.7 mm, anthers exceeded by to exceeding corolla lobes
 - 23. Corolla 6–8(13) mm, anthers exceeding corolla lobes *N. intertexta*
 - 23' Corolla 6.5–13.5 mm, anthers exceeded by to equalling corolla lobes
 - 24. Corolla 9.5–13.5 mm, pale blue to white, lobes 1.25–2.5 mm wide; n&c SNF (Calaveras, Tuolumne cos.) *N. paradoxiclara*
 - 24' Corolla 6.5–9.5 mm, white, lobes 0.5–1.25 mm wide; NCoRI (Lake, Napa, Colusa cos.) *N. paradoxinota*
- 19' Inner bracts widely membranous-winged at base, not concave-expanded; corolla lobes linear or narrowly ovate
 - 25. Inflorescence a head (flowers sessile); plant prostrate; calyx tube long-soft-wavy-hairy
 - 26. Corolla 7–9 mm, tube ± exserted; leaves at base of head lobed *N. prostrata*
 - 26' Corolla 12–21 mm, tube long-exserted; leaves at base of head entire or lobed in proximal 1/2 *N. myersii*
 - 27. Corolla blue, tube 1–1.2 × calyx; outer bract lobes many subsp. *deminuta*
 - 27' Corolla white, tube 2–4 × calyx; outer bracts lobes few subsp. *myersii*
 - 25' Inflorescence a dense cyme, flowers subsessile or short-pedicelled; plant generally not prostrate (except *Navarretia leucocephala*); calyx tube generally not long-soft-wavy-hairy (except *Navarretia fossalis*)
 - 28. Calyx lobes hairy; filament ≤ 1 mm; s CA *N. fossalis*
 - 28' Calyx lobes glabrous or ± hairy; filaments 1–3 mm; n&c CA *N. leucocephala*
 - 29. Stamens attached at corolla throat
 - 30. Corolla 7–9 mm, tube exserted, throat 2–3 mm wide subsp. *leucocephala*
 - 30' Corolla 4–6 mm, tube included, throat 1–2 mm wide subsp. *minima*
 - 29' Stamens attached at or just below corolla sinuses
 - 31. Inflorescence 2–20-flowered; outer bracts generally with 3–5 entire or forked lobes subsp. *pauciflora*
 - 31' Inflorescence 10–60-flowered; outer bracts generally with ≥ 7 lobes, each 3–4-branched
 - 32. Stem generally elongate, branches ascending; corolla white subsp. *bakeri*
 - 32' Stem short, branches spreading; corolla blue subsp. *plieantha*



Identification tools













calphotos.berkeley.edu

CalPhotos

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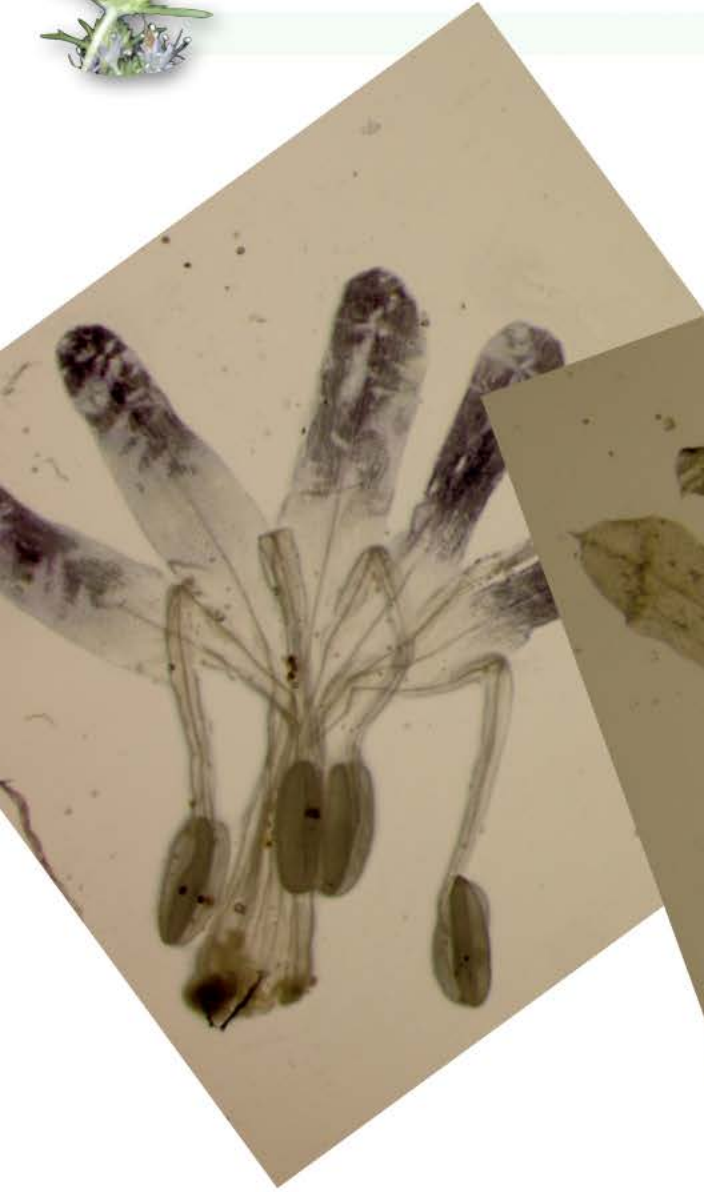
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Click on the thumbnail to see an enlargement

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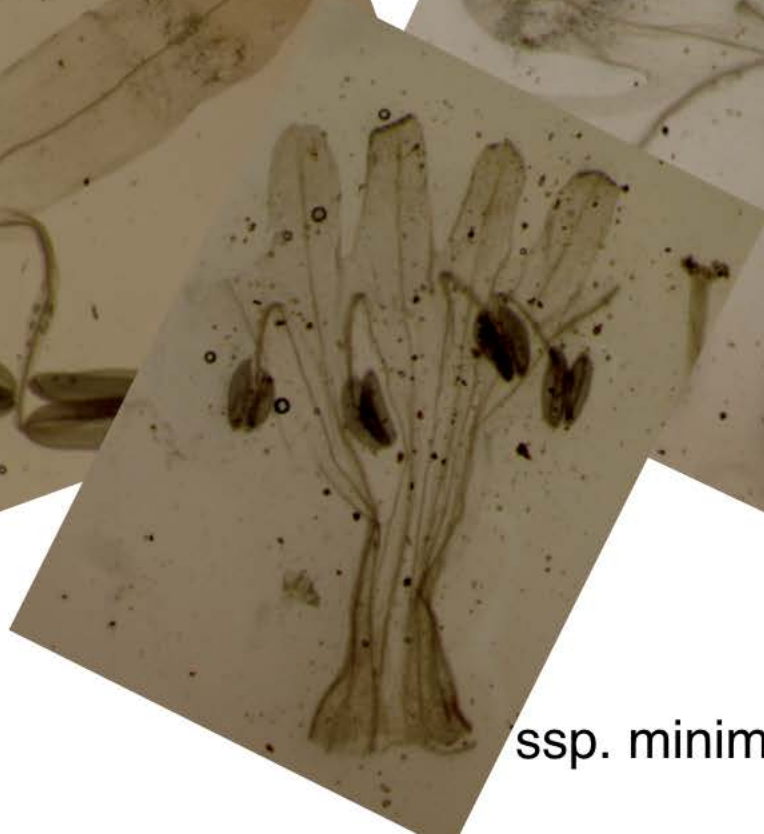
Identification tools



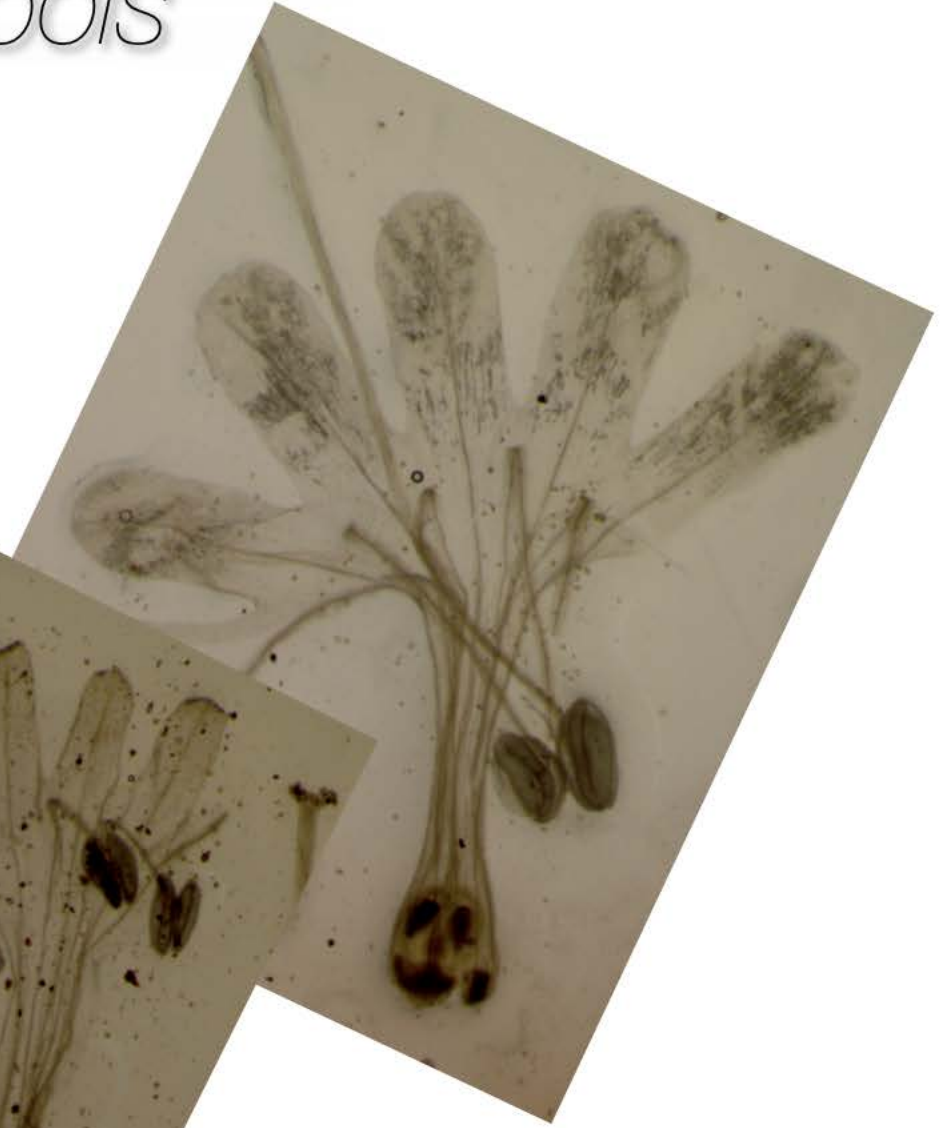
ssp. pauciflora



ssp. bakeri



ssp. minima



ssp. leucocephala



Identification tools



ssp. bakeri

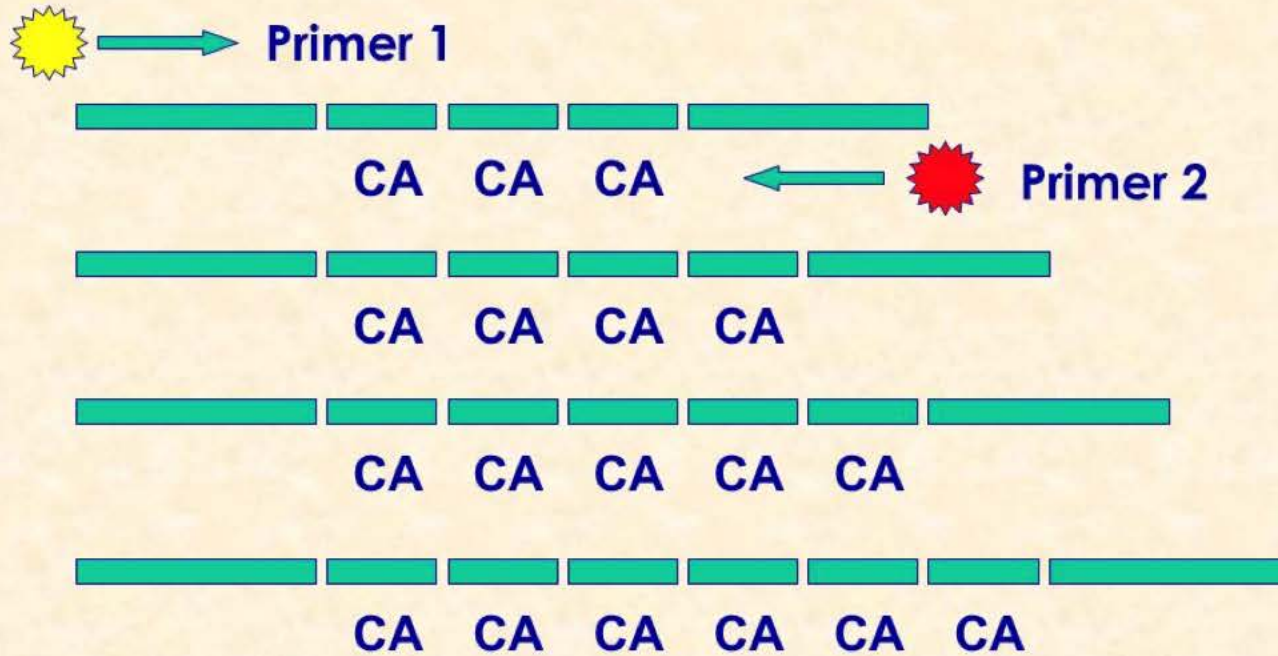




Genetic tools

SSR markers (microsatellites; used, e.g., in human DNA fingerprinting)

Microsatellite Markers





Genetic tools - community exchange

Have developed SSR primer pairs for 100 loci based on

Navarretia leucocephala ssp. *leucophala*

- Ready to screen to select informative loci for routine screening
- Goal: develop **multi locus** genotypes that characterize species in isolation, that can be used to 'fingerprint' unknowns, circumscribe species, investigate hybridization, etc

Use in combination with morphometrics of same population samples to identify reliable features for species/subspecies correlated with location of samples

Share data with community

more info: leigh@byu.edu



Summary

Complex diversification history

1. divergent evolution via vicariance or dispersal
2. reticulate evolution following secondary contact, with or without polyploidization

Thanks to all that have helped / asked questions / prodded along the way