Fremont cottonwoods on Sulphur Creek, Capitol Reef National Park
© Photo by Tom Whitham

Genetics solutions to climate change and invasive species in restoration

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Kevin Grady with 9000 Fremont cottonwoods at NAU research greenhouse - © Photo by Tom Whitham

Adaptive management using genetic variation in survival and other traits

Species at PVER	Genotype	Population
Populus fremontii	0-100%	0-85%
Salix gooddingii	0-100%	71-100%
Salix exigua	58-100%	77-97%

Genetics-Based Adaptive Management

Plant Growth 25-72% (architecture) Bailey et al. 2004 Evolution, (productivity) Lojewski et al. 2009 Tree Physiology, Grady et al. 2011 Global Change Biology, (sink-source) Compson et al. 2011 Oecologia, (leaf economic traits) Grady et al. 2013 Functional Ecology

Trophic Structure 80%
(tree-insects-birds) Bailey et al. 2006 Ecology Letters, Smith et al. 2011 Journal Evolutionary Biology, (aquatic) Marks et al. 2009 Freshwater Biology

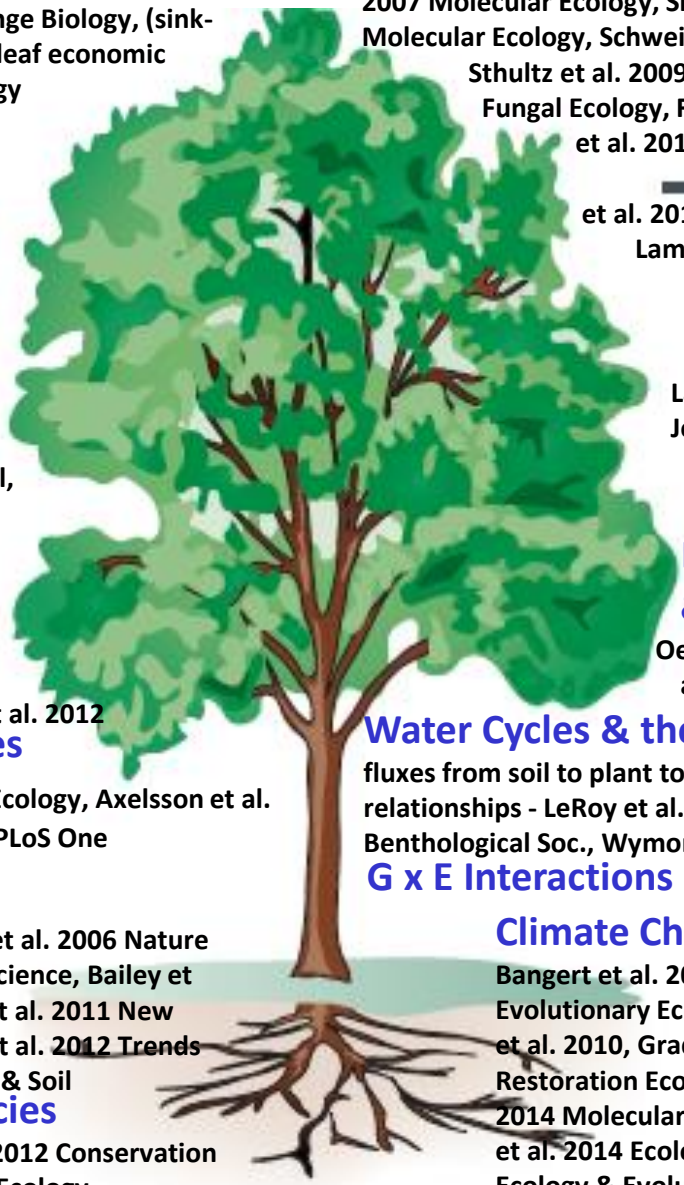
Nutrient Cycles 34-65%
Schweitzer et al. 2004 Ecology Letters, 2005 Ecology, 2005 Oikos, 2011 Population Ecology, Classen et al. 2007 J. of Ecology, Fischer et al. 2010 Plant & Soil, Schweitzer et al. 2011 Pop. Ecology, Classen et al. 2013 Ecosphere

Soil Feedbacks 20%
Pregitzer et al. 2010 Evolutionary Ecology, Smith et al. 2011 Plant & Soil, Gehring et al. 2014 Botany, Schweitzer et al. 2012

GMO Effects on Communities
25-33% Axelsson et al. 2011 J. Appl. Ecology, Axelsson et al. 2011 Chemoecology, Hjältén et al. 2012 PLoS One

Review and Meta-Analysis
Whitham et al. 2003 Ecology, Whitham et al. 2006 Nature Reviews Genetics, Whitham et al. 2008 Science, Bailey et al. 2009 Phil. Trans. R. Soc. B., Wymore et al. 2011 New Phytologist, Allen et al. 2012, Whitham et al. 2012 Trends in Plant Science, Fischer et al. 2014 Plant & Soil

Evolution of Associated Species
Evans et al. 2008 Evolution, Evans et al. 2012 Conservation Genetics, Evans et al. 2013 Evolutionary Ecology



Biodiversity 39-78% (Bacteria, Insects, Spiders, Birds, Mammals, Lichens, Endophytes, Pathogens, Mycorrhizae) Wimp et al. 2004 Ecology Letters, Wimp et al. 2007 Molecular Ecology, Shuster et al. 2006 Evolution, Bangert et al. 2006a,b Molecular Ecology, Schweitzer et al. 2008 Ecology, Bangert et al. 2008 Heredity, Sthultz et al. 2009 New Phytologist, Barbour et al. 2009, Lamit et al. 2011 Fungal Ecology, Ferrier et al. 2012 Arthropod-Plant Interactions, Meneses et al. 2012 EcoScience, Busby et al. 2013 J. Ecology, Lamit et al. 2014 Am J Botany, Busby et al. 2014 J of Ecology, Busby et al. 2014 Ecology, Gehring et al. 2014 Frontiers in Microbiology, Lamit et al. 2014 Ecology

Understory Plant Community Composition & Biomass 14-20%
Lamit et al. 2011 Botany, Adams et al. 2011 American Journal of Botany, Michalet et al. 2011 Ecology Letters

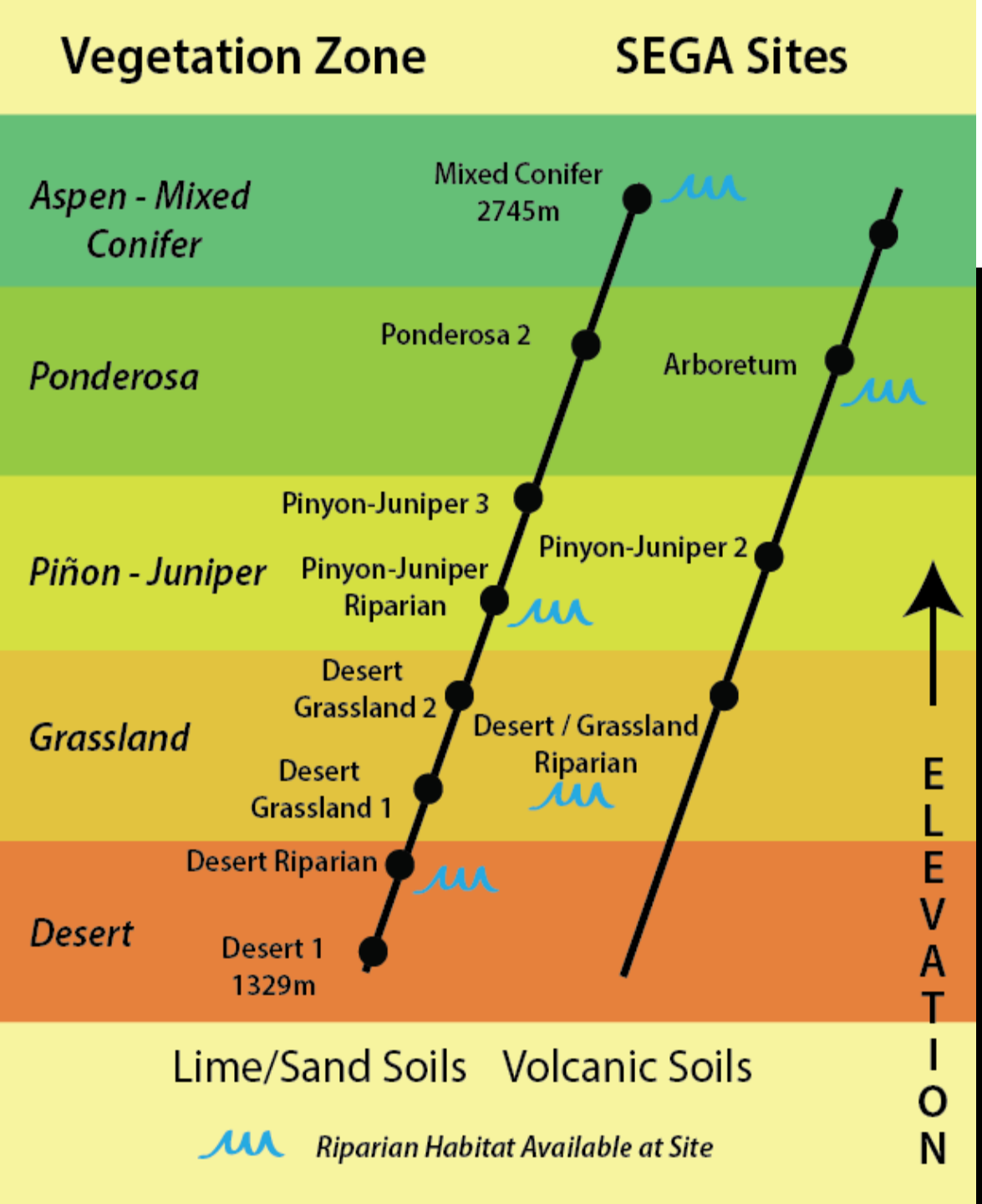
Community Stability 32%
Keith et al. 2010 Ecology

Belowground Carbon Storage & Root Production 77% Fischer et al. 2006 Oecologia, Fischer et al. 2007 New Phytologist, Lojewski et al. 2012 New Phytologist

Water Cycles & the Terrestrial-Aquatic Interface 35-40%
fluxes from soil to plant to atmosphere - Fischer et al. 2004 Oecologia; aquatic relationships - LeRoy et al. 2006 Ecology, LeRoy et al. 2007 J. N. American Benthological Soc., Wymore et al. 2014 Freshwater Science

G x E Interactions Evans et al. 2012 Oecologia, Busby et al. 2014 J of Ecology

Climate Change, Conservation & Modeling
Bangert et al. 2004 Conservation Biology, Bangert & Whitham 2007 Evolutionary Ecology, Sthultz et al. 2009 Global Change Biology, Whitham et al. 2010, Grady et al. 2011 Global Change Biology, Bangert et al. 2013 Restoration Ecology, Grady et al. 2013 Functional Ecology, Gehring et al. 2014 Molecular Ecology, Ikeda et al. 2014 Functional Ecology, Cushman et al. 2014 Ecological Applications, Woolbright et al. 2014 Trends in Ecology & Evolution



Southwest Experimental Garden Array

SEGA provides the infrastructure for genetics-based adaptive management to mitigate the impacts of:

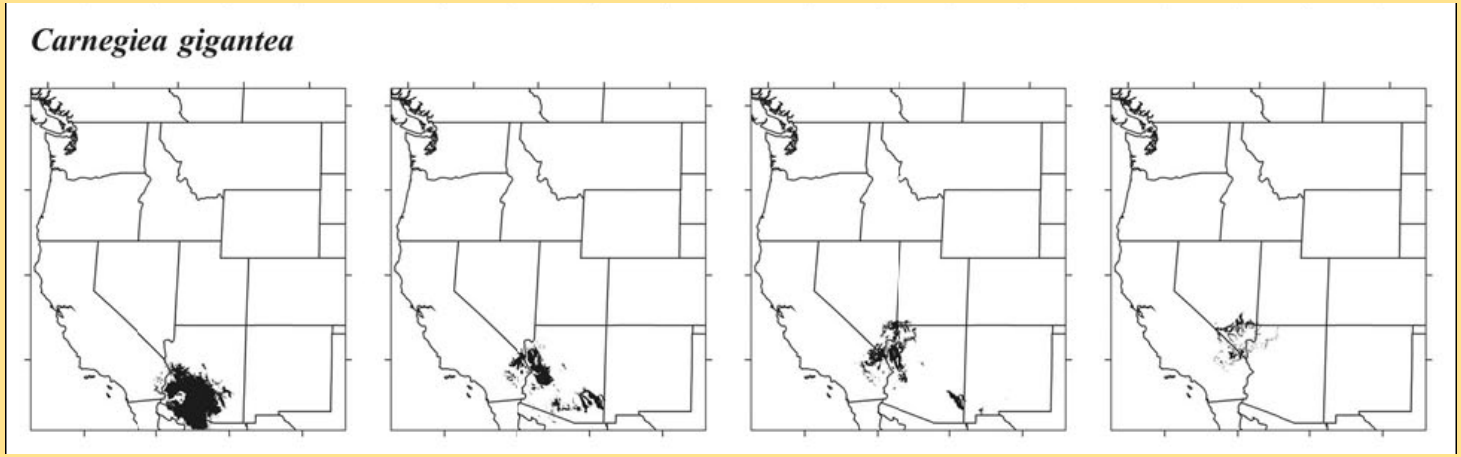
1. **climate change,**
2. **invasive species,**
3. **and other global changes.**

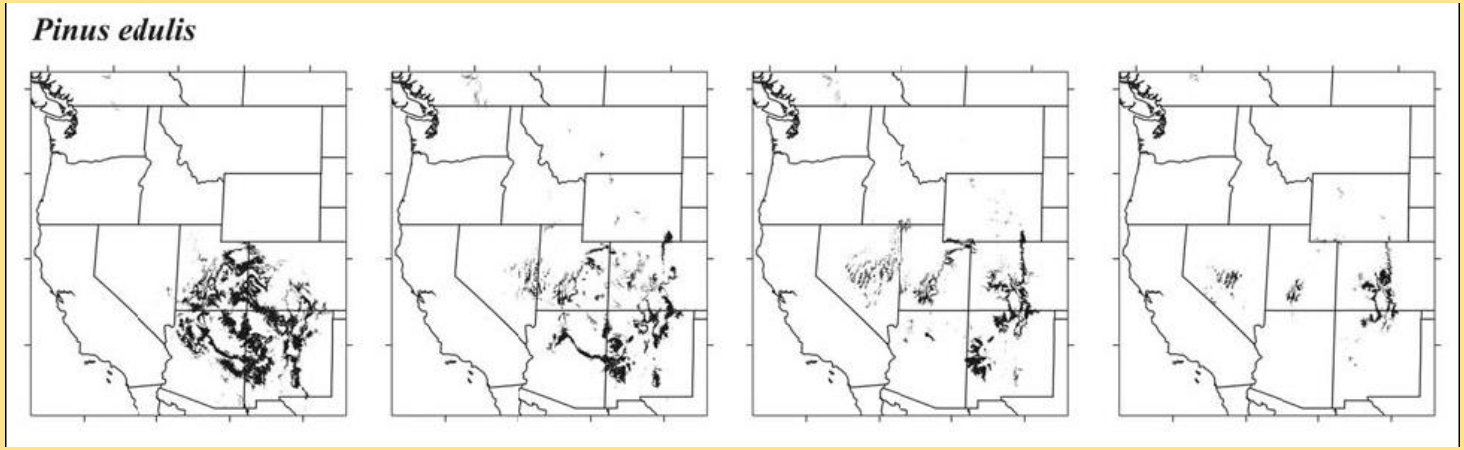
$4.5 million NSF/NAU funded

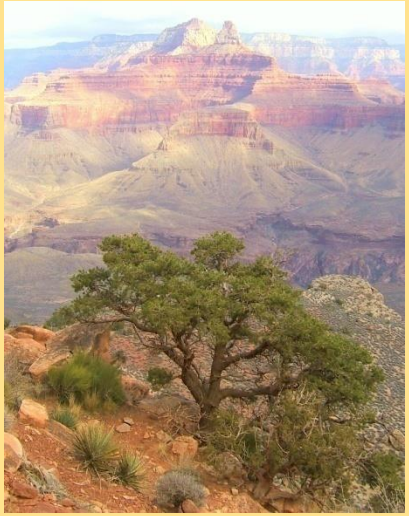
sega.nau.edu

Genetics Solutions for Climate Change

Projected climate change alters the distributions of saguaro & pinyon pine. Genetics solutions from PVER & SEGA can help with riparian and other species.

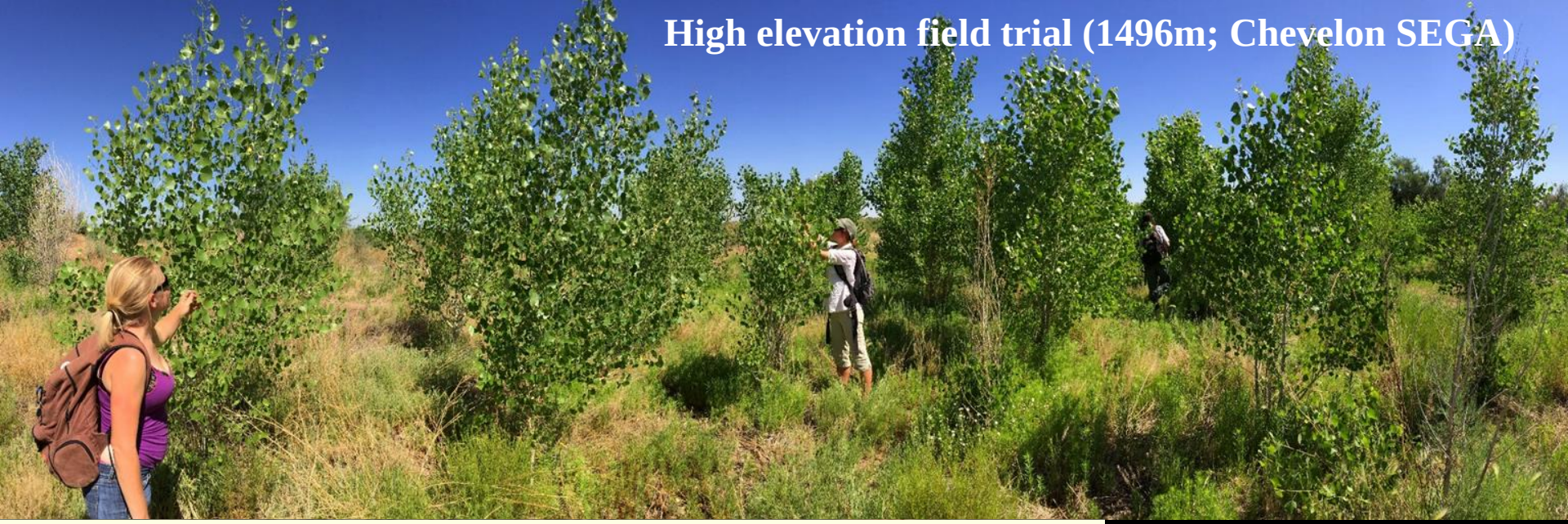




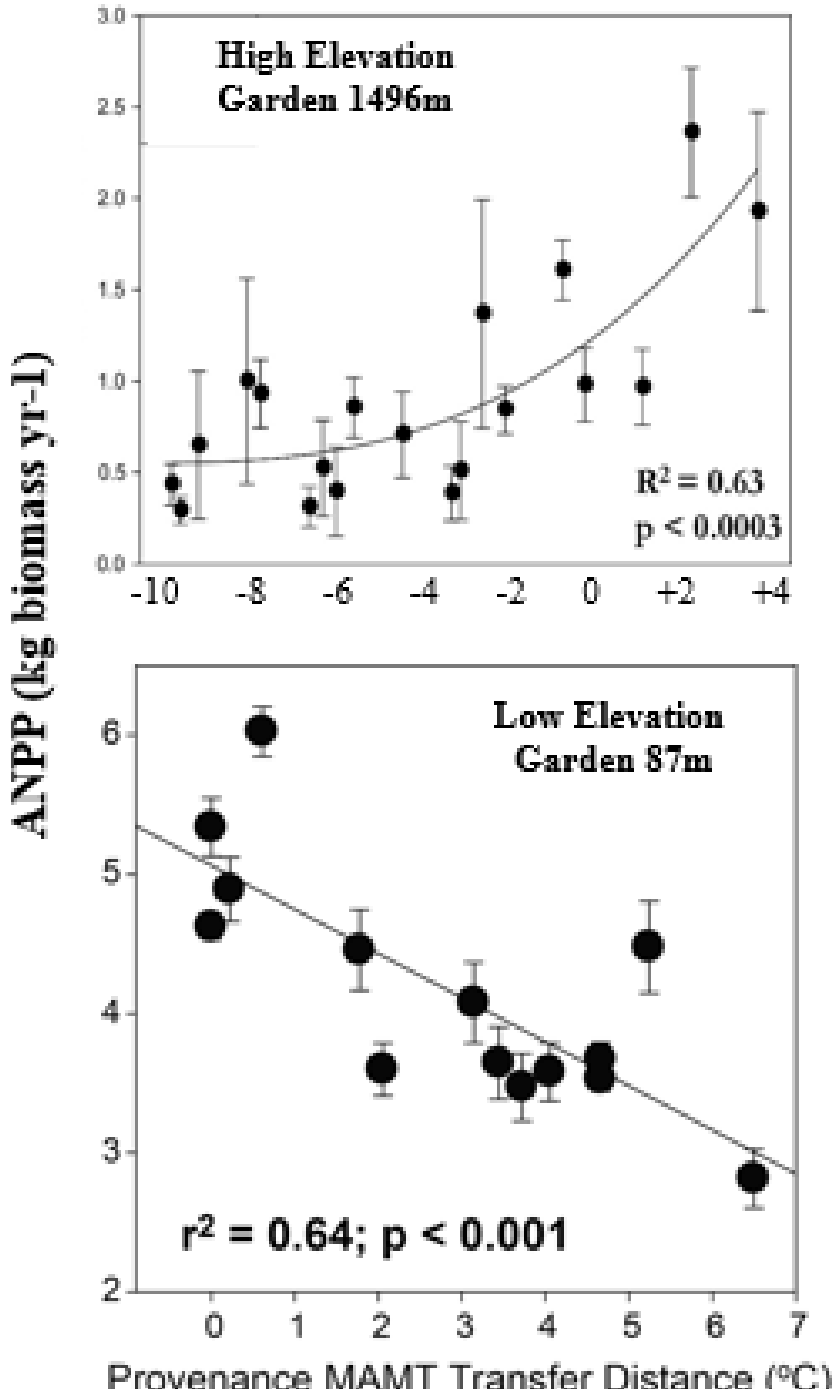


Current **2030** **2060** **2090**

Rehfeldt et al. 2006 Int. J. Plant Science



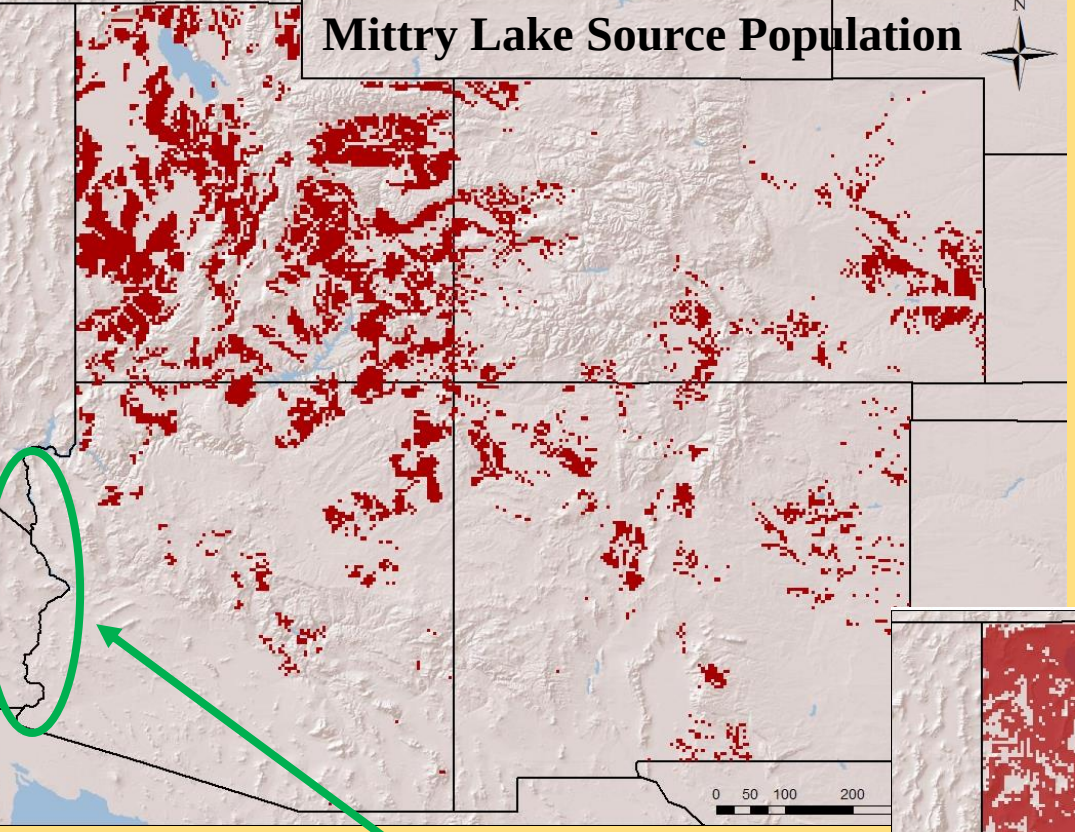
Reciprocal Fremont cottonwood gardens
© Photos by Tom Whitham



Reciprocal field trials at low and high elevations of Fremont cottonwood.

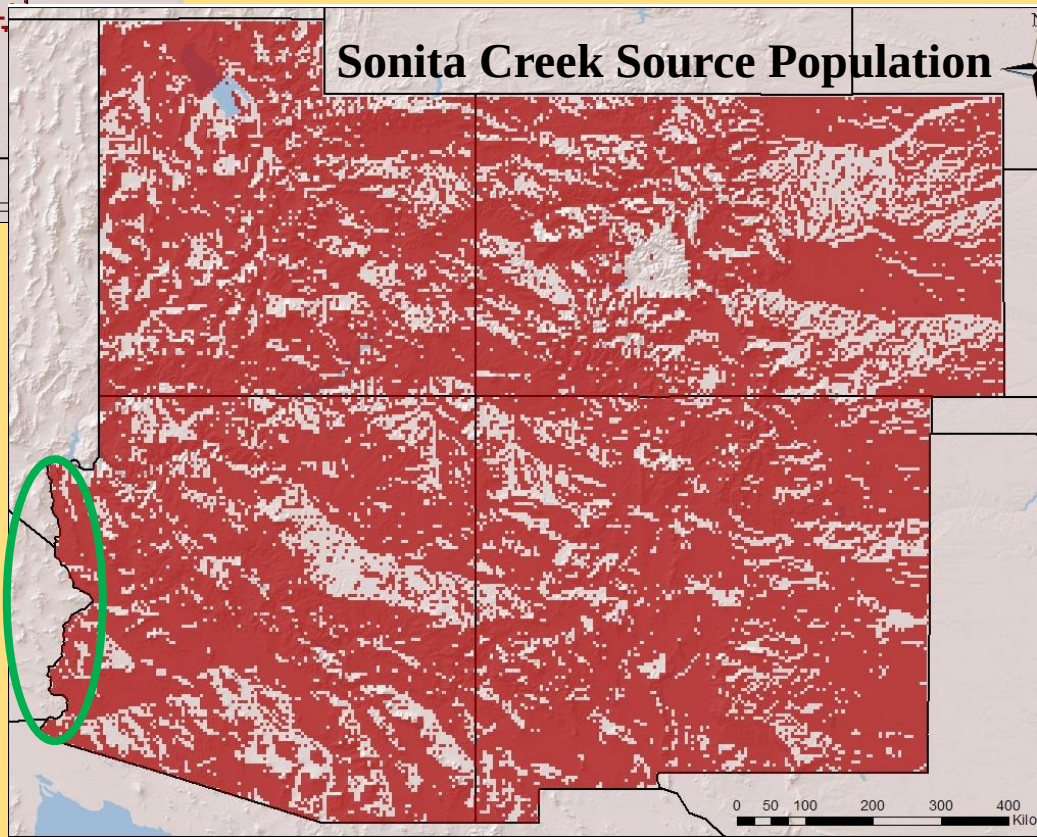
Plants that are locally adapted today will become locally maladapted for tomorrow's predicted climate; i.e., planting with local stock won't be the best practice.

Grady et al. 2011 Global Change Biology, 2013 Functional Ecology, unpublished data

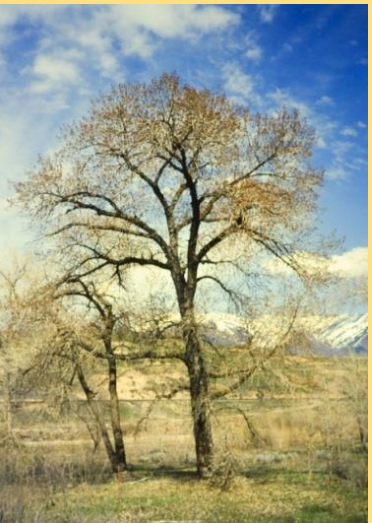


Using models to predict which genetic populations will survive tomorrow's climate. The success of major Reclamation projects can be enhanced using genetics approaches.

Maxent Models based on performance data from common garden and predicted climate change through 2100.



Area affected by restoration decisions



Populus fremontii

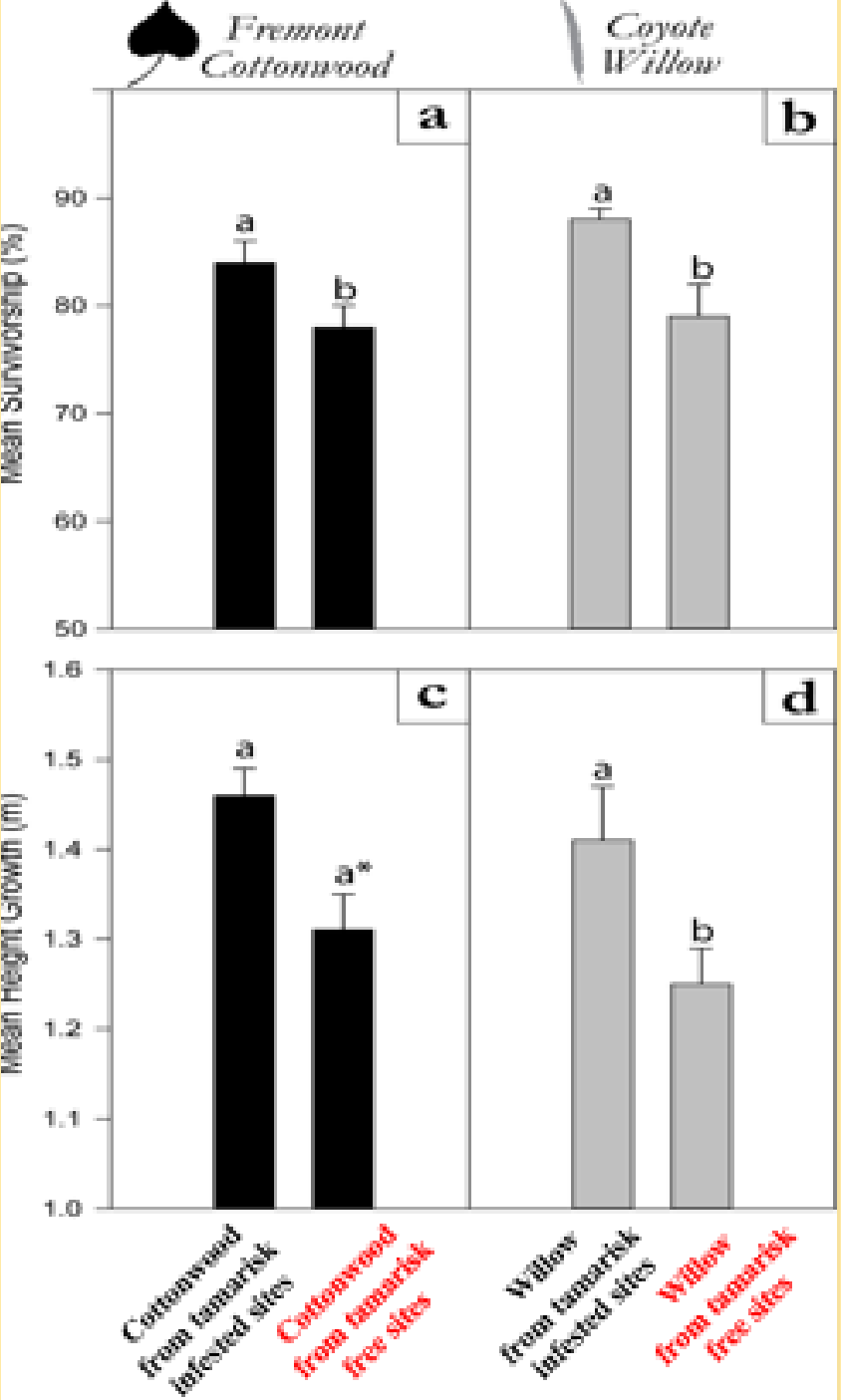
Dana Ikeda
unpub. data

Genetic solutions for invasive species

Using common gardens to identify superior genotypes to compete with invasive exotics

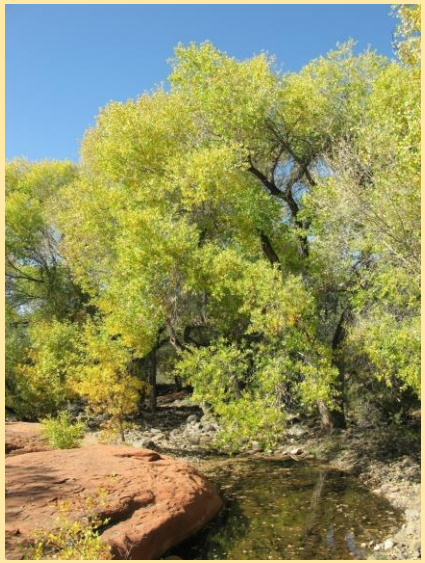
Cottonwoods and willows from tamarisk invaded stands do better in restoration than those from pristine stands because these survivors represent the toughest of the tough.

Cottonwoods and willows from sites with and without tamarisk were planted at the Chevelon SEGA site where tamarisk had been removed but was re-sprouting from the roots.



The native cottonwoods and willows that survive in tamarisk infested sites are better competitors with exotic tamarisk.

Cottonwoods and willows from tamarisk infested sites

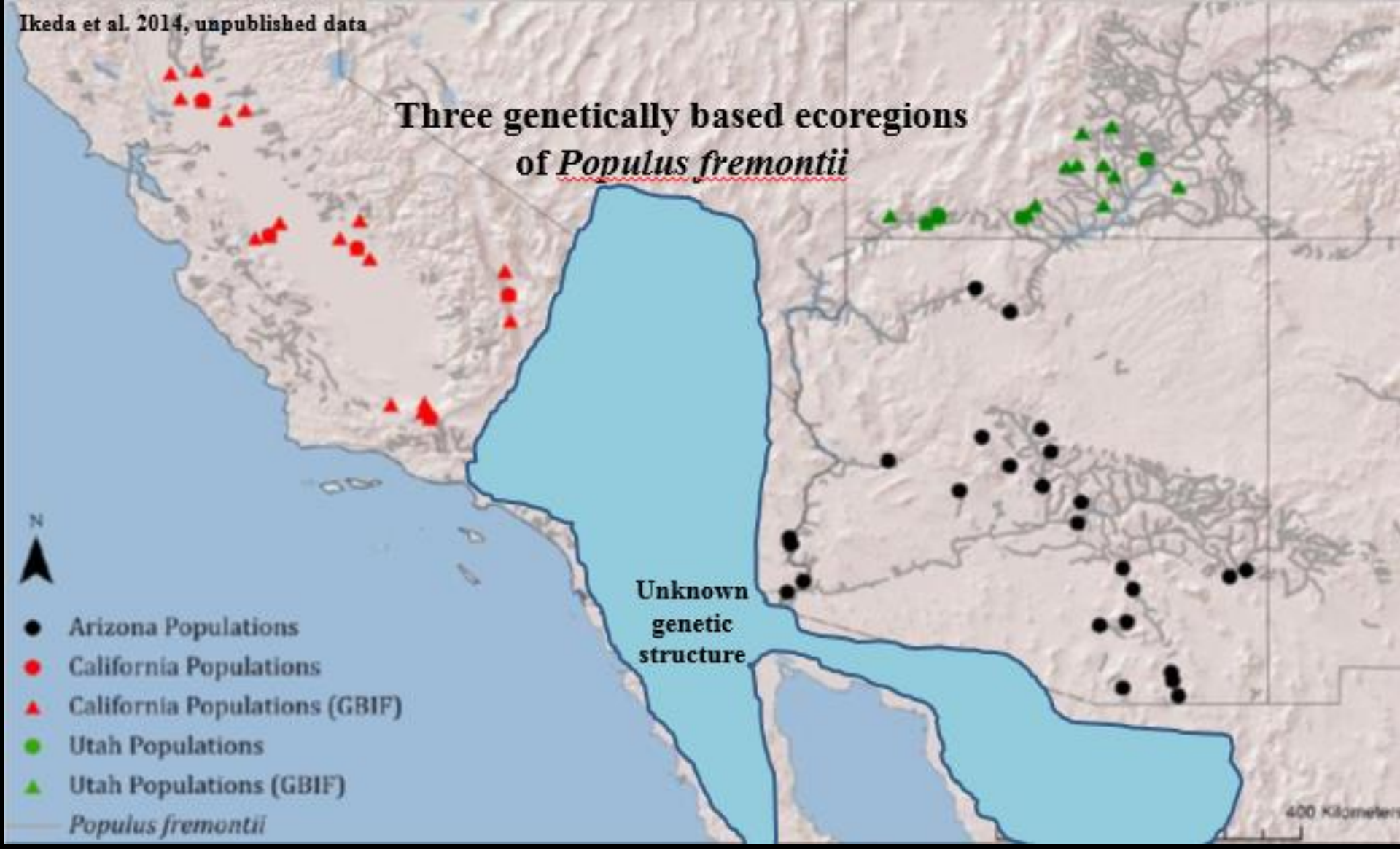


Cottonwoods and willows from tamarisk free sites

Kevin Grady et al. unpublished data

Recommendations

1. Use of source populations that have been pre-selected by invasive species will perform better in restoration than pristine populations that have never experienced invasive species.
2. Restoration should focus on the use of genetic stocks from local to more extreme environments that are 3-6°C hotter than current LCR conditions.
3. Tag plants in restoration plantings so the performance of individual genotypes and source populations can be quantified for adaptive restoration in future plantings.



Where will the plants for tomorrow's climate on the LCR be found?

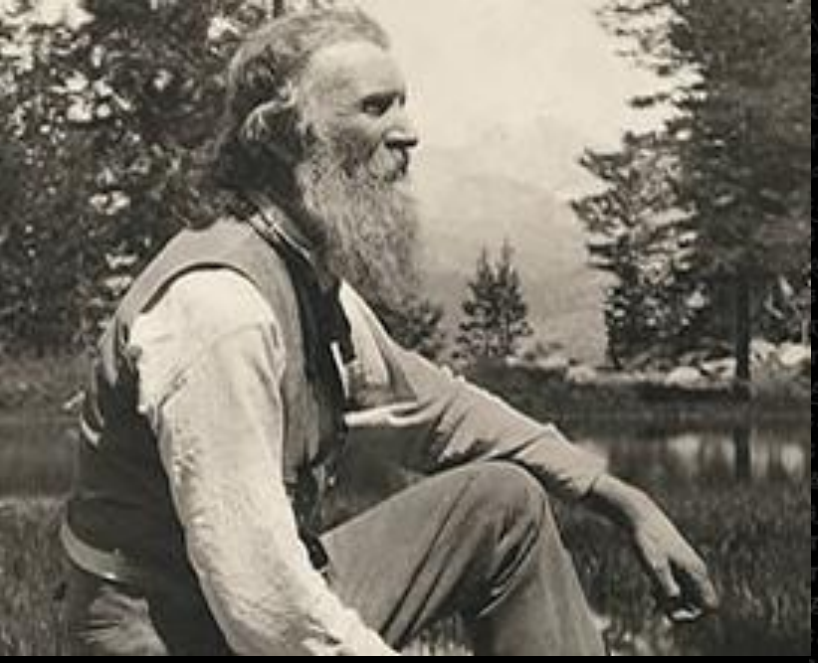
Collaborators in Genetics-Based Restoration

Rachel Adams – plant ecology
Joe Bailey – community ecology
Helen Bothwell – phylogeography
Aimée Classen – soil ecology
Sam Cushman – landscape genetics
Rachel Durben – community ecology
Dylan Fischer – ecophysiology
Catherine Gehring – microbial ecology
Steve Hart – ecosystem/soil ecology
Joakim Hjältén – ecology
Dana Ikeda – climate modeling
Karla Kennedy – gardens manager
Andrew Krohn - molecular ecology
Carri LeRoy – aquatic ecology
Eric Lonsdorf – genetic modeling
Richard Michalet - facilitation & ecology
Brad Potts – quantitative genetics
Steve Shuster – theoretical genetics
Faith Walker – mammalian ecology
Gina Wimp – community ecology
Stuart Wooley – chemical ecology
Matt Zinkgraf – molecular genetics

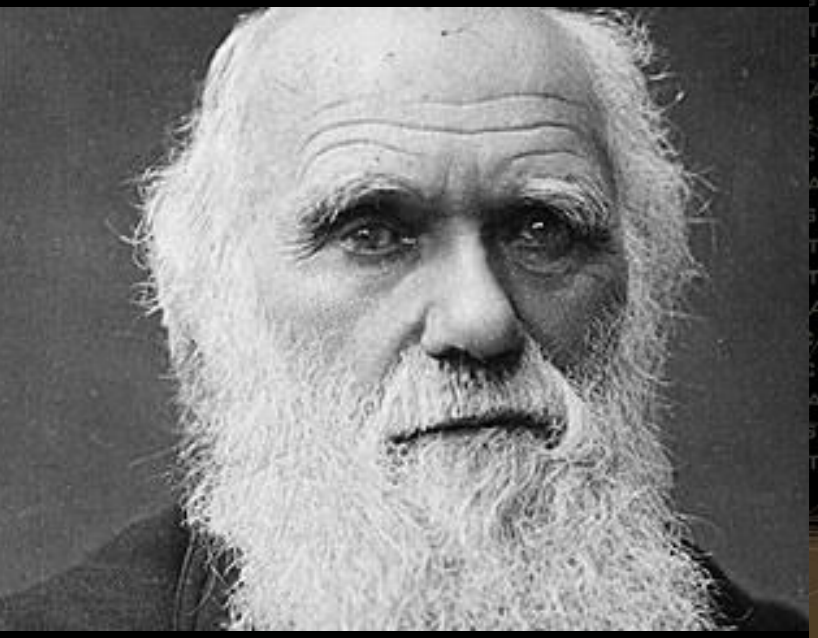
Gery Allan – molecular ecology
Randy Bangert – biogeography
Bill Bridgeland – avian ecology
Zacchaeus Compson – aquatic ecology
Steve DiFazio – molecular ecology
Luke Evans – population ecology
Paul Flikkema – systems engineering
Kevin Grady – nutrient cycling
Kim Haase – climate change modeling
Lisa Holeski – genetics & chemistry
Nathalie Isabel – molecular ecology
George Koch – ecophysiology
Jamie Lamit – microbial ecology
Rick Lindroth – chemical ecology
Jane Marks – aquatic ecology
Nashelly Meneses – ecological genetics
Jen Schweitzer – ecosystems
Adrian Stone – community ecology
Amy Whipple – ecological genetics
Todd Wojtowicz – litter arthropods
Scott Woolbright - molecular genetics

Petter Axelsson – transgenic trees
Brad Blake – greenhouse manager
Posy Busby – ecological plant pathology
Hillary Cooper – phylogenetics
Rodolfo Dirzo – community ecology
Sharon Ferrier – conservation ecology
Kevin Floate – insect ecology
Laura Hagenauer - biodiversity
Erika Hersch – ecological genetics
Kevin Hultine – invasive species
Art Keith – insect community ecology
Tom Kolb – plant physiology
Matthew Lau – network modeling
Nathan Lojewski – system productivity
Tamara Max – molecular ecology
George Newcombe – plant pathology
David Smith – landscape ecology
Chris Sthultz – plant ecology
Tom Whitham – community ecology
Troy Wood – ecology
Adam Wymore – aquatic ecology

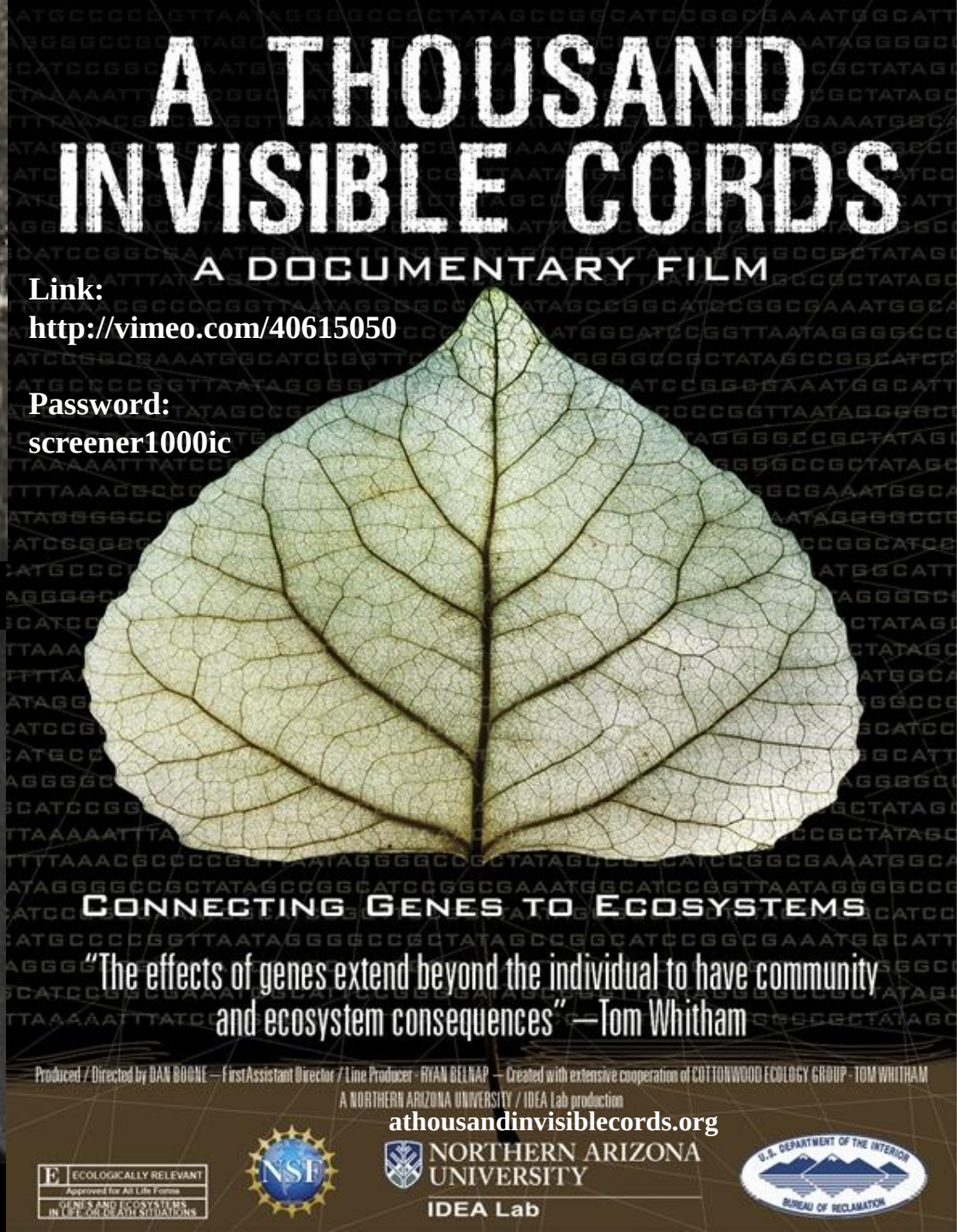
<u>GO & NGO collaborators</u> Mike Ingraldi, Dave Cagle – Arizona Game & Fish Charles Schelz – National Park Service
Mary McKinley – Ogden Nature Center Gregg Garnett – Bureau of Reclamation Kris Haskins – The Arboretum at Flagstaff
Paul Burnett – Utah Dept. of Natural Resources
<u>Outreach</u> – Dan Boone, Ryan Belnap, Lara Schmit
Victor Leshyk



John Muir's "1000 invisible cords"



Charles Darwin's "entangled bank"



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