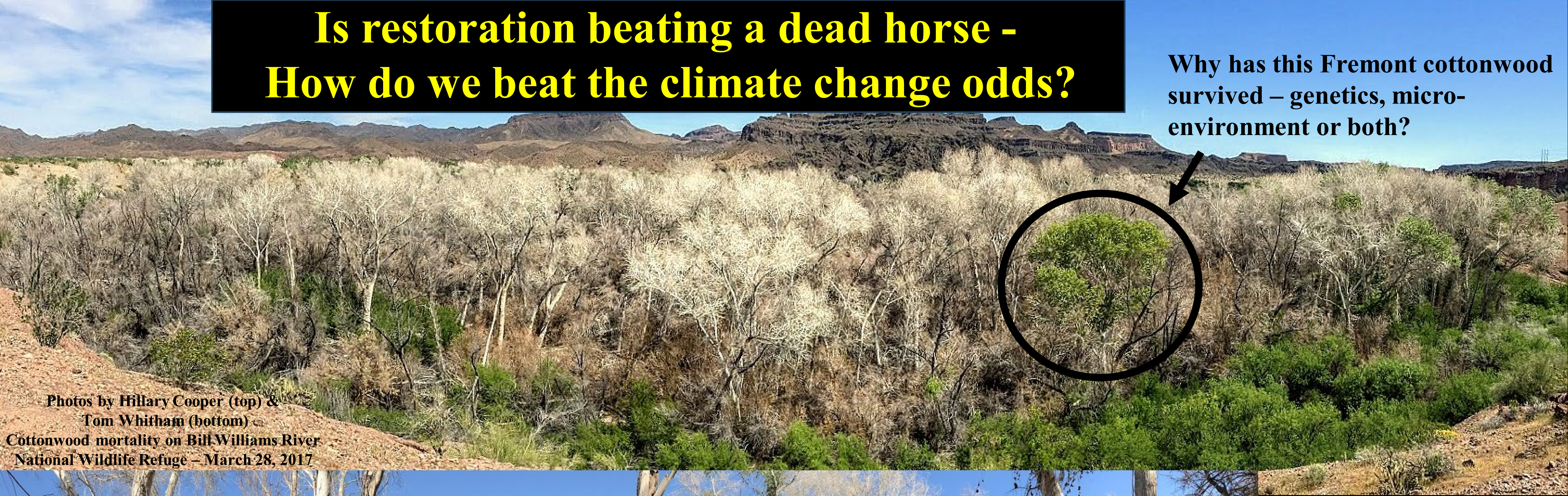
Is restoration beating a dead horse - How do we beat the climate change odds?



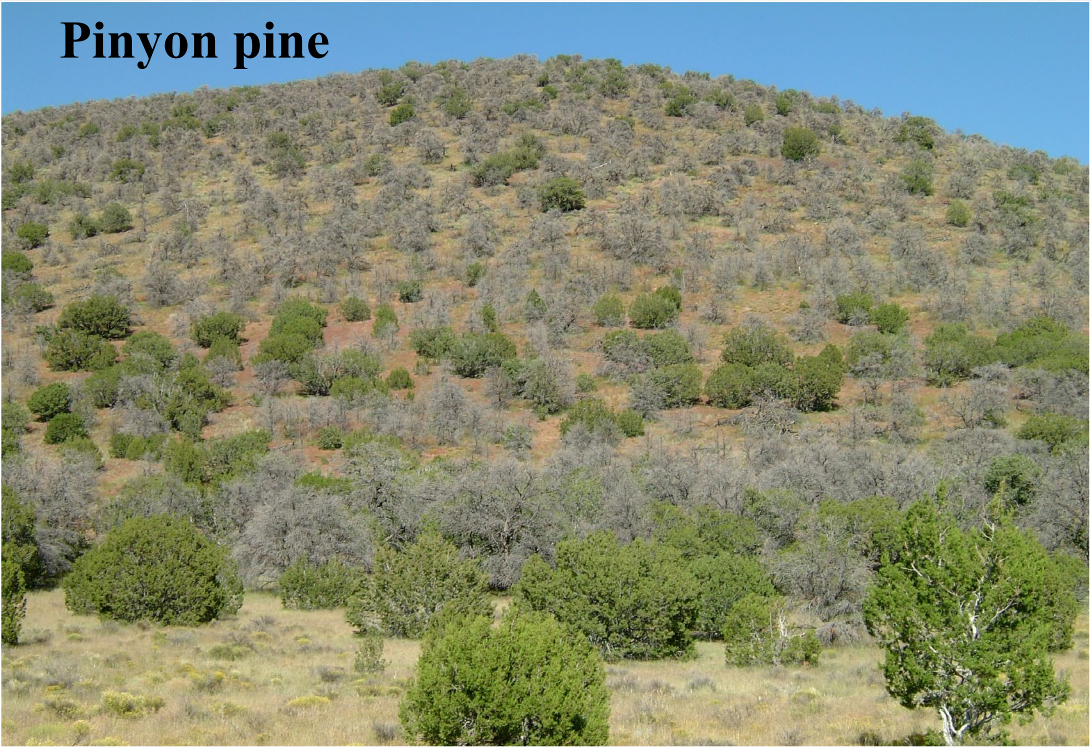
Why has this Fremont cottonwood survived – genetics, micro-environment or both?

Photos by Hillary Cooper (top) &
Tom Whitham (bottom)
Cottonwood mortality on Bill Williams River
National Wildlife Refuge – March 28, 2017

Tom Whitham, Department of Biological Sciences and the Center for Adaptable Western Landscapes, Northern Arizona University

One-seed juniper

Ponderosa pine



Pinyon pine

Not just cottonwoods, but many other dominante tree species that characterize their community types. Upward shifts of species by as much as 1000’ in 49 years.

Important to know about failed restoration attempts and map their distribution

Field trail lost to declining water table. Fortunately, we learned a lot before they died and they did not die at random. How have your projects fared?

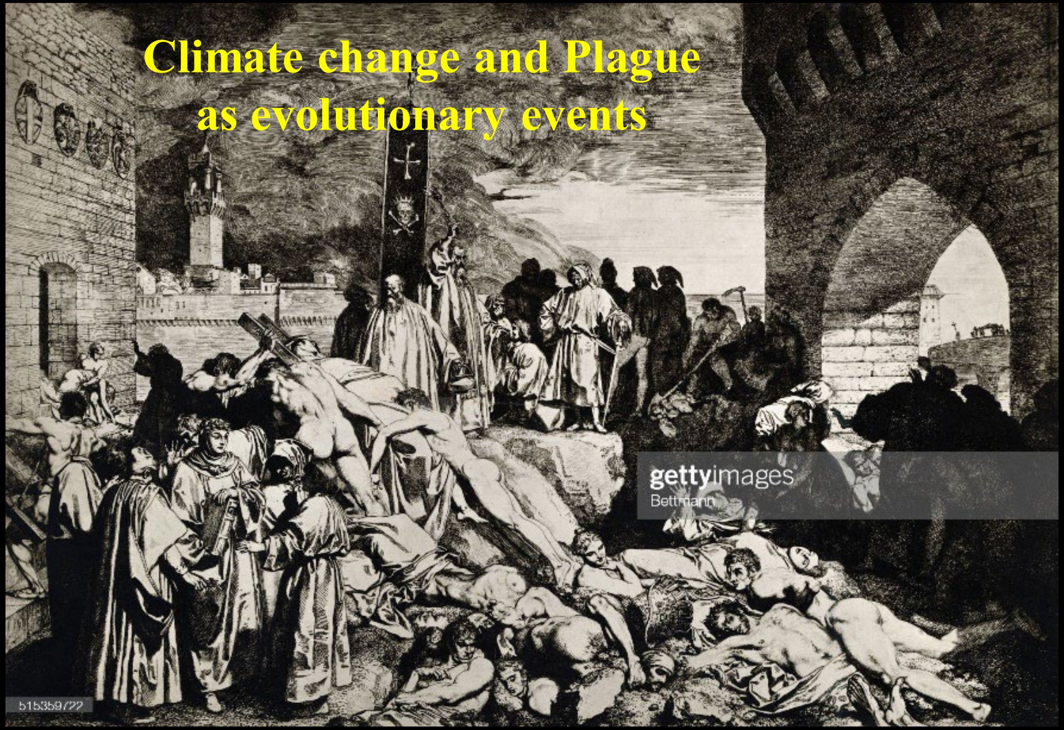
How bad is it?

1. We’re in an ongoing megadrought that began in 2000 that is the worst in 1200 years (Williams et al. 2022 Nature Climate Change), which is compounded by record high temperatures (hot droughts) (King et al. 2024 Science Advances).

2. Extinction of Trees – 30% of world’s trees are threatened with extinction (2021, State of the World’s Trees, Botanic Garden Conservation International).

3. Migratory species – 44% of worlds migratory species are in decline and 22% are threatened with extinction (UN - State of World’s Migratory Species 2024)

4. In human terms, climate change as an evolutionary event affecting trees is greater than the plague that killed 1/3 to ½ of the human population in Europe and N. Africa in the 1300s (Shuster and Whitham in prep).



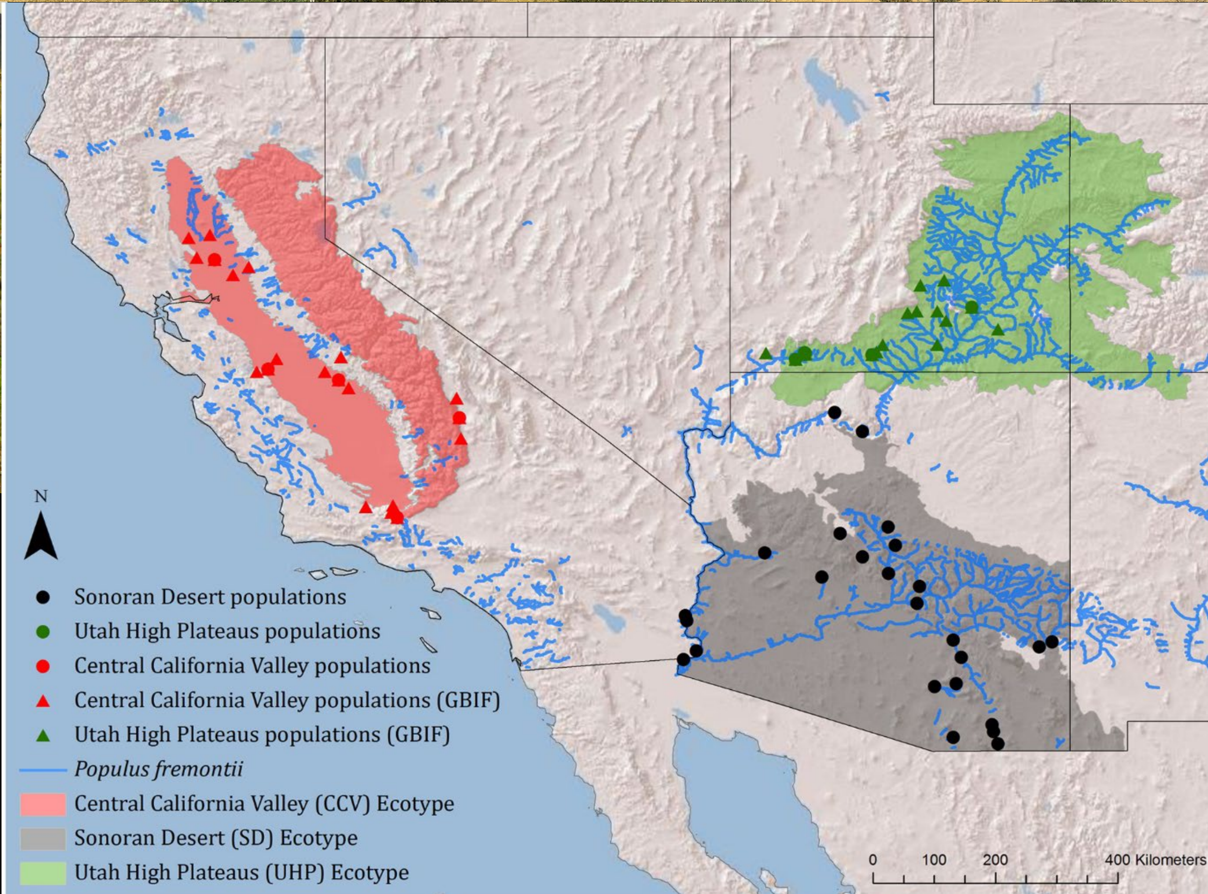
Climate change and Plague as evolutionary events

gettyimages
Bettmann


Cold Utah High Plateau Ecotype


Hot California Ecotype


Sonoran Desert Ecotype



Solutions

1. Select appropriate ecotypes - **Geographical adapted ecotypes have evolved in response to environmental differences across the range of *P. fremontii*.**

Ikeda et al. 2017 Global Change Biology; Photos by Tom Whitham

Three Ecotypes has now expanded to 6 different ecotype of *Populus fremontii* requiring even finer matching of plants used in restoration for specific sites. Importantly each ecotype supports different arthropod and endophyte communities requiring conservation of each ecotype to support their unique communities (Bothwell et al. 2023 Forests).

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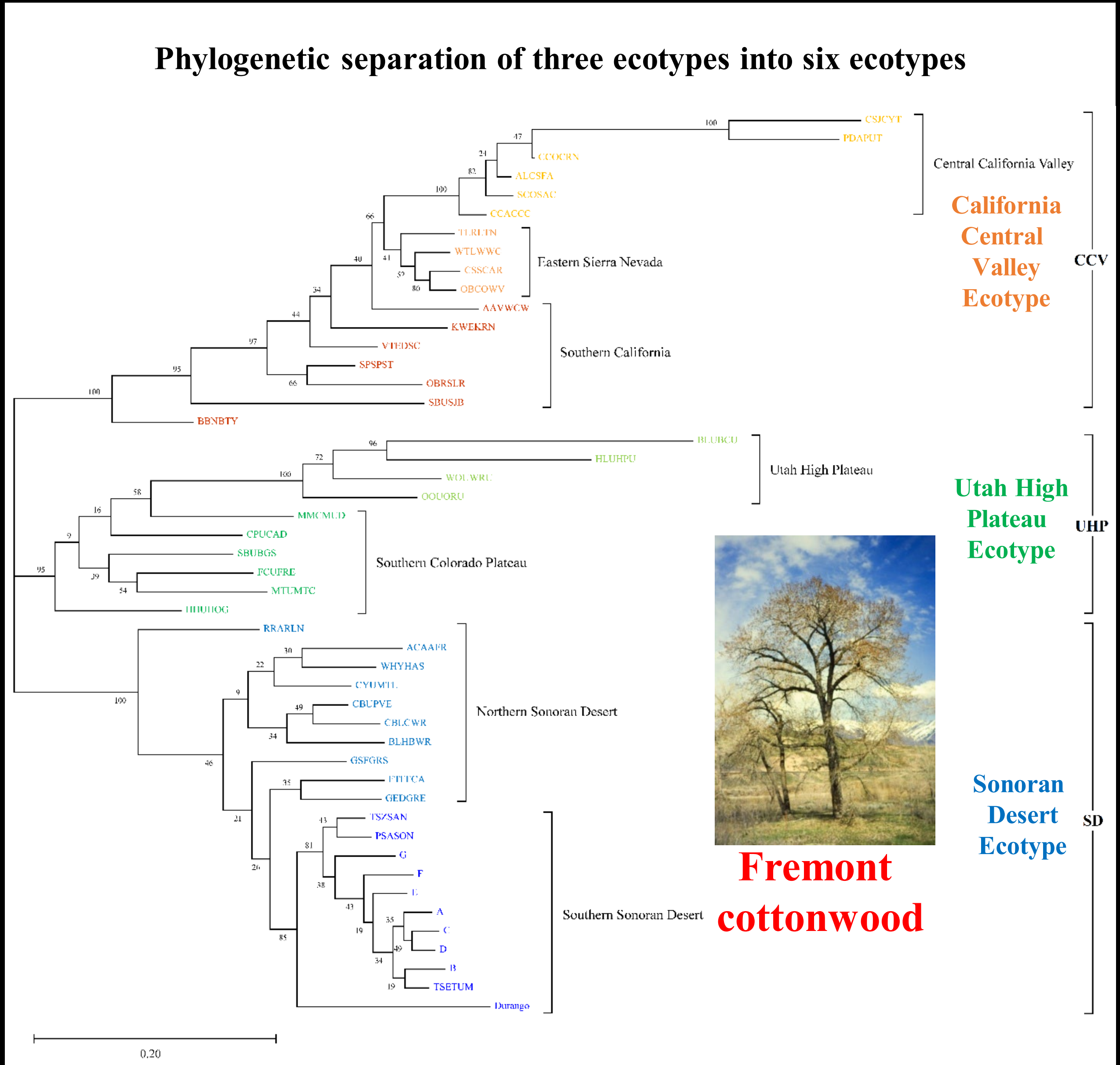
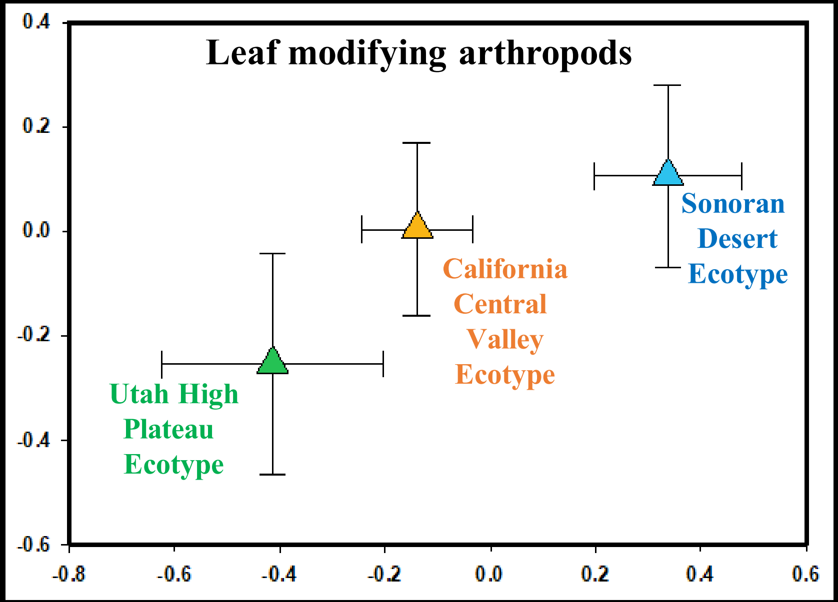
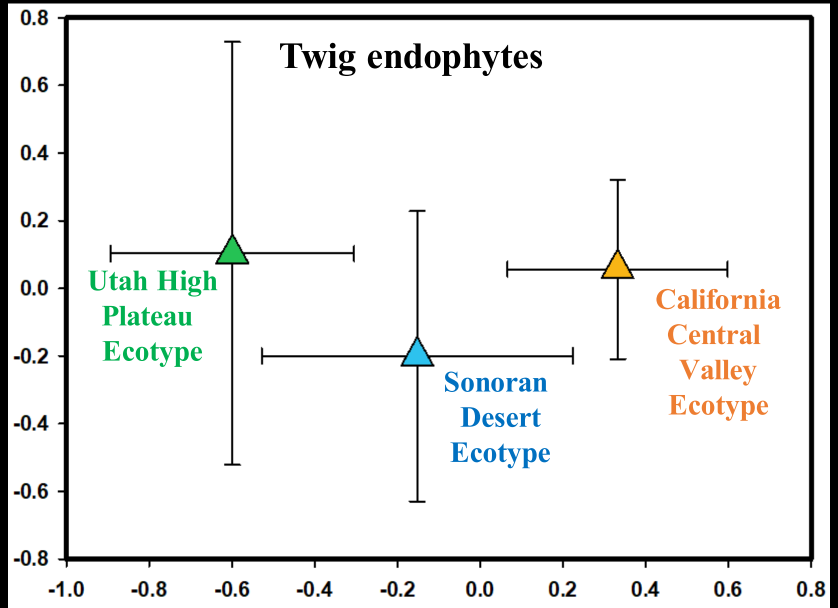


Phylogenetic separation of three ecotypes into six ecotypes

Fremont cottonwood

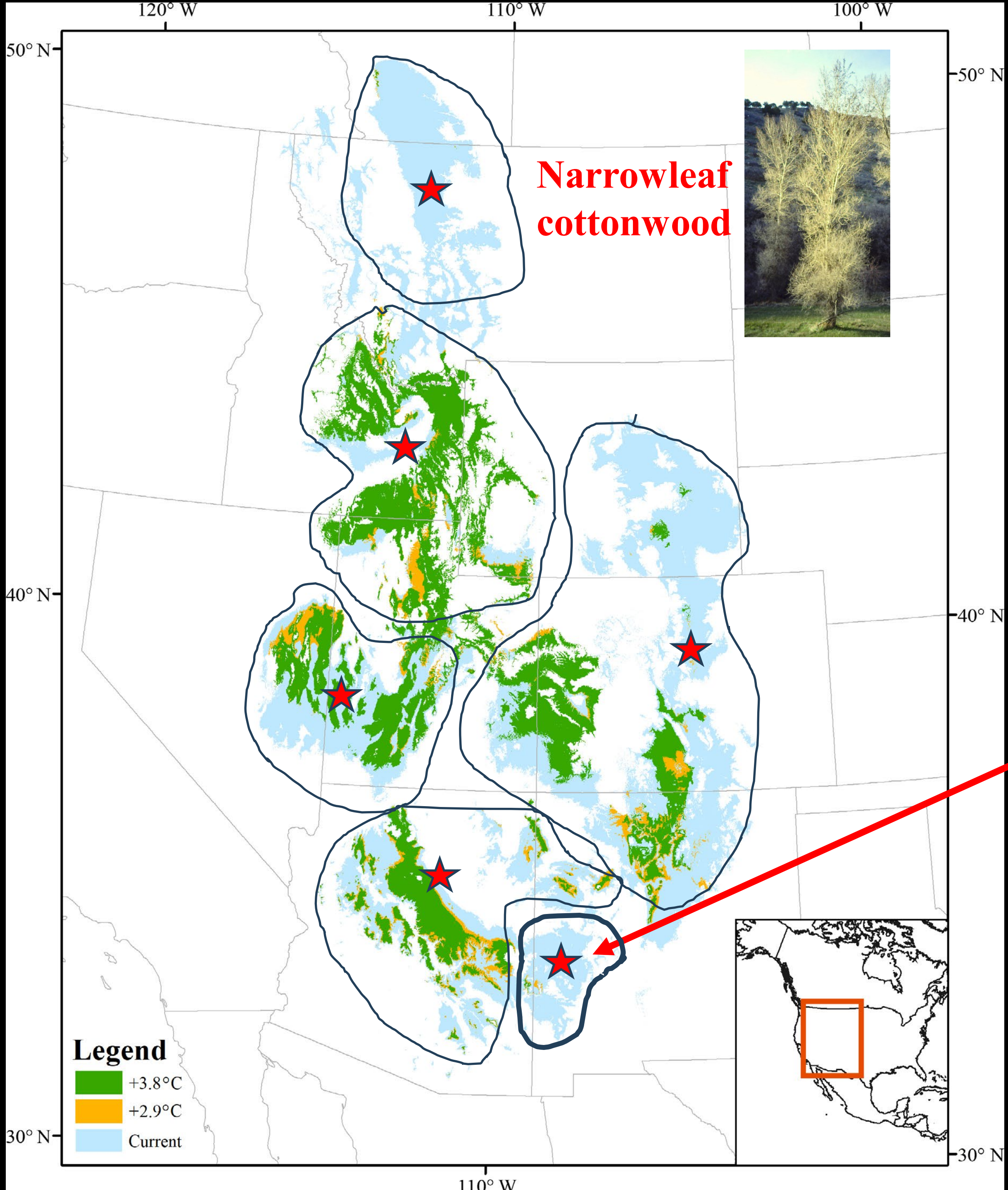


Leaf modifying arthropods



Twig endophytes

2. Avoid restoration in marginal habitats as risk of failure with continued climate change is high.



Genetics based niche models predict major loss of suitable narrowleaf habitat this century with major contractions into refugia shown in green. Ecotypes with narrow niches in marginal habitats will be most heavily impacted and some may be completely lost.

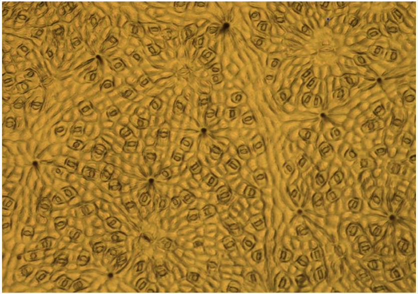
Range of Western New Mexico Ecotype and its associated community that may be lost.

Bothwell et al. 2021 Ecological Applications

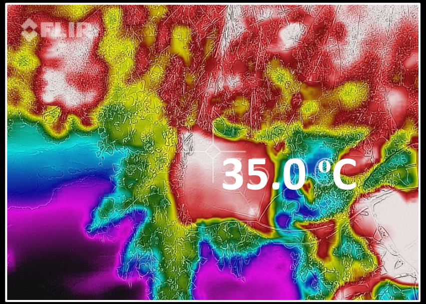
3. Selection for heat tolerance

Heat Tolerant Genotype

Small leaves

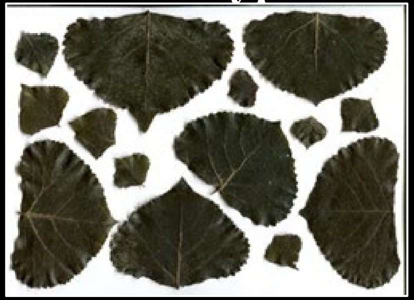


High stomatal density

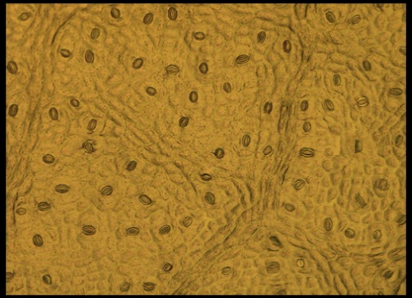


Can cool leaf temperature below ambient

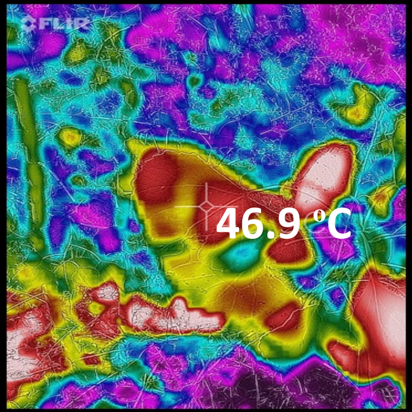
Heat Intolerant Genotypes



Large leaves



Low stomatal density



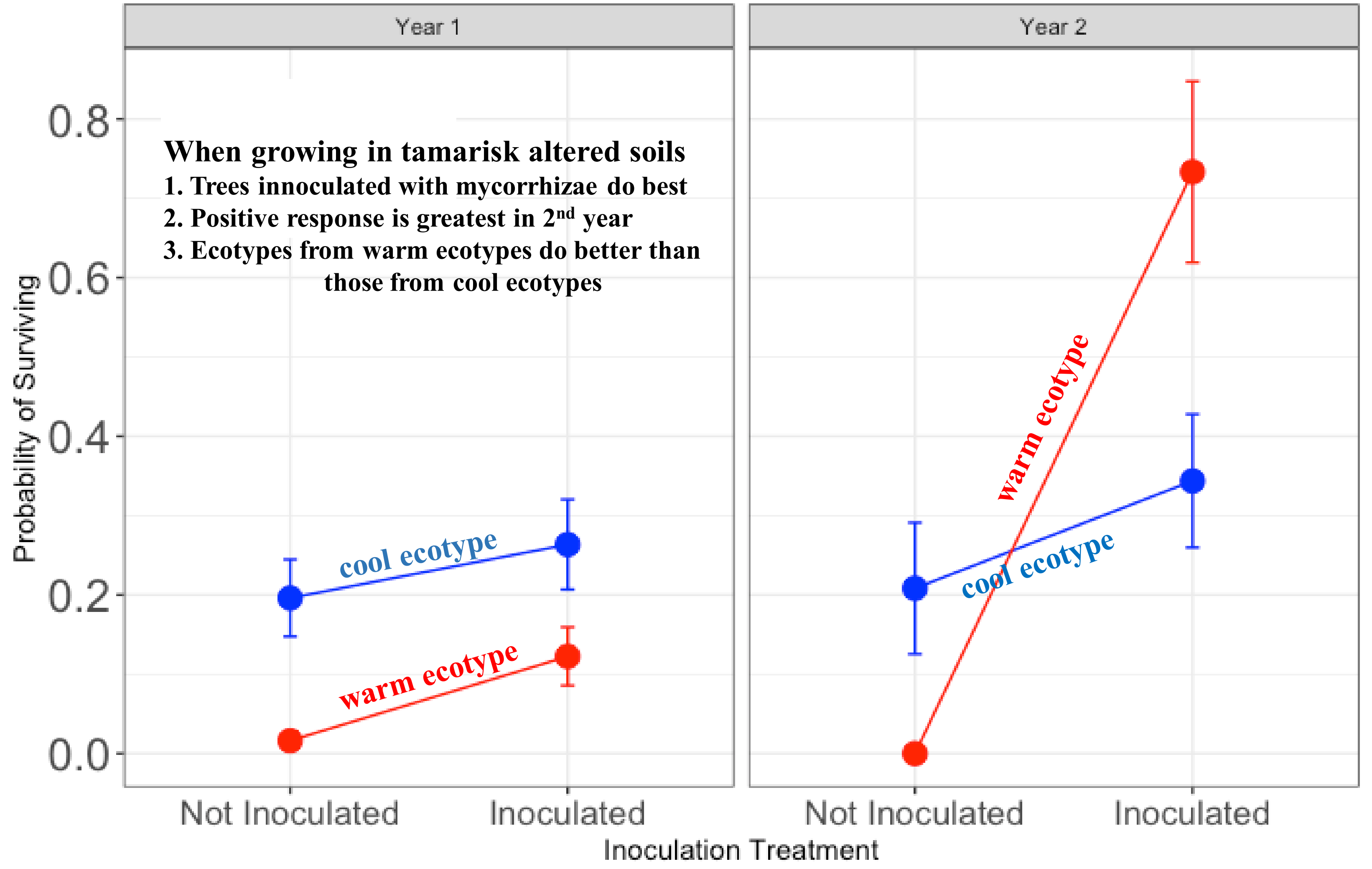
Hotter leaf temperature than ambient

Genetic differences in leaf cooling traits are key to surviving drought and extreme temperature events, but maintaining water is critical for cooling.

Photos by Davis Blasini
Blasini et al. 2021 J of Ecology,
Blasini et al. 2022 Plant Cell Environment
Moran et al. 2023 New Phytologist

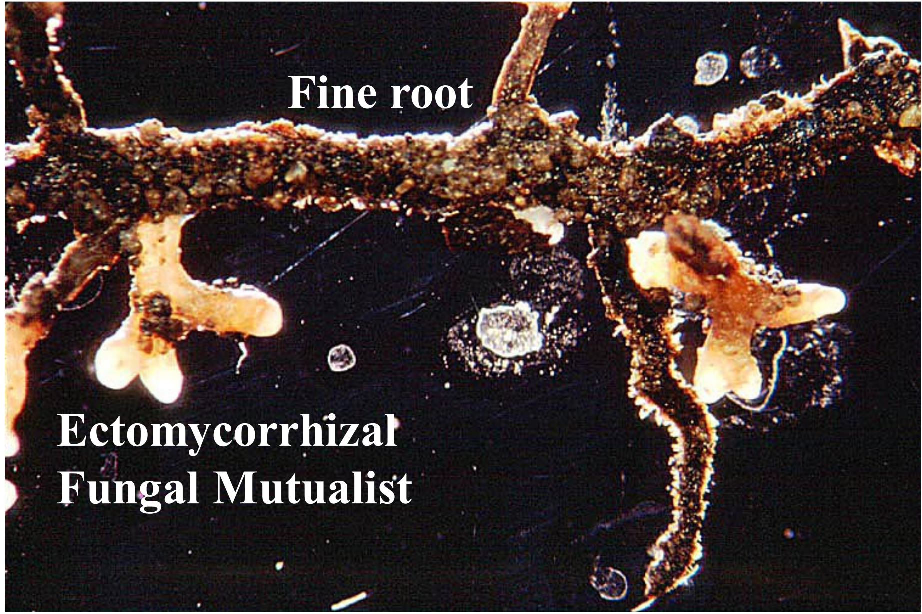
A lot is going on underground that is important for restoration.

Unknown photographer



When growing in tamarisk altered soils

1. Trees innoculated with mycorrhizae do best
2. Positive response is greatest in 2nd year
3. Ecotypes from warm ecotypes do better than those from cool ecotypes



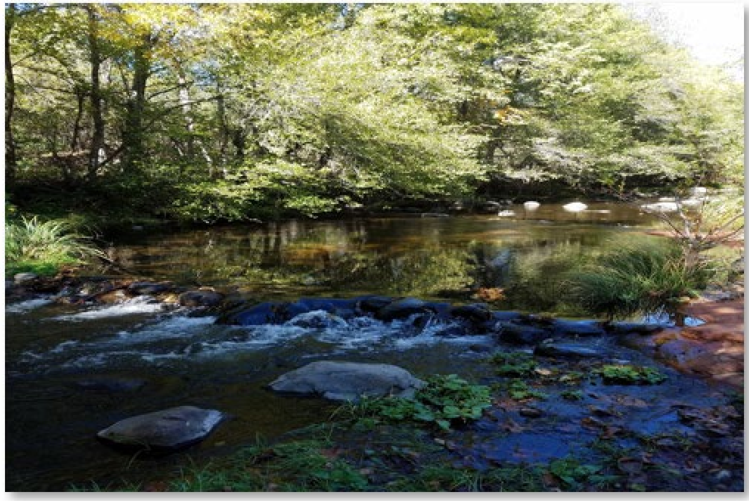
Ectomycorrhizae play an important role in determining who lives and who dies.

4. Inoculate cottonwood plantings with native mycorrhizal communities, especially when they are planted into soils previously occupied by tamarisk.

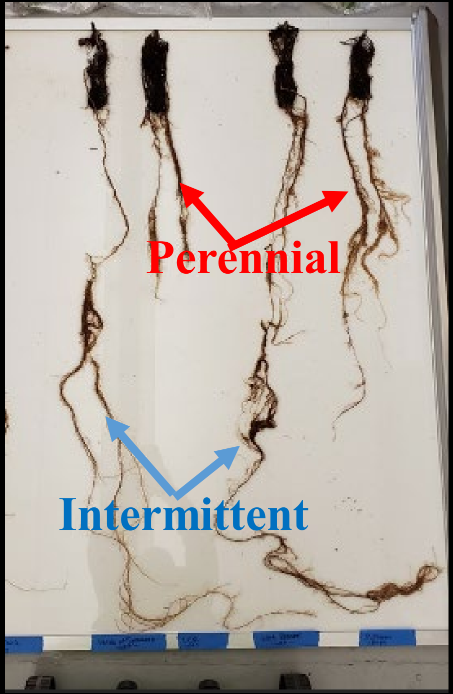
Markovchick et al. 2024 Frontiers in Plant Science (in review).

5. Target genotypes from intermittent streams for use in restoration. In the race to the water table, roots from **Intermittent** stream trees are genetically programmed to go down faster than trees from **Perennial** streams making them superior for successful restoration during a time of drought and declining water tables (Abraham Cadmus, unpub. data).

Intermittent Stream

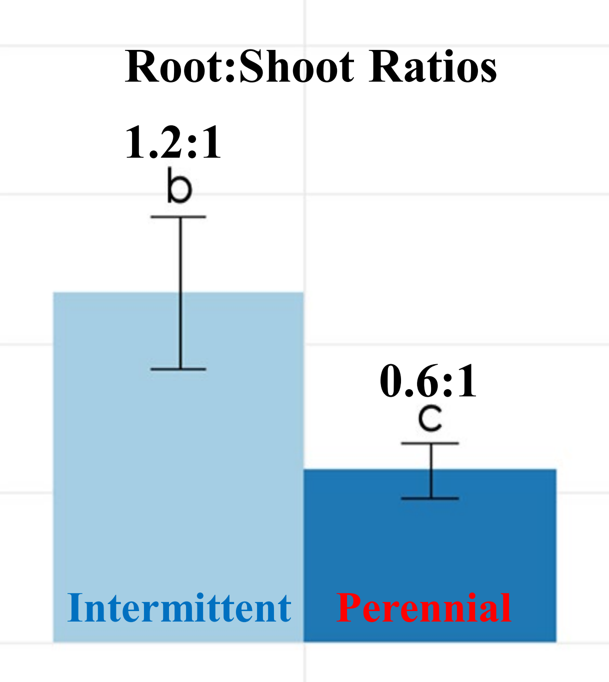


Perennial Stream



Roots from **Intermittent** stream trees grow deepest.

In the race to the water table, growing down is critical to survival.



Intermittent stream trees invest 2X more in roots than perennial stream trees.

What management can do using genetics-based traits to maximize restoration success?

1. Before large-scale plantings, plant small experimental test plots embedded in the larger restoration area in which the plants are taged and you know exactly where they came from. Based on the performance in these test plots select the most promising populations and genotypes for expanded use outside the test plots. This is rish avoidance and cost effective by avoiding plants that are doomed to die and you focus on the ones that have a demonstrated history of survival.

2. Site selection is extremely important – Our success has been highest in sandy soils where the water table is about 2 m where supplemental water is available to get enable plants to grown down to the water table. Also, be careful about planting too close to the river as floods can also take out a lot of plantings.
Do NOT plant in marginal habitats as they are likely to fail with further changes in climate.

3. At the time of planting inoculate cottonwoods with ectomycorrhizal mutualists that can help them cope with the planting site and altered soils from invasive species like tamarisk.

4. As a rule of thumb, use different populations derived from an same ecotype. I.e., don't cross ecotypes unless the climate change models show that one ecotype is likely to replace another.

5. Because different tree genotypes and ecotypes support different species and communities, planting with a wide range of genotypes will promote biodiversity and greater ecosystem processes. Since some species of birds and insects favor specific tree genotypes, field trials will also identify genotypes that might be best for rare and threatened species.

6. Selecting stock from intermittent streams will have deeper root systems than from perennial streams.

7. Restoration contractors should not be paid for how many trees and shrubs they plant, but for how many that survive a given period of time. E.g., I once witnessed 100,000 trees die within 24 hours and the contractor was paid the agreed amount even though nothing survived.

8. Use genetically appropriate stock including local to up to 3^{o}C warmer environments. This provides insurance for both current and future conditions.

9. Transfer distances greater than 3^{o}C are not advised as they likely can't survive current conditions or will be poor competitors and will get overtopped as the surrounding better competitors grow over them.

10. At the hotter, drier edges of the species distribution, future changes in climate are likely to result in massive dieoffs. Plant other species that are adapted to a hotter, drier environment. E.g., mesquite as a substitute for cottonwoods at the southern range of cottonwoods.

11. Naturally occurring hybrids are more drought tolerant than their parental species.

12. Plant with multiple species of cottonwoods, willows and other co-occurring species derived from the same source sites as they have evolved together and when planted together as intact communities, their overall performance is greater.

Riparian “Ribbon of Green”, Boulder Creek, Grand Staircase-Escalante National Monument, Utah - Photo by Tom Whitham

Support climate change bill HR5145 in Congress that allows the Secretary of the Interior to establish a grant program to support to field trials in sites slated for restoration where we can quantify what is best for adjacent lands.

Collaborators in Community Genetics and Genetics-Based Restoration

Rachel Adams – plant ecology
Joe Bailey – community ecology
Davis Blasini – ecophysiology
Abraham Cadmus – ecophysiology
Hillary Cooper – ecological genetics
Rodolfo Dirzo – community ecology
Luke Evans – population ecology
Paul Flikkema – systems engineering
Heather Gillette – molecular ecology
Erika Hersch – ecological genetics
Kevin Hultine – invasive species
Nathalie Isabel – molecular ecology
Paul Keim – molecular genetics
Tom Kolb – plant physiology
Matthew Lau – network modeling
Lisa Markovchick – mycorrhizal ecology
Nashelly Meneses – ecological genetics
Jackie Parker – plant ecology
David Smith – landscape ecology
Amy Whipple – ecological genetics
Gina Wimp – community ecology
Scott Woolbright - molecular genetics

Gery Allan – molecular ecology
Randy Bangert – biogeography
Helen Bothwell – phylogeography
Aimée Classen – soil ecology
Sam Cushman – landscape genetics
Chris Doughty – remote sensing
Sharon Ferrier – conservation ecology
Kevin Floate – insect ecology
Kevin Grady – restoration
Joakim Hjältén – ecology
Dana Ikeda – climate modeling
Karl Jarvis – phylogeny
Art Keith – insect community ecology
Lela Andrews - molecular ecology
Carri LeRoy – aquatic ecology
Jane Marks – aquatic ecology
George Newcombe – plant pathology
Brad Potts – quantitative genetics
Steve Shuster – theoretical genetics
Tom Whitham – community ecology
Todd Wojtowicz – litter arthropods
Matt Zinkgraf – molecular genetics

Petter Axelsson – transgenic trees
Rebecca Best – ecology & evolution
Posy Busby – ecological plant pathology
Zacchaeus Compson – aquatic ecology
Steve DiFazio – molecular ecology
Michael Eisenring – chemical ecology
Dylan Fischer – ecophysiology
Catherine Gehring – microbial ecology
Steve Hart – ecosystem/soil ecology
Lisa Holeski – genetics & chemistry
Julia Hull – fungal endophytes
Joann Jeplawy – aquatic ecology
George Koch – ecophysiology
Jamie Lamit – microbial ecology
Rick Lindroth – chemical ecology
Sean Mahoney – mammalian ecology
Emily Palmquist – hydrology
Jen Schweitzer – ecosystems
Chris Sthultz – plant ecology

<u>Outreach & Facilities</u> – Lara Schmit, Paul Heinrich,
Victor Leshyk

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