

Emily Swartz



# Overcoming ecological barriers to dryland restoration: innovative techniques and community-engaged approaches across spatial scales and environmental gradients

Emily H. Swartz



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Committee:

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Dr. Seth Munson

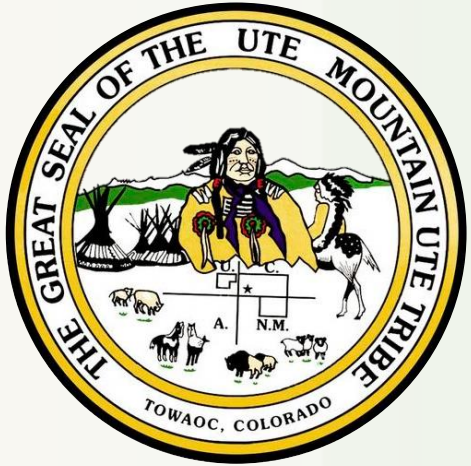




GRADUATE DEGREE PROGRAM IN ECOLOGY  
COLORADO STATE UNIVERSITY



FOREST AND RANGELAND STEWARDSHIP  
COLORADO STATE UNIVERSITY



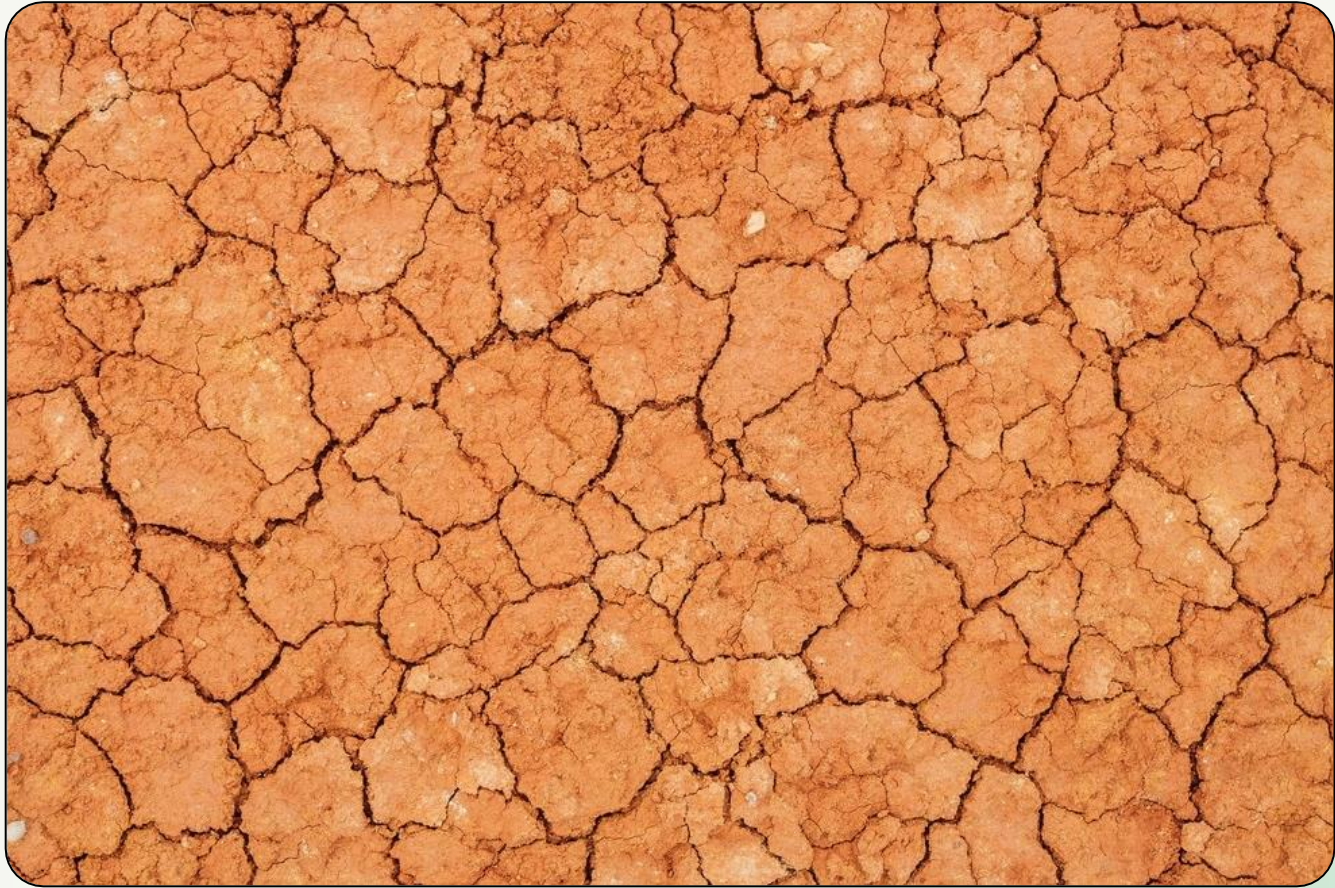








Drylands are often considered “wastelands”



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# Drylands are diverse and ecologically important



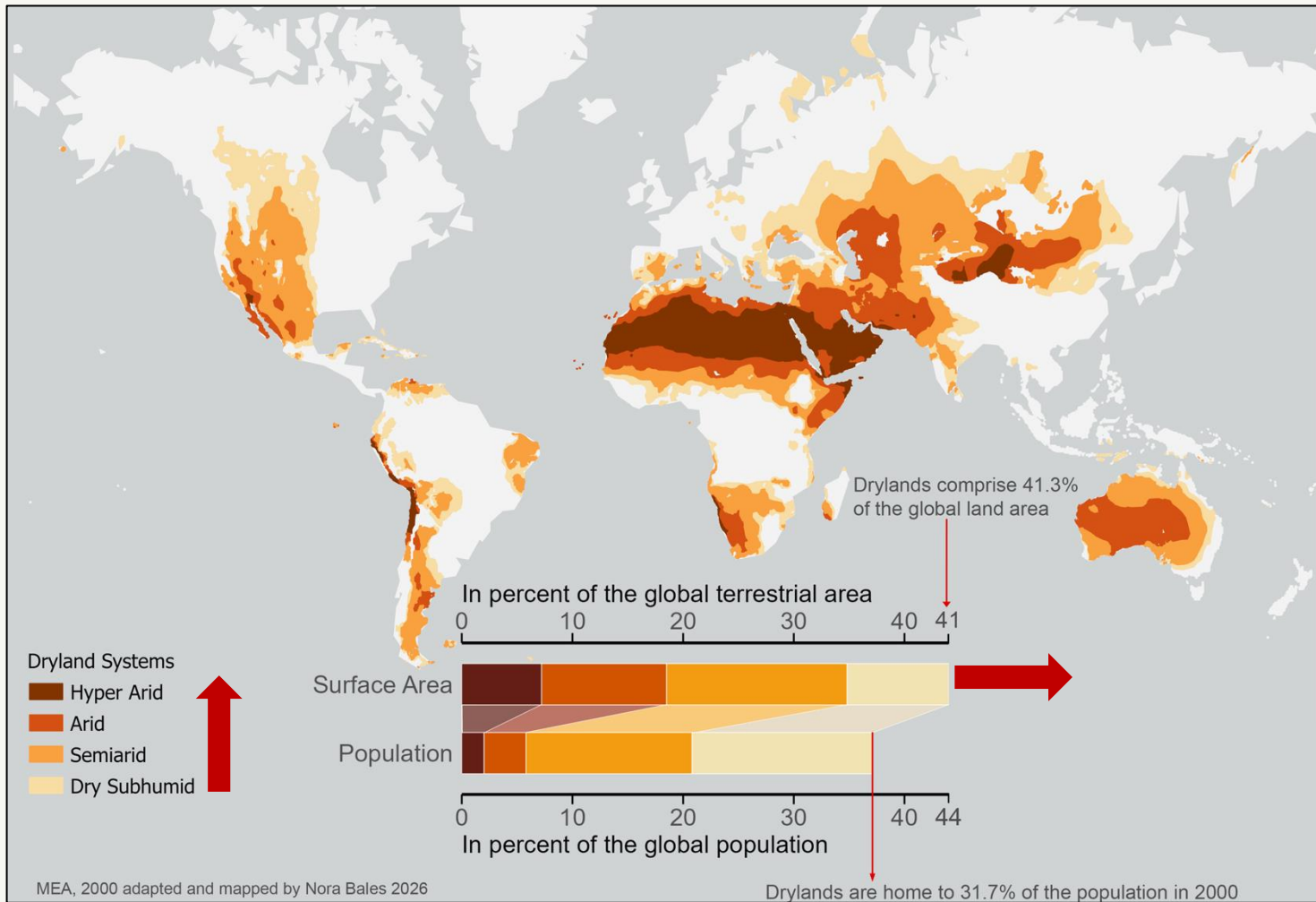
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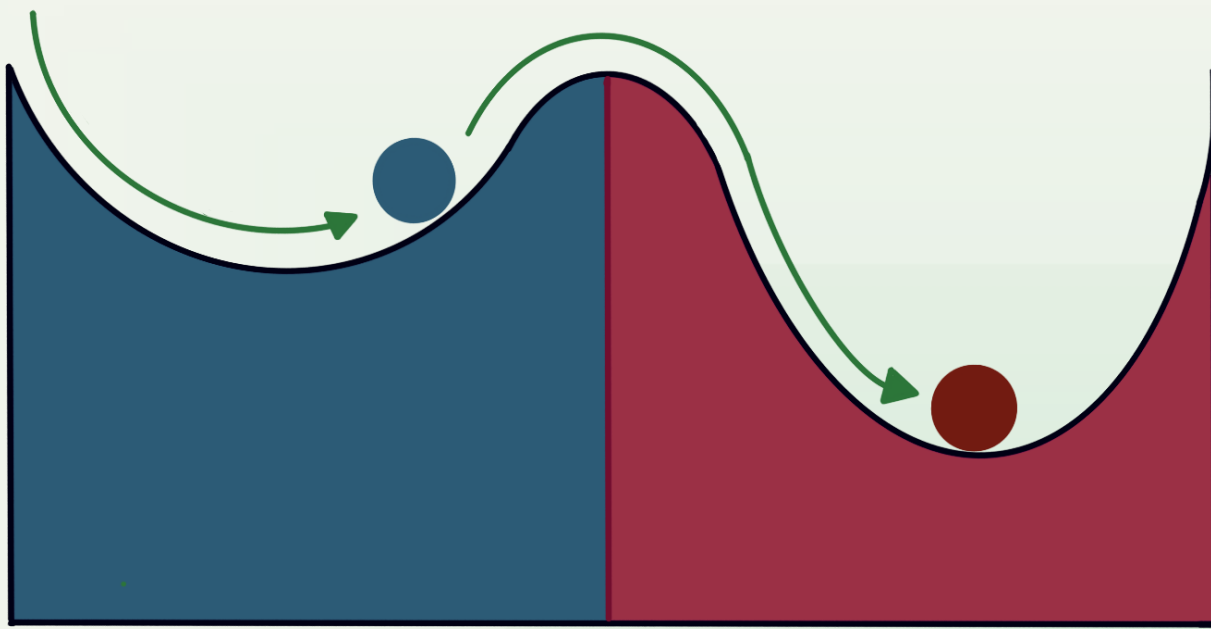
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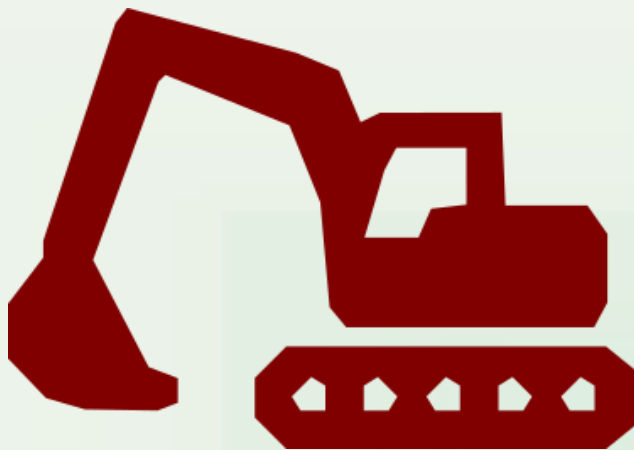
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# Seed-Based Restoration Success in Drylands is Low



Molly McCormick

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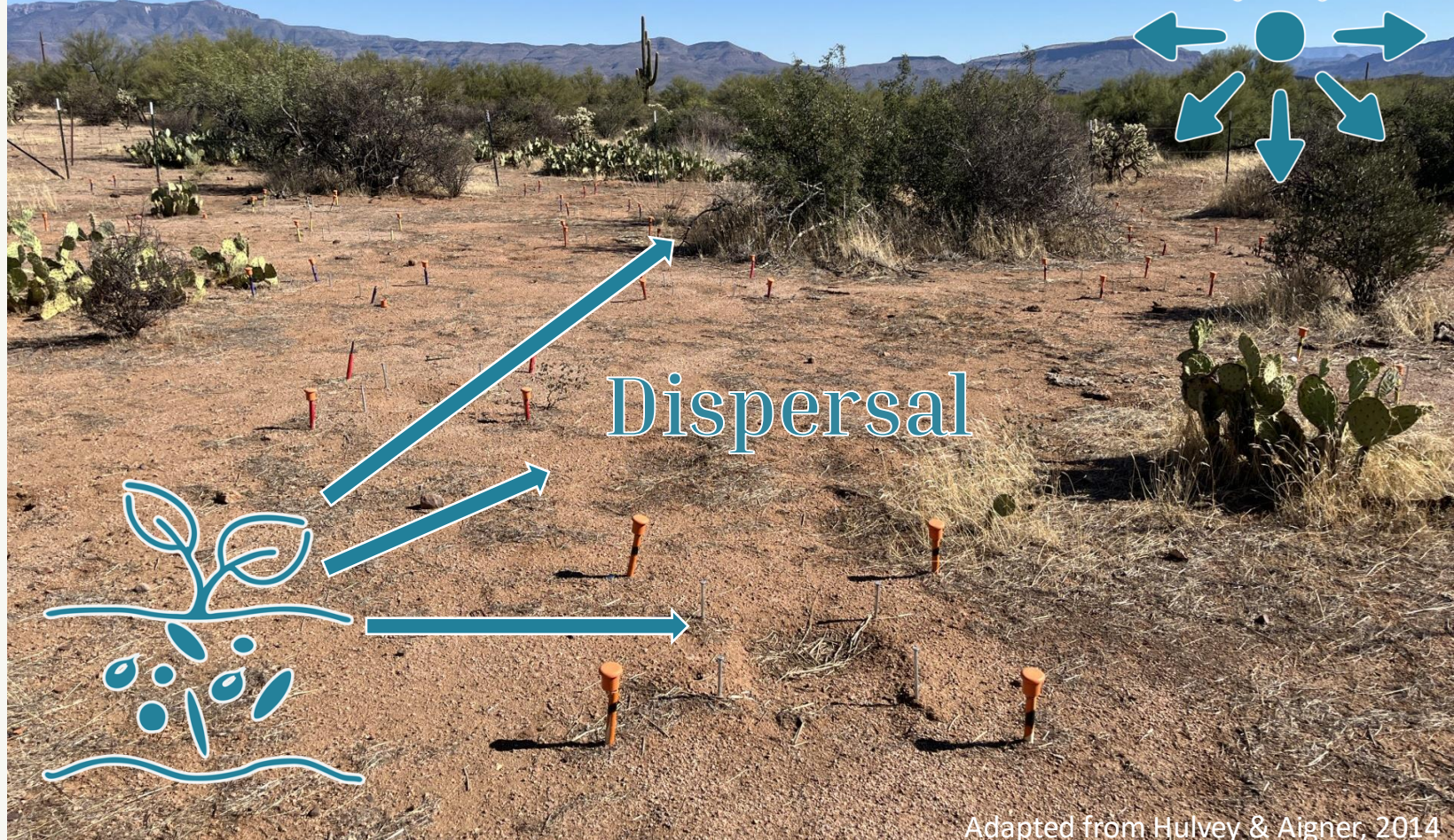
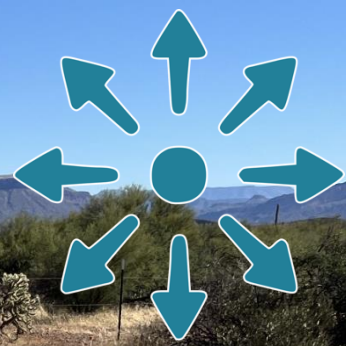
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# Barriers to dryland restoration



# Barriers to dryland restoration



Dispersal



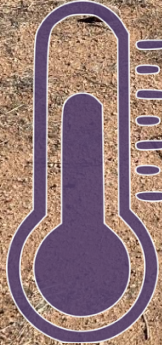
# Barriers to dryland restoration



NPK

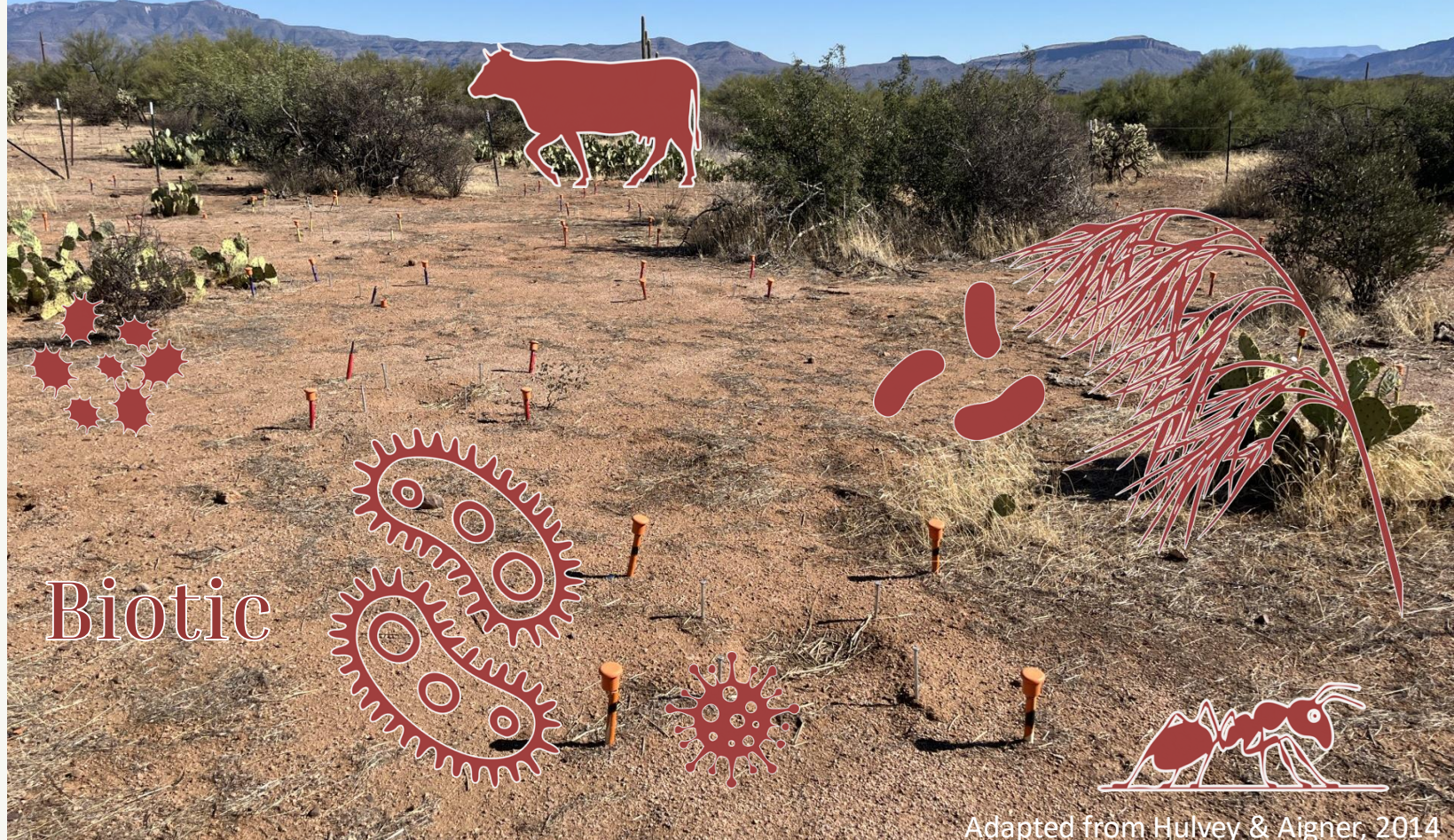


NPK



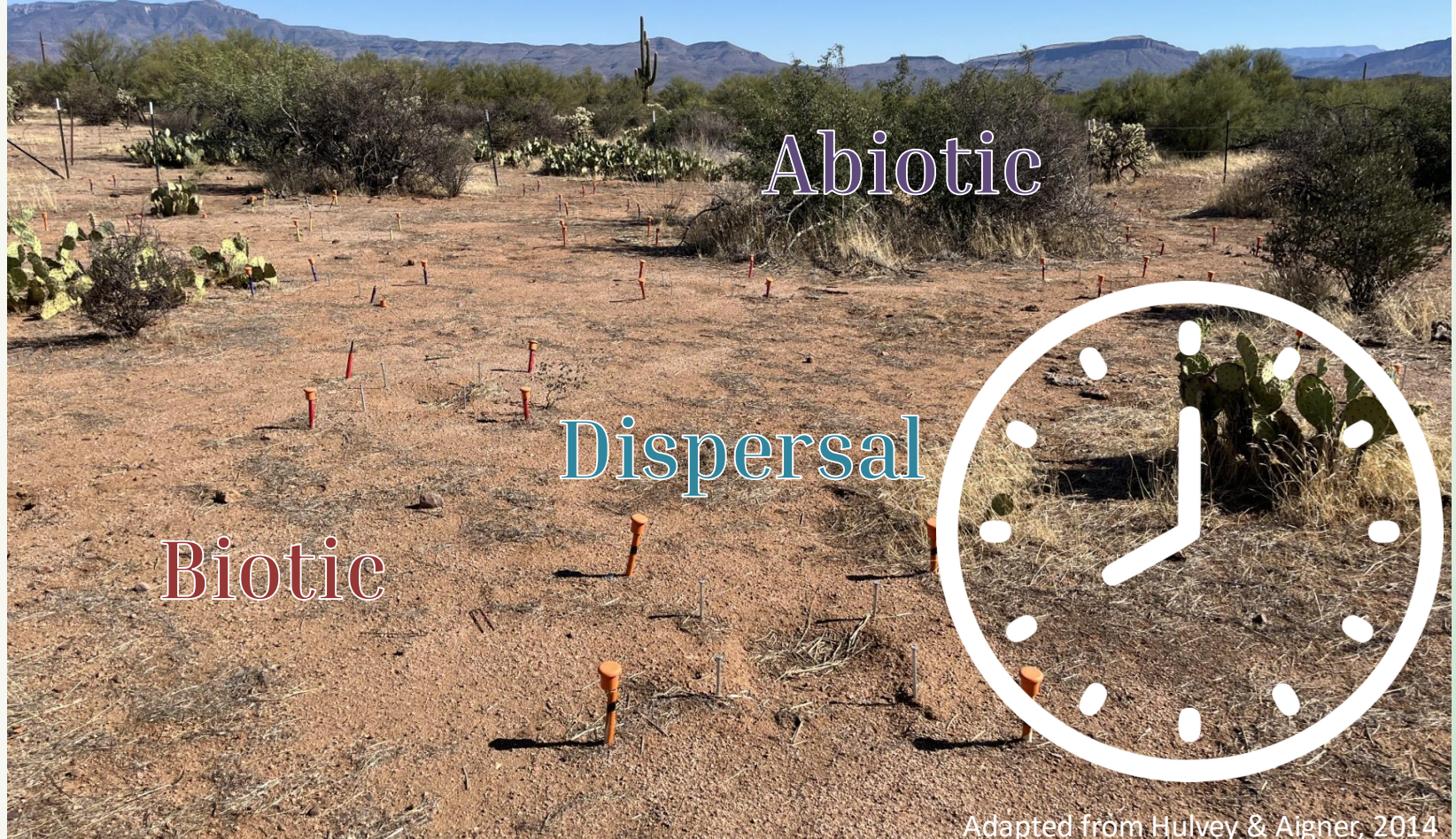
Abiotic

# Barriers to dryland restoration



Biotic

# Barriers to dryland restoration



Abiotic

Dispersal

Biotic





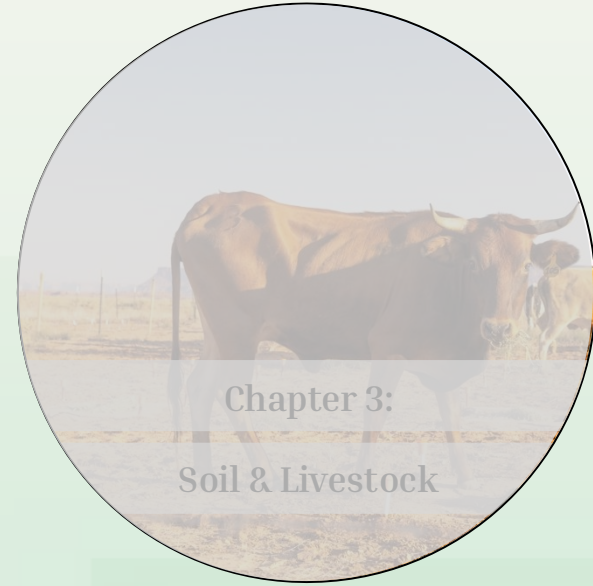
**Chapter 1:**

**Place-Based Restoration**



**Chapter 2:**

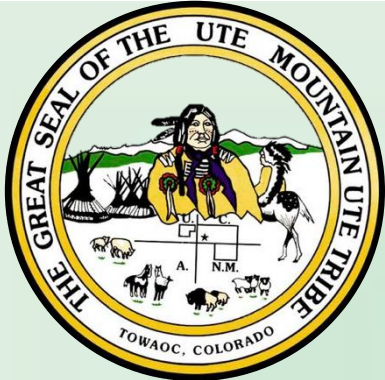
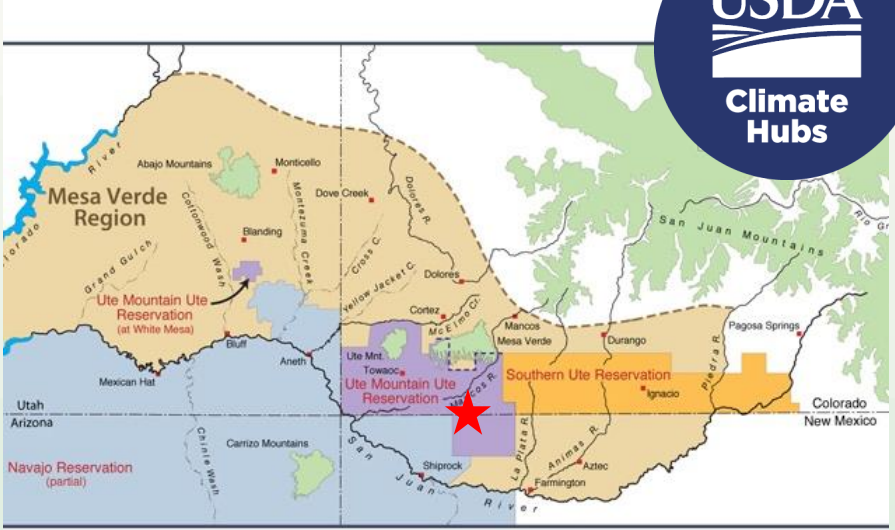
**Seed Pellet Synthesis**



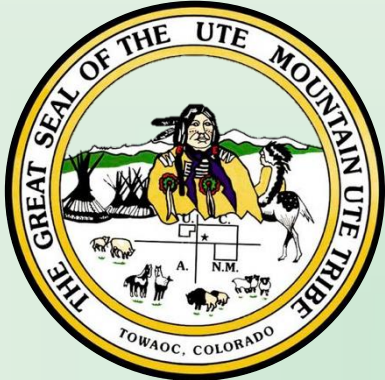
**Chapter 3:**

**Soil & Livestock**

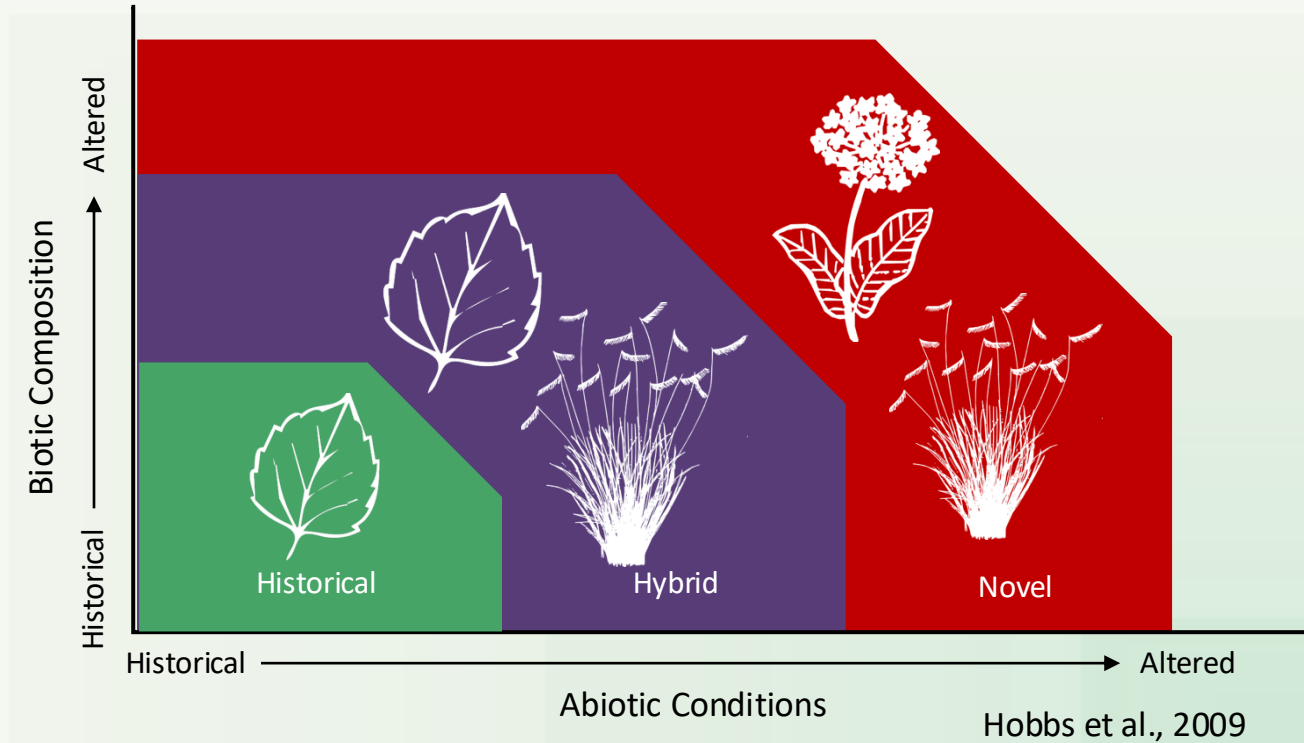
# Chapter 1: Place-Based Restoration



# Chapter 1: Place-Based Restoration



# Climate-adapted restoration strategies need to reflect novel conditions



Introduction

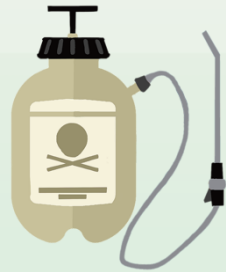
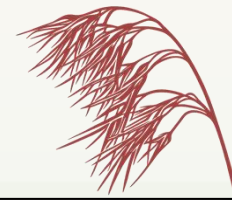
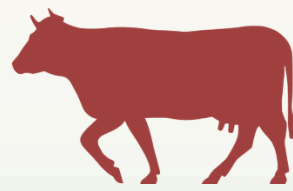
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# Biotic Barriers



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# Broadcast Seeding



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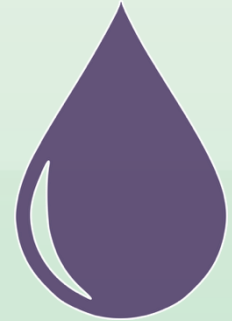
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# Coarse Woody Debris



# Media Luna Rock Structure



# Seed Pellets



Seed + Clay + Amendments






Control



Broadcast Seeding




Coarse Woody Debris

+ seed 




Media Luna Rock Structures

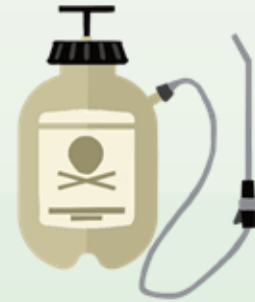
+ seed 



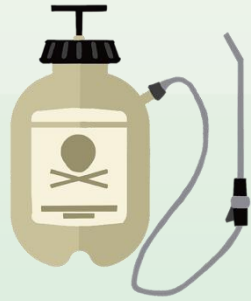
Seed Pellets

+ seed 

**X**



Milestone™  
(aminopyralid)



Introduction

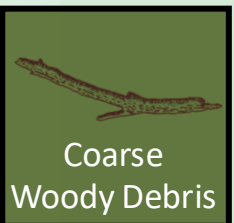
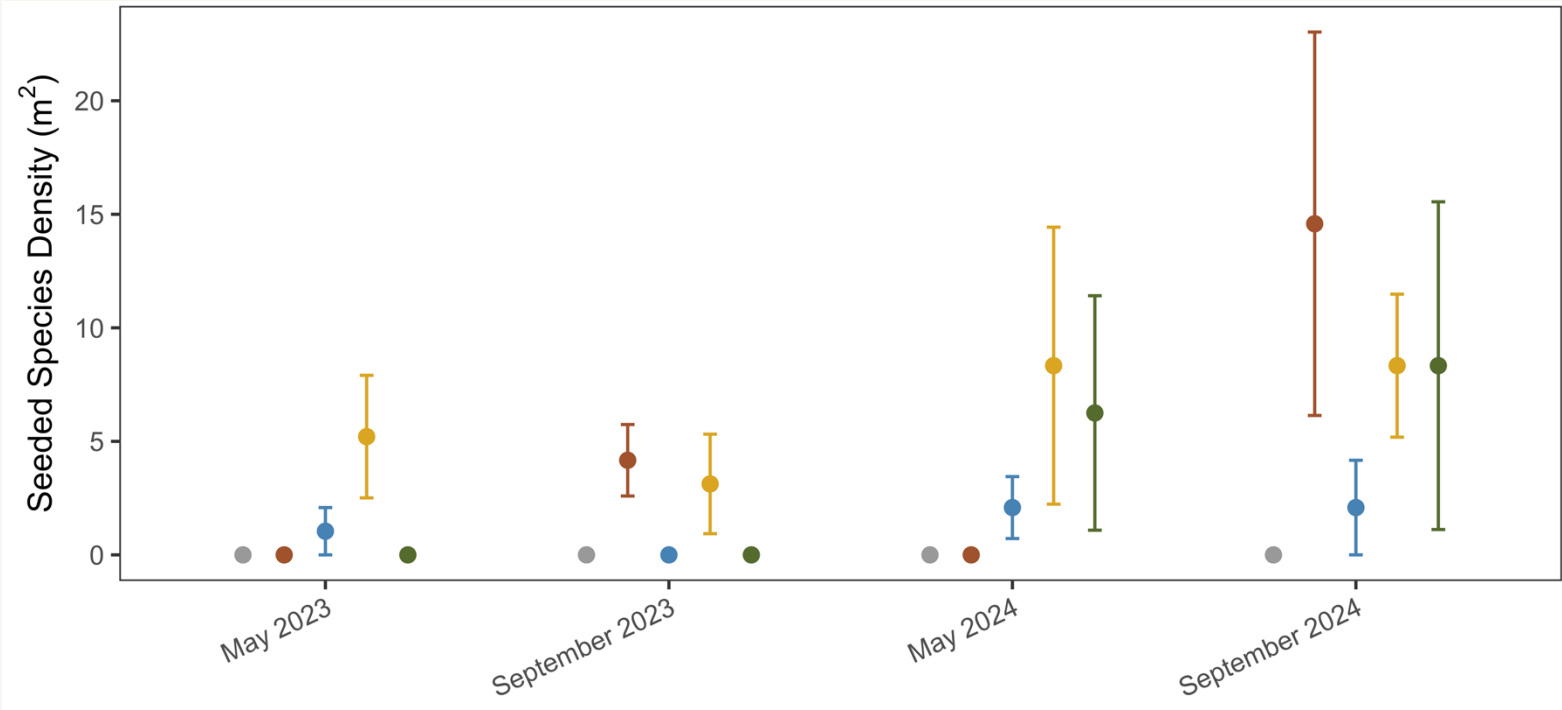
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# Moisture retention strategies show promise



# Chapter 1: Key Results

- Techniques to improve moisture retention showed promise and may be more effective in less competitive sites
- Need for more iterative and adaptative invasive species management to deal with multi-species invasion
- Increased precision restoration intensity may be needed at highly degraded sites facing numerous barriers



Katie Laushman




Rick Merrill

RE-AL THEMATIC SERIES

RESEARCH ARTICLE

THEMATIC  
SERIES  
*Arid Lands*

# Seed pellets containing activated carbon increase emergence of native plant species used in dryland restoration following herbicide application

Emily H. Swartz<sup>1,2,3</sup> , Bailey Caldwell<sup>1</sup>, Caroline A. Havrilla<sup>1,2</sup>

Chapter 1:

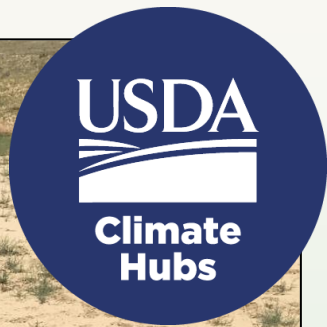
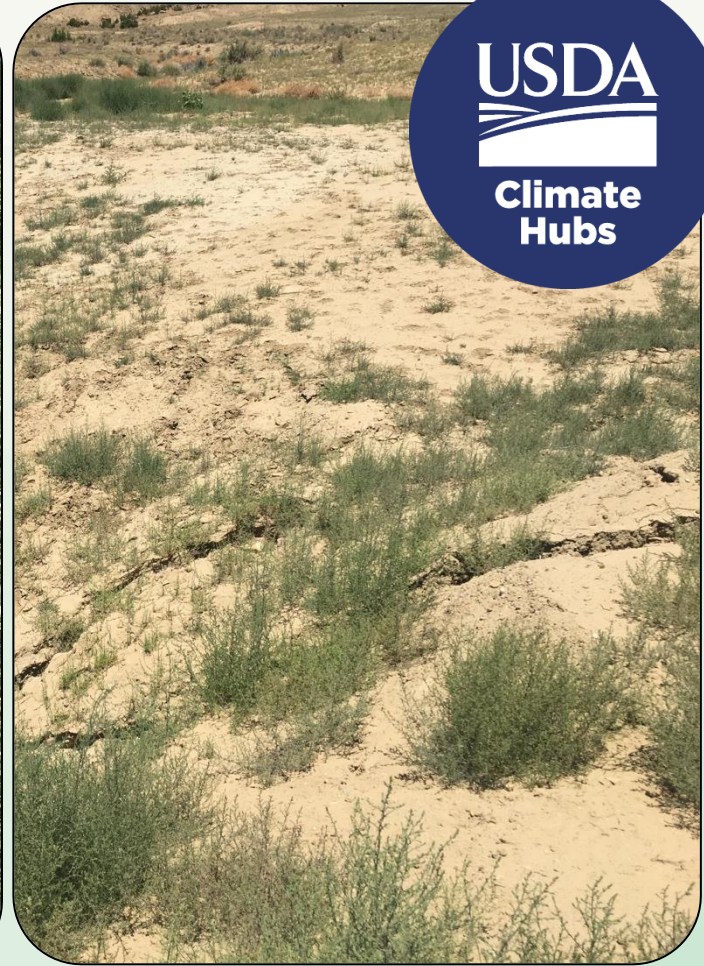
Place-Based Restoration

Chapter 2:

Seed Pellet Synthesis

Chapter 3:

Soil & Livestock



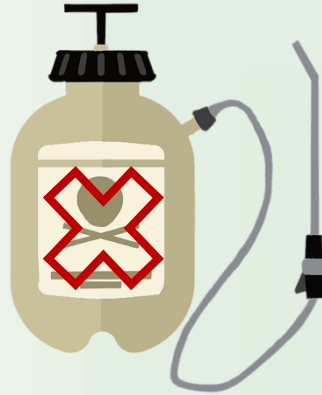
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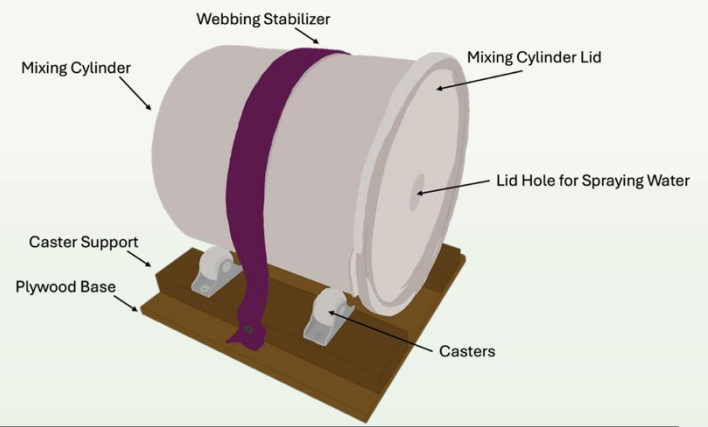
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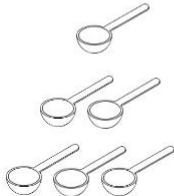




# Seed Pellets



## Seed + Clay + Amendment(s)



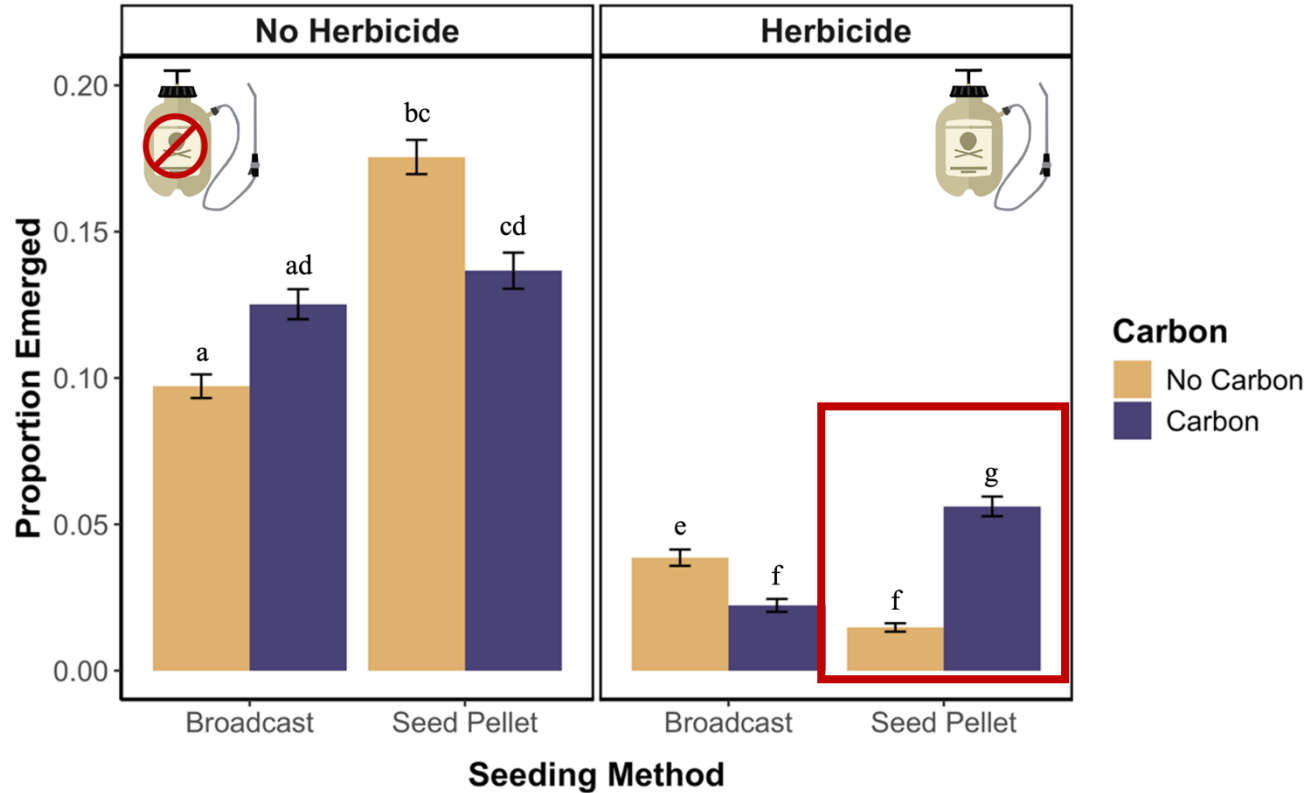


	Seed Pellet or Broadcast	Clay	Carbon	Herbicide
Experiment 1: Activated Carbon and Herbicide			 or 	 or 
			 +  or 	 or 
Experiment 2: Composition				
			 or  or 	

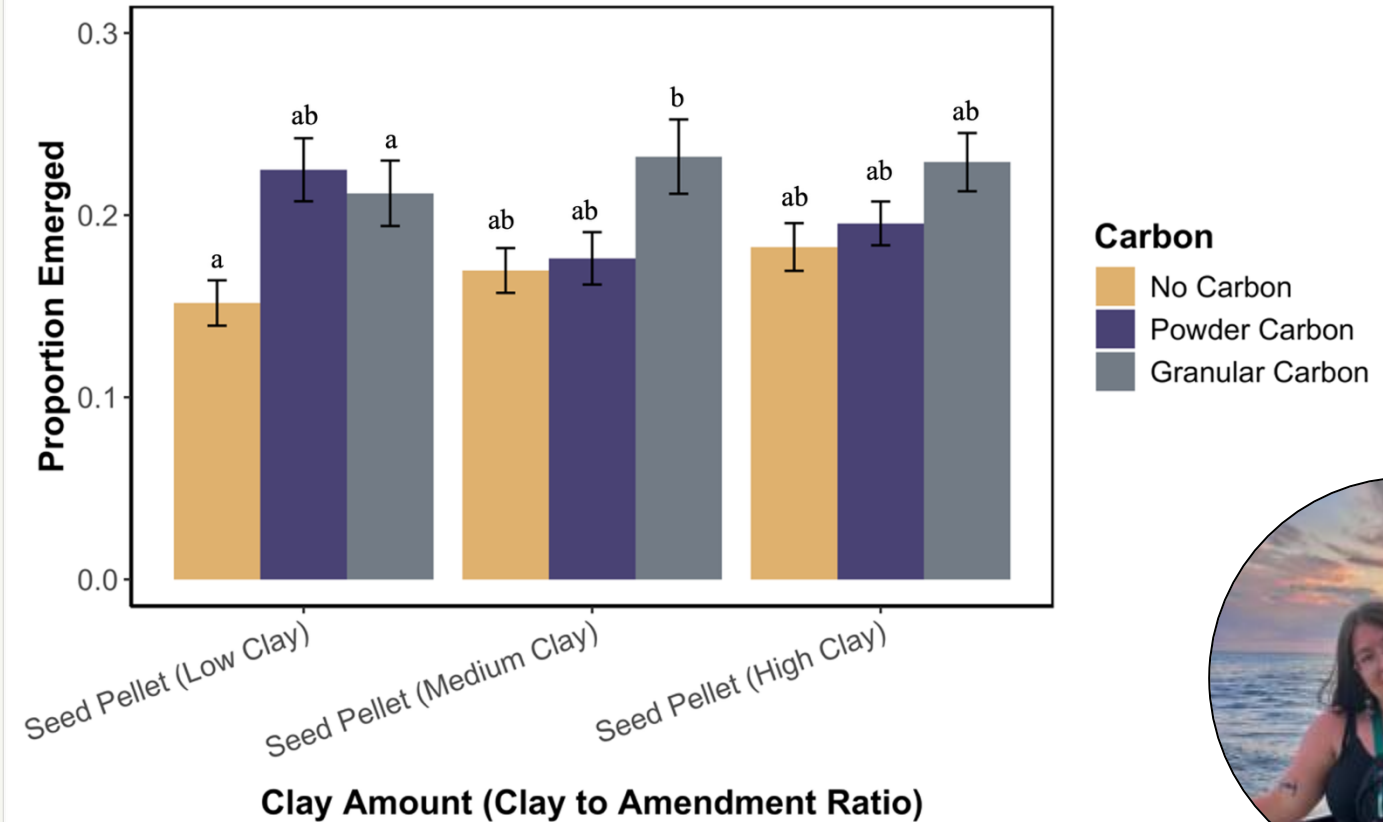
# Seed pellets improved emergence relative to broadcast seeding



Under herbicide treatment, seed pellets containing activated carbon had the highest emergence.



# Pellet composition had limited effects on emergence.



## Chapter 2: Key Results

- Seed pellets enhanced emergence compared to broadcast seeding.
- Where chemical weed management is necessary, seed pellets containing activated carbon had higher emergence and should be considered.
- Activated carbon additions provided no clear benefit in the absence of herbicide.





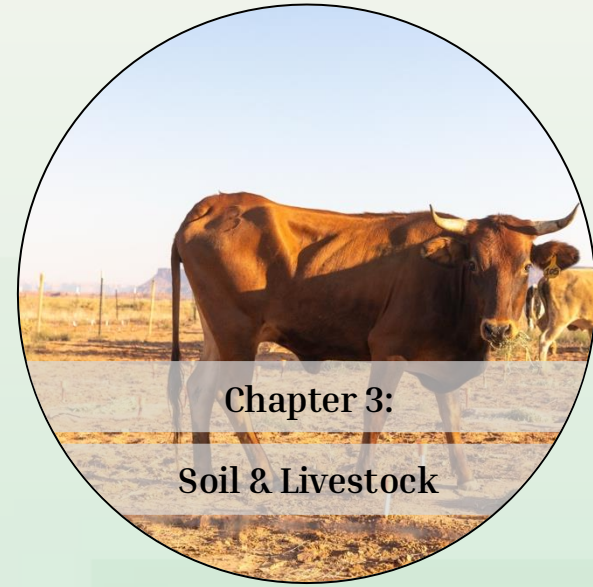
**Chapter 1:**

**Place-Based Restoration**



**Chapter 2:**

**Seed Pellet Synthesis**



**Chapter 3:**

**Soil & Livestock**

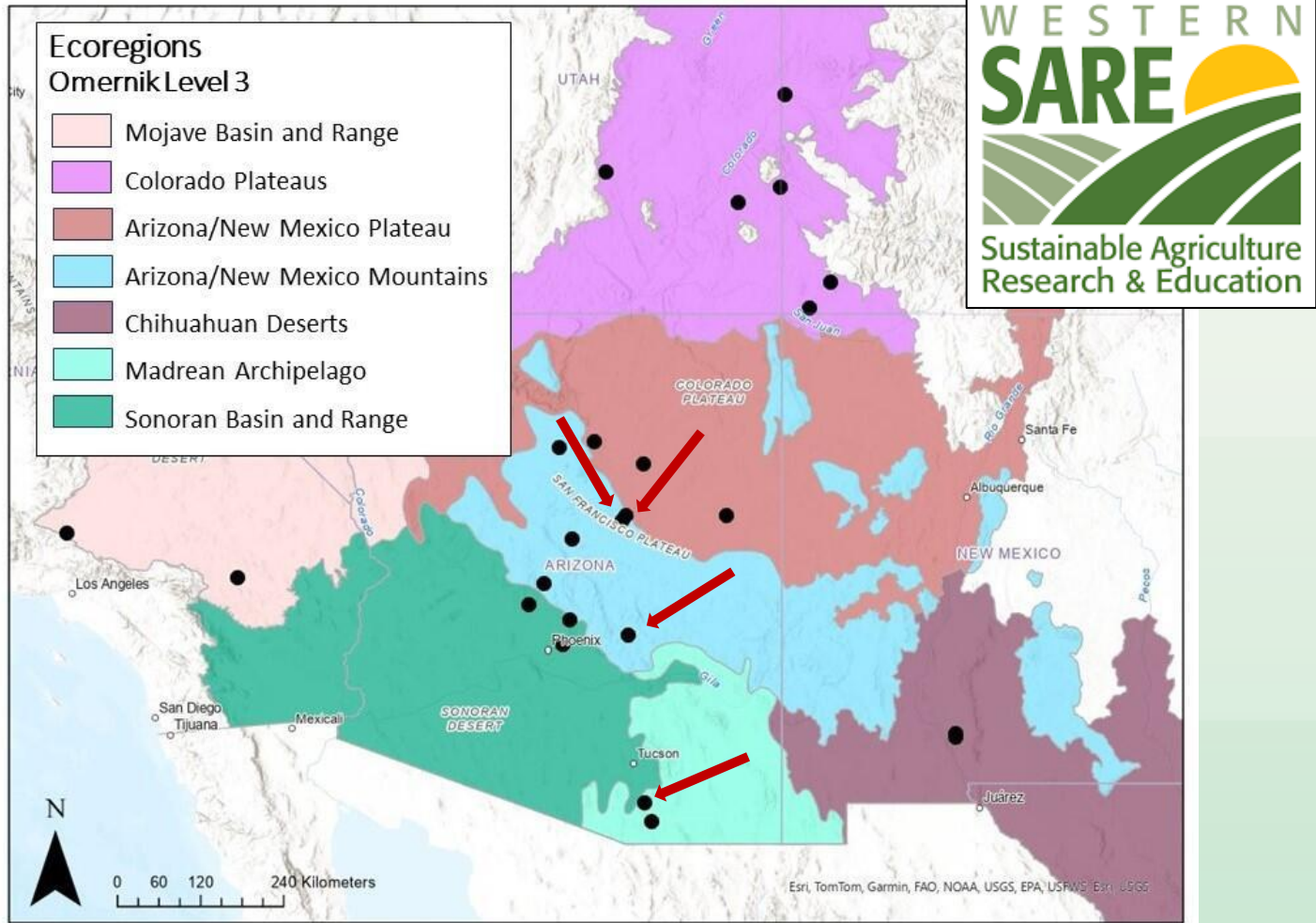
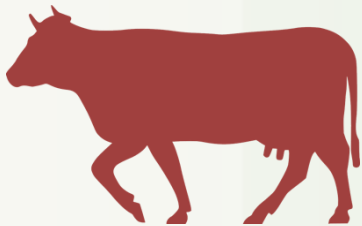
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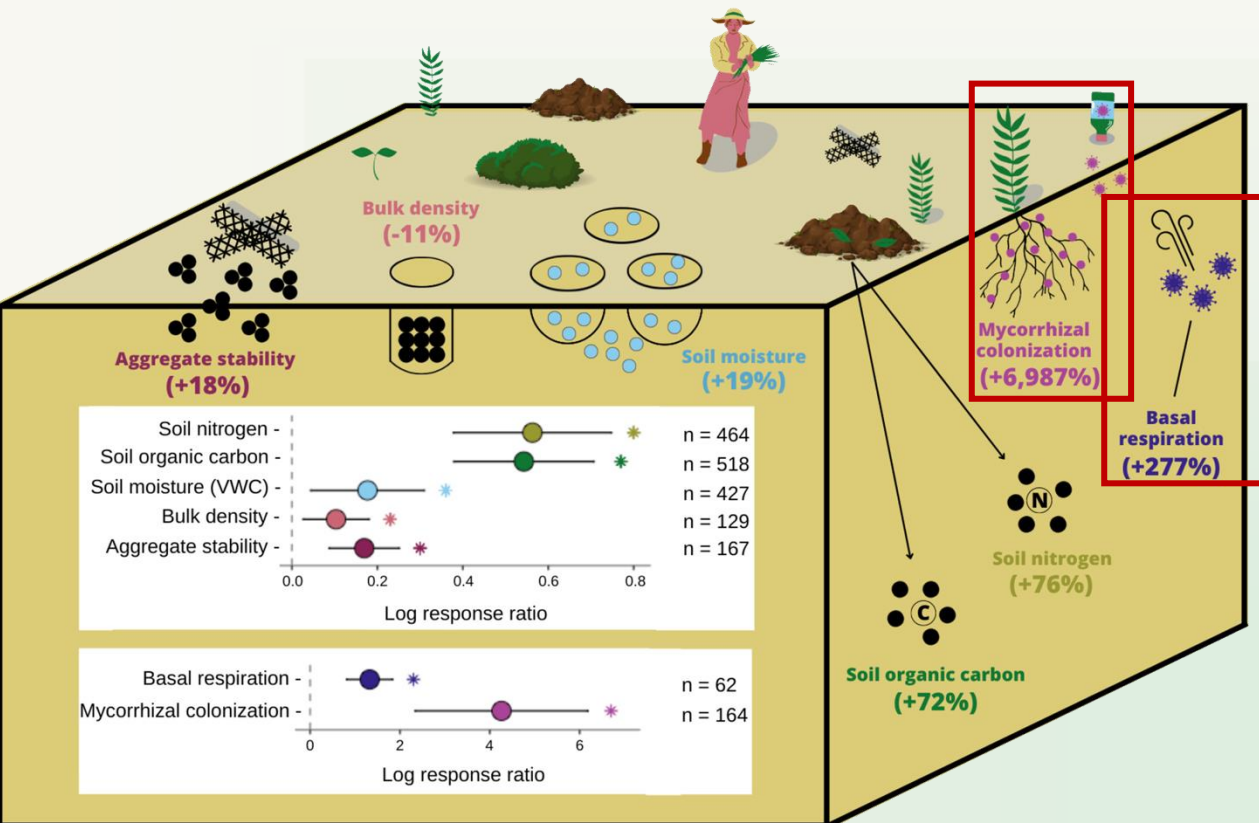
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# Soil restoration increases soil health across global drylands



Kimmell et al., 2023

# Broadcast Seeding

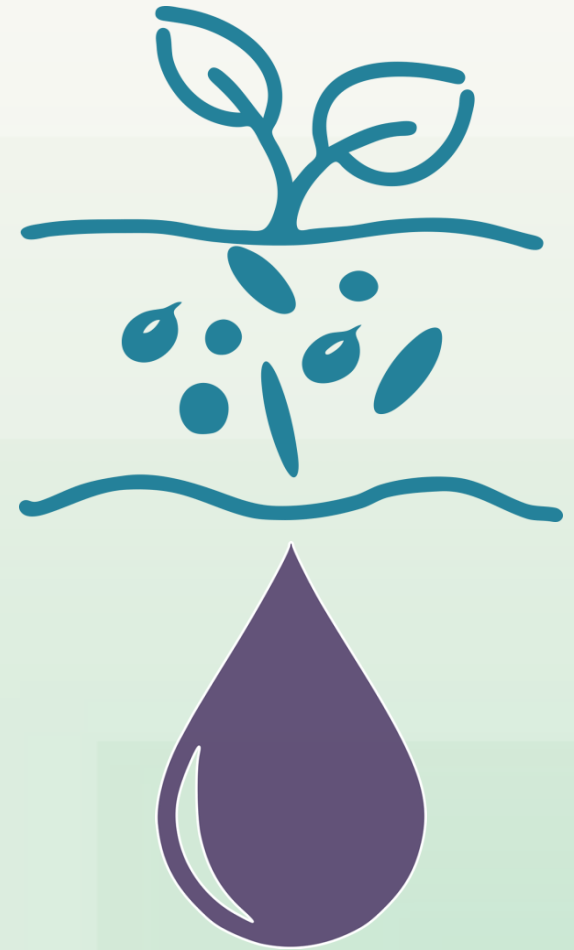


Laura Shriver



# Pitting

Pits



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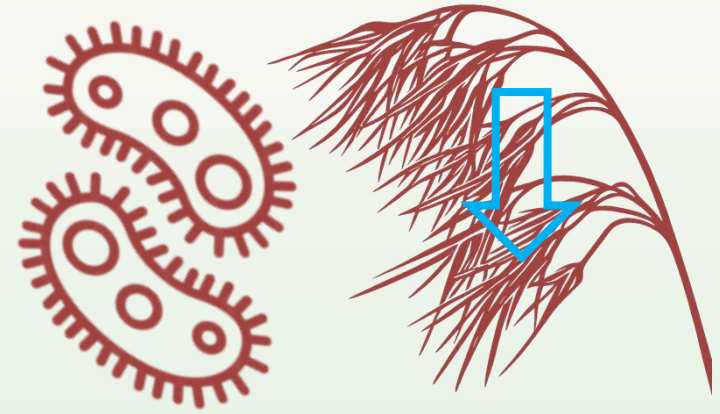
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# Seed Pellets

Seed  
Pellets



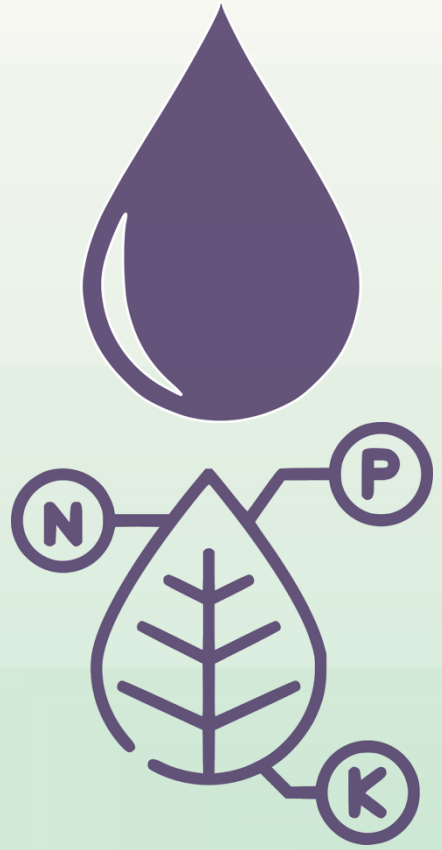
# Soil Inoculum






















# Targeted Livestock Treatment



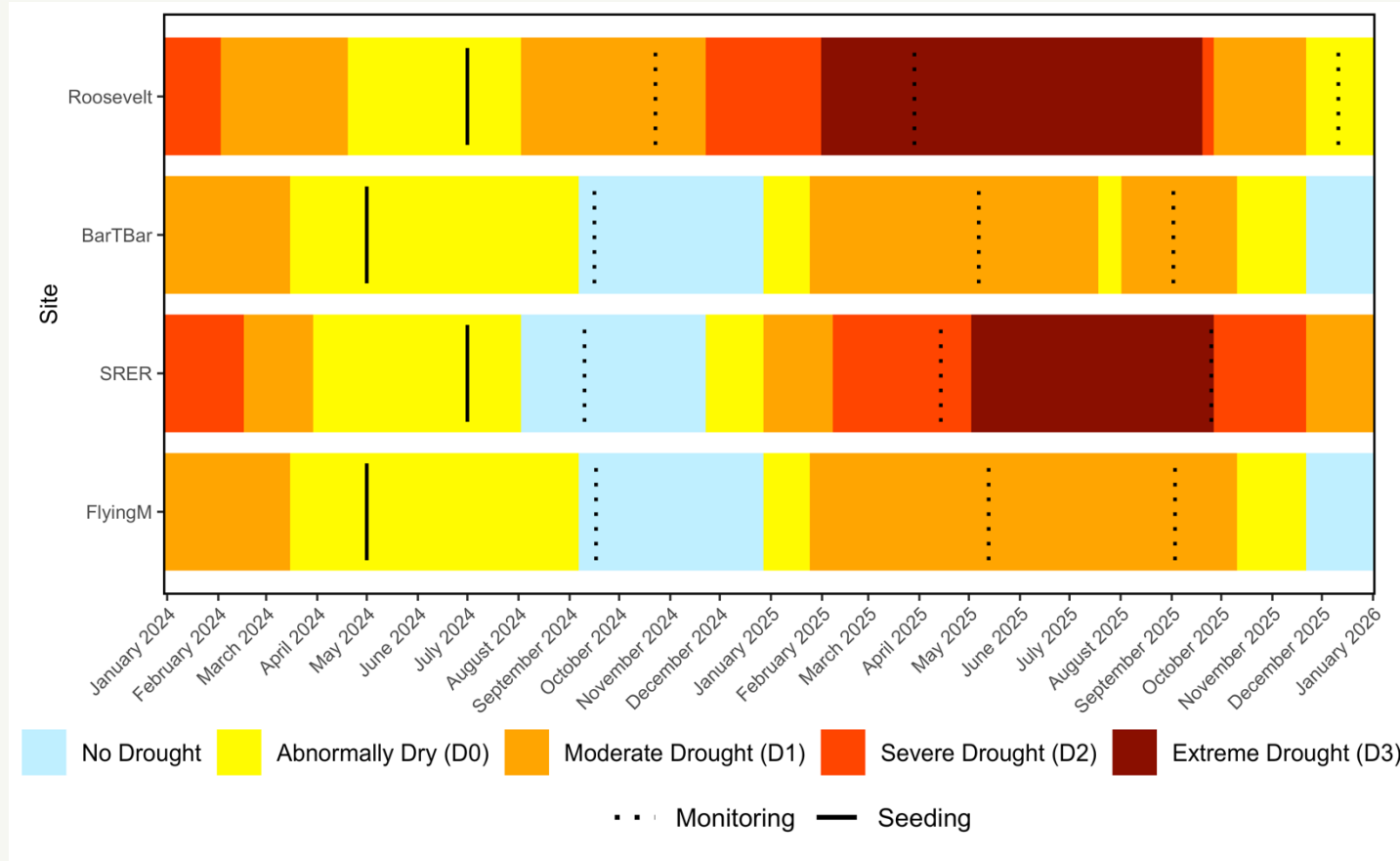
Katy Stites



 Control	 +  Control + Soil Inoculum (High Volume)
 Broadcast Seed	 +  Broadcast Seed + Soil Inoculum (High Volume)
 +  Pits + Broadcast Seed	 +  +  Pits + Broadcast Seed + Soil Inoculum (High Volume)
 Seed Pellets	 +  Seed Pellets + Soil Inoculum (Low Volume)
 +  Pits + Seed Pellets	 +  +  Pits + Seed Pellets + Soil Inoculum (Low Volume)



# Treatment effects were constrained by drought



Most Arid

Least Arid

Data from U.S. Drought Monitor

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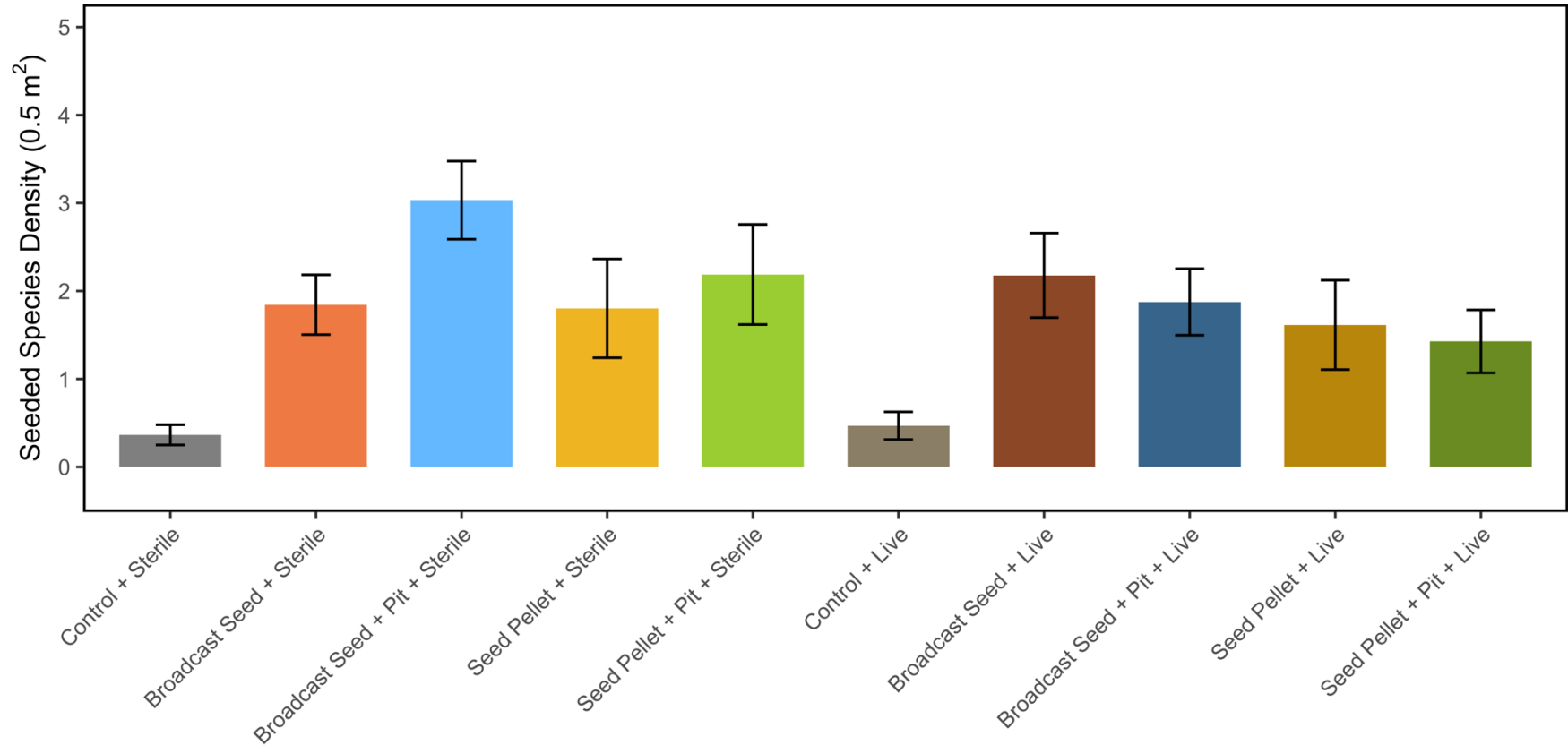
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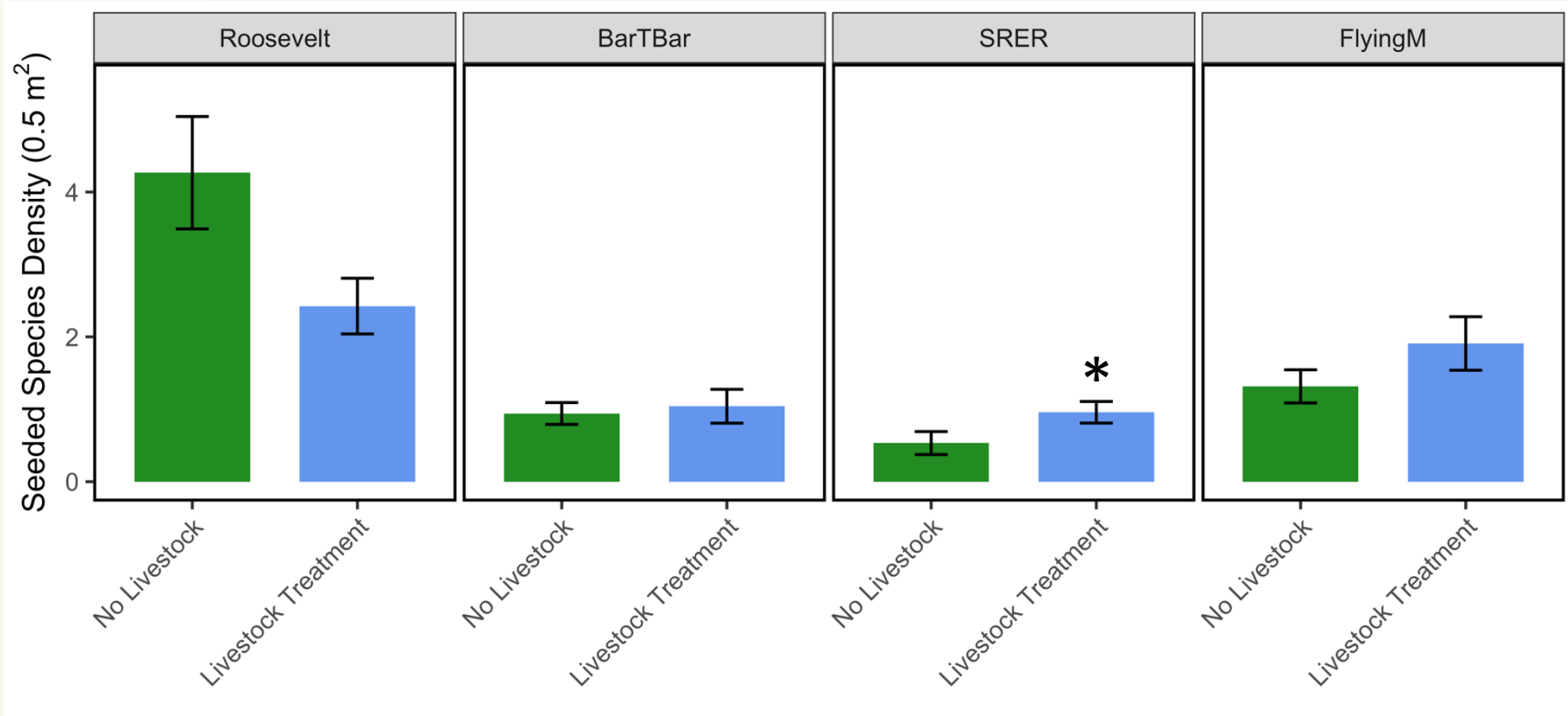
# Active seeding increased desirable species density, but soil inoculum had neutral effects



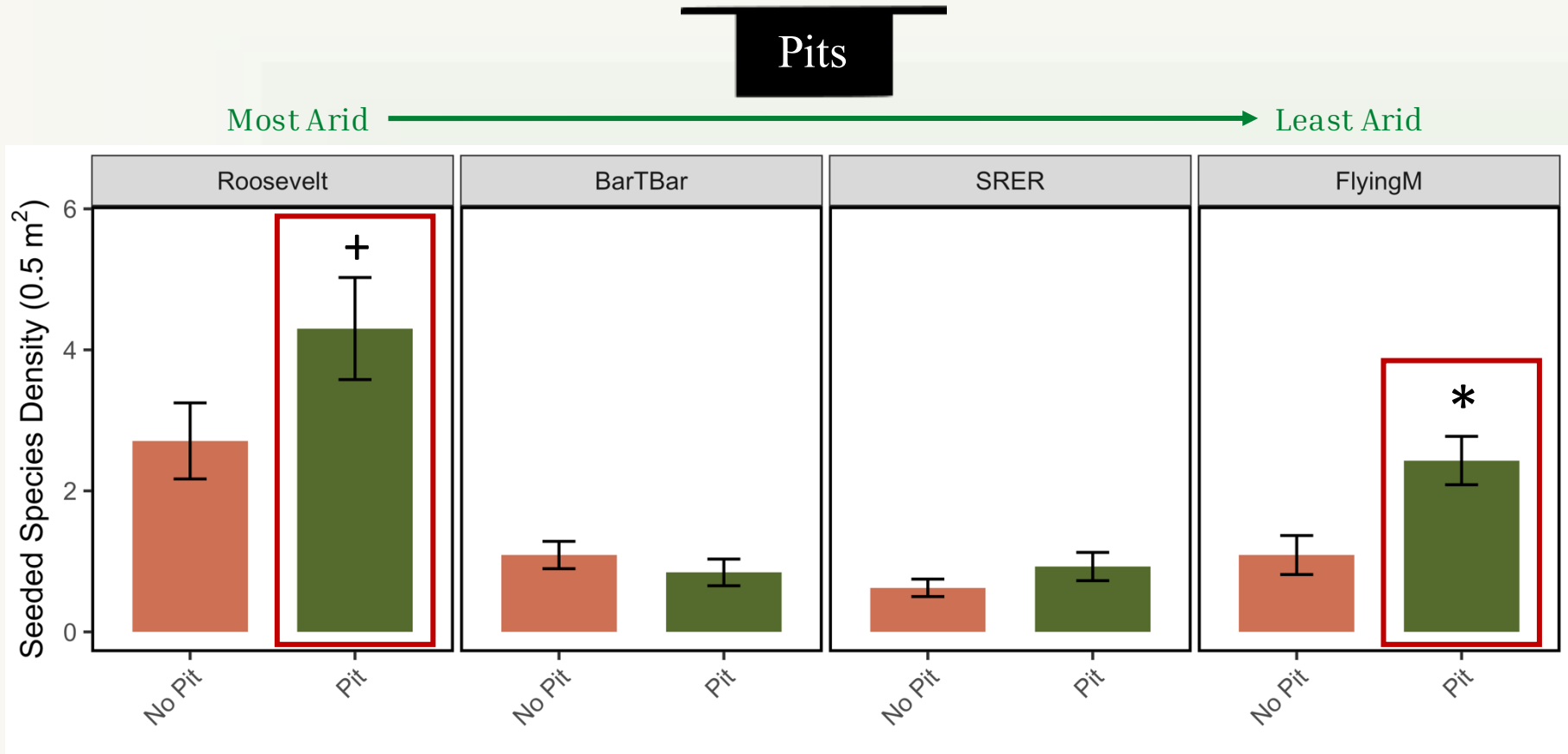


# Targeted livestock treatment had largely neutral effects

Most Arid → Least Arid



# Pitting increased density at sites characterized by pulse precipitation



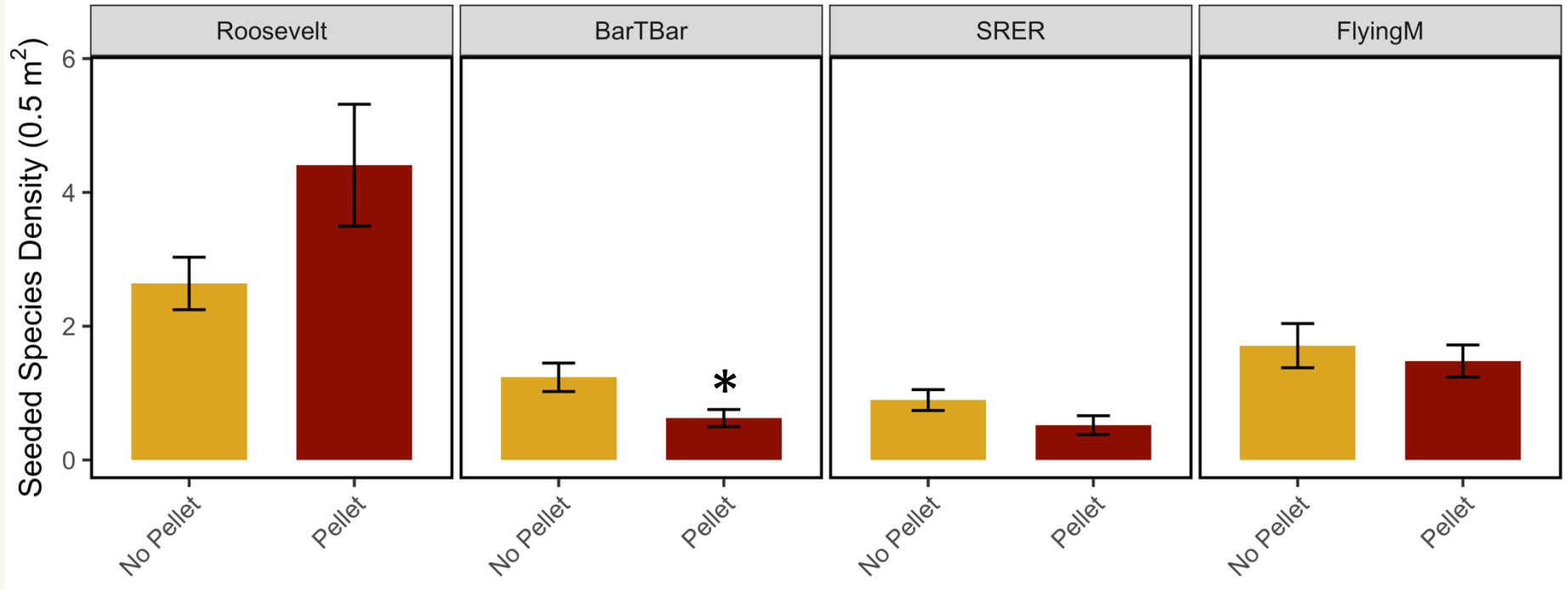
# Pitting increased density at sites characterized by pulse precipitation



# Seed pellets had neutral or negative effects

Seed Pellets

Most Arid → Least Arid



# Chapter 3: Key Results

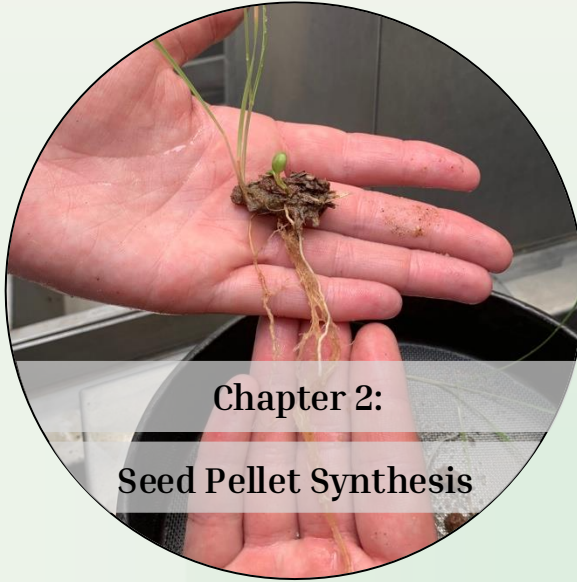
- Environmental conditions likely constrained treatment impacts
- Soil moisture retention through pitting showed promise, while seed pellets, soil inoculum and livestock treatment had largely neutral effects
- Layered restoration interventions did not increase success under drought conditions





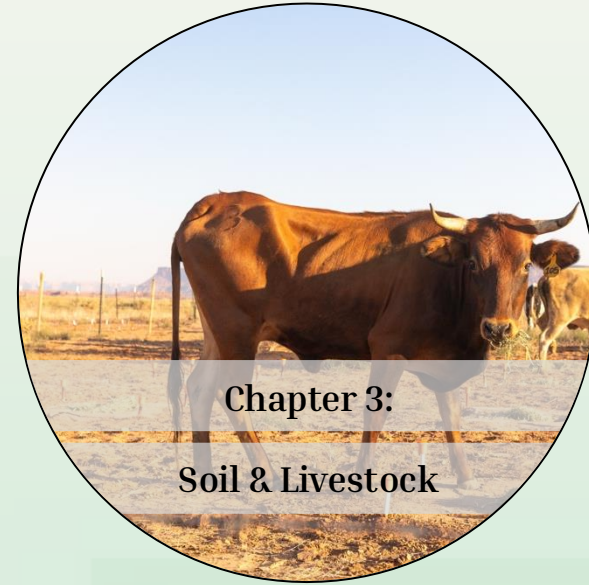
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**Chapter 2:**

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**Chapter 3:**

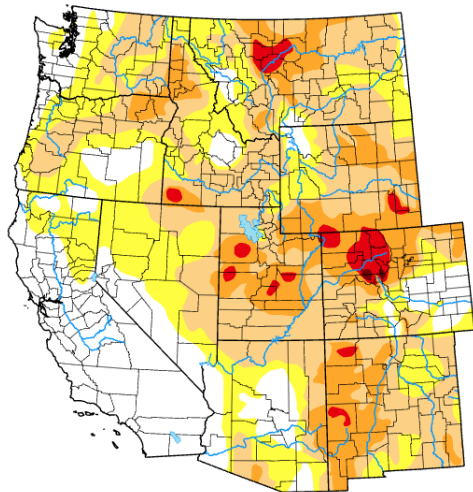
**Soil & Livestock**

# Key Results

- Moisture retention treatments (e.g., pits, coarse woody debris, media lunas) have potential to increase seeded species success
- Seed pellets show promise under greenhouse conditions but need further refinement for field applications
- Site conditions likely constrained treatment impacts







Map released: Thurs. March 12, 2026

Data valid: March 10, 2026 at 8 a.m. EDT

### Intensity

- None
- D0 (Abnormally Dry)
- D1 (Moderate Drought)
- D2 (Severe Drought)
- D3 (Extreme Drought)
- D4 (Exceptional Drought)
- No Data

### Authors

United States and Puerto Rico Author(s):

[Brad Pugh](#), NOAA/CPC

Pacific Islands and Virgin Islands Author(s):

[Denise Gutzmer](#), National Drought Mitigation Center

RESTORATION  
ECOLOGY

The Journal of the Society for Ecological Restoration

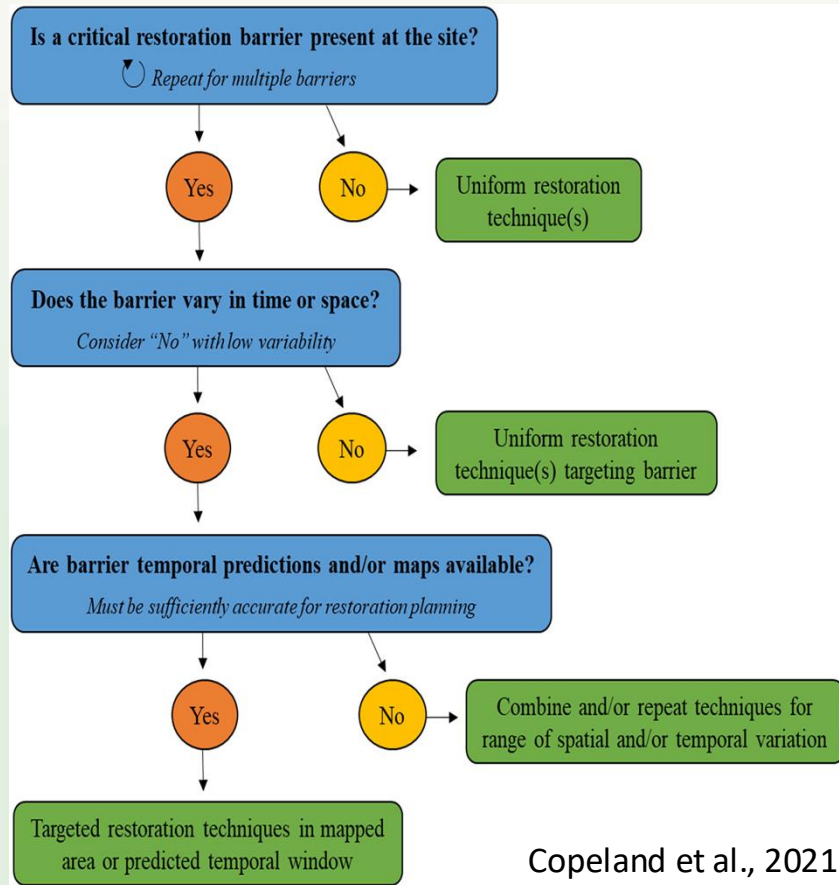


RE-AL THEMATIC SERIES

REVIEW ARTICLE

## Supporting dryland restoration success with applied ecological forecasting of seeding outcomes

Gregor-Fausto Siegmund<sup>1,2</sup>, Daniel R. Schlapfer<sup>1,3</sup>, Caitlin Andrews<sup>1</sup>, Leland D. Bennion<sup>4,5</sup>, Jacob Ferguson<sup>6</sup>, Michelle I. Jeffries<sup>4</sup>, Peggy Olwell<sup>7</sup>, David S. Pilliod<sup>4</sup>, Allison Simler-Williamson<sup>5</sup>, Alice E. Stears<sup>1,3</sup>, Regina Zweng<sup>7</sup>, John B. Bradford<sup>1,8</sup>



Copeland et al., 2021



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Thank you!  
Questions?



# Literature Cited

Copeland, S. M., Baughman, O. W., Boyd, C. S., Davies, K. W., Kerby, J., Kildisheva, O. A., & Svejcar, T. (2021). Improving restoration success through a precision restoration framework. *Restoration Ecology*, 29(2), e13348. <https://doi.org/10.1111/rec.13348>

Hobbs, R. J., Higgs, E., & Harris, J. A. (2009). Novel ecosystems: Implications for conservation and restoration. *Trends in Ecology & Evolution*, 24(11), 599–605. <https://doi.org/10.1016/j.tree.2009.05.012>

Hulvey, K. B., & Aigner, P. A. (2014). Using filter-based community assembly models to improve restoration outcomes. *Journal of Applied Ecology*, 51(4), 997–1005. <https://doi.org/10.1111/1365-2664.12275>

Kimmell, L. B., Fagan, J. M., & Havrilla, C. A. (2023). Soil restoration increases soil health across global drylands: A meta-analysis. *Journal of Applied Ecology*, 60(9), 1939–1951. <https://doi.org/10.1111/1365-2664.14459>

Swartz, E. H., Caldwell, B., & Havrilla, C. A. (2026). Seed pellets containing activated carbon increase emergence of native plant species used in dryland restoration following herbicide application. *Restoration Ecology*, e70316. <https://doi.org/10.1111/rec.70316>

