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Advances in Techniques for Restoring Mojave Desert Habitats and Ecosystem Functions

Roadside Outplanting and Vertical Mulching, Joshua Tree National Park

Building on earlier work UNLV Conservation Ecology Lab

Species selection for performance, functions, treatment effectiveness

Continual need for innovative restoration practices to reduce costs, new envts

A Systematic Review of Species Performance and Treatment Effectiveness for Revegetation in the Mojave Desert, USA

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2009, in Arid Environments and Wind Erosion

Abstract

Land managers need ecologically and cost-effective strategies for revegetating arid lands, such as the Mojave Desert in the southwestern United States. Many disturbances – failed agricultural attempts, grazing by exotic herbivores (e.g., burros, cattle), creating roads, land clearing for military or mining activities, off-road vehicle use, and wildfires fueled by exotic grasses – have modified or eradicated native vegetation. Natural revegetation often is slow, or consists of exotic species that do not meet management objectives. As a result, active revegetation using native species may be required to accomplish ecological and utilitarian objectives, such as enhancing native plant communities, curtailing fugitive dust that poses a human health hazard, or establishing non-flammable vegetation for reducing wildfires. We evaluated the following questions by systematically reviewing published revegetation studies in the Mojave Desert: (1) Which species have been most commonly and effectively planted or seeded? (2) Which treatments have increased plant establishment? (3) What are the relative performances of planting and seeding, and are these species specific? Fifteen planting studies assessed a total of 41 species, 33 of them shrubs. None of the nine species planted in ≥ 3 studies avoided a complete failure (0% survival) in one or more treatments in one or more studies, but several species (e.g., *Larrea tridentata*, *Atriplex* spp.) consistently exhibited high (> 50%) survival. Fencing, shelters, and irrigation increased survival of some species, but these treatments require cost/benefit analyses. Though seeding frequently has been discouraged relative to planting, seeding success is species and situational specific.

Restoration Ecology
THE JOURNAL OF THE SOCIETY FOR ECOLOGICAL RESTORATION INTERNATIONAL

RESEARCH ARTICLE 2012

Identifying Native Vegetation for Reducing Exotic Species during the Restoration of Desert Ecosystems

Scott R. Abella,[1,2] Donovan J. Craig,[1] Stanley D. Smith,[3] and Alice C. Newton[4]

Abstract

There is currently much interest in restoration ecology in identifying native vegetation that can decrease the invasibility by exotic species of environments undergoing restoration. However, uncertainty remains about restoration's ability to limit exotic species, particularly in deserts where facilitative interactions between plants are prevalent. Using candidate native species for restoration in the Mojave Desert of the southwestern U.S.A., we experimentally assembled a range of plant communities from early successional forbs to late-successional shrubs and assessed which vegetation types reduced the establishment of the priority invasive annuals *Bromus rubens* (red brome) and *Schismus* spp. (Mediterranean grass) in control and N-enriched soils. Compared to early successional grass and shrub and late-successional shrub communities, an early forb community best resisted invasion, reducing exotic species biomass by 88% (N added) and 97% (no N added) relative to controls (no native plants). In native species monocultures, *Sphaeralcea ambigua* (desert globemallow), an early successional forb, was the least invasible, reducing exotic biomass by 91%. However, the least-invaded vegetation types did not reduce soil N or P relative to other vegetation types nor was native plant cover linked to invasibility, suggesting that other traits influenced native-exotic species interactions. This study provides experimental field evidence that native vegetation types exist that may reduce exotic grass establishment in the Mojave Desert, and that these candidates for restoration are not necessarily late-successional communities. More generally, results indicate the importance of careful native species selection when exotic species invasions must be constrained for restoration to be successful.

Key words: *Bromus rubens*, competition, invasion-reducing communities, native-exotic species relationships, nitrogen, restoring resistance, *Schismus*, soil.

Major Themes with Case Studies

– Mojave Desert monograph on long-term post-fire recovery
– Active revegetation, abiotic structural restoration
– Biocrust and soil restoration techniques
– Field guide for non-native grass fuel loads (fire risk tool)

Mojave Desert Fire Chronosequence

Ecological Monographs, 91(1), 2021, e01432

Resilience and alternative stable states after desert wildfires

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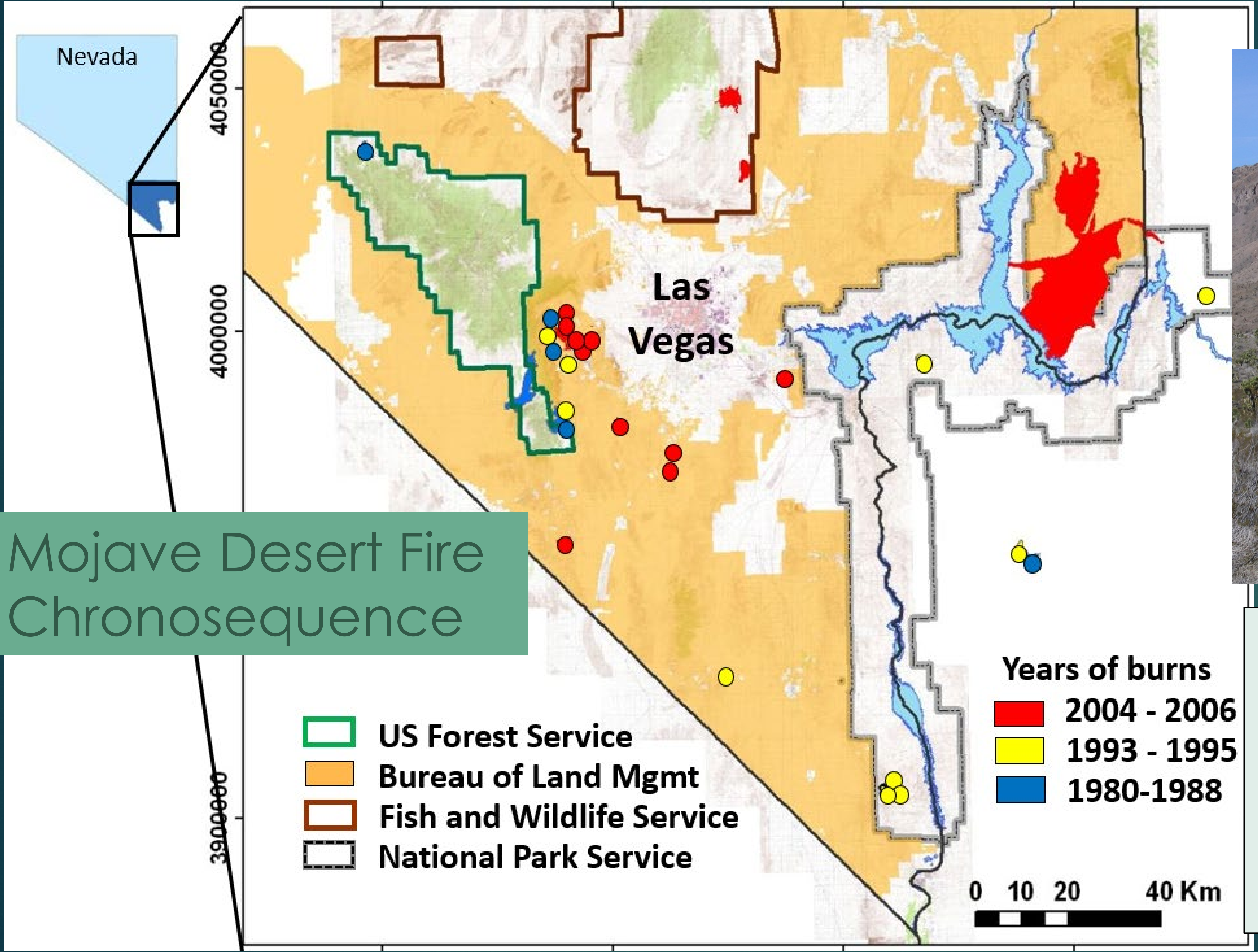
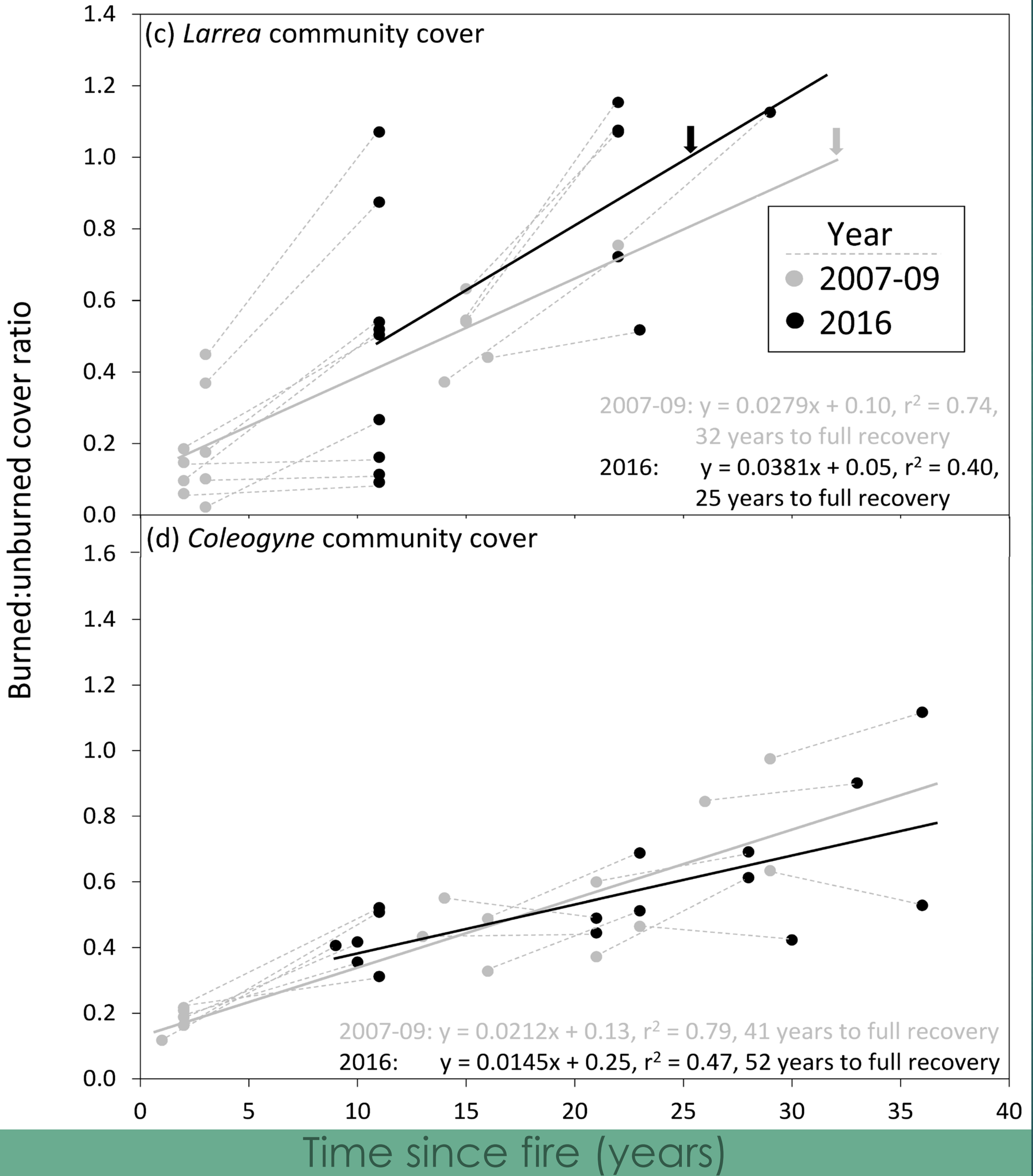
Citation: Abella, S. R., D. M. Gentilcore, and L. P. Chiquoine. 2021. Resilience and alternative stable states after desert wildfires. Ecological Monographs 91(1):e01432. 10.1002/ecm.1432

Abstract. Improving models of community change is a fundamental goal in ecology and has renewed importance during global change and increasing human disturbance of the biosphere. Using the Mojave Desert (southwestern United States) as a model system, invaded by nonnative plants and subject to wildfire disturbances, we examined models of resilience, alternative stable states, and convergent-divergent trajectories for 36 yr of plant community change after 31 wildfires in communities dominated by the native shrubs *Larrea tridentata* or *Coleogyne ramosissima*. Perennial species richness on average was fully resilient within 23 yr after disturbance in both community types. Perennial cover was fully resilient within 25 yr in the *Larrea* community, but recovery was projected to require 52 yr in the *Coleogyne* community. Species composition shifts were persistent, and in the *Coleogyne* community, the projected compositional recovery time of 550 yr and increasing resembled a deflected trajectory toward potential alternative states. Disturbed sites contained a perennial species composition of predominately short-statured forbs, subshrubs, and grasses, contrasting with the larger-statured shrub and tree structure of undisturbed sites. Auxiliary data sets characterizing species recruitment, annual plants including nonnative grasses, biocrust communities, and soils showed persistent differences between disturbed and undisturbed sites consistent with positive feedbacks potentially contributing to alternative stable states. Resprouting produced limited resilience for the large shrubs *L. tridentata* and *Yucca* spp. important to population persistence but did not forestall long-term reduced abundance of the species. The nonnative annual grass *Bromus rubens* increased on disturbed sites over time, suggesting persistently abundant nonnative plant fuels and reburn potential. Biocrust cover on disturbed sites was half and species richness a third of amounts on undisturbed sites. Soil nitrogen was 30% greater on disturbed sites and no significant trend was evident for it to decline on even the oldest burns. Disturbed desert plant communities simultaneously supported all three models of resilience, alternative stable states, and convergent-divergent trajectories among community measures (e.g., species richness, composition), timeframes since disturbance, and spatial resolutions. Accommodating expression within ecosystems of multiple models, including those opposing each other, may help broaden theoretical models of ecosystem change.

Mojave Desert Fire Chronosequence



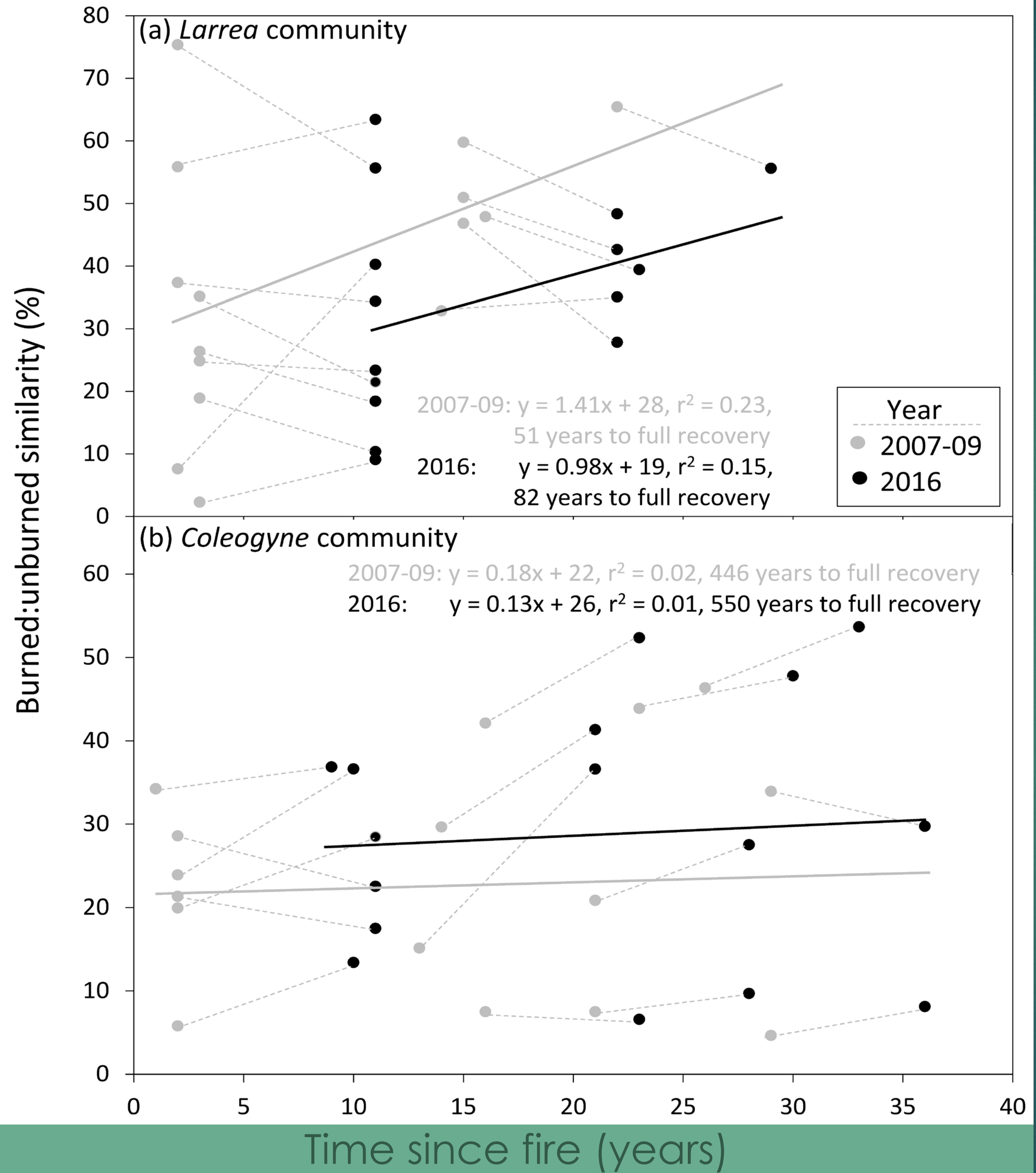
- 32 fires (1980-2006)
- Burned/unburned pairs (264 plots total)
- Veg, resprouting, soils, biocrust
-2007-09, 2016



Perennial richness, cover

Cover recovery rate faster in *Larrea* between 2007-09 and 2016, slowed in *Coleogyne*

Recovery debt



Community Composition

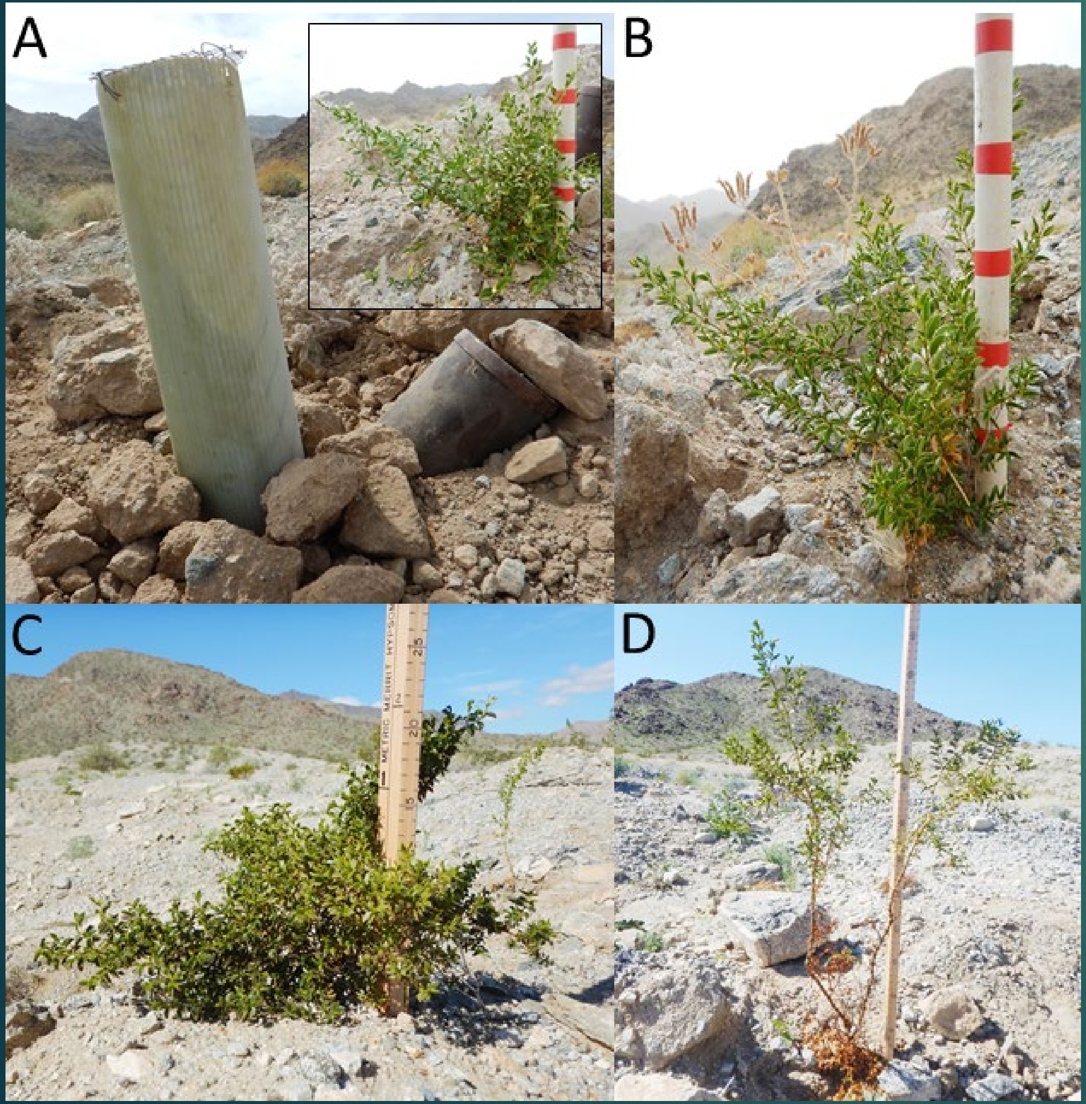
Minimal relationship between TSF and B:U similarity

Burned *Larrea* communities become less similar to unburned between 2007/09 and 2016

Assisted Natural Regeneration

Helping organisms overcome barriers to regeneration

Example potential advantages: local genetics, cheaper, feasibility, adaptable



- Dead Mountains Wilderness (BLM Needles)
- Decommissioned road/parking area
- 72 *Larrea* seedlings (age 1-2 yrs)
- 4 tmts (Irrigation gel, shelter, both, none)
- Feb 2017 to March 2019

Assisted Natural Regeneration

Shelters reduced two-year survival but tripled growth

Irrigation had no effect

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RESEARCH NOTE

Developing methods of assisted natural regeneration for restoring foundational desert plants

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ABSTRACT
Assisted natural regeneration (ANR) is a restoration and management technique for enhancing the natural recruitment of desired species. To test ANR strategies in an arid environment, we applied irrigation and shelters to natural seedlings of the ecologically foundational shrub *Larrea tridentata* to enhance revegetation of a disturbed site in the Mojave Desert, USA. Irrigation did not improve seedling survival and growth. Shelters reduced 2-year survival by 31% but tripled height growth of surviving seedlings. Utility of shelter for ANR thus hinged on uncertain tradeoffs among seedling survival, height growth, and implementation costs. Mixed results suggest that further evaluating other combinations of treatments and with different species is required to understand ANR's potential for restoration in arid lands.

ARTICLE HISTORY
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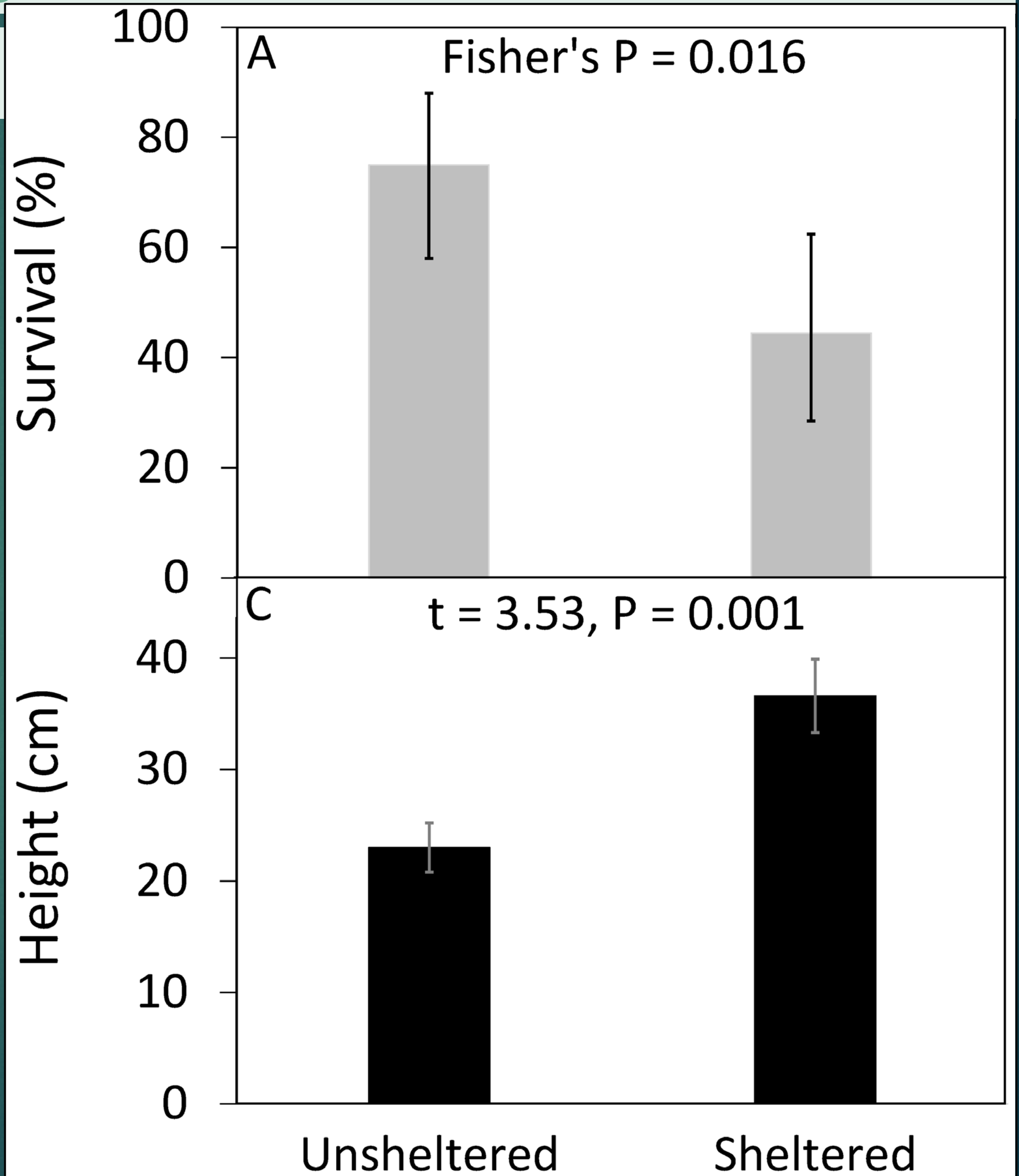
KEYWORDS
Irrigation; foundation species; *Larrea tridentata*; Mojave Desert; protection; recruitment; tree shelter



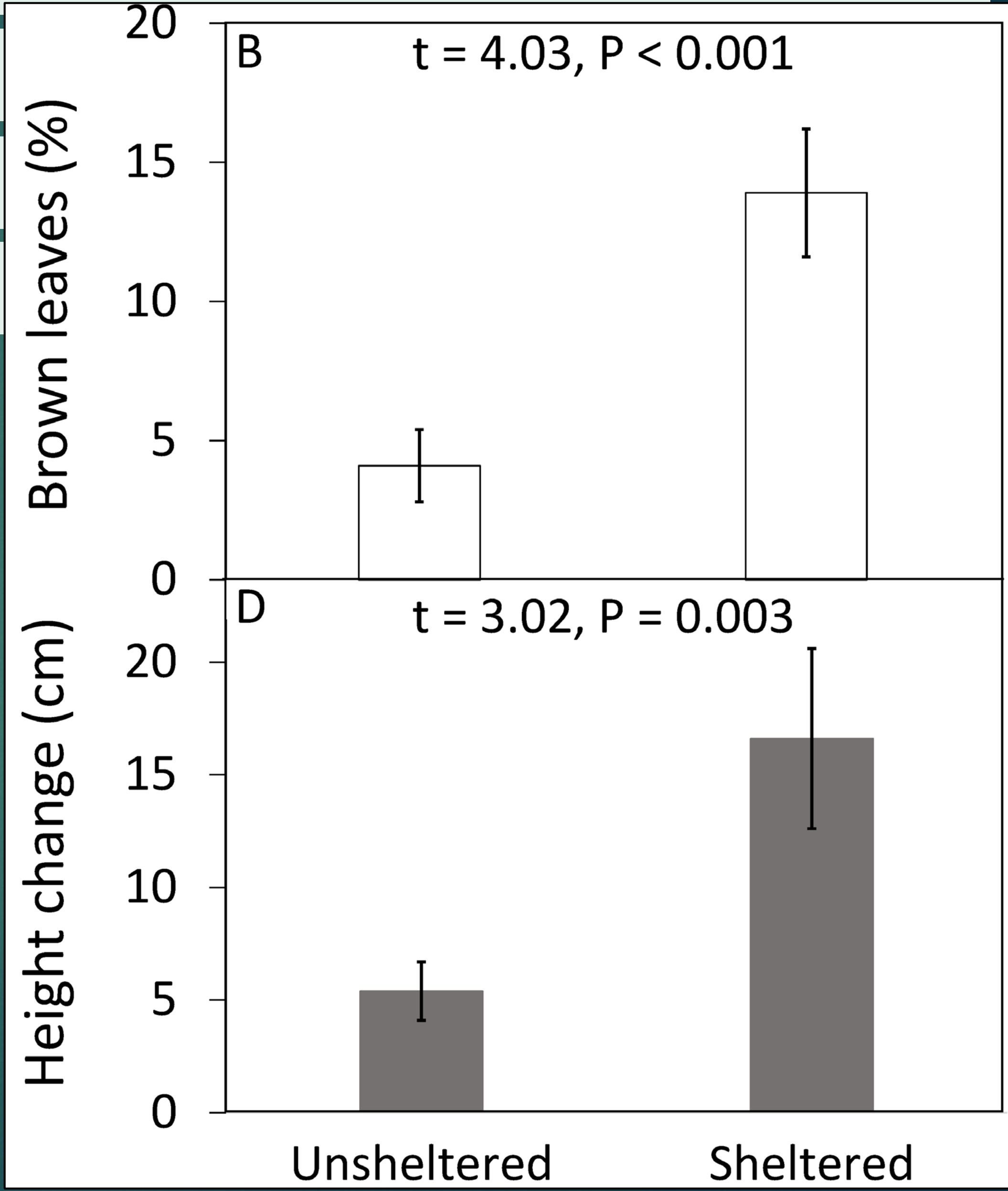
Assisted Natural Regeneration

$3/shelter, 15 minutes labor per plant to transport, install, and remove shelter

2017-2018 dry: 57%, 66% of 11 cm/yr avg precip

Temperature, CO_2 – test shelter variations?

Same tmts for natural seedlings, outplants?



Rock nurses as minimum input restoration

Utilizing on-site materials as nurses to overcome barriers to perennial reestablishment and minimize costs

Frequent limitations for restoration of aridlands: propagule sources, precipitation, and **microhabitat**

Can rocks act as abiotic nurses to facilitate transplant survival for restoring cacti to disturbed sites?

-On-site materials, reduce infrastructure, maintenance, & cost
-Infrastructure that remains in place

Beavertail cactus (*Opuntia basilaris*)

Rock nurses as minimum input restoration

Woody perennial plant cover limited-ecosystem

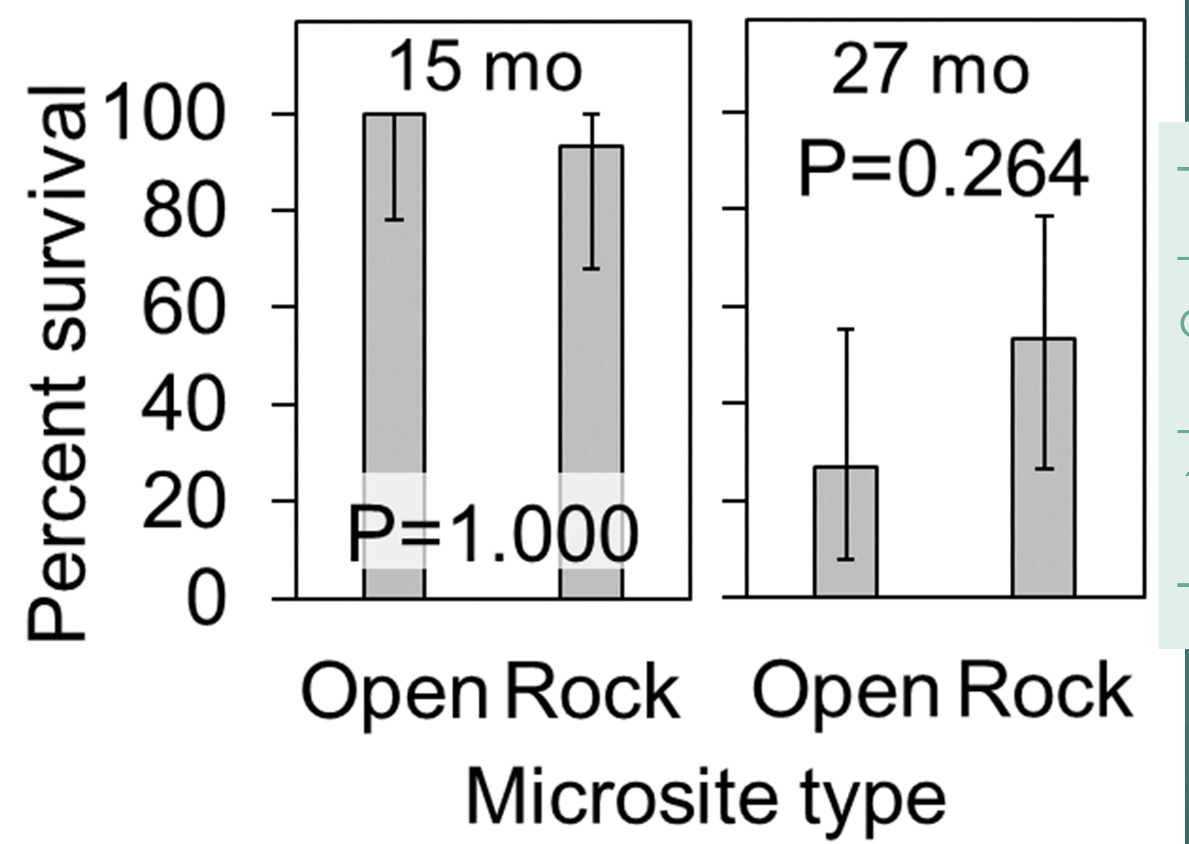
Natural recolonization limited

Significantly altered surface features

- Field site near Vidal Junction, CA (BLM Needles)
- Former surface mining area; Mn-varnished rocks removed in the 1940s-1950s for regional infrastructure
- 30 rooted *Opuntia basilaris* pads planted
- 15 with protective rock structures (Rock microsites) / 15 open, flat spaces >1 m from varnished material
- Dec 2018-April 2021

Rock nurses as minimum input restoration

Initially no survival difference between open and rock microsites, but after 2020 severe drought conditions, see higher survival with rock structures.



– 29/30 individuals survived to 15 months

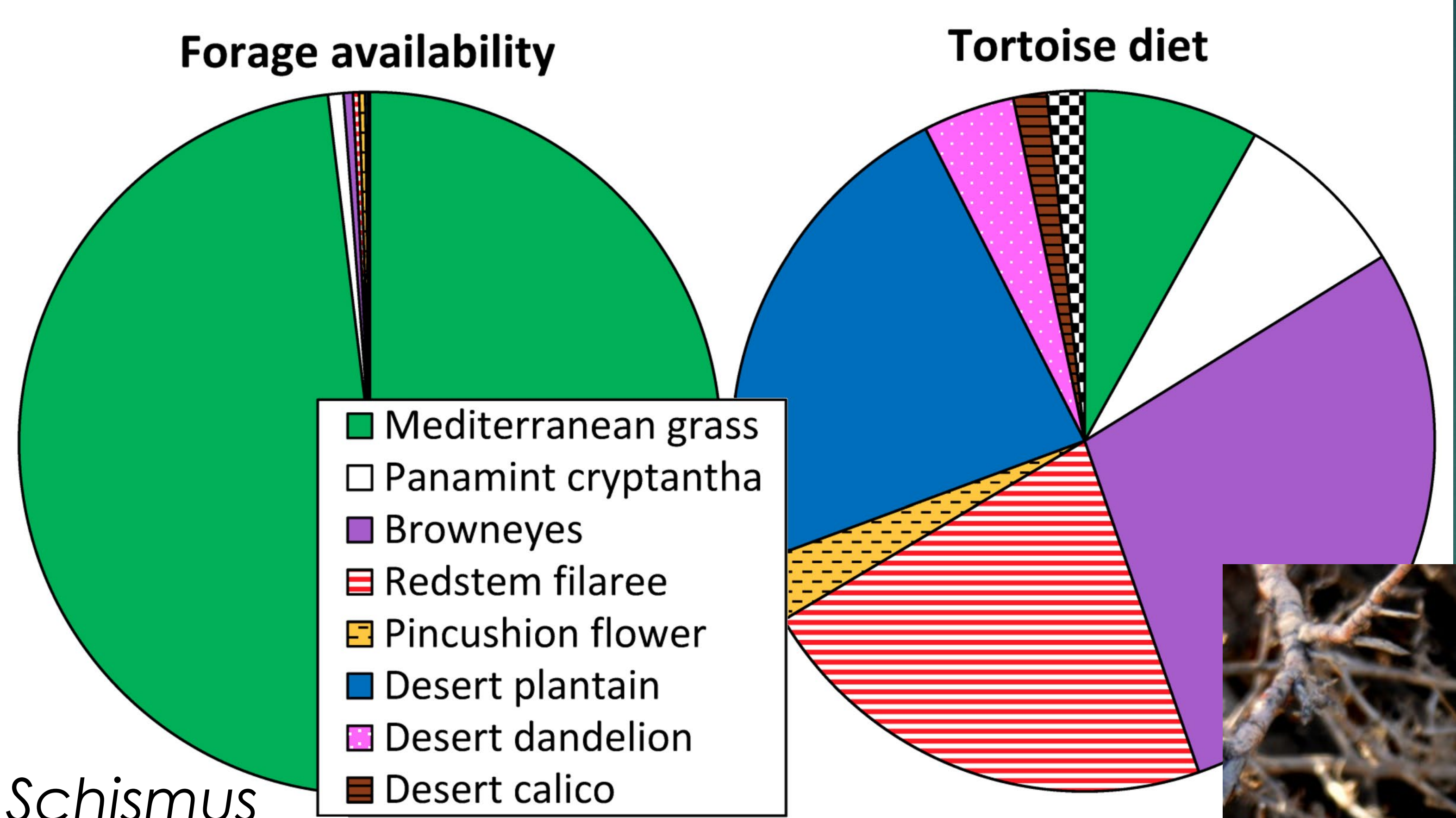
– 28% individuals flowering in rock microsites compared to 0% in open microsites

– After 2020 drought and late spring rains in 2021, 12/30 individuals survived to 27 months

– 8 Rock vs. 4 Open microsites

Rock microsites encouraged flowering

Rock microsites did not overcome extreme drought conditions, although fewer individuals died



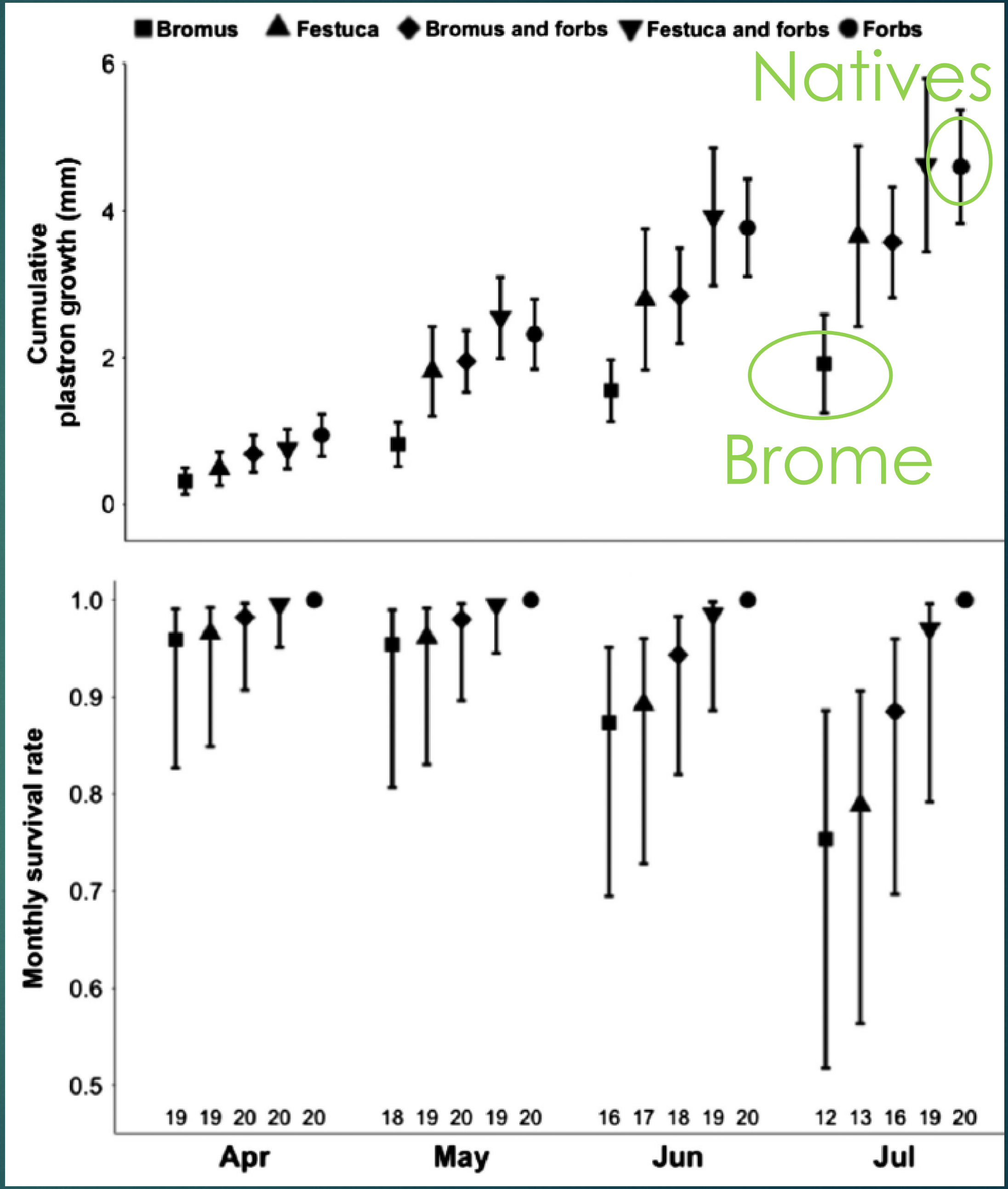
Desert plantain

Schismus

esa 2016 ECOSPHERE

Negative impacts of invasive plants on conservation of sensitive desert wildlife

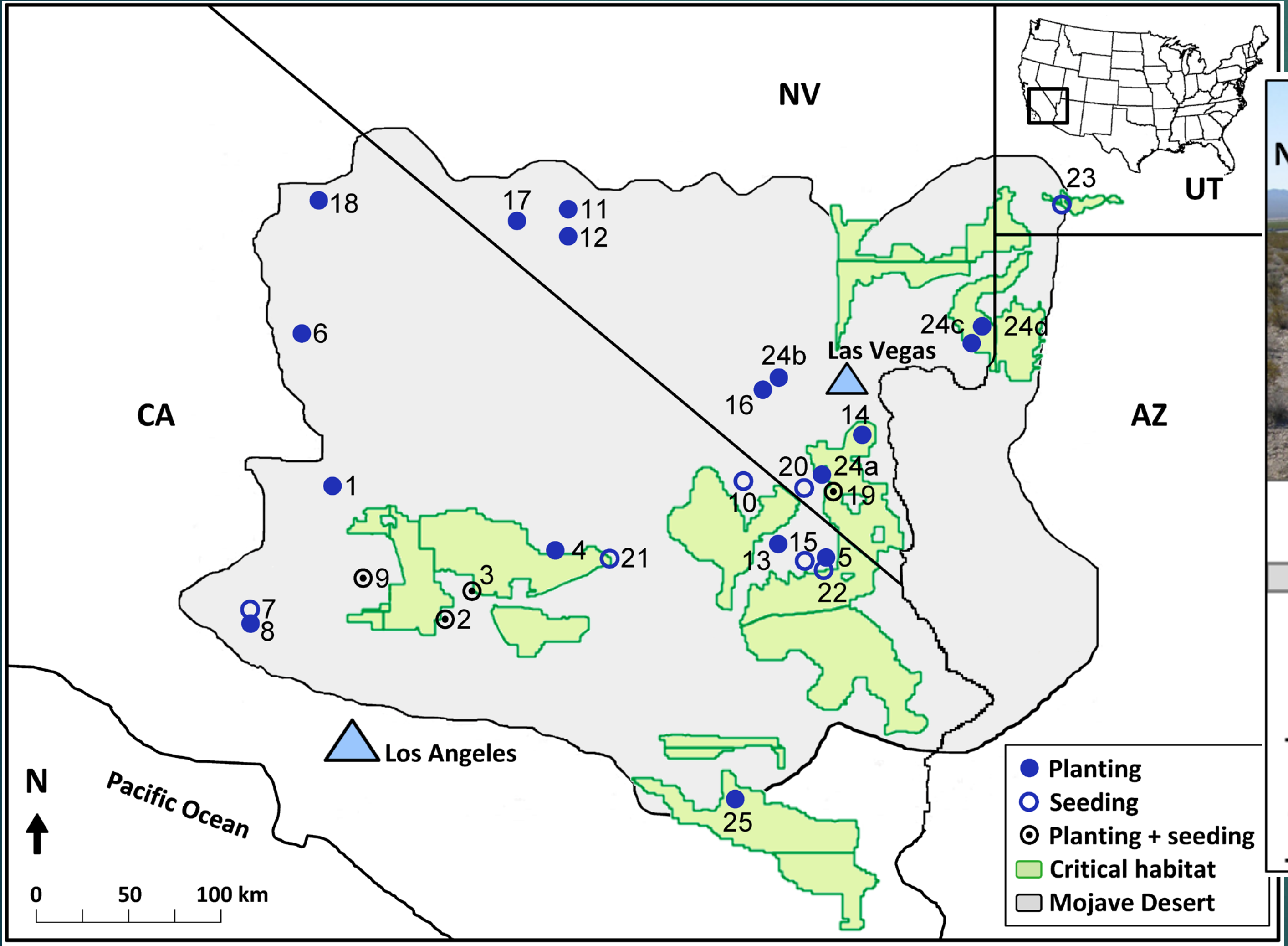
K. Kristina Drake,[1,2,3,†] Lizabeth Bowen,[4] Kenneth E. Nussear,[5] Todd C. Esque,[1] Andrew J. Berger,[1] Nathan A. Custer,[1] Shannon C. Waters,[4] Jay D. Johnson,[6] A. Keith Miles,[1,3] and Rebecca L. Lewison[2]

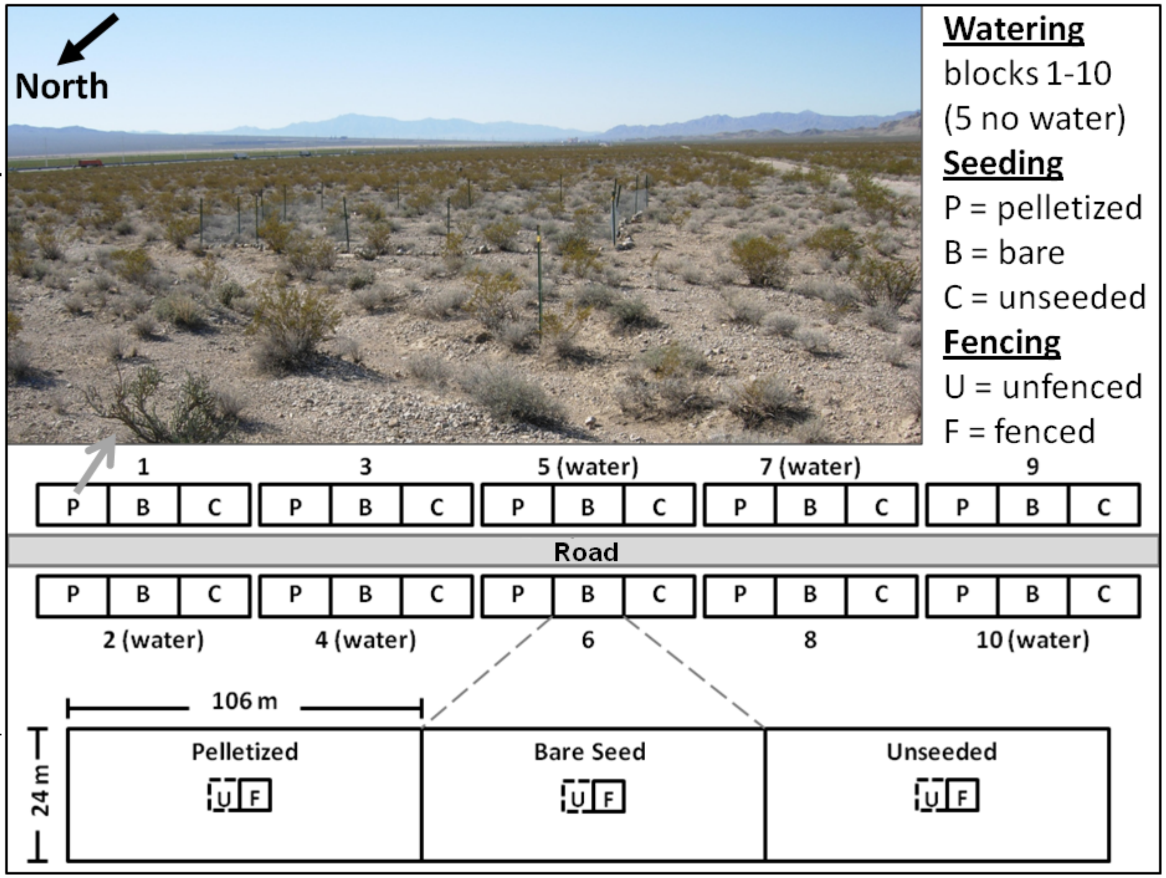


Pelletized seeding for enhancing desert tortoise forage

Seeding success in Mojave early research (1970s, moist) but less since

Examine variations, here pelletizing with native annual forb desert plantain





Pelletized seeding for enhancing desert tortoise forage

Seeding rate: 5,300 seeds/m2 (Jan 2013, monitored 20 months to Sep 2014)

Mineral and organic material and binding (clay, starch sugar); Gro-Coat (CA)

2013: 21%, 2014: 70% seasonal precip

Enhancing Quality of Desert Tortoise Habitat: Augmenting Native Forage and Cover Plants

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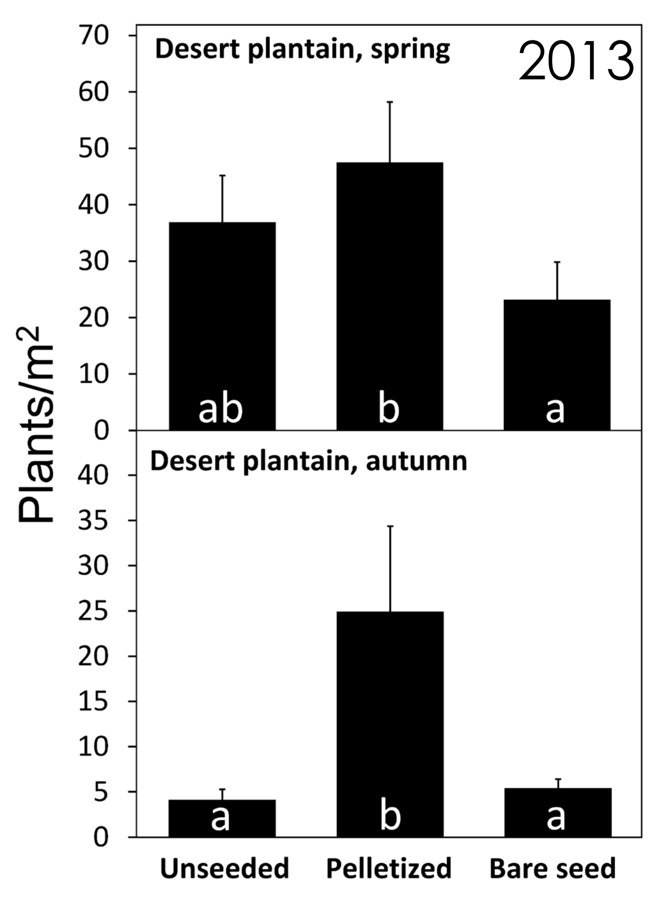
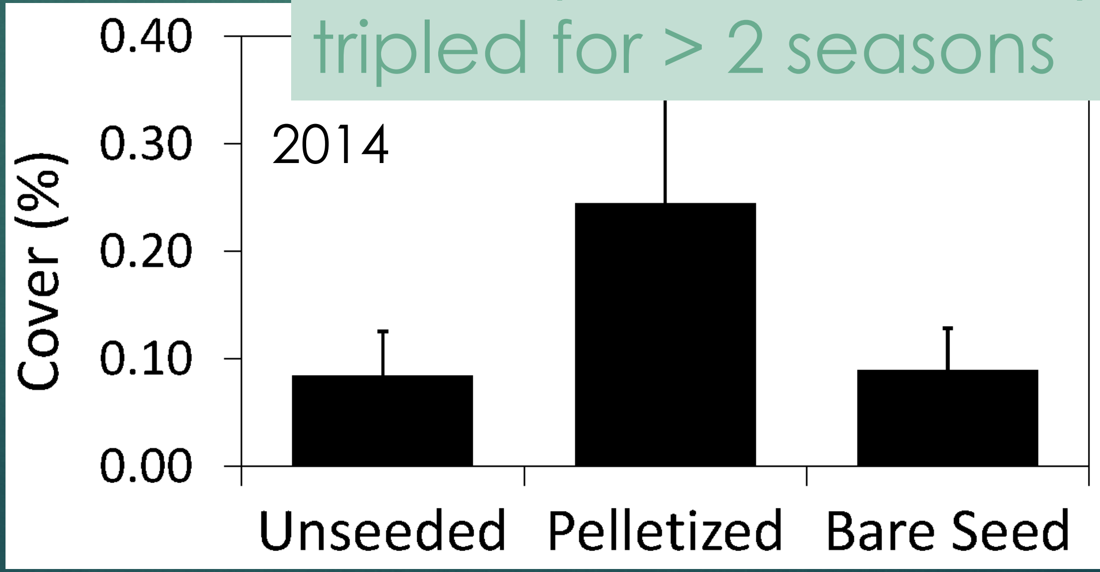
Abstract

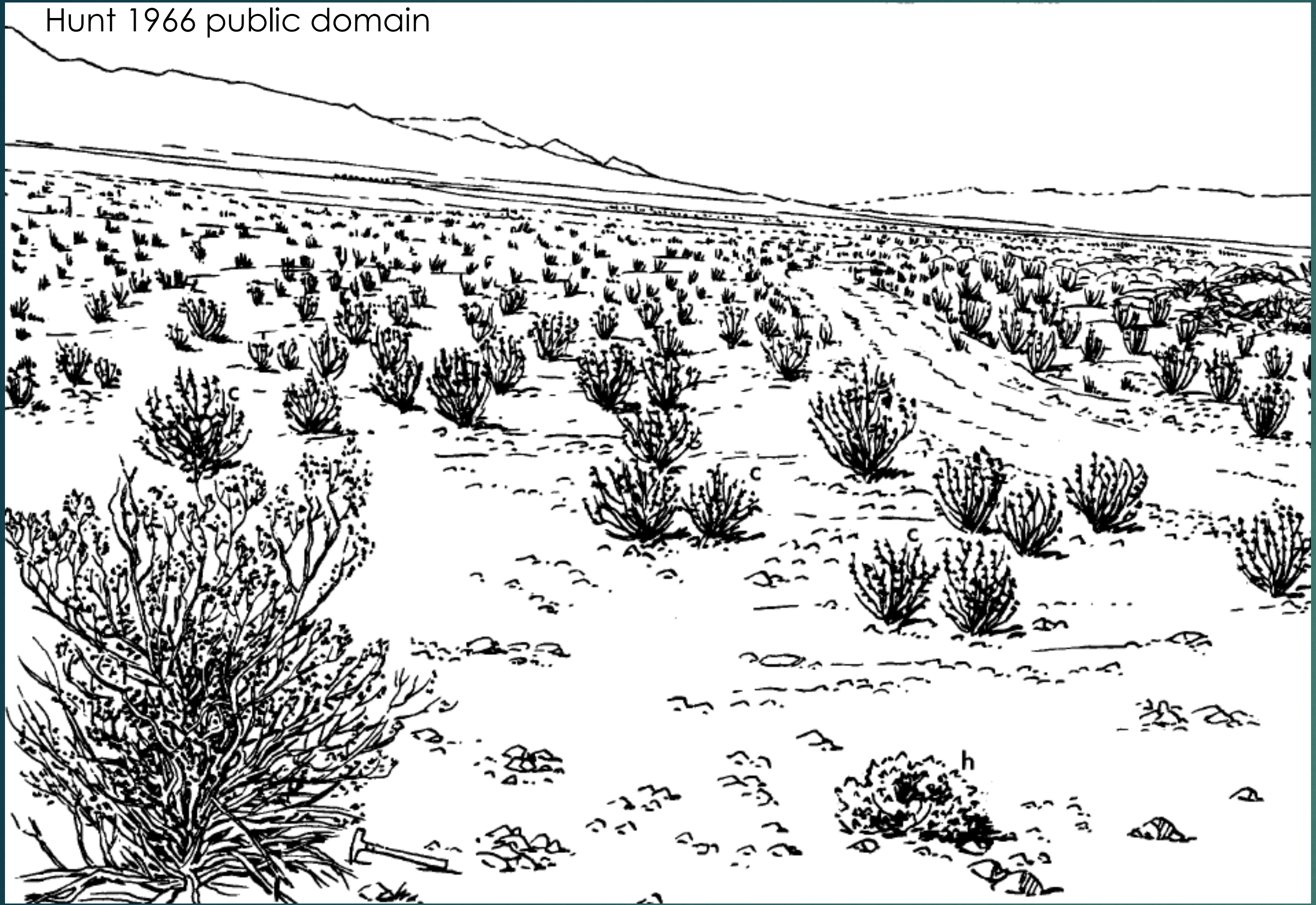


Desert plantain density tripled for > 2 seasons



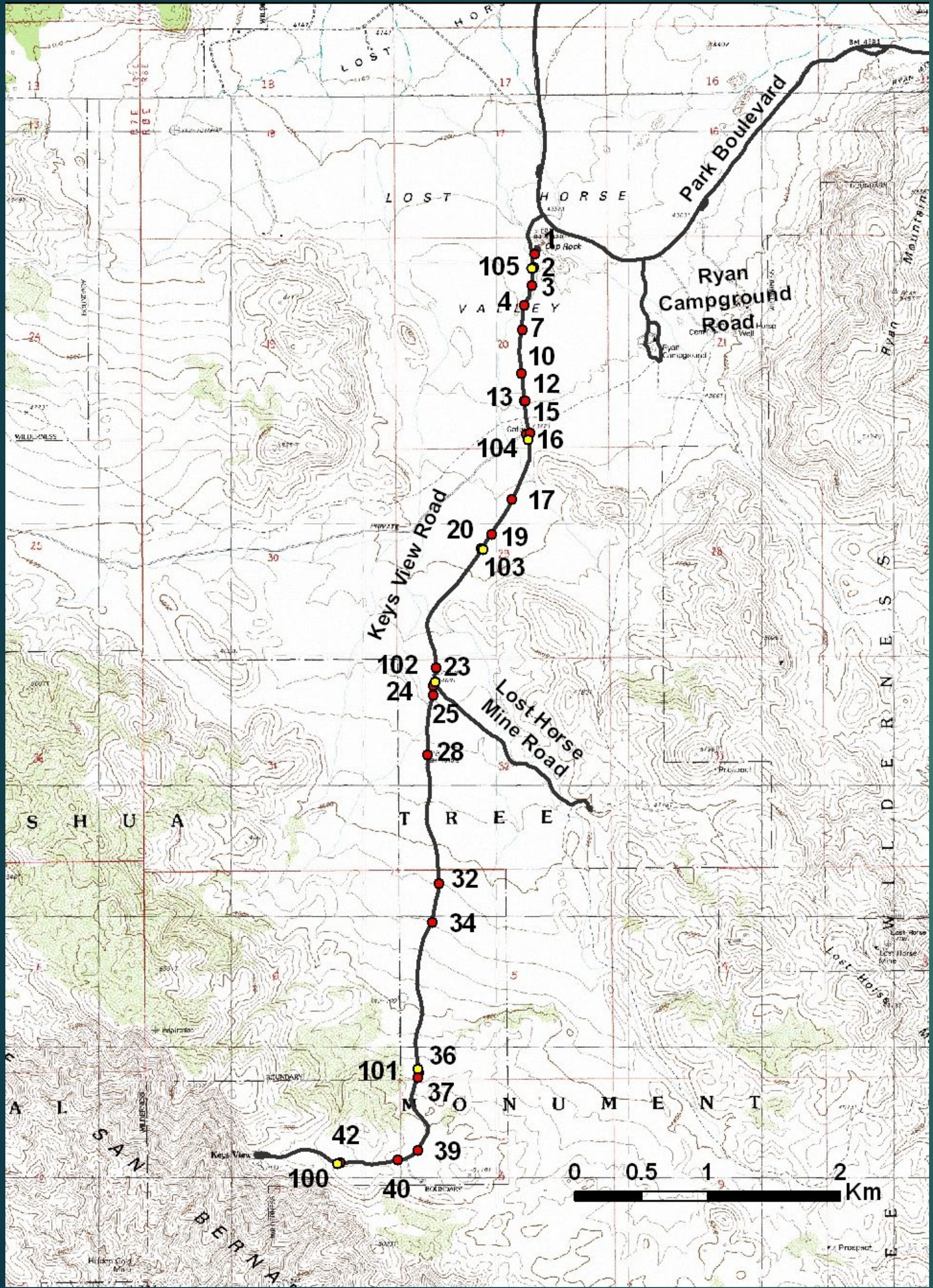
Fertile Islands Underpin Desert Restoration

Hunt 1966 public domain



- Microsites below many perennials (often shrubs)
- Enriched nutrients, shaded, seed deposition
- Restore for structure and function

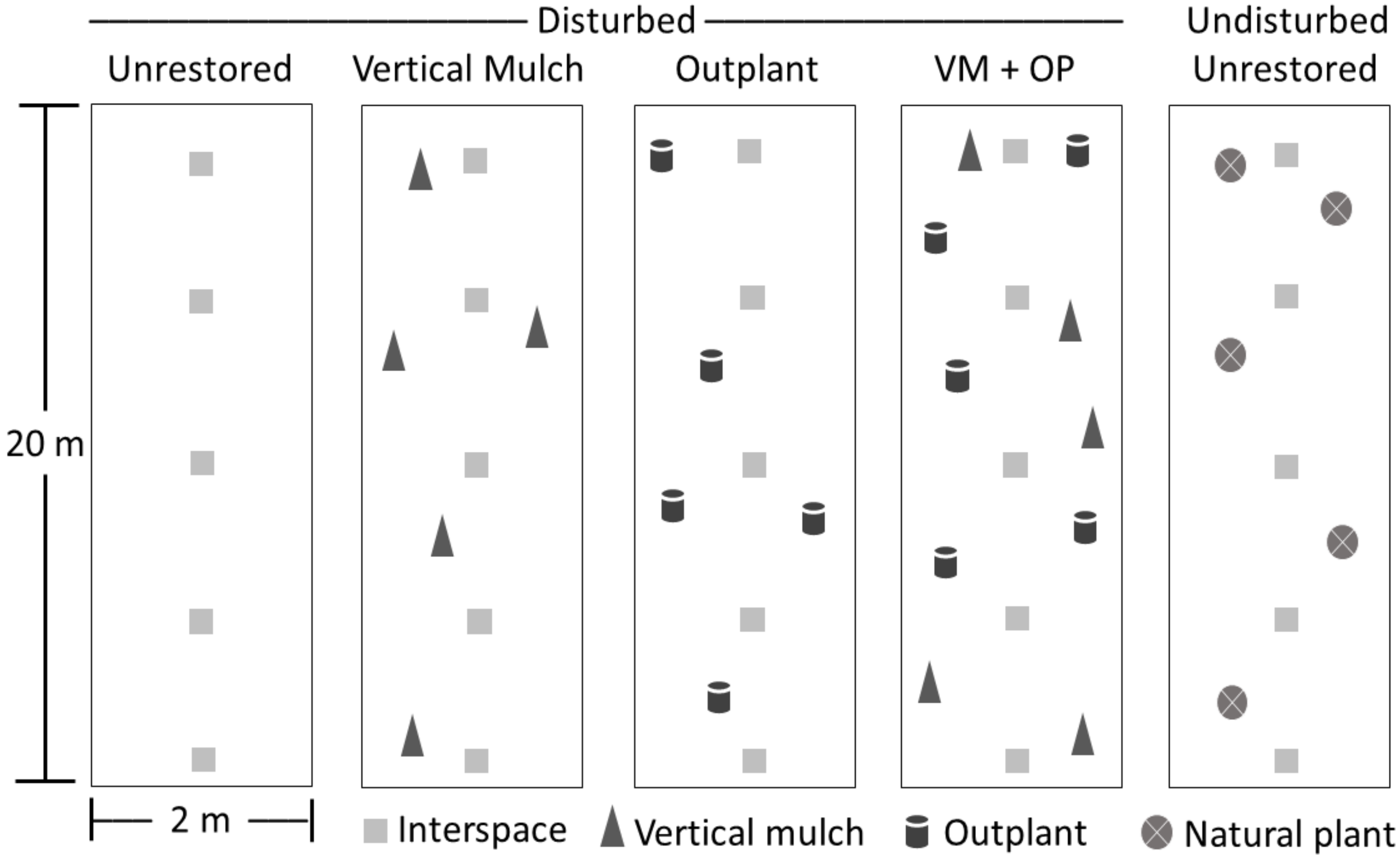
Pairing active revegetation/structural restoration with weed control



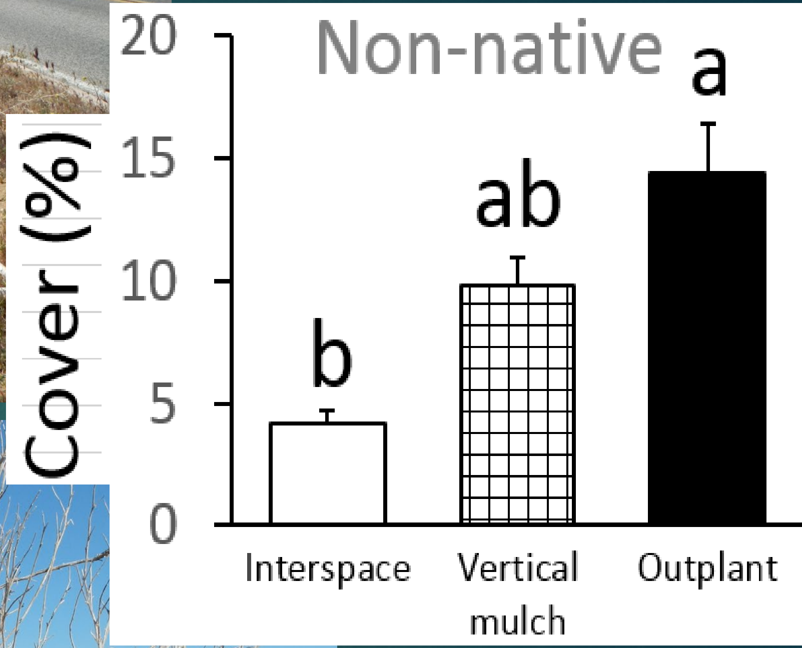
Joshua Tree National Park, road maintenance

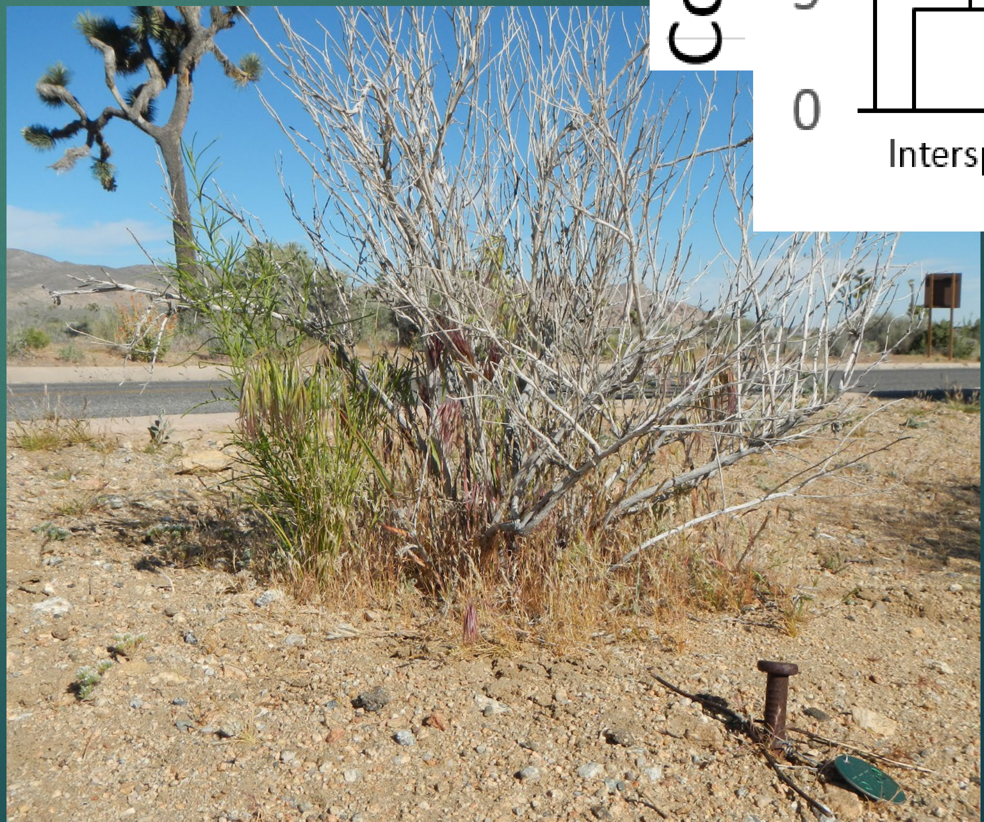
30 plots, 5 treatments (6 plots each) [2008]

Monitoring 2009-2011, 2017-2020



Outplants





Vertical mulch

Interchangeability, proportional success treatment(s), bet-hedging approach

Implications for Practice

- Outplanting native perennials can facilitate recruitment of both native and non-native annual plants, creating a tradeoff for using outplanting to restore fertile islands.
- Placing vertical mulch in the soil can be used to produce effects on annual plant communities that are intermediate between those of outplants and interspaces.
- Restoring structure required by native species but that also benefits non-natives is a conundrum. Fertile island restoration should be accompanied by consideration of potential facilitative effects to non-native plants.
- Reducing non-native annuals could enable native annuals to more fully utilize the facilitative benefits provided by restored fertile islands.

RESTORATION ECOLOGY
The Journal of the Society for Ecological Restoration
SER SOCIETY FOR ECOLOGICAL RESTORATION

RESEARCH ARTICLE

The good with the bad: when ecological restoration facilitates native and non-native species

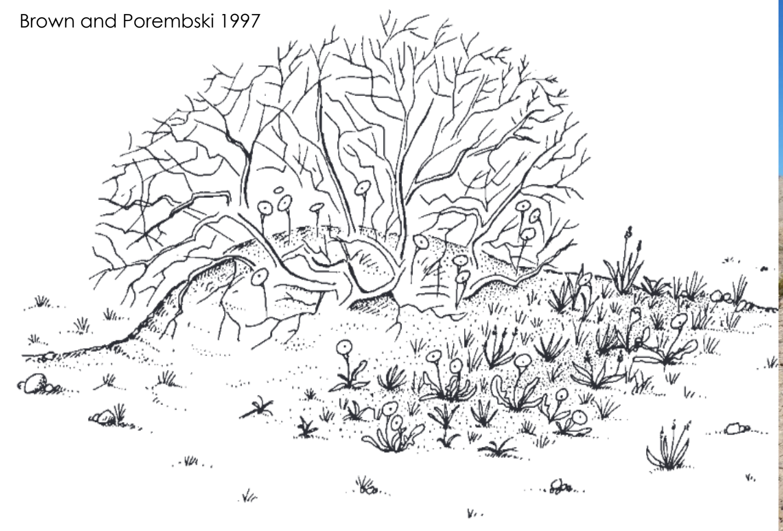
Scott R. Abella[1,2], Lindsay P. Chiquoine[1]

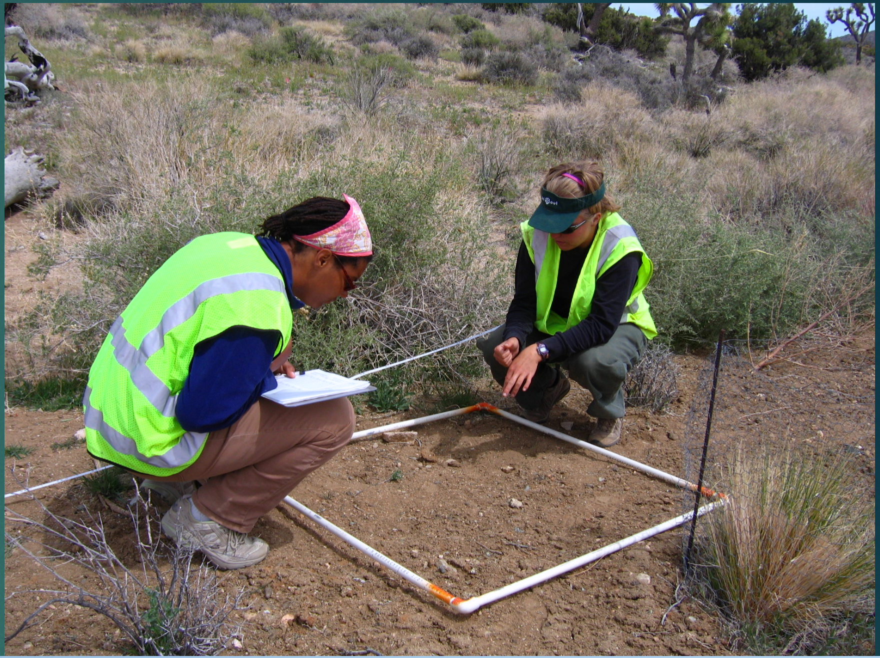
Organisms interact with each other along a spectrum ranging from competition to facilitation. A theme in restoration ecology is tipping the balance of these interactions to favor desired species and site conditions, exemplified by restoring fertile islands and their nurse plant effects to encourage plant recruitment. We tested the effectiveness of outplanting nursery-grown native perennials and vertical mulching (placing dead plant material upright in soil) for stimulating annual plant recruitment in a disturbed Mojave Desert shrubland in Joshua Tree National Park, California, U.S.A. Over 9 years, differences in annual species richness and cover between interspaces and below outplants and vertical mulch varied among years, potentially via inter-annual fluctuations in precipitation or maturation of restoration sites. In the ninth year, which was the wettest, both native and non-native cover averaged 3× higher
non-native annual plants more consistentl
did native annuals. However, these restora
disturbed plots that received outplanting s
By facilitating both non-native and native
for restoration. Treatments reducing non-
facilitative plant interactions in favor of n

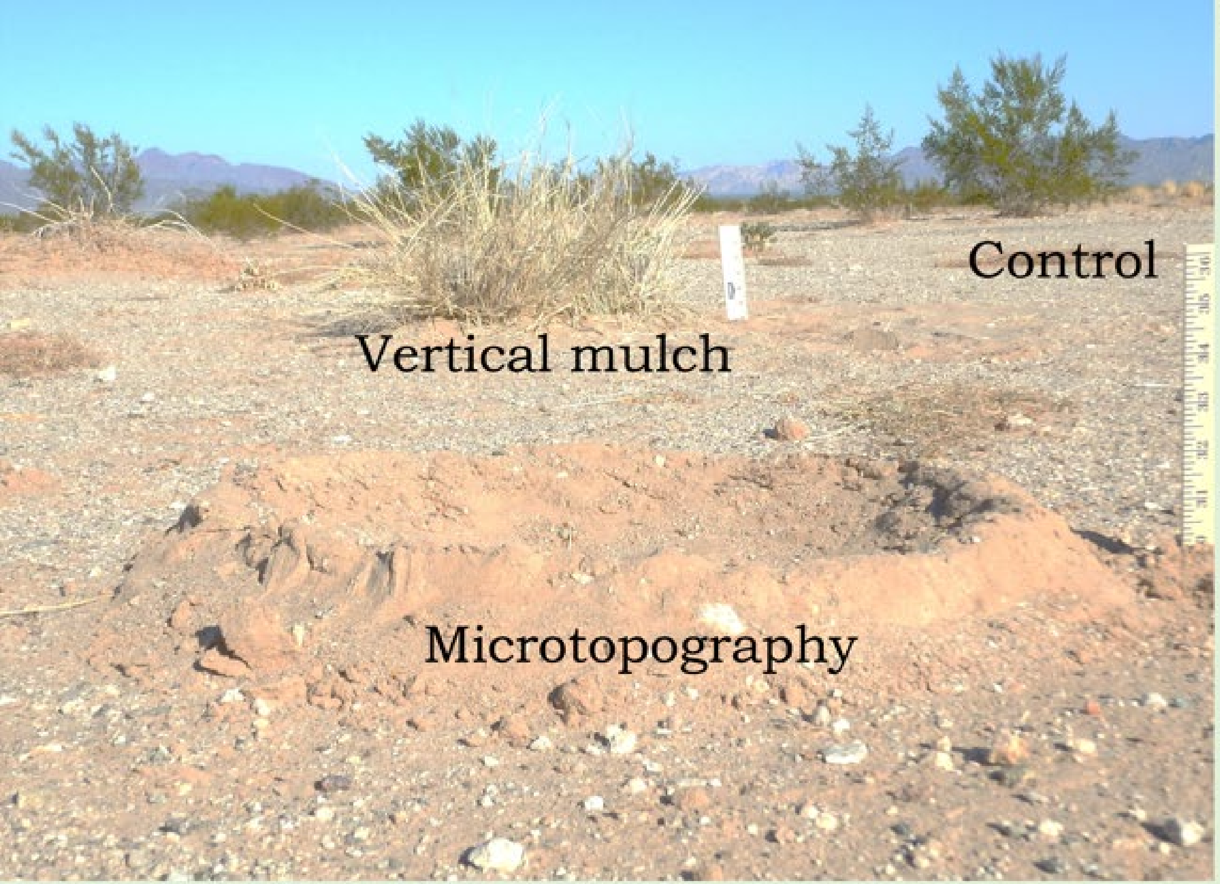
Can abiotic structures serve as surrogates for live plants?

Interchangeability, proportional success treatment(s), bet-hedging approach

Lower cost, take advantage of rare conditions for recruitment, functions







Experimental factors

Abiotic treatments
- Control (no treatment)
- Microtopography
- Vertical mulch

Outplanting treatments
- No planting
- Planting *Pleuraphis rigida*, *Bebbia juncea*, *Hymenoclea salsola*

Sites
- N = 4

Years
- 2019
- 2020

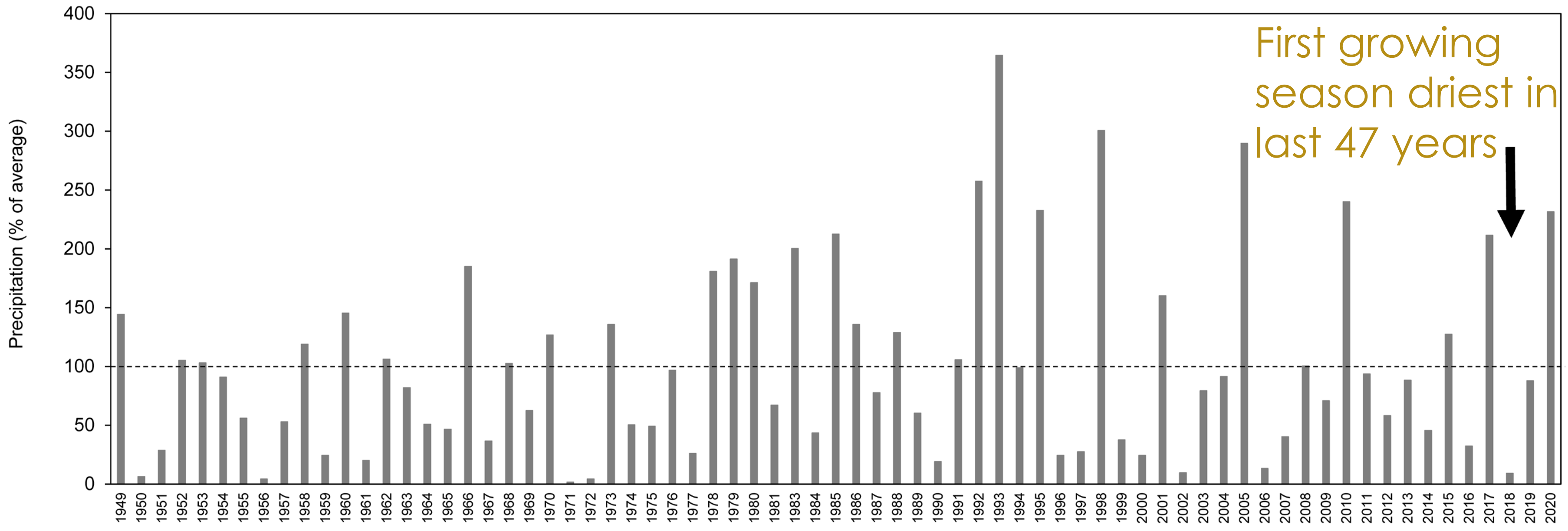
Response variables
- Outplant survival (2019-2020)
- Plant community (2019-2020)
- Soil functions (2019)

Randomized complete block design (4 sites as blocks); each site:
- 6 factorial combinations (3 abiotic × 2 outplanting treatments)
- 4 replicates per combination (0.5 m × 0.5 m quadrats)

Sonoran Desert (Mojave Ecotone) I-10 corridor

I-10 corridor, Palm Springs-Blythe, BLM lands

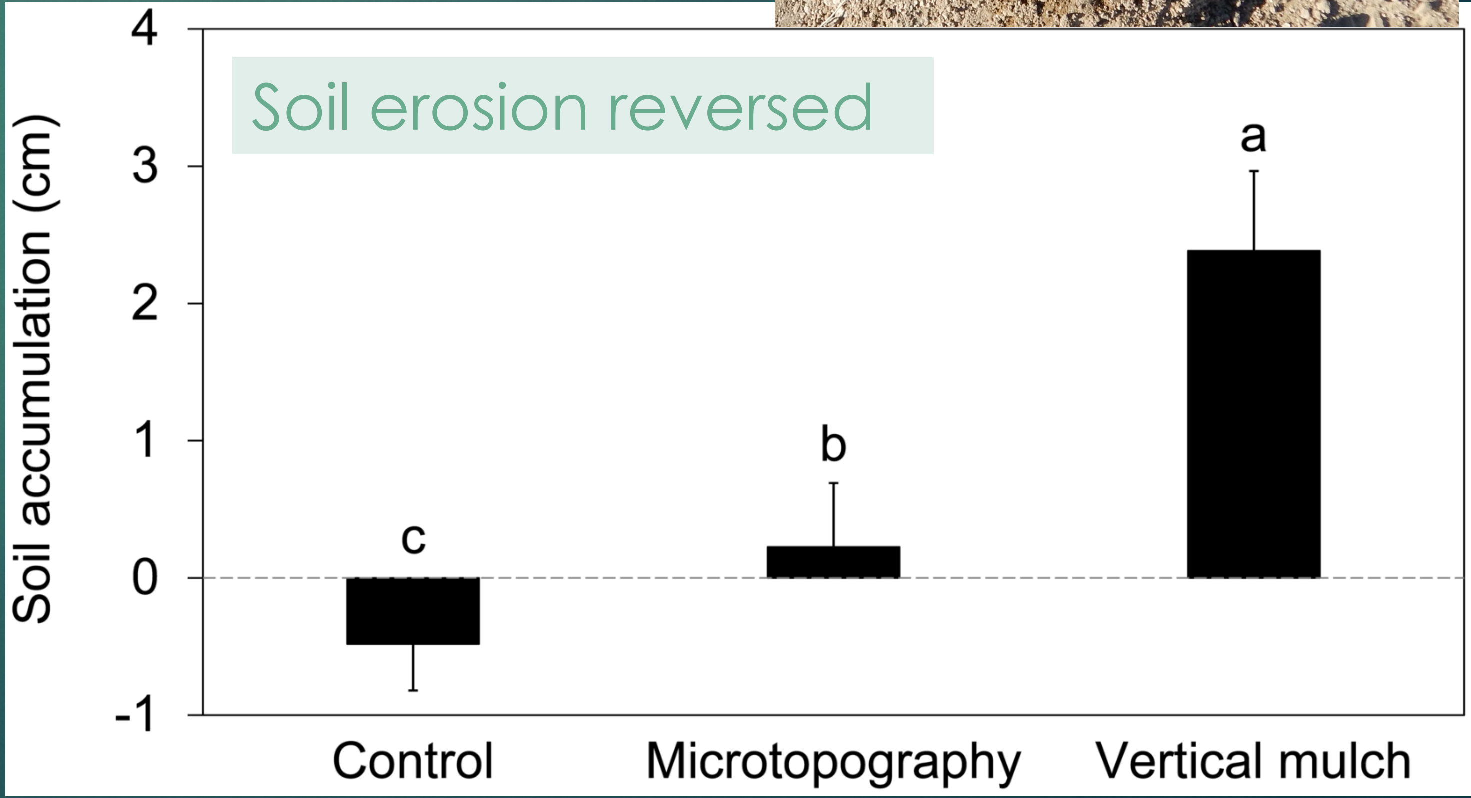
VM was big galleta grass; veg and soil measurements



0/144 outplants alive at 28 months

One component (outplanting) failed, yet other components succeeded to produce overall positive restoration outcome

Shrub seedling cover increased within abiotic treatments, remarkable during record drought



Salvaging topsoil, perennials, and biocrust for ecosystem restoration

Journal of Arid Environments 115 (2015) 44–52

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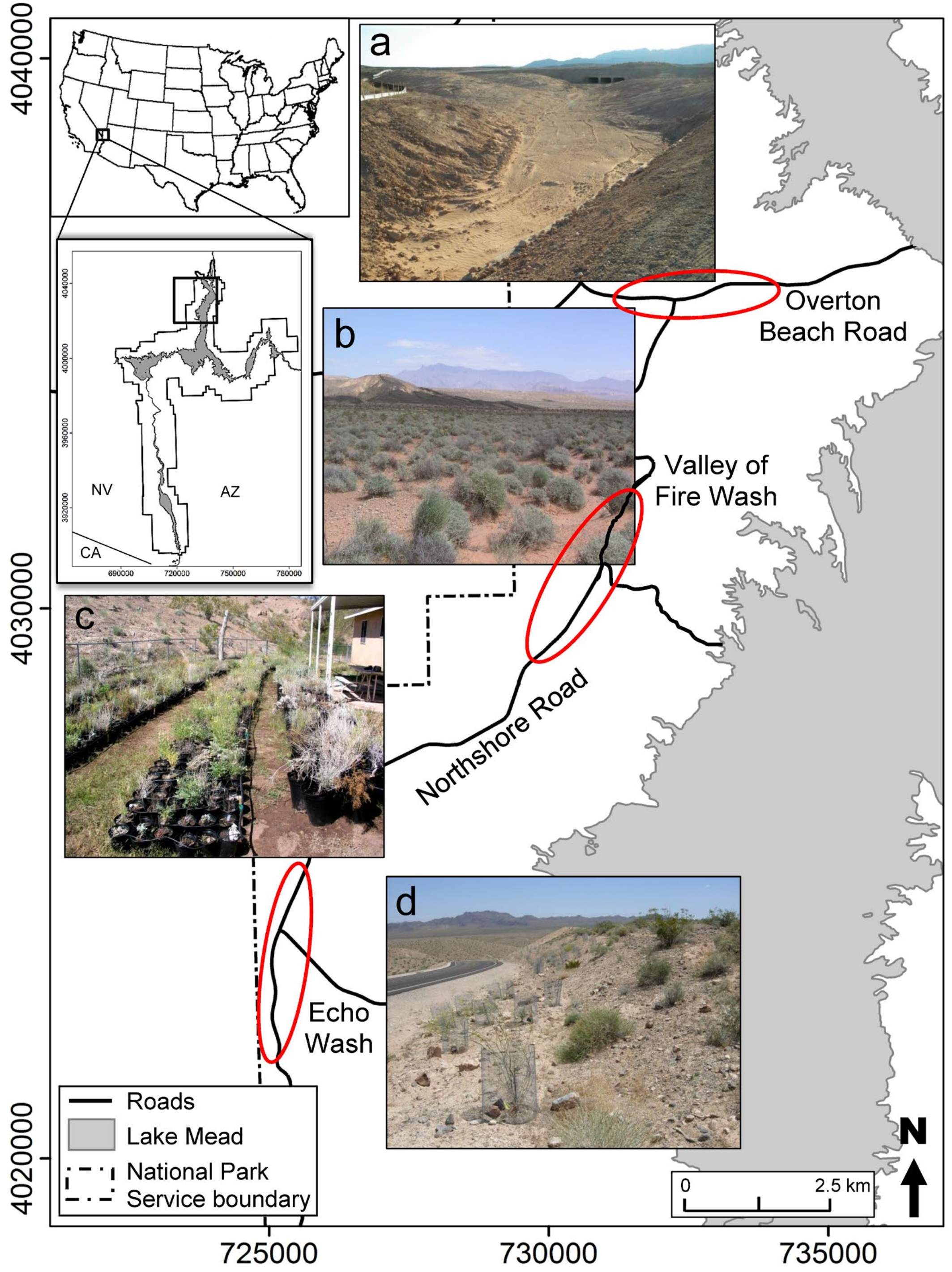
journal homepage: www.elsevier.com/locate/jaridenv

Restoring a desert ecosystem using soil salvage, revegetation, and irrigation

Scott R. Abella [a,*], Lindsay P. Chiquoine [b], Alice C. Newton [c], Cheryl H. Vanier [b]

Events and their timing during a desert restoration experiment in Lake Mead National Recreation Area, Mojave Desert.

Events	Timing	Description
Salvage + treatments	Oct 2008	Plants salvaged, treated with IBA, slurry, or water
Construction	Nov 2008–Dec 2009	Old road removed, site re-contoured
Salvage nursery care	Oct 2008–Jan 2010	Plants reside in pots with drip irrigation
Final salvage assessment	Nov 2009	Plant survival assessed after 12 mo of nursery care
Topsoil application	Dec 2009–Jan 2010	Stockpiled topsoil applied to old roadbed
Planting + treatments	Jan 2010	Salvaged plants installed in field; irrigation started
Field planting assessment	Mar 2010, 2011, 2012	Plant survival after 3, 15, and 27 mo in field



Salvaging topsoil, perennials, and biocrust for ecosystem restoration

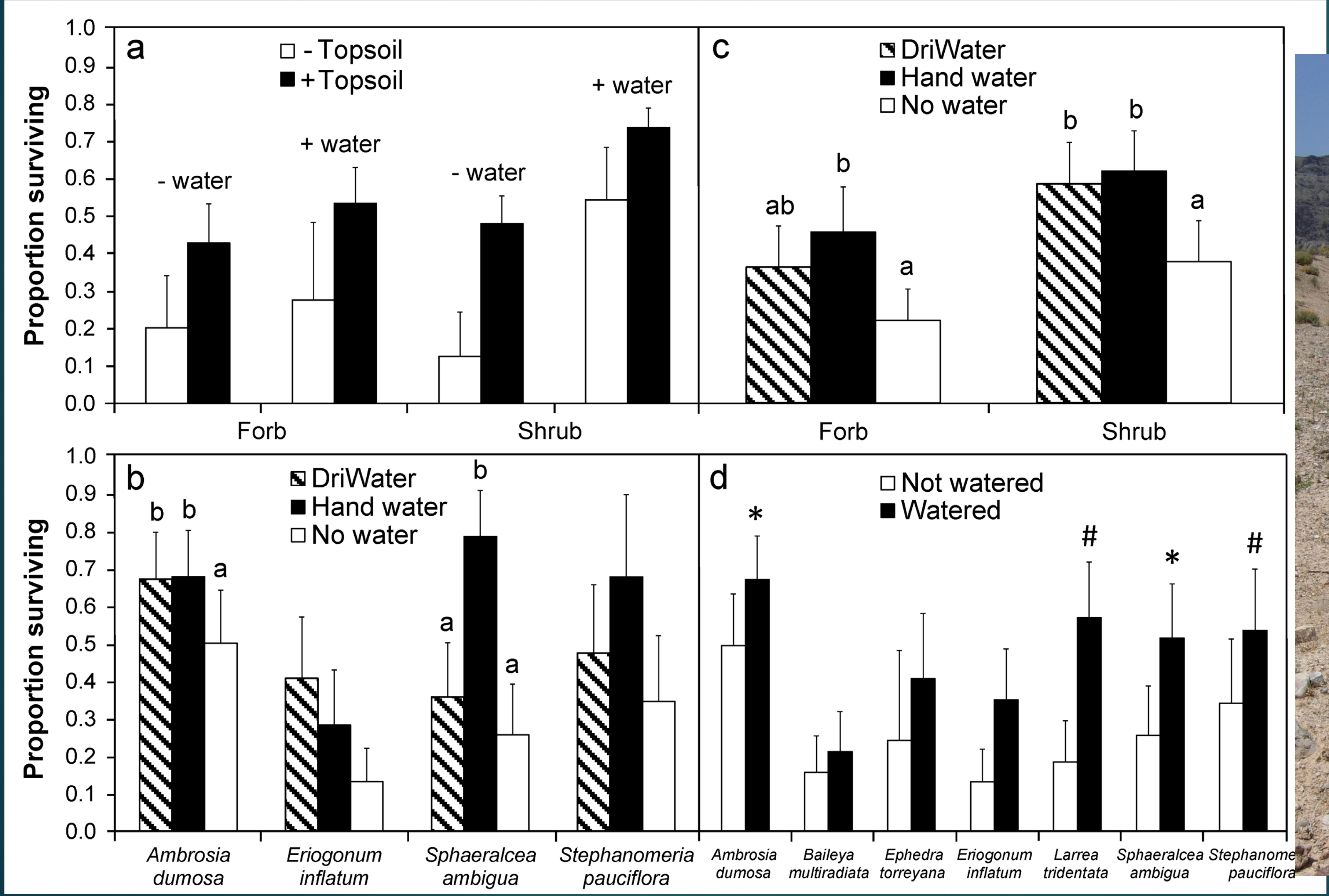
Species selection (23 species) and topsoil were drivers

Best performers

Species	Salvage Survival % (95% CI[a])	Salvage Plants (no.)	Field Survival % (95% CI)	Field Plants (no.)	Survival (Tot. %)
Cactus					
Ferocactus cylindraceus	100 (100–100)	5	100 (100–100)	5	100
Opuntia acanthocarpa	86 (57–100)	7	67 (33–100)	6	57
Opuntia basilaris	100 (100–100)	103	93 (88–97)	103	92
Sclerocactus johnsonii	100 (100–100)	8	100 (100–100)	8	100
Grass					
Pleuraphis rigida	41 (31–53)	75	14 (3–28)	29	5
Forb					
Astragalus preussii	33 (23–43)	91	3 (0–9)	33	1
Baileya multiradiata	38 (31–46)	160	30 (21–39)	104	19
Enceliopsis argophylla	24 (15–35)	74	17 (0–39)	18	4
Eriogonum inflatum	28 (22–33)	280	27 (18–36)	89	9
Gutierrezia sarothrae	50 (13–88)	8	25 (0–75)	4	13
Sphaeralcea ambigua	61 (53–68)	136	50 (40–60)	105	38
Stephanomeria pauciflora	42 (32–51)	98	47 (35–60)	55	27
Suaeda moquinii	26 (17–35)	98	50 (31–69)	26	13
Shrub					
Acacia greggii	19 (0–38)	16	0 (0–0)	3	0
Ambrosia dumosa	68 (64–72)	475	60 (55–65)	360	45
Atriplex confertifolia	84 (72–97)	32	54 (36–71)	28	47
Atriplex hymenelytra	59 (41–74)	27	47 (24–71)	17	30
Encelia virginensis	67 (44–89)	18	36 (14–57)	14	28
Ephedra torreyana	15 (10–20)	147	36 (18–55)	22	28
Hymenoclea salsola	72 (55–90)	29	19 (5–38)	21	14
Isocoma acradenia	52 (32–72)	25	38 (13–63)	16	24
Larrea tridentata	48 (41–55)	154	53 (43–64)	73	25
Psorothamnus fremontii	40 (21–51)	39	14 (0–36)	14	5

Salvaging topsoil, perennials, and biocrust for ecosystem restoration

Irrigation and irrigation type was secondary factor



Salvaging biocrust for ecosystem restoration

Salvaging and transplanting to facilitate biocrust restoration

Rapidly restoring biological soil crusts and ecosystem functions in a severely disturbed desert ecosystem

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Abstract. Restoring biological soil crusts (biocrusts) in degraded drylands can contribute to recovery of ecosystem functions that have global implications, including erosion resistance and nutrient cycling. To examine techniques for restoring biocrusts, we conducted a replicated, factorial experiment on recently abandoned road surfaces by applying biocrust inoculation (salvaged and stored dry for two years), salvaged topsoil, an abiotic soil amendment (wood shavings), and planting of a dominant perennial shrub (*Ambrosia dumosa*). Eighteen months after treatments, we measured biocrust abundance and species composition, soil chlorophyll *a* content and fertility, and soil resistance to erosion. Biocrust addition significantly accelerated biocrust recovery on disturbed soils, including increasing lichen and moss cover and cyanobacteria colonization. Compared to undisturbed controls, inoculated plots had similar lichen and moss composition, recovered 43% of total cyanobacteria density, had similar soil chlorophyll content, and exhibited recovery of soil fertility and soil stability. Inoculation was the only treatment that generated lichen and moss cover. Topsoil application resulted in partial recovery of the cyanobacteria community and soil properties. Compared to untreated disturbed plots, topsoil application without inoculum increased cyanobacteria density by 186% and moderately improved soil chlorophyll and ammonium content and soil stability. Topsoil application produced 22% and 51% of the cyanobacteria density g^{-1} soil compared to undisturbed and inoculated plots, respectively. Plots not treated with either topsoil or inoculum had significantly lower cyanobacteria density, soil chlorophyll and ammonium concentrations, and significantly higher soil nitrate concentration. Wood shavings and *Ambrosia* had no influence on biocrust lichen and moss species recovery but did affect cyanobacteria composition and soil fertility. Inoculation of severely disturbed soil with native biocrusts rapidly restored biocrust communities and soil stability such that restored areas were similar to undisturbed desert within three years. Using salvaged biocrust as inoculum can be an effective tool in ecological restoration because of its efficacy and simple implementation. Although salvaging biocrust material can be technically difficult and potentially costly, utilizing opportunities to salvage material in planned future disturbance can provide additional land management tools.

Key words: Biocrust; cyanobacteria; dryland; inoculation; Mojave Desert; restoration; soil fertility; soil stability.

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- Opportunistic harvesting of source material for restoration and research
- Biocrust restoration is still a young field of research
- Still developing adequate methods for biocrust restoration

Salvaging biocrust for ecosystem restoration

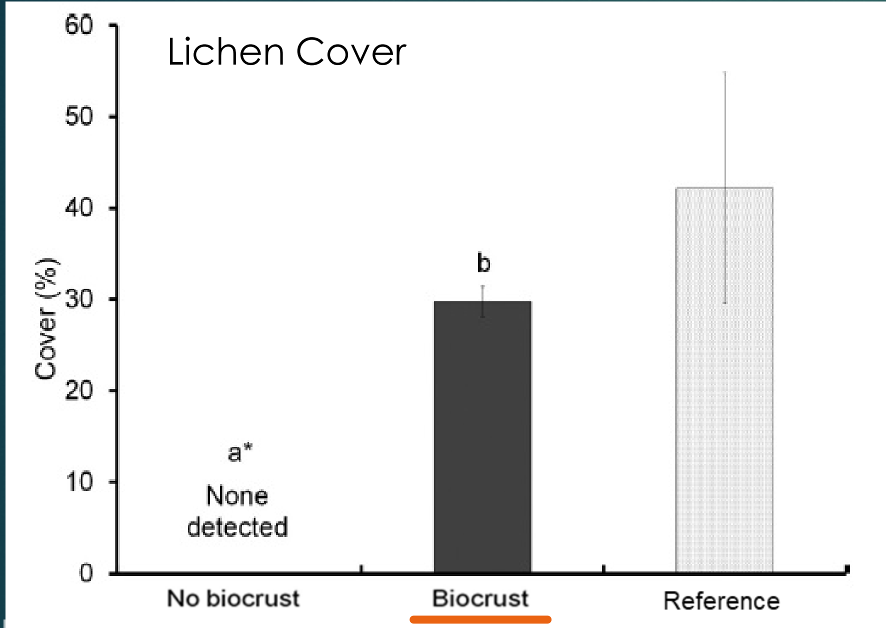
Salvaging and transplanting to facilitate biocrust restoration

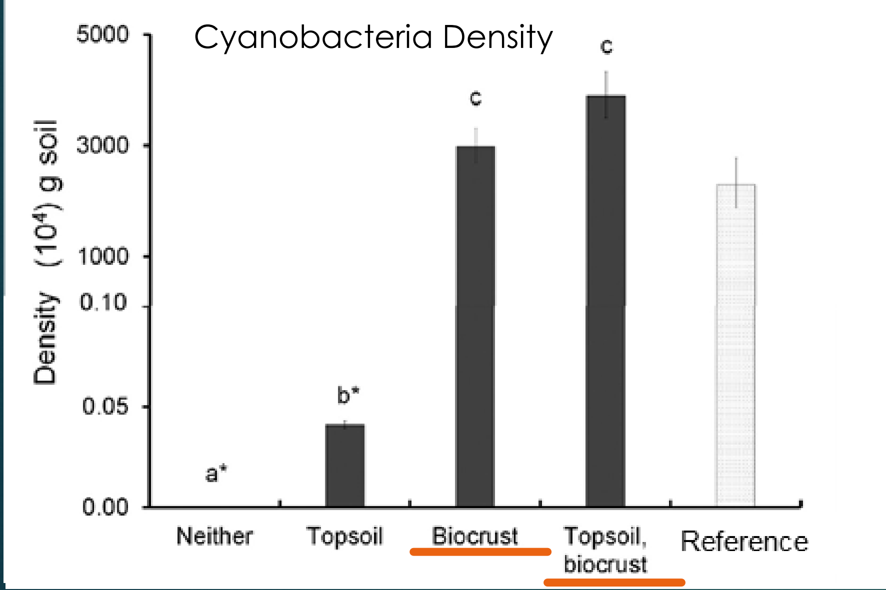
- No topsoil/no biocrust
- Topsoil
- No topsoil with biocrust inoculation
- Topsoil with biocrust inoculation

- Lake Mead National Recreation Area
- Gypsum soils
- Salvaged biocrust
- Inoculation two years later
- Topsoil × biocrust

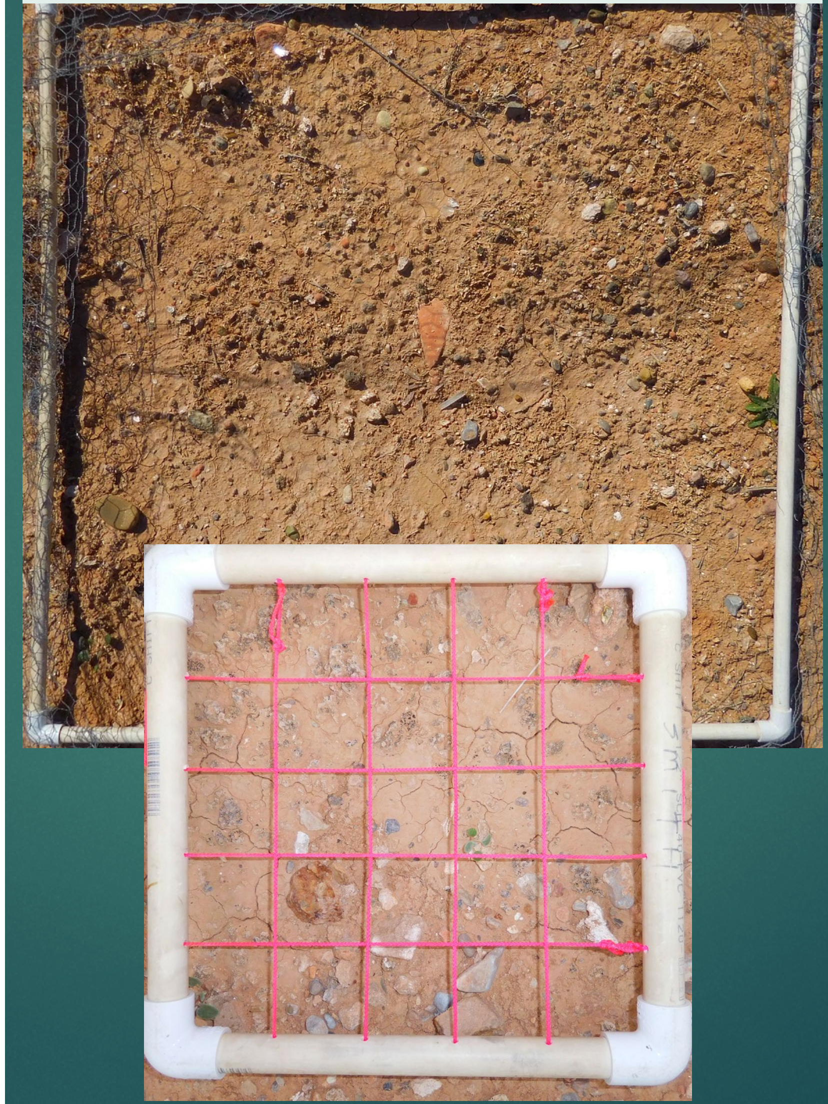
Salvaging biocrust for ecosystem restoration

Inoculated plots comparable to reference





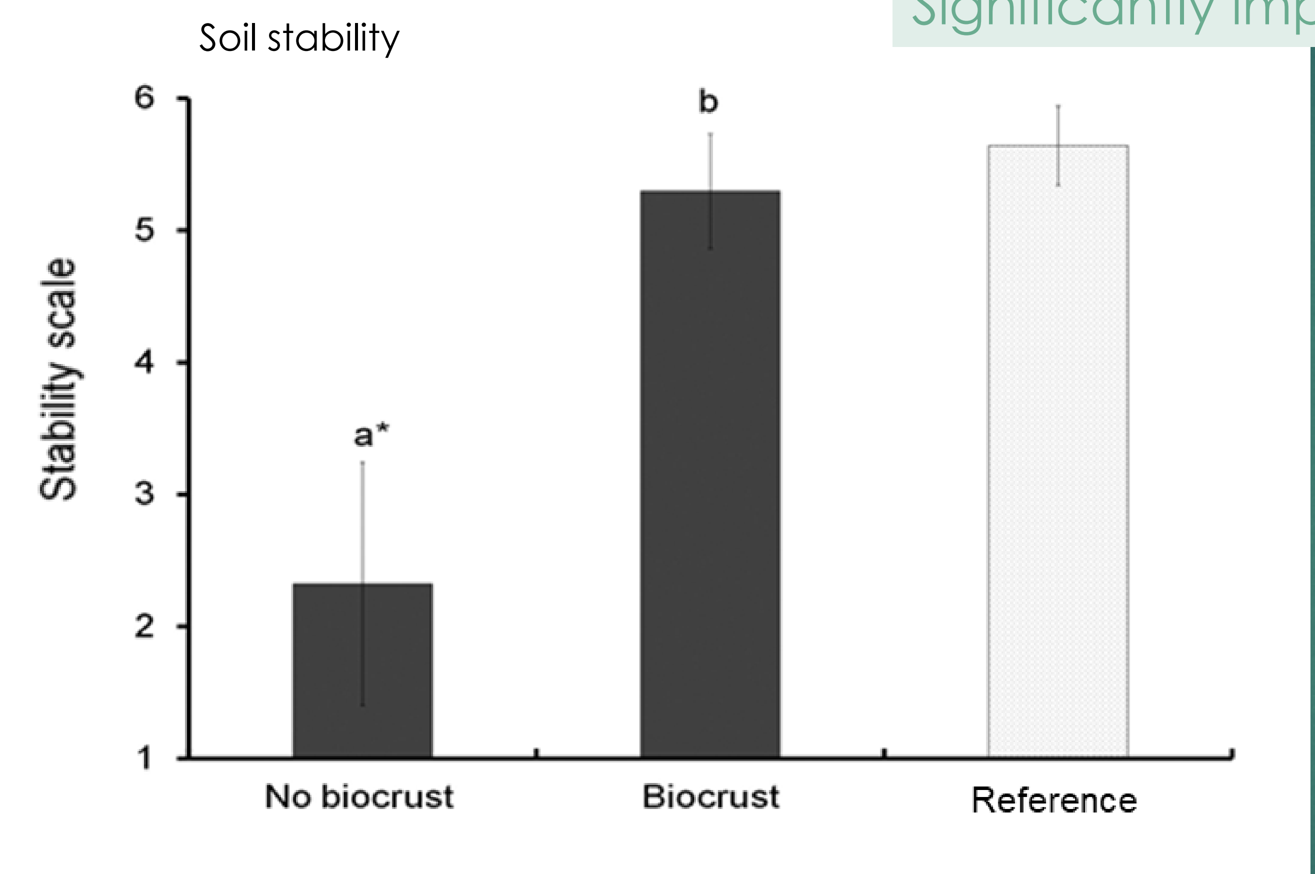
Inoculated



Reference

Salvaging biocrust for ecosystem restoration

Inoculated plots comparable to reference



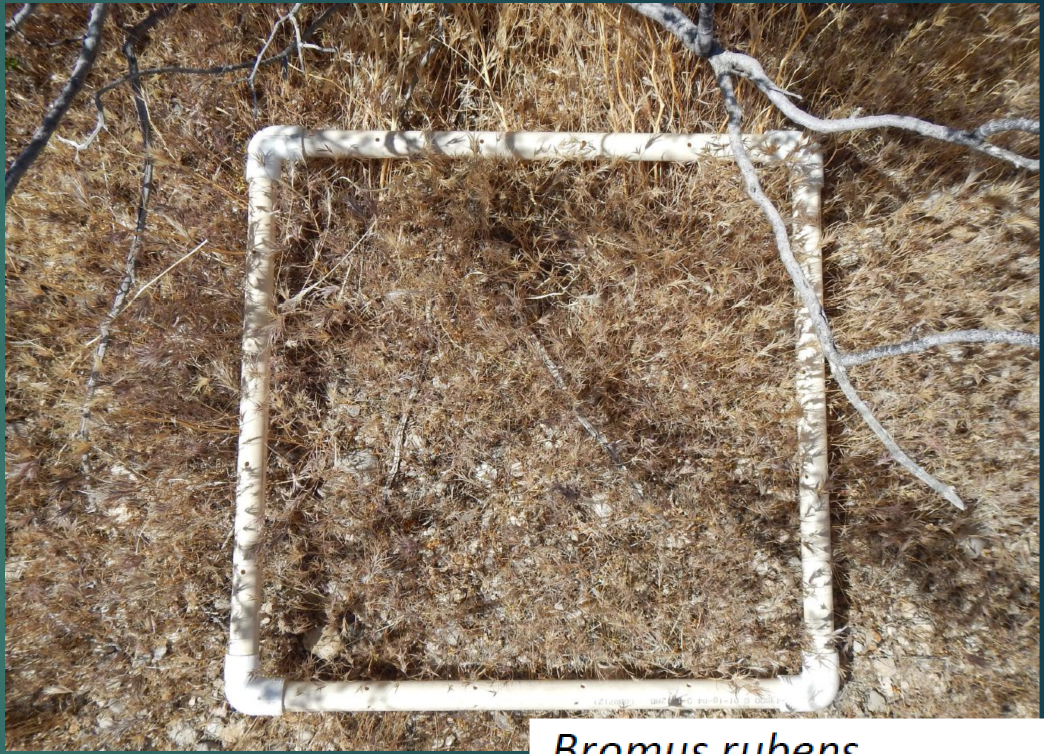
Significantly improved soil stability with inoculation

Demonstrates significance of reintroducing specific biocrust components

Field Guide to Estimating Red Brome Fuel Loads and Fire Risk

Use fast, easy measure (cover) to estimate red brome fuel loads (biomass)

3 Mojave Desert sites and across years varying in precipitation



Part of field guide

Bromus rubens
Cover: 62.5%
Biomass: 236.2 g m^{-2}

Quadrat is 0.5 m × 0.5 m (#20)

Cover–biomass relationships of an invasive annual grass, *Bromus rubens*, in the Mojave Desert

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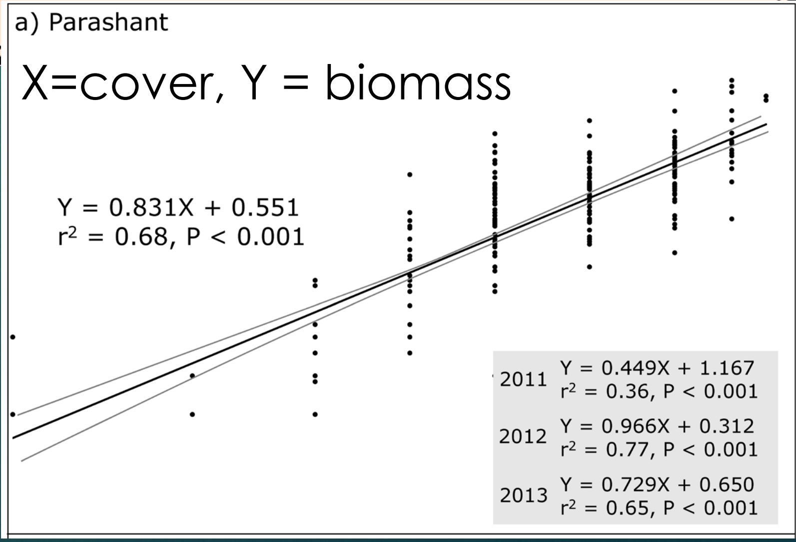
Abstract

Estimates of plant biomass are helpful for many applications in invasive plant science and management, but measuring biomass can be time-consuming, costly, or impractical if destructive sampling is inappropriate. The objective of this study was to assess feasibility of developing regression equations using a fast, nondestructive measure (cover) to estimate aboveground biomass for red brome (*Bromus rubens* L.), a widespread nonnative annual grass in the Mojave Desert, USA. At three study sites, including one measured for three consecutive years, *B. rubens* cover spanned 0.1% to 85% and aboveground biomass 1 to 321 g m^{-2}. In log_{10}-transformed linear regressions, *B. rubens* cover accounted for 68% to 96% of the variance in *B. rubens* biomass among sites, with all coefficients of determination significant at $P < 0.05$. For every doubling of percent cover, biomass was predicted to increase by 78%, 83%, and 144% among the three sites. At the site measured for three consecutive years, which ranged in rainfall from 65% to 159% of the long-term average, regression slopes each year differed from other years. Regression results among sites were insensitive to using cover classes (10 classes encompassing 0% to 100% cover) compared with simulated random distribution of integer cover within classes. Biomass of *B. rubens* was amenable to estimation in the field using cover, and such estimates may have applications for modeling invasive annual plant fuel loads and ecosystem carbon storage.

Management Implications

By altering biomass structure, invasion of nonnative grasses has changed fuels and fire behavior in drylands. Modeling fuels and many other features of nonnative plants requires estimates of biomass, which can be time-consuming or infeasible to measure directly. As an alternative, this study developed regression equations to estimate biomass from the rapid, nondestructive measure of plant cover for *Bromus rubens* (red brome), a pervasive, nonnative annual grass in the Mojave Desert, USA. For every doubling of *B. rubens* cover, predicted *B. rubens* biomass increased by 78% to 144% among sites. In applying the equations to estimate fire-risk thresholds of hazardous fuels using cover, a provisional threshold of 100 g m^{-2} of *B. rubens* biomass required for fire spread was exceeded at 19%, 25%, and 45% *B. rubens* cover among sites. The equations, and suggested refinements in future work, may be helpful for rapidly estimating fuel loads and assessing effectiveness of invasive plant management, including levels required to keep fuels below wildfire spread risk thresholds. Accompanying the equations, a photographic guide showing cover classes and their associated biomass is provided.



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