Lessons from five years of RestoreNet networked restoration experiments

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Overview of presentation

1. What is RAMPS?
2. What is RestoreNet?
3. RestoreNet 1.0 results
4. RestoreNet 2.0 overview
5. Communication and collaboration

RAMPS: Restoration Assessment & Monitoring Program for the Southwest

RAMPS
Connecting Science and Land Management To Enhance Southwest Ecosystems

Mission

Strengthen restoration and rehabilitation outcomes in the Southwest U.S. by proving science and guidance on effective strategies

http://usgs.gov/sbsc/ramps

USGS
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Why RAMPS?

RAMPS

Connecting Science and Land Management To Enhance Southwest Ecosystems

3. Communication and Outreach

2. Research

1. Partner Engagement

3-Part Collaborative Approach to Restoring Ecosystems

USGS science for a changing world

NATIONAL SYSTEM OF PUBLIC LANDS
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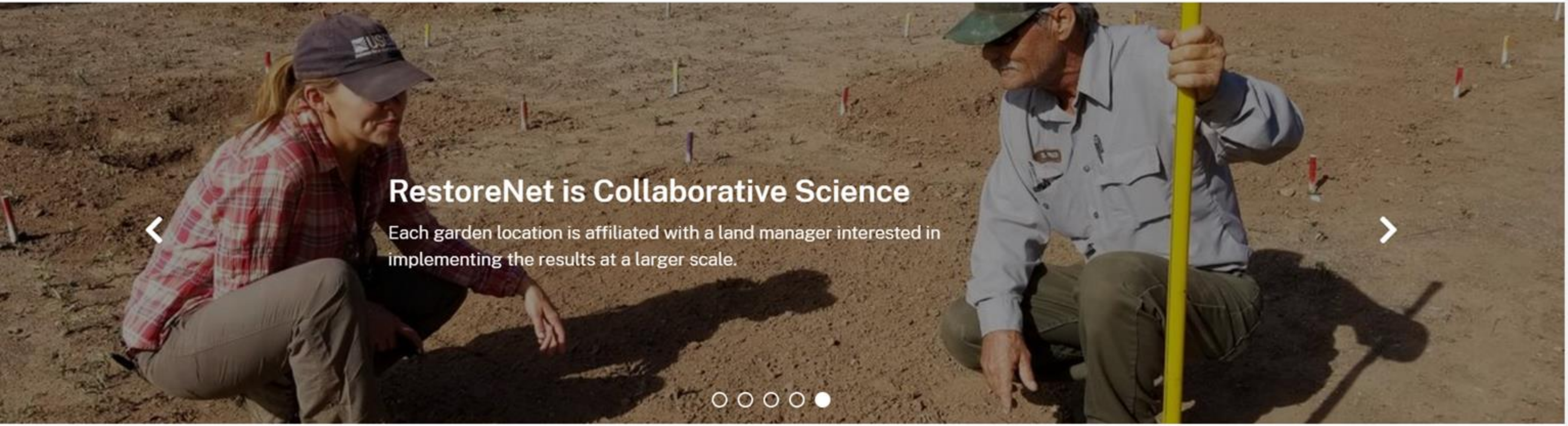
RestoreNet: Distributed Field Trial Network for Dryland Restoration

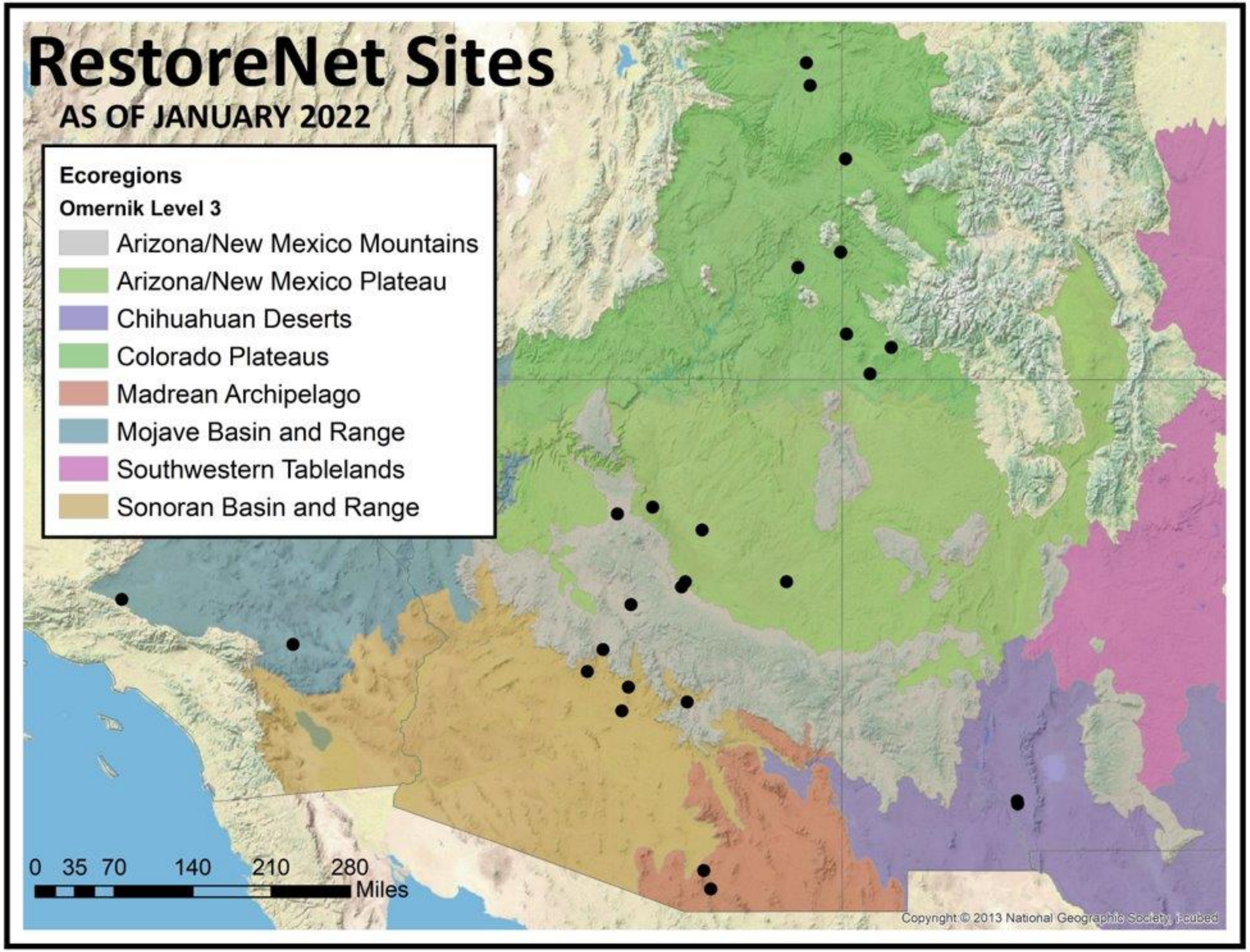
ACTIVE

By Southwest Biological Science Center August 5, 2017



RestoreNet is a co-produced research network that systematically tests dryland restoration treatments across environmental gradients in the Southwest

http://usgs.gov/sbsc/restorenet

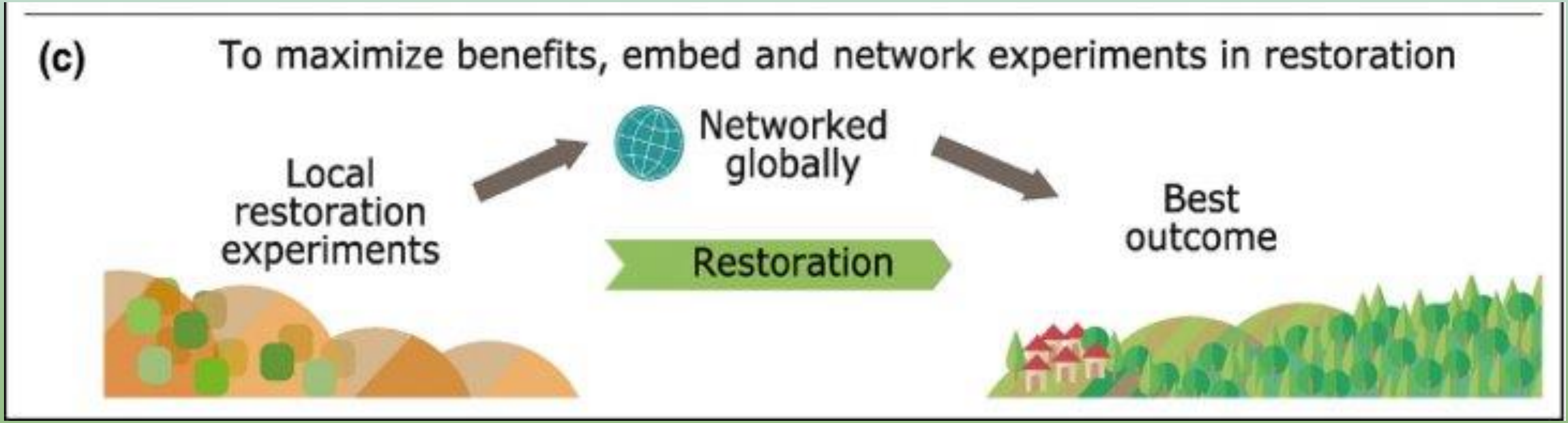

RestoreNet Sites
AS OF JANUARY 2022
Ecoregions
Omernik Level 3
Arizona/New Mexico Mountains
Arizona/New Mexico Plateau
Chihuahuan Deserts
Colorado Plateaus
Madrean Archipelago
Mojave Basin and Range
Southwestern Tablelands
Sonoran Basin and Range
0 35 70 140 210 280
Miles
Copyright © 2013 National Geographic Society, i-cubed

RestoreNet benefits land managers

- Knowledge co-production
- Demonstration sites
- Low risk testing

RestoreNet improves restoration outcomes

- Standard treatments across environmental gradients
- Can explore how environmental characteristics interact with treatments to influence outcomes



Gellie et al (2018) Front. Ecol. Environ.

Treatments

Seed mixes

Soil surface modifications

Outplants

Seedballs

Live topsoil inoculation

Targeted livestock grazing

RestoreNet improves soil health

- Revegetation can improve soil health
- Treatments aimed at improving soil health

Live topsoil inoculation

Targeted livestock grazing

Monitoring

- Germination, growth, and survival
- Plant composition and structure
- Ecosystem services
- Soil health and properties
- Post-precipitation monitoring in fall and spring

RestoreNet 1.0
2018-2022

Katie Laushman

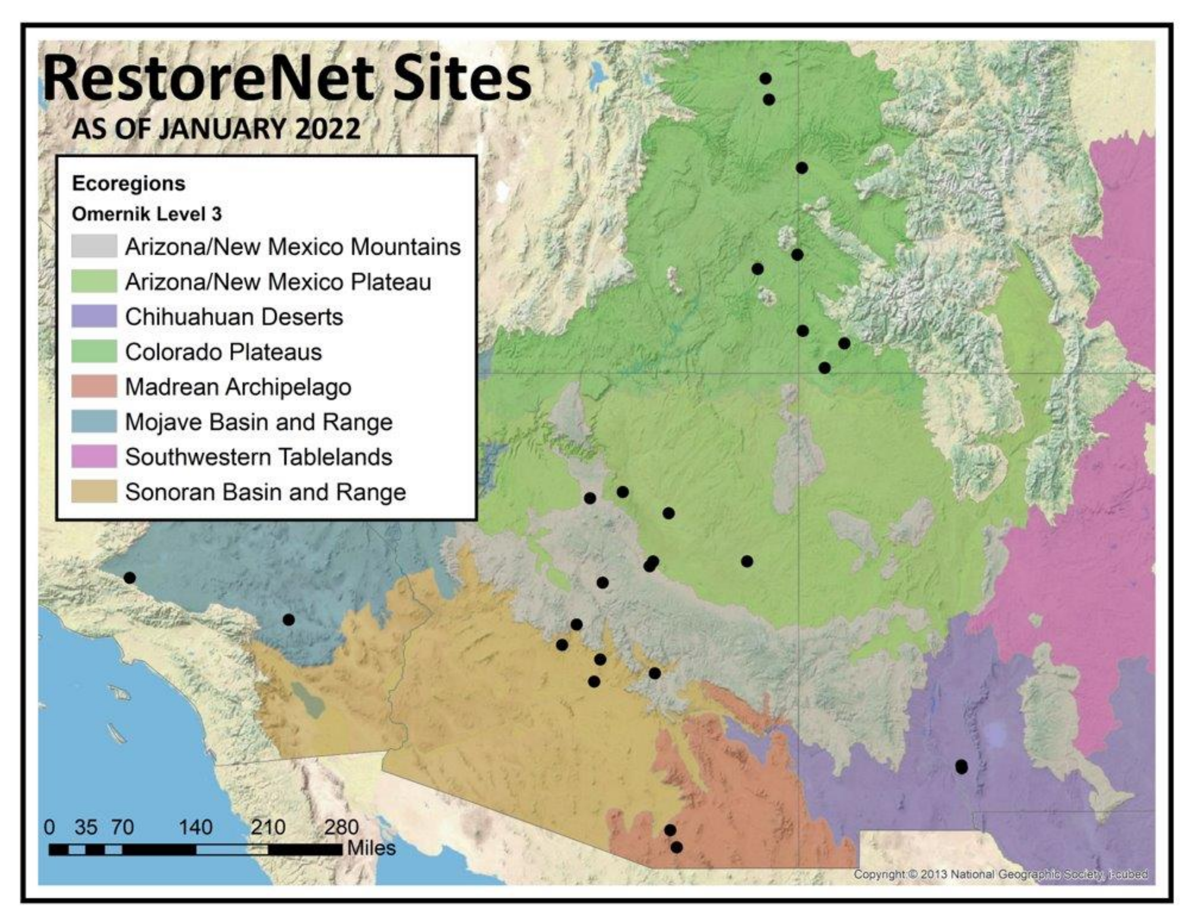
Molly McCormick

Seed x Soil Surface Treatments

Outplanted Seedlings

RestoreNet 1.0: Seed mixes

- Native forbs, grasses, shrubs
- Cool and warm species relative to each region



Example cool seed mix

Sporobolus cryptandrus (sand dropseed)

Heliomeris multiflora (showy goldeneye)

Region	Scientific name	Common Name	Seed mix
Madrean Archipelago	*Bouteloua gracilis*	blue grama	Cool
Madrean Archipelago	*Elymus elymoides*	squirreltail	Cool
Madrean Archipelago	*Heliomeris multiflora*	showy goldeneye	Cool
Madrean Archipelago	*Hesperostipa neomexicana*	New Mexico feathergrass	Cool
Madrean Archipelago	*Machaeranthera tanacetifolia*	tansey aster	Cool
Madrean Archipelago	*Poa secunda*	Sandberg bluegrass	Cool
Madrean Archipelago	*Sporobolus cryptandrus*	sand dropseed	Cool
Madrean Archipelago	*Aristida purpurea*	purple three-awn	Warm
Madrean Archipelago	*Asclepias tuberosa*	pleurisy root	Warm
Madrean Archipelago	*Baileya multiradiata*	desert marigold	Warm
Madrean Archipelago	*Bouteloua curtipendula*	sideoats grama	Warm
Madrean Archipelago	*Penstemon palmeri*	Palmer's penstemon	Warm
Madrean Archipelago	*Pleuraphis jamesii*	James galleta	Warm
Madrean Archipelago	*Senna covesii*	desert senna	Warm

Photos by Max Licher via SEINet

Example warm seed mix

Bouteloua curtipendula
(sideoats grama)

Senna covesii
(*desert senna*)

Region	Scientific name	Common Name	Seed mix
Madrean Archipelago	*Bouteloua gracilis*	blue grama	Cool
Madrean Archipelago	*Elymus elymoides*	Squirreltail	Cool
Madrean Archipelago	*Heliomeris multiflora*	showy goldeneye	Cool
Madrean Archipelago	*Hesperostipa neomexicana*	New Mexico feathergrass	Cool
Madrean Archipelago	*Machaeranthera tanacetifolia*	tansey aster	Cool
Madrean Archipelago	*Poa secunda*	Sandberg bluegrass	Cool
Madrean Archipelago	*Sporobolus cryptandrus*	sand dropseed	Cool
Madrean Archipelago	*Aristida purpurea*	purple three-awn	Warm
Madrean Archipelago	*Asclepias tuberosa*	pleurisy root	Warm
Madrean Archipelago	*Baileya multiradiata*	desert marigold	Warm
Madrean Archipelago	*Bouteloua curtipendula*	sideoats grama	Warm
Madrean Archipelago	*Penstemon palmeri*	Palmer's penstemon	Warm
Madrean Archipelago	*Pleuraphis jamesii*	James galleta	Warm
Madrean Archipelago	*Senna covesii*	desert senna	Warm

Photos by Max Licher and Sue Carnahan via SEINet

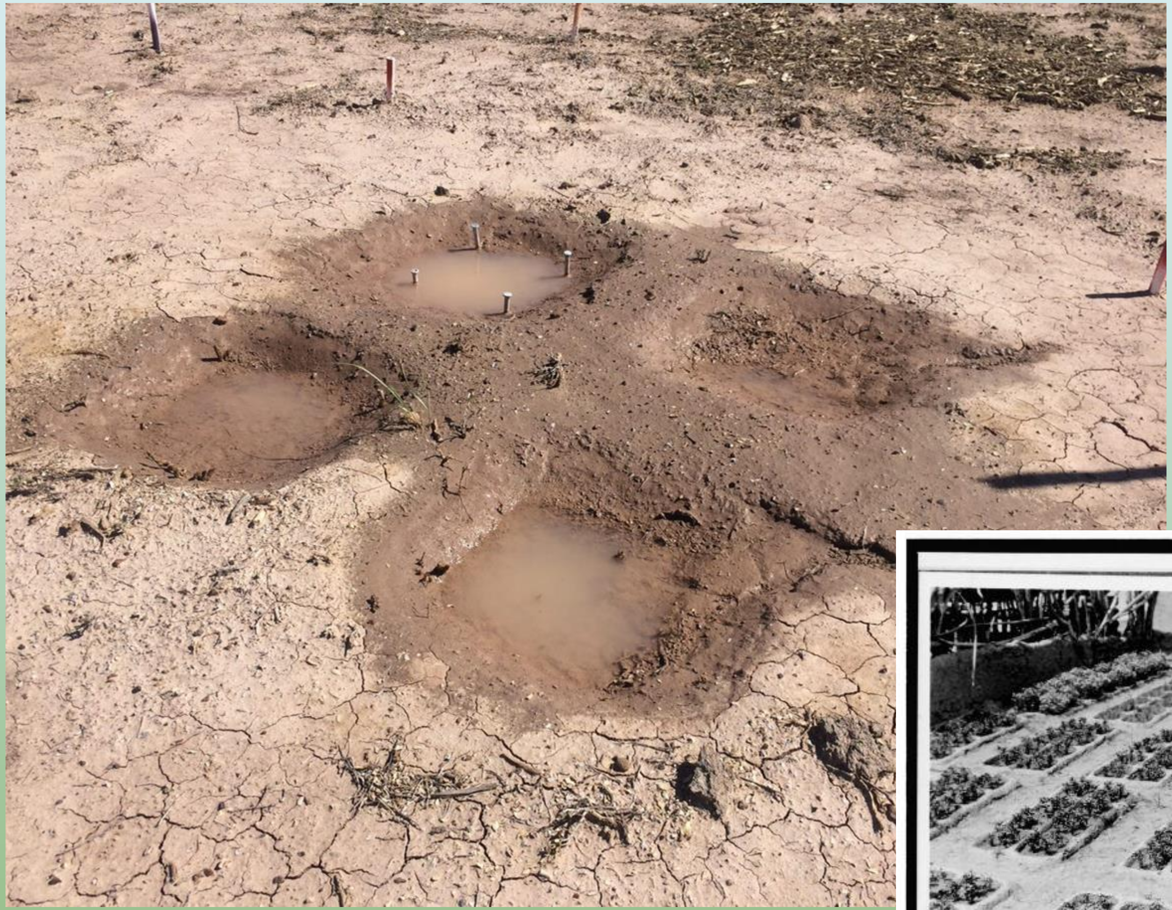
RestoreNet 1.0: Soil surface modifications

Soil Pits

Mulch

ConMods

Soil pits



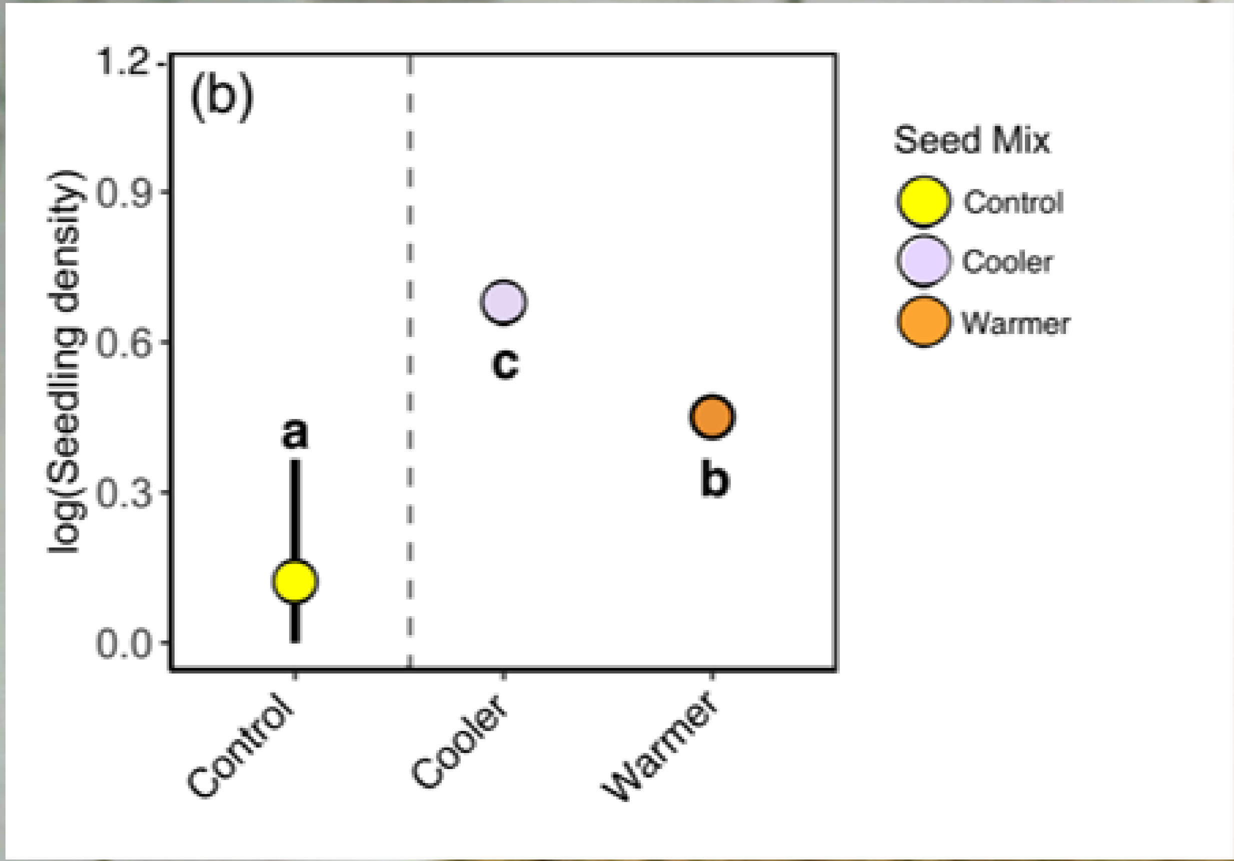
Edward Curtis, Library of Congress, via Johnston et al. 2023 *Society For Range Mgmt*

Mulch

ConMods – artificial nurse plants

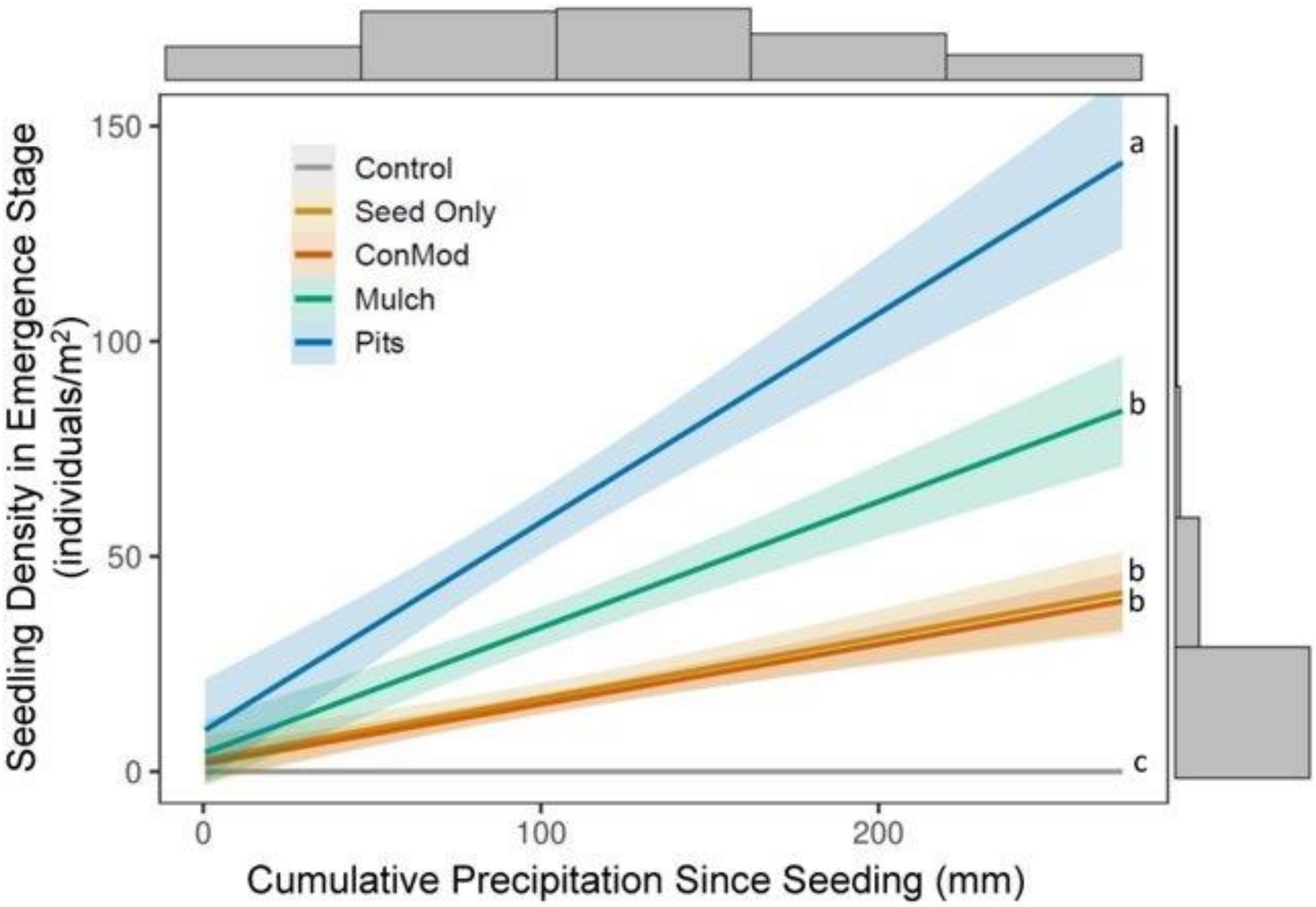

RestoreNet site after 1.0 seeding treatment installation

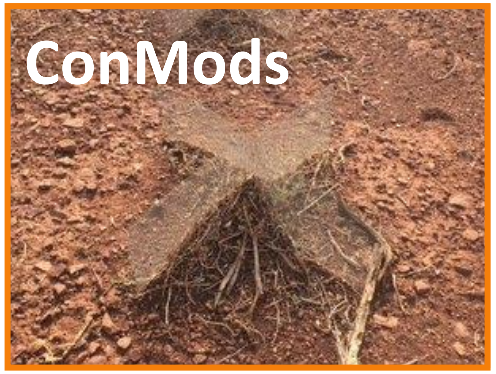
Cool seed mix outperformed warmer (during above average precipitation)



Harvilla et al. (2020) Journal of Applied Ecology

Soil surface modifications improved seeding success





Farrell et al. (2023) Ecological Applications

Soil pits increased soil moisture and improved seedling emergence

Farrell et al. (2023) Ecological Applications

Invasive species limited seeded emergence, but not survival

Farrell et al. (2023) Ecological Applications

Key takeaways

Seed mix for current and future climate

Use soil surface modifications, pits

Align seeding with precipitation

Treat exotic species

Harvilla et al. (2020) Journal of Applied Ecology; Farrell et al. (2023) Ecological Applications

RestoreNet 1.0 - In the works

How does a species climatic tolerance predict performance

- Across aridity gradient
- Across ecoregions
- With varying precipitation

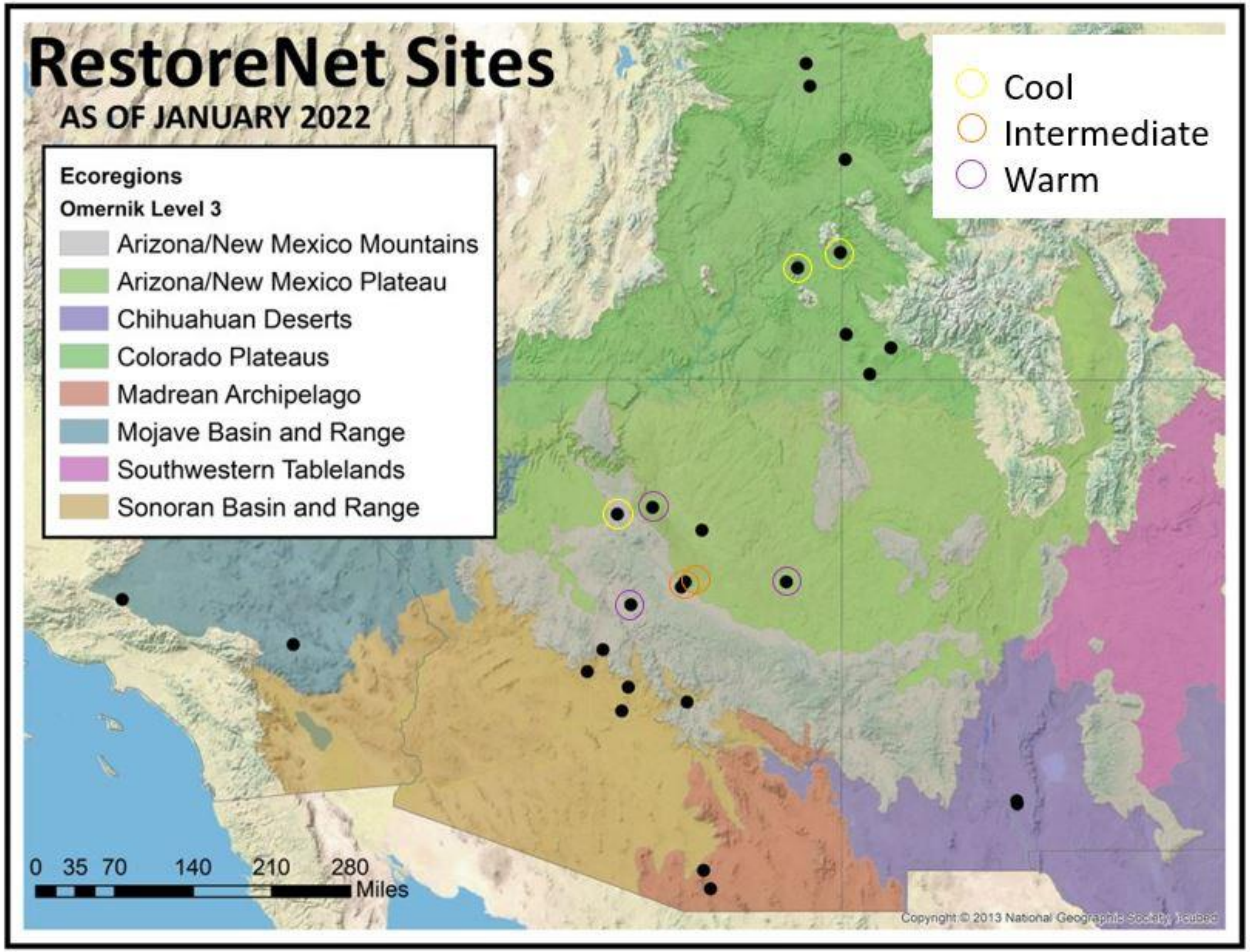
RestoreNet Outplants

- Same species as seeding experiments
- Seedlings grown in greenhouse then outplanted
- Some plants harvested for trait-screening in greenhouse

Kathleen Balazs

RestoreNet site during outplant installation

RestoreNet site after outplants have established, weed cloth removed



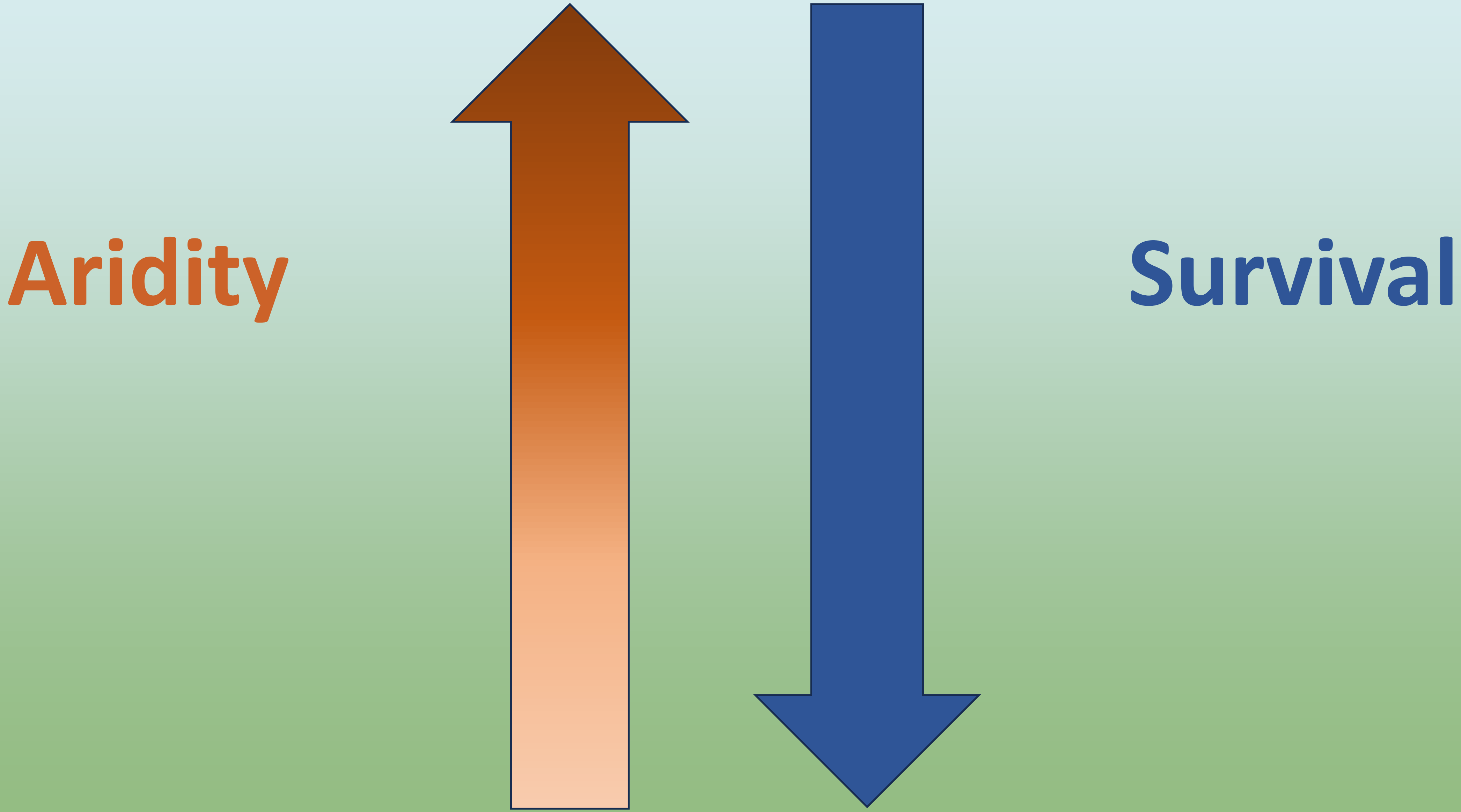
RestoreNet sites that received ouutplants in CO Plateau are circled

Categorized as cool, intermediate, or warm based on climate

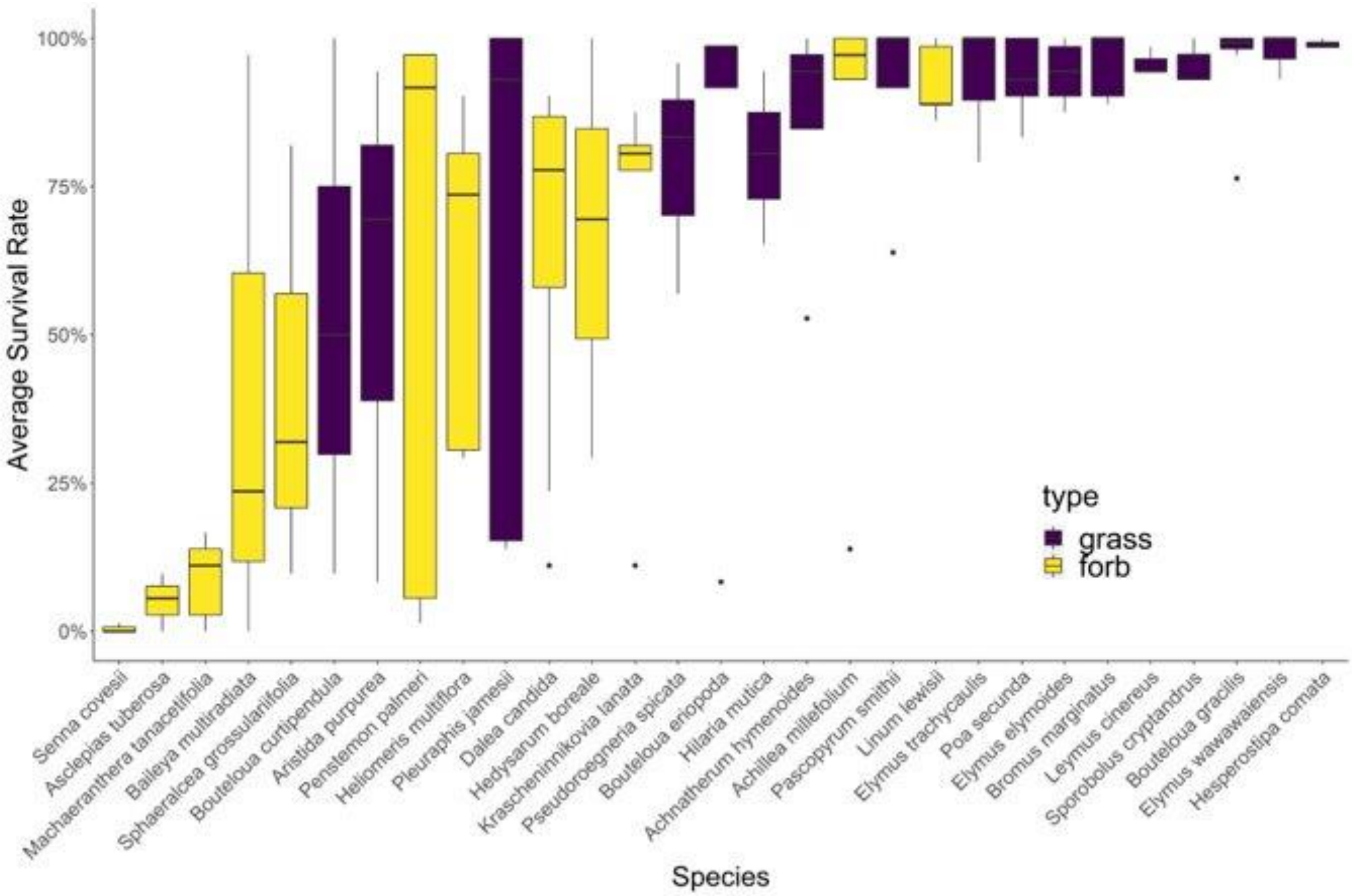
TABLE 3 Species pools. Each site has 16 species with unique species in blue and red, and shared species between cool and intermediate in green; cool, intermediate and warm in yellow; and intermediate and warm in orange. MAT95 values represent 95th percentile of species mean annual temperature distributions after removing outliers

Cool species pool			Intermediate species pool			Warm species pool		
Species	Growth form	MAT 95	Species	Growth form	MAT 95	Species	Growth form	MAT 95
Pseudoroegneria spicata	Grass	11.4	*Linum lewisii*	Forb	13.3	*Achillea millefolium*	Forb	15.5
Hedysarum boreale	Forb	11.7	*Heliomeris multiflora*	Forb	13.7	*Dalea candida*	Forb	15.7
Elymus trachycaulis	Grass	5.9	*Bromus marginatus*	Grass	14.2	*Bouteloua gracilis*	Grass	15.9
Elymus wawawaiensis	Grass	12.0	*Pascopyrum smithii*	Grass	14.2	*Poa secunda*	Grass	16.7
Leymus cinereus	Grass	12.1	*Pleuraphis jamesii*	Grass	15.1	*Sporobolus cryptandrus*	Grass	16.9
Hesperostipa comata	Grass	12.2	*Elymus elymoides*	Grass	15.5	*Machaeranthera tanacetifolia*	Forb	17.0
Sphaeralcea grossulariifolia	Forb	12.7	*Achillea millefolium*	Forb	15.5	*Bouteloua eriopoda*	Grass	17.1
Linum lewisii	Forb	13.3	*Dalea candida*	Forb	15.7	*Krascheninnikovia lanata*	Forb	17.4
Heliomeris multiflora	Forb	13.7	*Bouteloua gracilis*	Grass	15.9	*Penstemon palmeri*	Forb	18.1
Bromus marginatus	Grass	14.2	*Poa secunda*	Grass	16.7	*Achnatherum hymenoides*	Grass	18.3
Pascopyrum smithii	Grass	14.2	*Sporobolus cryptandrus*	Grass	16.9	*Bouteloua curtipendula*	Grass	18.7
Pleuraphis jamesii	Grass	15.1	*Machaeranthera tanacetifolia*	Forb	17.0	*Asclepias tuberosa*	Forb	19.4
Elymus elymoides	Grass	15.5	*Bouteloua eriopoda*	Grass	17.1	*Aristida purpurea*	Grass	21.1
Achillea millefolium	Forb	15.5	*Krascheninnikovia lanata*	Forb	17.4	*Baileya multiradiata*	Forb	21.4
Dalea candida	Forb	15.7	*Penstemon palmeri*	Forb	18.1	*Hilaria mutica*	Grass	21.5
Bouteloua gracilis	Grass	15.9	*Achnatherum hymenoides*	Grass	18.3	*Senna covesii*	Forb	21.7

Survival was highest at cool and intermediate sites, lowest at warm/arid sites



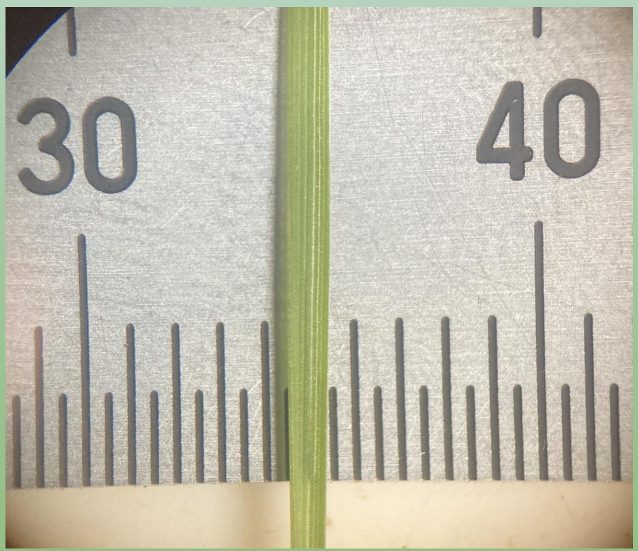
Survival differed by species, grasses had higher survival than forbs



Balazs et al. (2021) Journal of Ecology

Plant traits

- Characteristics that influence how plants interact with their environment
- Restoration species can be chosen based on traits that match environmental and ecological conditions



Trait measurements taken from outplants in greenhouse

Successful traits across all environments

Successful

Dense leaves

Thin roots

Unsuccessful

Thin leaves

Thick roots

Balazs et al. (2021) Journal of Ecology

Successful at all CO Plateau sites




Needle and thread
(*Hesperostipa comata*)

Snake river wheatgrass
(*Elymus wawawaiensis)*

Blue grama
(Bouteloua gracilis)

Sand dropseed
(*Sporobolus cryptandrus)*

Mountain bromegrass
(*Bromus marginatus)*

Great Basin wildrye
(*Leymus cinereus)*

Bottlebrush squirreltail
(*Elymus elmoides)*

Sandberg bluegrass
(*Poa secunda)*




Not successful at any site on the CO Plateau

Butterfly milkweed
(*Asclepias tuberosa*)

Desert senna
(*Senna covesii*)

Tansy aster
(*Machaeranthera tanacetifolia*)

Trait suitability can depend on environment

Successful at cool sites:

Short fine roots

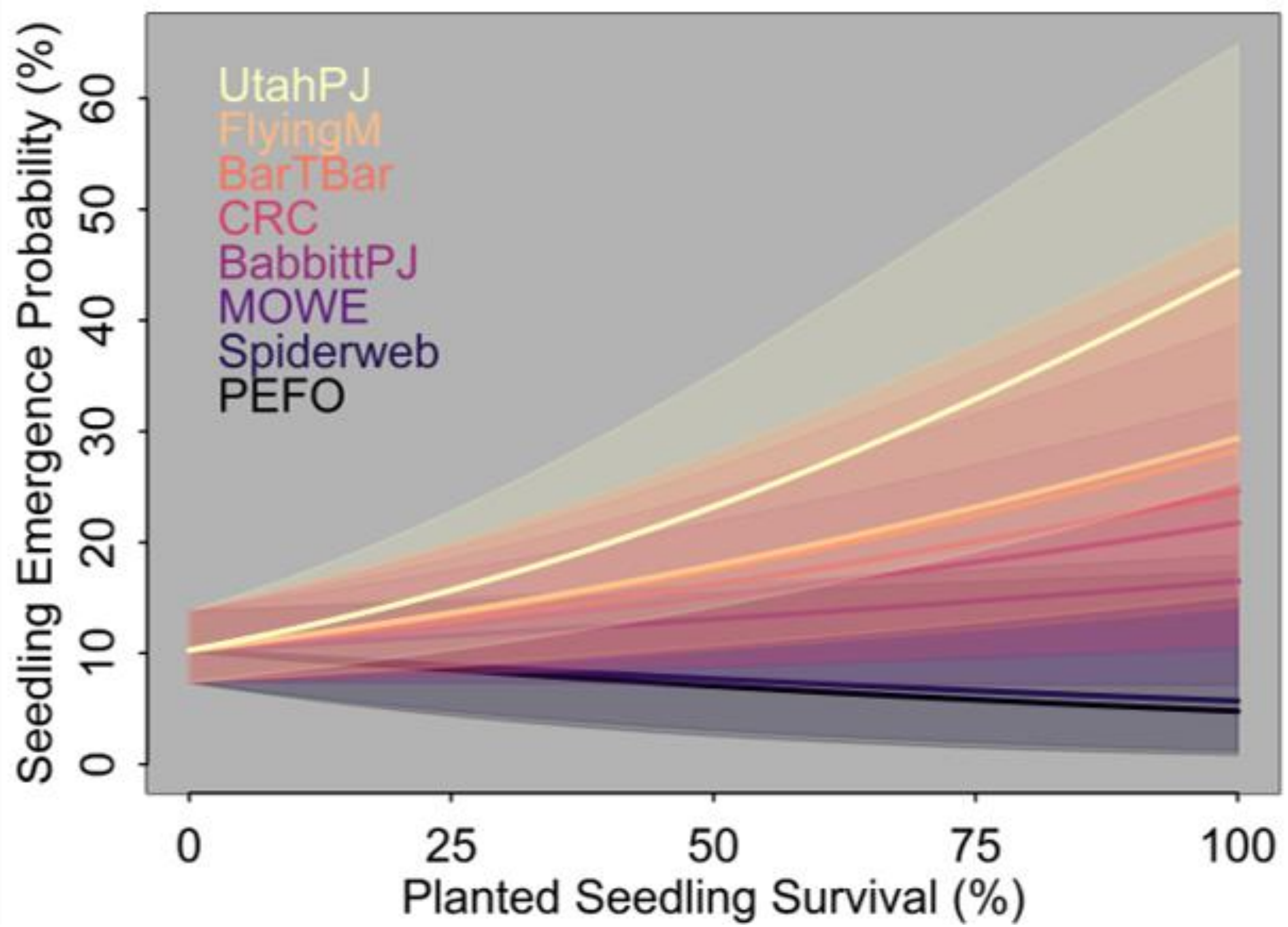
Successful at arid sites:

Drought tolerance

Long fine roots

Balazs et al. (2021) Journal of Ecology, Butterfield et al. (2023) Journal of Applied Ecology

Seedling emergence and outplant survival were correlated at cooler sites



Butterfield & Munson, In Press, Appl Veg Science

Key takeaways

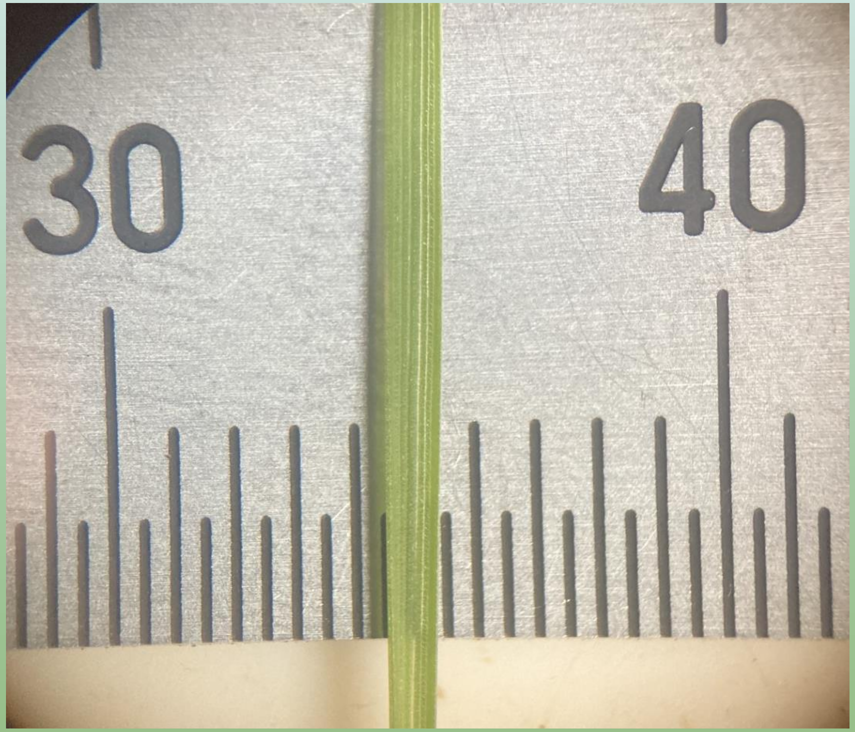
Restoration sites are harsh, limiting which traits confer success

Establish hardy, drought-tolerant species

Balazs et al. (2021) Journal of Ecology

Key takeaways

Functional traits may predict outplant success → Consider plant traits when selecting restoration species



Balazs et al. (2021) Journal of Ecology

Key takeaways

Trait variation was restricted at arid sites → Consider plant drought-tolerant plants for arid sites

Balazs et al. (2021) Journal of Ecology, Butterfield et al. (2023) Journal of Applied Ecology

Outplants - In the works

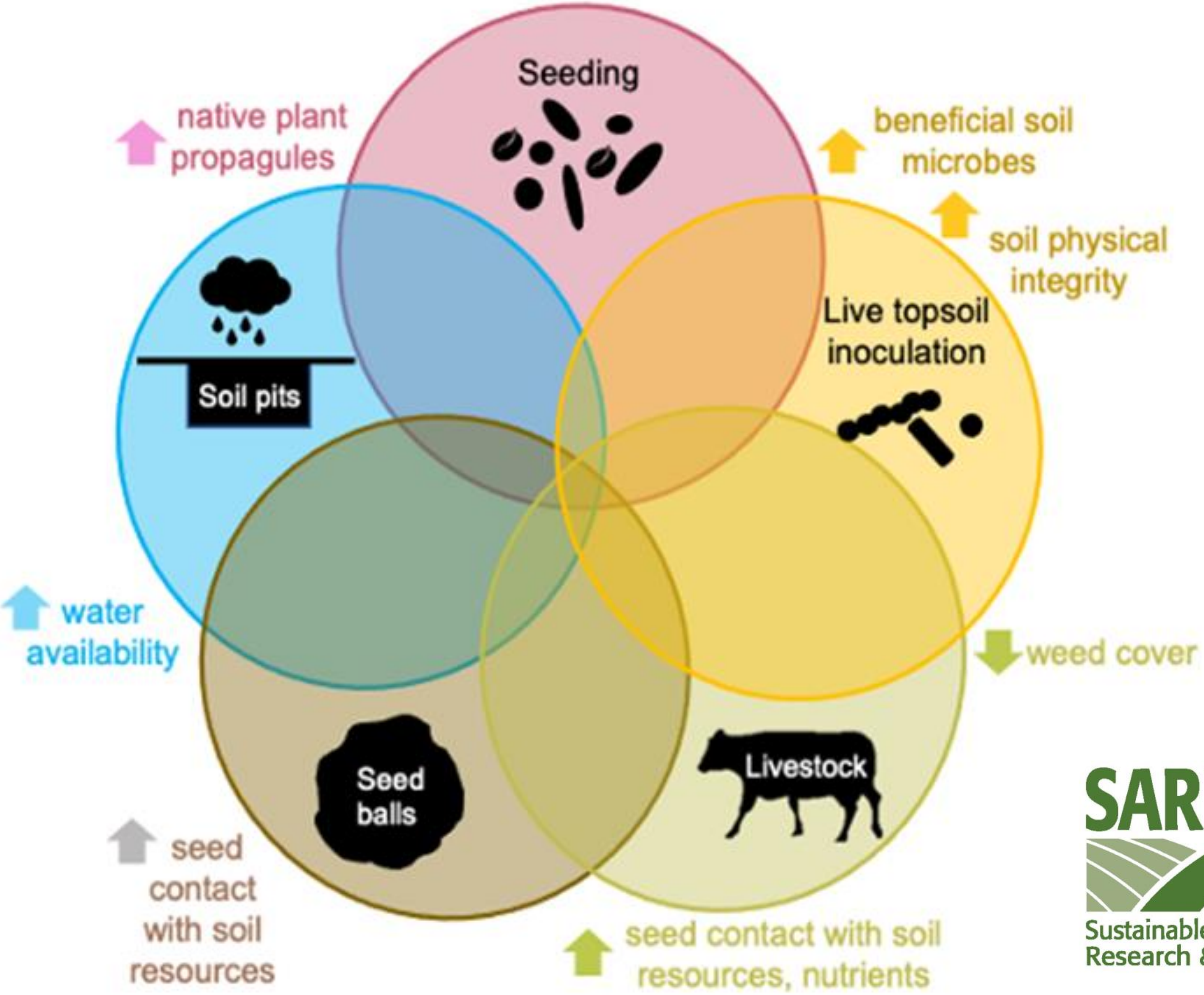
How does survival over time relate to

- Temperature and precipitation trends
- Changes in soil moisture

RestoreNet 2.0
2022-present

Hannah Farrell

RestoreNet 2.0



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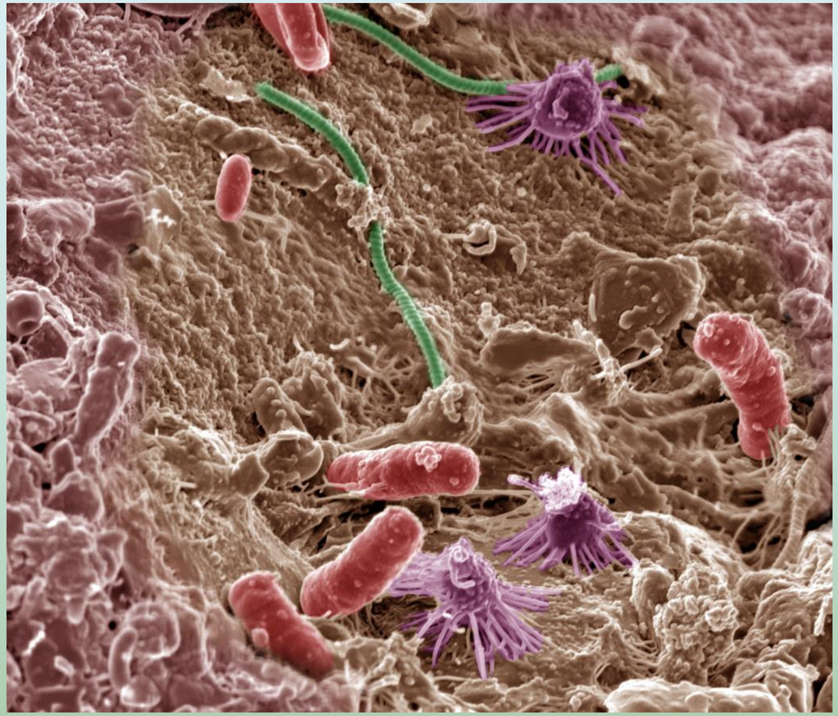
Newly installed RestoreNet 2.0 site, see crossed treatment in foreground (pits x seedballs)

Soil microbes

- Soil-dwelling archaea, bacteria, fungi
- Soil microbes in drylands can improve ecosystem health



Soil microbes, courtesy of Pacific Northwest National Laboratory

Yang et al. 2021, find at www.usgs.gov/sbsc/ramps

How did restoration affect soil microbes?

- Examined effects of RestoreNet outplant restoration on soil microbiome
- 1 year after restoration

Ben Yang

Yang et al. 2021, find at www.usgs.gov/sbsc/ramps

No difference in soil microbiome

Revegetated plot

Vs.

Control plot (no revegetation)

Yang et al. 2021, find at www.usgs.gov/sbsc/ramps

Soil inoculation as a treatment

- Identified site-specific reference sites for each RestoreNet site that may have beneficial soil microbes
- Soil from reference site collected → bulked → applied




Reference site selection

Selected based on factors that may influence soil community:

- Lower historic and current disturbance
- Desirable native plants, few invasives
- Biocrust presence



RestoreNet site

Reference site

Do the reference sites have unique microbes?

- Examined soil microbiome in paired reference vs. degraded sites

Louisa Kimmell

Small but significant differences in soil microbiome

Disturbed RestoreNet site

Vs.

Intact reference site

Disclaimer: This information is preliminary and subject to revision. IT is being provided to meet the need for timely best science. The information is provided on the condition that neither the U.S. Geological Survey nor the U.S. Government shall be held liable for any damages resulting from the authorized or unauthorized use of the information.

Reference site indicators

- Biocrust-forming bacteria
- Dark septate endophytic fungi
- Good targets for inoculation treatments

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Again, revegetation did not change microbiome

- No changes in soil microbiome 3 years after revegetation

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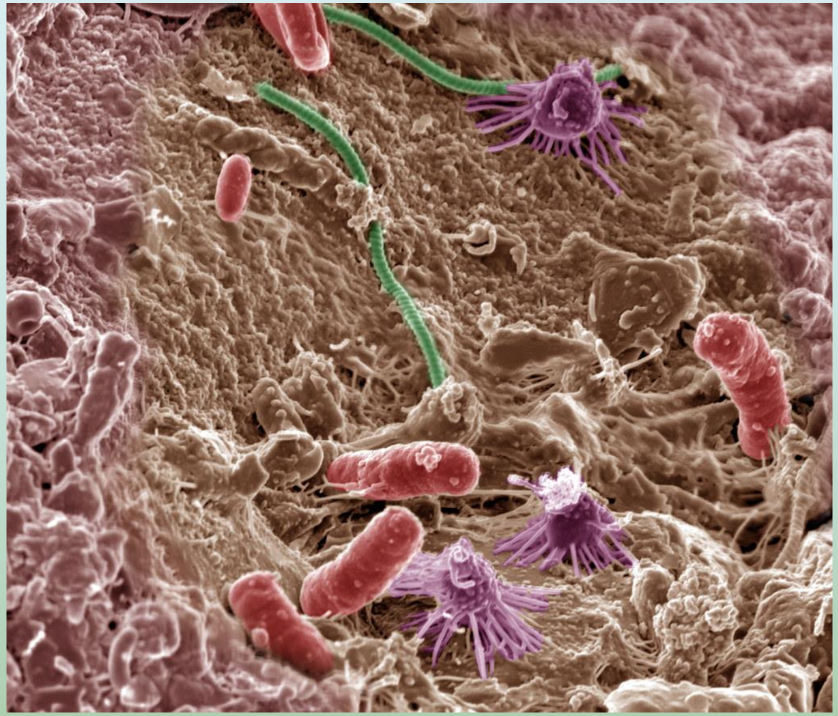
Summary so far

- No changes in soil microbiome 1 or 3 years after revegetation
- Reference sites have biocrust-forming and potentially beneficial soil microbes

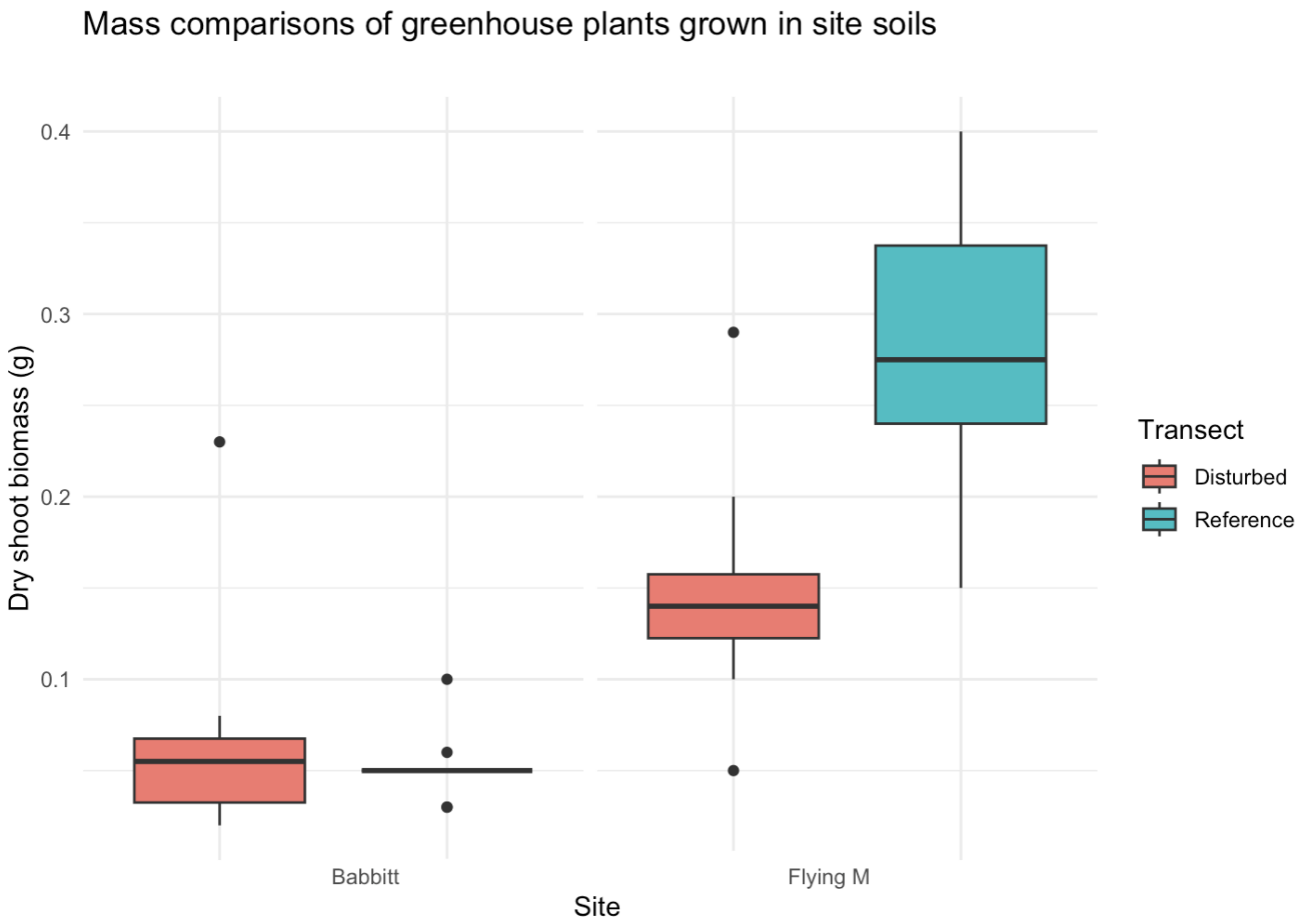


Soil microbes, courtesy of Pacific Northwest National Laboratory

How are the microbes affecting plants?

- Measured plant response to growing in reference or RestoreNet soil

Ri Corwin



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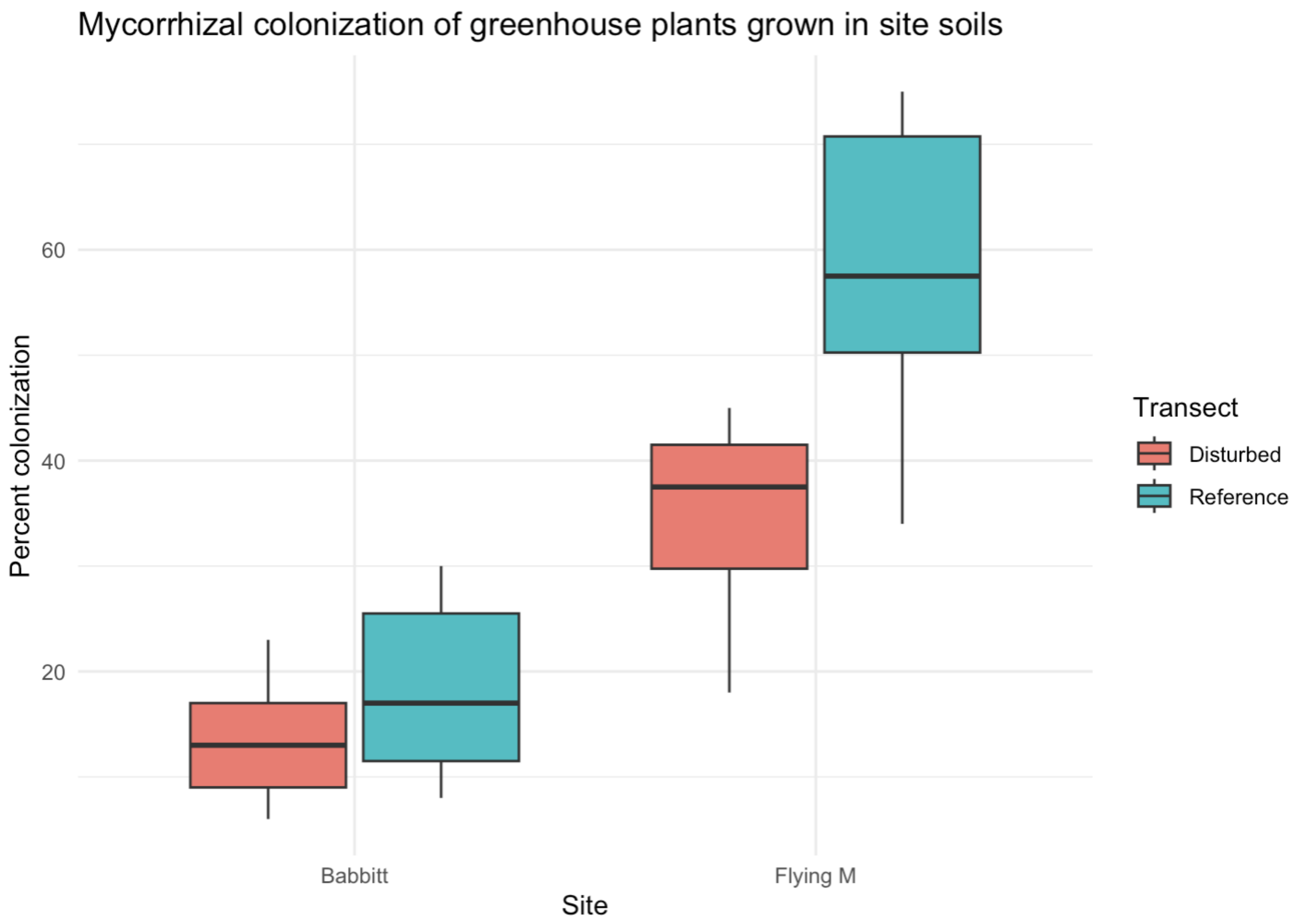

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What we've learned so far

- Plant responses to soil type differed at some, but not all sites
- Could be due to reference site "quality", and/or site selection criteria

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What we're asking next

- If plants respond positively to reference soil in the greenhouse, will they respond positively to inoculation in the field?
- How will topsoil inoculation, and other treatments affect soil health in the field?

RestoreNet 2.0: Seed balls, pits

- Soil pits – increased soil moisture and seedling emergence in RestoreNet 1.0
- Seedballs – can increase seed contact with soil, nutrients, and moisture, and protect seeds from predation and blowing away

RestoreNet 2.0: Targeted livestock treatments

- Flash grazing immediately after seeding, then cattle excluded as seedlings develop
- Could increase soil-seed contact and nutrients
- Hoof action could create microtopography
- Grazing could reduce weed cover

RestoreNet 2.0: Seed mix, standardized across sites

Scientific name	**Common name**
Aristida purpurea	Purple three-awn
Atriplex canescens	4 wing saltbush
Baileya multiradiata	Desert marigold
Bouteloua gracilis	Blue grama
Bouteloua rothrockii	Rothrock's grama
Dalea candida	White prairie clover
Elymus elymoides	Squirreltail
Krascheninnikovia lanata	Winterfat
Linum lewisii	Blue flax
Machaeranthera tanacetifolia	Tansey aster
Pascopyrum smithii	Western wheatgrass
Penstemon palmeri	Palmer's penstemon
Plantago ovata	Desert indianwheat
Poa secunda	Sandberg bluegrass
Senna covesii	Desert senna
Sphaeralcea ambigua	Desert globemallow
Vulpia octoflora	Six weeks fescus

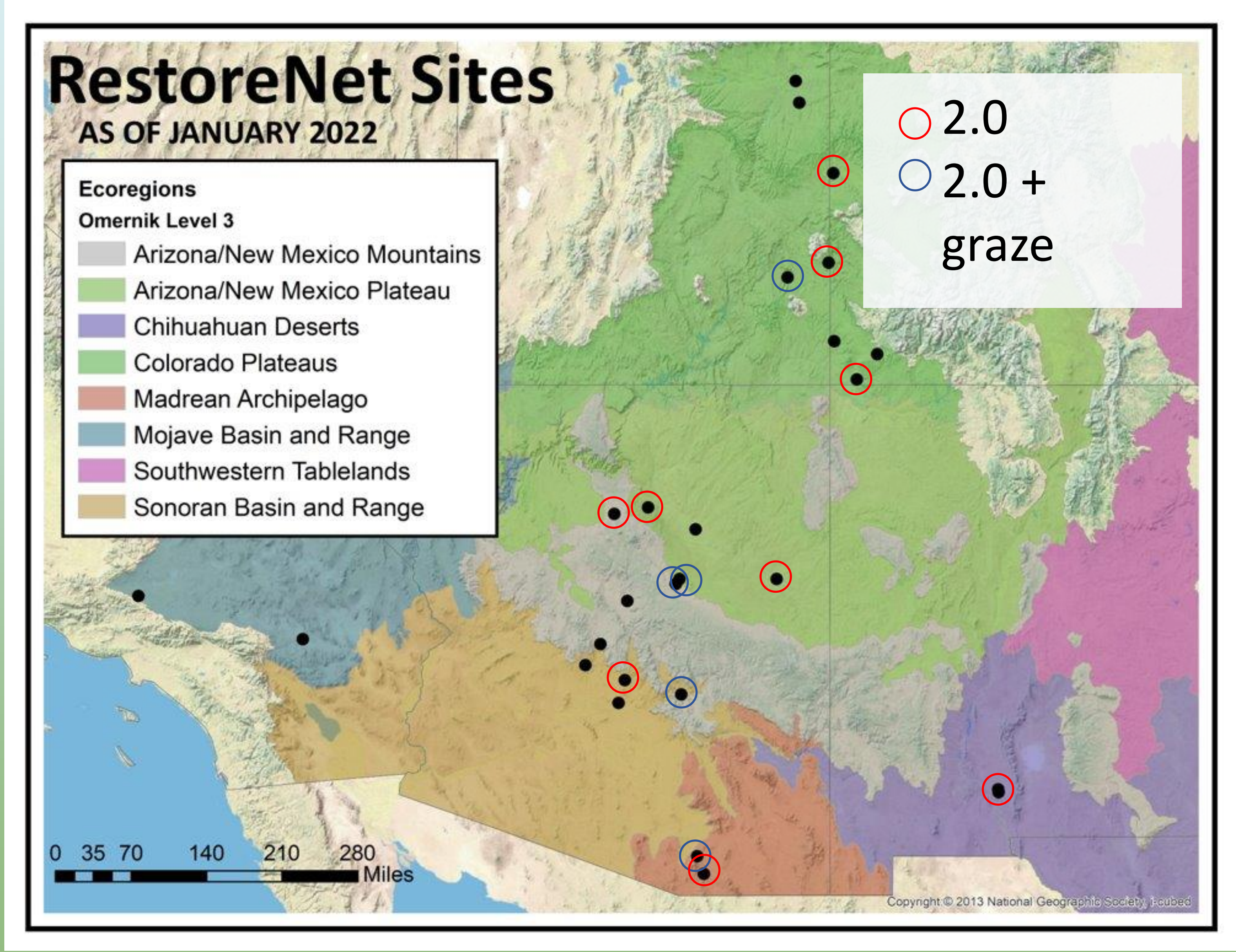
RestoreNet 2.0: Monitoring

- Monitoring seeded and non-seeded emergence and growth
- Collecting soil health measures
- Assessing soil microbes

RestoreNet 2.0 - In the works

Several sites received 2.0 in 2022, analyzing data

Will re-install 2.0 with improved methods and flash grazing at five sites in 2024



APRIL 19, 2023

RESEARCH BRIEF: Lessons from five years of RestoreNet

RestoreNet is a networked ecological restoration experiment spanning drylands of the American Southwest to inform land management. Since 2017, we have investigated how different site preparation, seed mixes, soil modifications, and other treatments affect seeding and restoration success across environmental gradients. This article explores what we've learned over the past five years of RestoreNet.

By: Southwest Biological Science Center

RestoreNet Website: http://usgs.gov/sbsc/restorenet

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RestoreNet serves as a laboratory for researchers across the Southwest. Contact us if you are a researcher interested in using RestoreNet for your ecological inquiries.

Read briefs about RestoreNet research and get updates here.

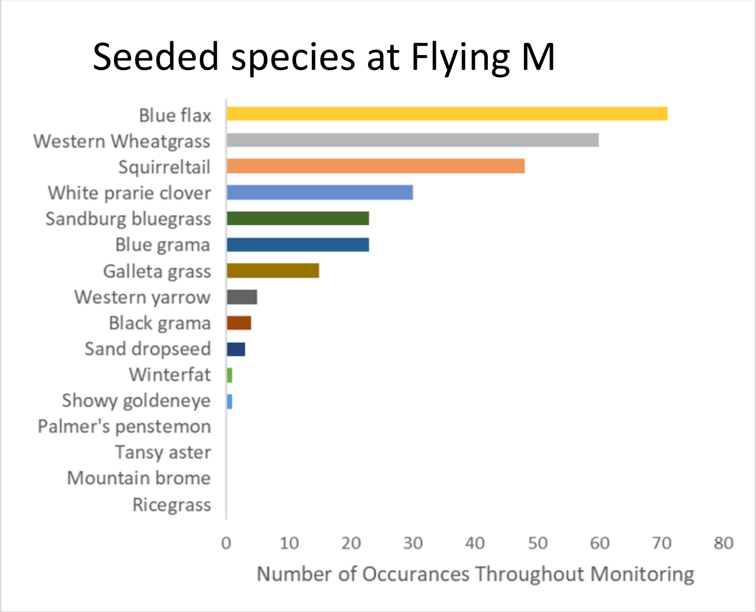
MARCH 2, 2023

Soil surface treatments and precipitation timing determine seedling development across southwestern US restoration sites

Restoration in dryland ecosystems often has poor success due to low and variable water availability, degraded soil conditions, and slow plant community recovery rates. Restoration treatments can mitigate these constraints but, because treatments and subsequent monitoring are typically limited in space and time, our understanding of their applicability across broader environmental gradients remains

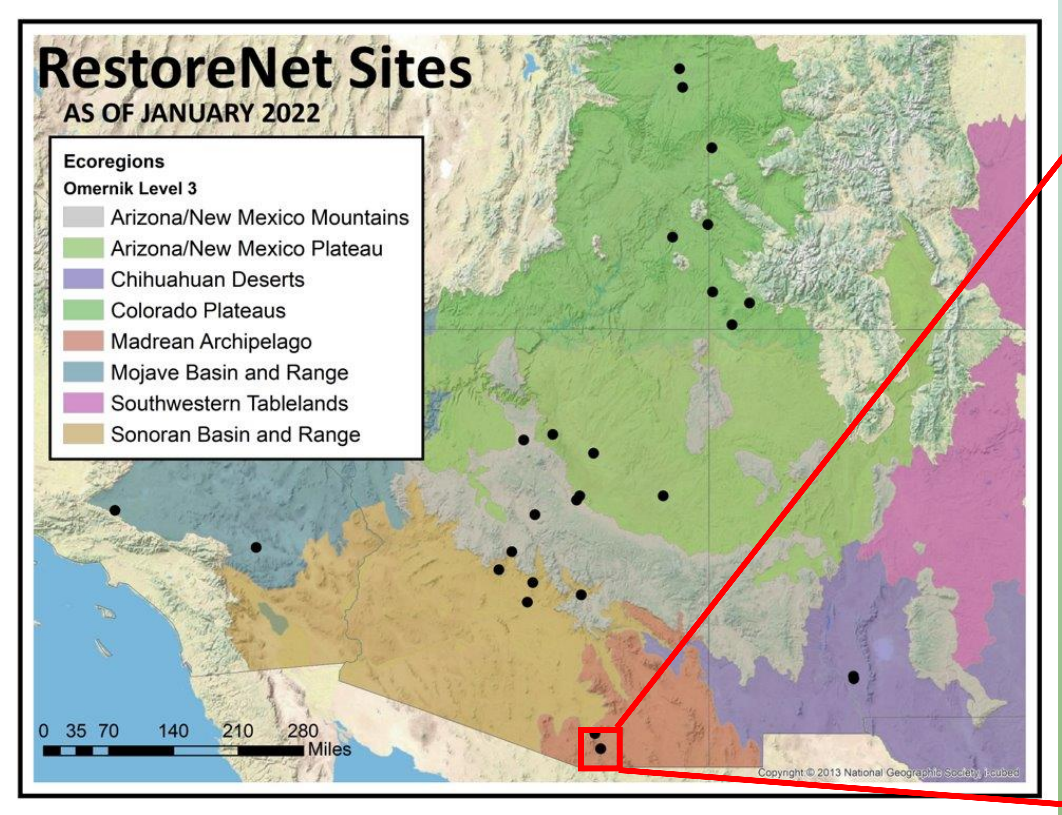
Authors: Hannah Lucia Farrell, Seth M. Munson, Bradley J. Butterfield, Michael C. Duniway, Aksasha M Faist, Elise S Gornish, Caroline Havrilla, Loralee Larios, Sasha C. Reed, Helen I Rowe, Katherine M. Laushman, Molly L. McCormick

By: Ecosystems Mission Area, Southwest Biological Science Center



Case Study: Patagonia RestoreNet Site

- Managed in partnership with Borderlands Restoration Network
- Area cleared for development then taken over by Lehman's lovegrass



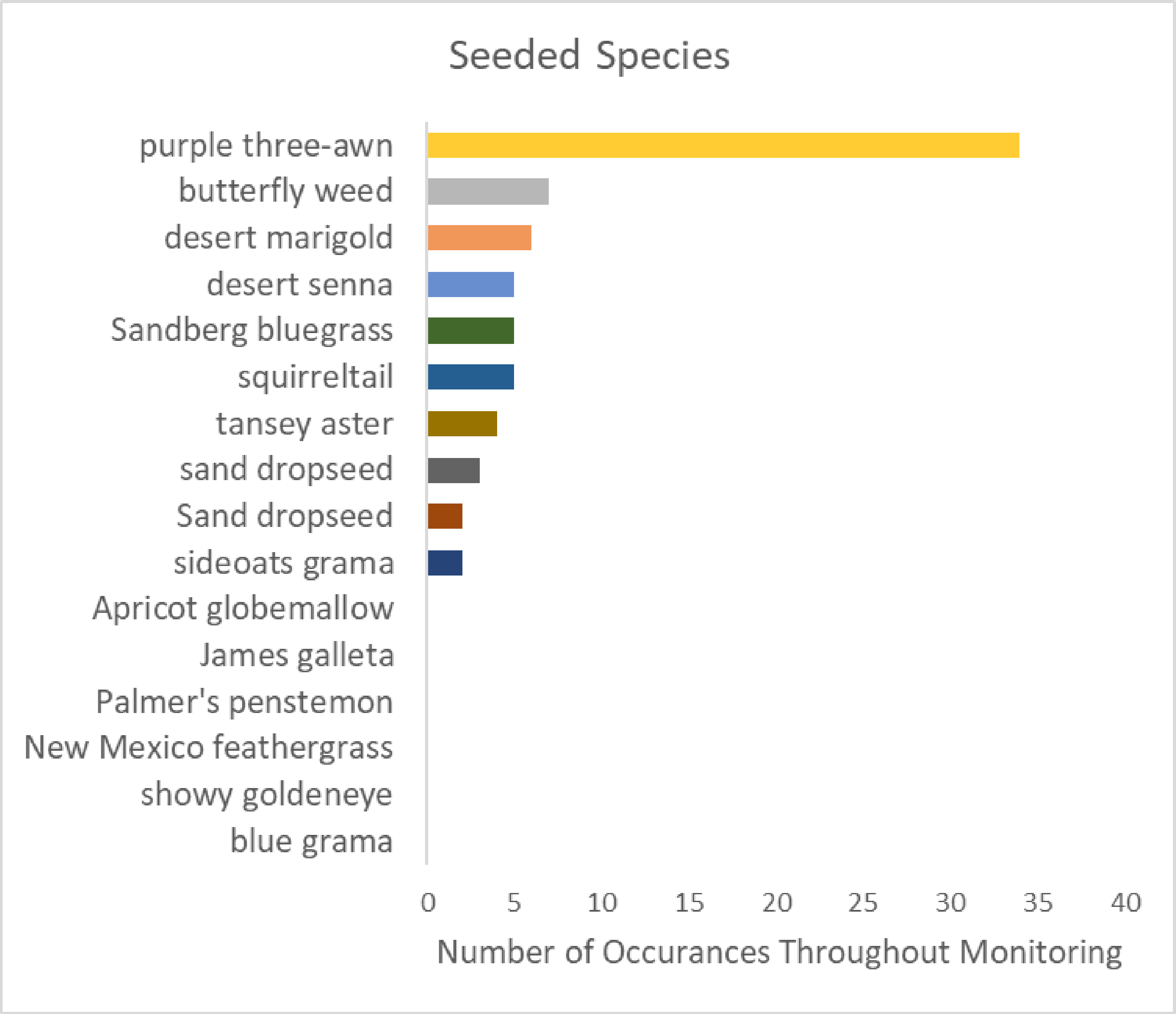
Case Study: Patagonia RestoreNet Site

Invasive Lehman’s lovegrass removed before seeding

RestoreNet 1.0 seeding and treatments installed summer 2019

Site in 2021 – some establishment despite poor 2019 monsoon

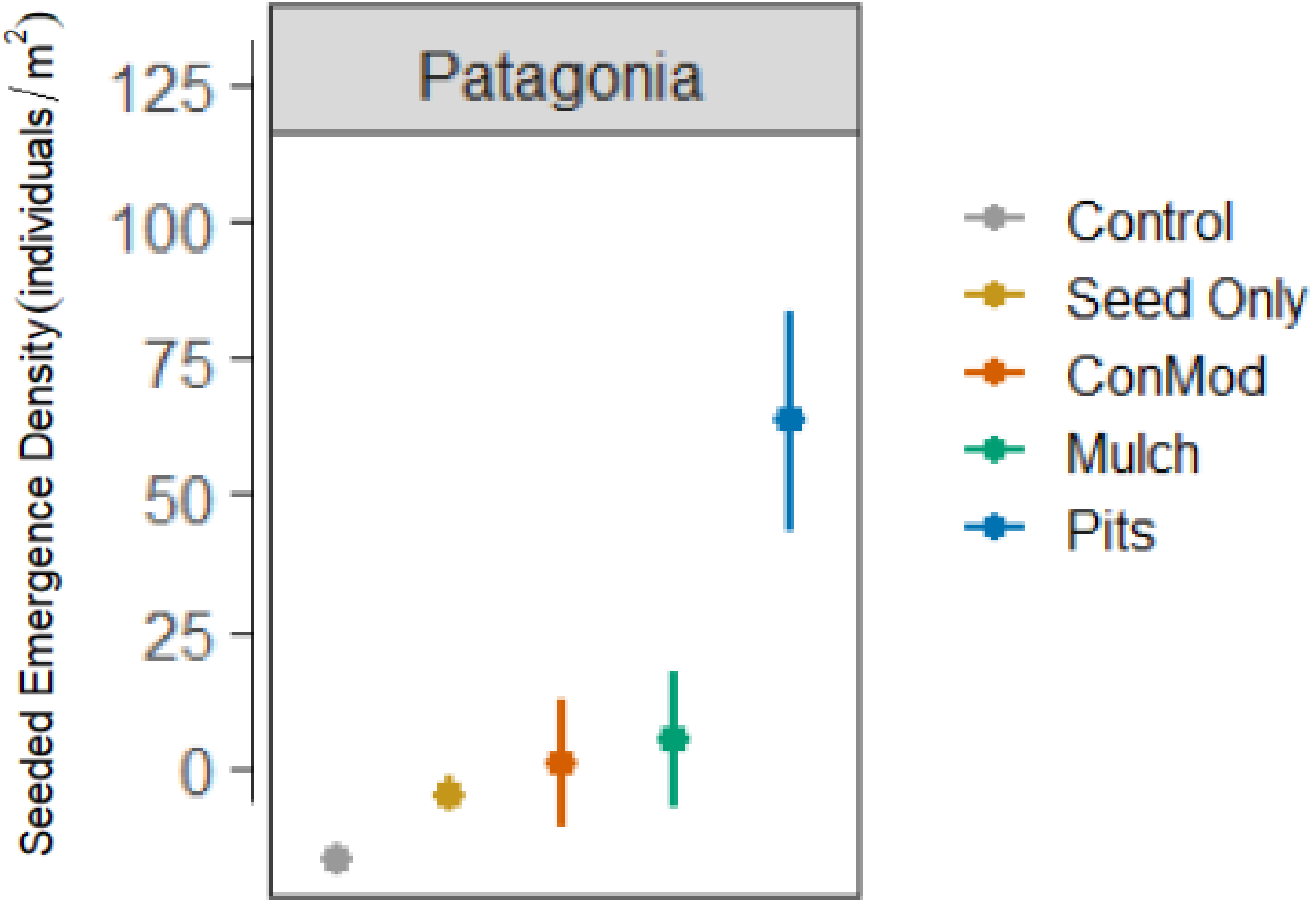
Seeded species density at Patagonia



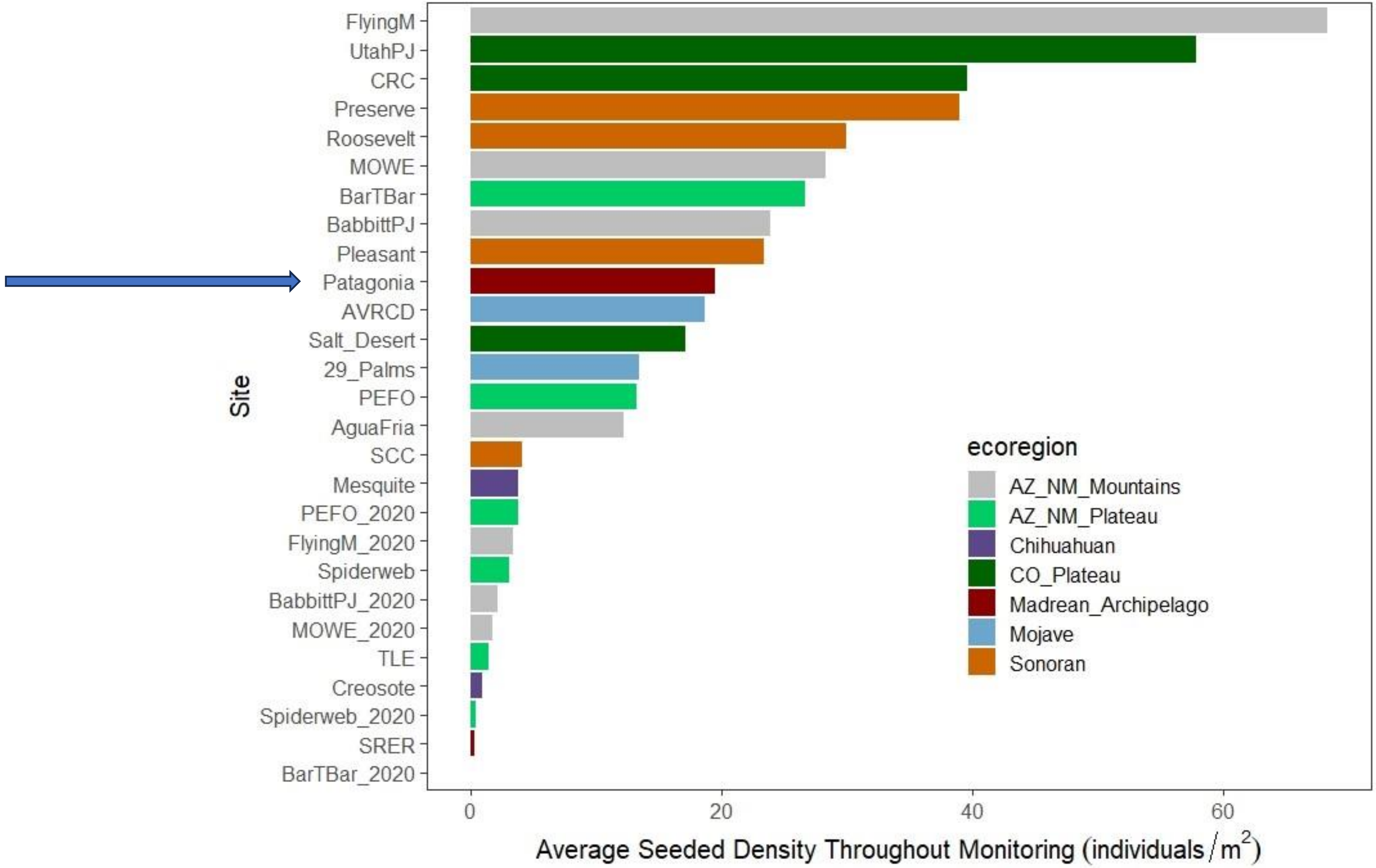
Purple three-awn (*Aristida purpurea)*

Photo by Max Licher via SEINet

Restoration treatments at Patagonia

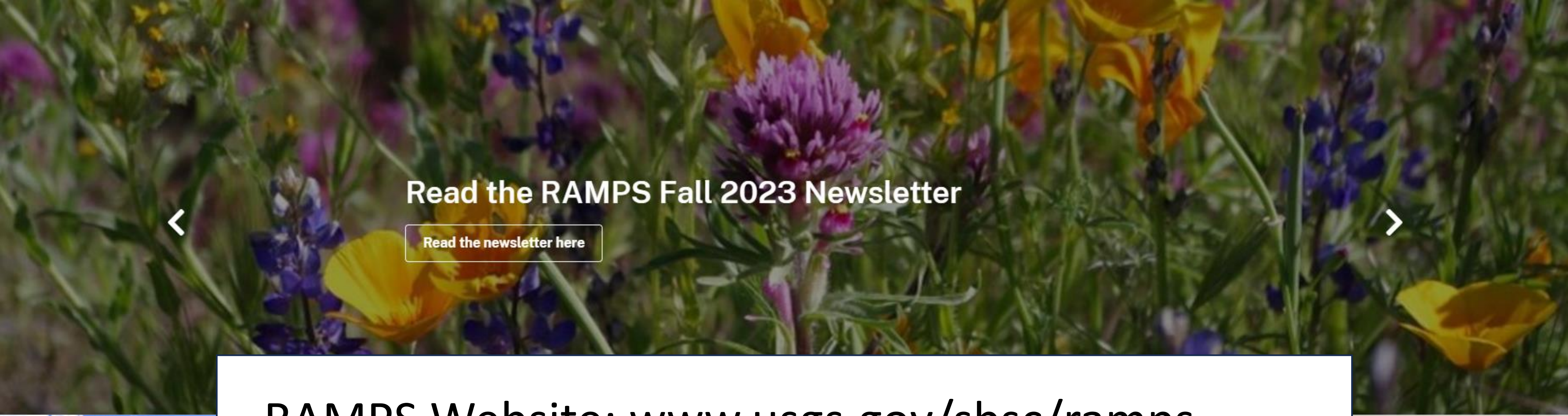


Results across sites

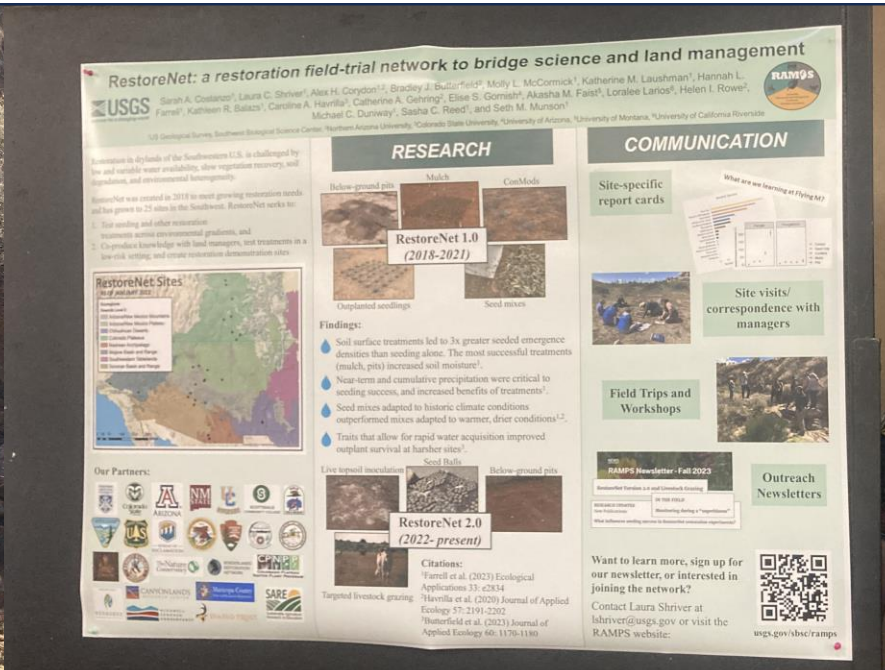


What's next for Patagonia? RestoreNet 2.0!

Photos by Albert Kline

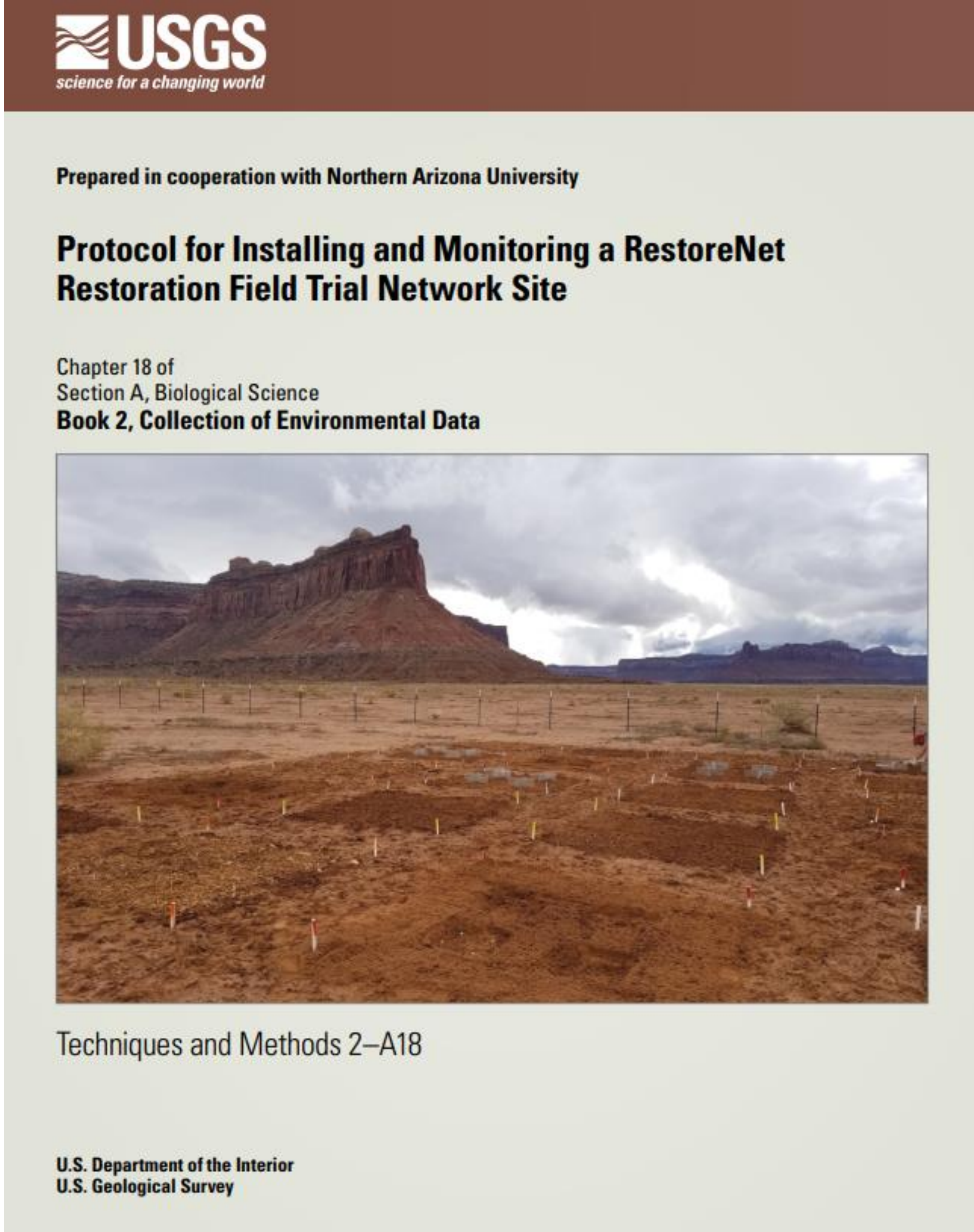


RAMPS Website: www.usgs.gov/sbsc/ramps



Get involved!

- Reach out to Laura Shriver (lshriver@usgs.gov) with questions or to collaborate
- Sign up for the RAMPS newsletter: U.S. Geological Survey (govdelivery.com)
- View RAMPS and RestoreNet websites:
  - https://www.usgs.gov/sbsc/ramps
  - https://www.usgs.gov/sbsc/restorenet
- View and use protocol for installing RestoreNet sites:
  - Protocol for installing and monitoring a RestoreNet restoration field trial network site | U.S. Geological Survey (usgs.gov)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science for a changing world

Prepared in cooperation with Northern Arizona University

Protocol for Installing and Monitoring a RestoreNet Restoration Field Trial Network Site

Chapter 18 of
Section A, Biological Science
Book 2, Collection of Environmental Data

Techniques and Methods 2–A18

U.S. Department of the Interior
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