Using Native Annual Plant Species to Suppress Weedy Invasives in Post-Fire Habitats

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Master's Thesis

Presentation Roadmap

- Introduction
- Methods
- Results
- Discussion
- Management considerations
- Future research

Introduction

Introduction – Wildfire in the West

- Fires are becoming more frequent in Western North America (60)
- Historically, fires have been a common element of Western landscapes (61)
- Invasive annuals like *Bromus tectorum* increase the frequency of fire (60)
- Initial post-fire restoration is an important practice

Introduction – Historic Post-Fire Rehabilitation

- Prevent loss of soil and soil productivity (48)
- Species used haven't taken into account long-term effects on ecosystem dynamics (47)
- Crested wheatgrass, Siberian wheatgrass, and alfalfa have been used extensively in the west (47)
- Resulting communities hinder native plant regeneration (8,58,33)

Introduction – Shifting Paradigm

- Seed mixes with exotic perennials have been shown to be insufficient for dealing with exotic species (4,18)
- Current methods are changing to using more native species (11,55)
- Social values, shifts in policies, and advancements in ecological knowledge are responsible (25,21,49)

Introduction – Natural Community Assembly

- Native species are a good start
- The desire to establish a later-seral plant community may skip important ruderal feedbacks
- Intense fires can negatively affect plant and soil communities (40)

Introduction – Natural Community Assembly

- After these disturbances, pioneer or ruderal species typically establish first (5,2,59,41,27)
- Annuals have dominated initial post-fire period in piñon-juniper ecosystems (31,14,51)
- Perennials follow after pioneer and ruderal species (3,56)

Introduction – Annual & Perennial Plants in Early Seral Conditions

- Establishing perennials in post-fire settings may be tempting but may not be the best choice
- Studies have shown that later-seral species perform poorly in early-seral soils (26,34)
- Post-fire soils can be high in nitrogen (64)
- Annual species perform better than perennial species in high nitrogen conditions (56,3,42)

Introduction – Increasing Trend of Exotic Annuals

- Increasingly, *B. tectorum* is establishing in post-fire settings instead of native annuals (63,64,39,12,24)
- This could be due to a number of factors , including altered fire regimes (28)
- It is possible that altered fire regimes may be responsible for destroying native annual seed supplies

Introduction – Case for Native Annuals

- Native annuals have been indicated as a potential means to combat *B. tectorum* (61)
- Native annuals have similar growth forms and phenology which could make them effective competitors for soil resources (9)
- They may act as a cover crop to compete for light resources (44)

Introduction – Case for Native Annuals

- Native annuals may also provide a foundation for successional management and ecologically based invasive plant management (32)
- Native annuals may accelerate succession by (61):
  - Stabilizing soil
  - Increasing soil organic matter
  - Enriching soil nutrients
  - Competitively excluding less desirable pioneer species

Hypotheses

- H1 – native annual species will provide a better match for post-burn sites than the commonly planted perennial species and thus provide better initial plant cover
- H2 – the native annual species will be superior competitors with exotic annual species and would thus result in reduced cover of exotic annuals

Methods

Methods - Sites

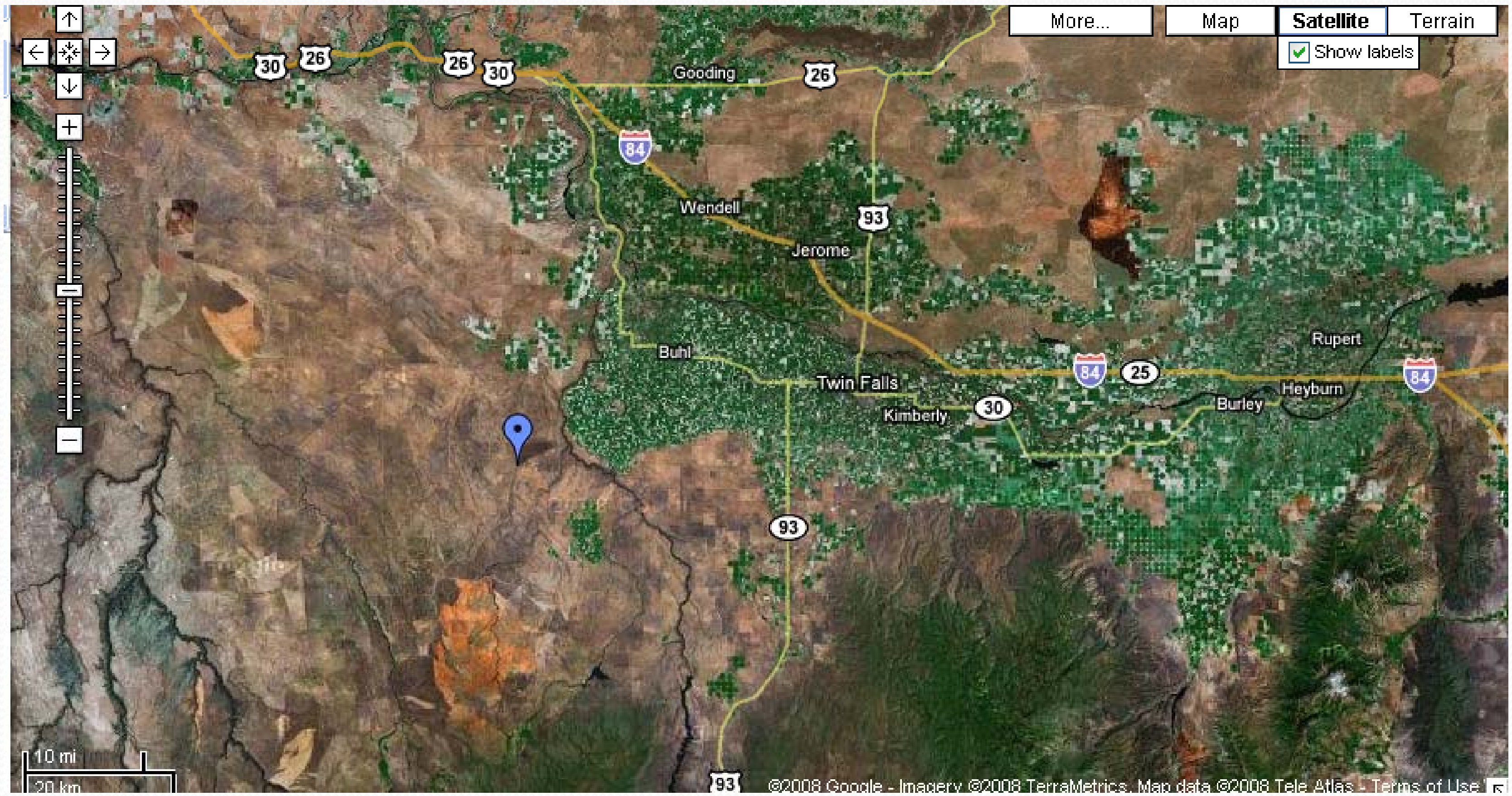
- Field study at four separate sites
- Sites were selected based on:
  - How recently they burned
  - Within close proximity to an existing population of *B. tectorum*
  - It was an area where land managers were concerned about post-fire invasion of *B. tectorum*
- A welded-wire fence was installed at each site in spring 2008 to prevent grazing by livestock

Methods – Sites: Craters

SE Idaho (43º 10’45.73” N, 113º 29’54.46” W)

Methods – Sites: Twin Falls

SE Idaho, southwest of Twin Falls (42º 27’45.74” N, 115º 01’14.4” W)



Methods – Sites: Dinosaur

NW Colorado (40º 10'22.5" N, 108º 56'34.6" W)

Methods – Sites: DeBeque

NW Colorado, along I-70 (39º 17’46’636” N, 108º 56’34.6” W)

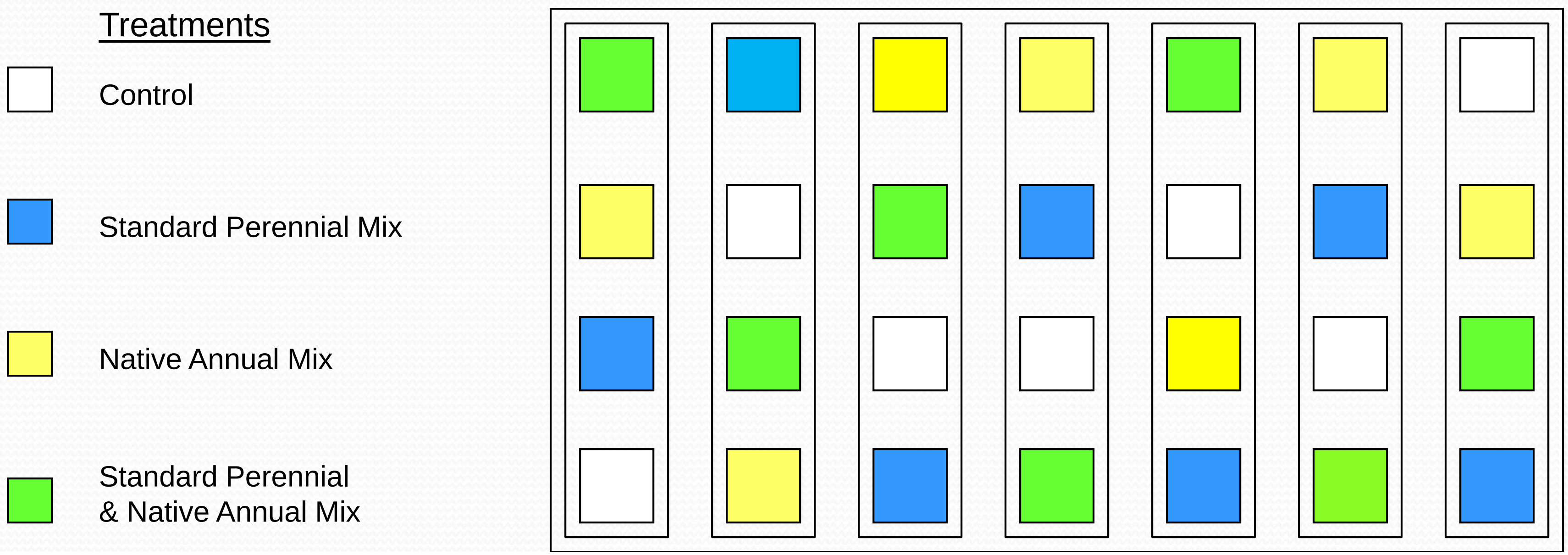
Methods - Sites

Table 1. Characteristics of the four field sites used in this study. Habitat, historic climate, and soil information are from: Soil Survey Staff, NRCS (2009).

Site	Fire	Habitat Type	Precip. (mm.)	Temp. (°C)	Soils
Craters, ID	Bear Den Butte	Basin big sagebrush/Bluebunch wheatgrass	35-40	7-10	Loamy-skeletal, mixed, superactive, mesic Calciargidic Argixerolls
Twin Falls, ID	Murphy Complex	Basin big sage/Bluebunch wheatgrass – Thurber's needlgrass	25-30	8-10	Loamy, mixed, mesic, shallow Xerollic Durargids
Dinosaur, CO	Steuwe	Piñon-Juniper	25-30	6-8	Fine-loamy, mixed Borollic Haplargids
DeBeque, CO	Pyramid	Piñon-Juniper	25-30	8-11	Fine-loamy, mixed, mesic Ustollic Natrargids

Methods – Experimental Design

- Randomized complete block design
- Each site contained seven blocks with four treatment plots
- Each treatment plot was 2- x 2- meters



Methods – Experimental Design

- Seeding treatments and rates:

Table 2. Species seeded in Native Annual treatment (1) and Perennial treatment (2); the combination seed treatment (3) used all species listed at a combined rate. Seeding rates are represented as Pure Live Seeds per square meter.

Seed Mix	Scientific name	Common name	PLS m^{-2}
Native Annual	Amaranthus retroflexus	Redroot amaranth	78
	Cleome serrulata	Rocky Mountain bee-plant	65
	Coreopsis tinctoria	Golden tickseed	78
	Helianthus annuus	Annual sunflower	65
	Verbena bracteata	Big bract verbena	65
	Aristida purpurea	Purple three-awn	39
	Vulpia microstachys	Small fescue	130
	Vulpia octaflora	Six-weeks fescue	130
Native Perennial	Balsamorhiza sagitatta	Arrowleaf balsamroot	84.5
	Eriogonum umbellatum	Sulfur-flower buckwheat	97.5
	Oenothera pallida	Pale evening primrose	52
	Sphaeralcea munroana	Munro's globemallow	84.5
	Achnatherum hymenoides	Indian ricegrass	65
	Elymus elemoides	squirreltail	58.5
	Elymus lanceolatus	Thickspike wheatgrass	71.5
	Pascopyrum smithii	Western wheatgrass	58.5
	Pseudoroegnaria spicata	Bluebunch wheatgrass	78

Methods – Experimental Design

- Treatment plots were prepared by raking with a leaf rake to remove debris and then followed with a garden rake to prepare the seedbed
- Seeds were hand broadcast and then lightly raked to incorporate
- Removed debris and *B. tectorum* duff was pooled at each site and added to their respective plots to ensure exotic annual seed would be present so the hypotheses could be tested

Methods – Experimental Design

- Each plot was rolled with a water-filled lawn roller to firm up the seedbed and reduce loss of seed to wind
- Precipitation was monitored at each site
- Idaho sites were below the 30 year average
- A volume of water was added to provide an additional centimeter of water to each plot one time only during May, 2008

Methods – Seedbank Analysis

- Before treatments were applied soil cores were taken from each plot within a block at each site
- Resulting in 8 samples per block that were pooled to be representative of that block
- Soil samples were cold stratified for 16 weeks at 5°C

Methods – Seedbank Analysis

- Half of each block's soil sample was spread onto a mixture of sand and Fafard™ Superfine Germination Mix potting soil in a growth flat (26.7cm x 53cm)
- Growth flats were place on top of heat pads (24°C) to improve germination
- Flats were watered as needed
- Germinating plants were collected and identified as possible
- Germinated plants were counted to calculate density in the seedbank (# of germs. of a species divided by the 0.8m^2 cross-sectional area sampled)

Methods – Sampling and Data Collection

- Data collection occurred during May of 2008 & 2009
- Percent cover by species was measured
- Number of individuals of seeded species was counted in each plot
- Comparing cover estimates allowed us to test each of the hypotheses
- Counts of seeded species yielded densities that were used to track seeding success and evaluate potential treatment effects

Methods – Statistical Analysis

- Each site was analyzed separately by year
- Total plant cover, exotic annual cover, native perennial cover, seeded annual cover, and seeded perennial cover were analyzed
- SAS™ 9.2 was used to analyze data at $\alpha=0.05$
- Block effects were present and subsequently accounted for

Methods – Statistical Analysis

- Variables were square-root transformed to meet normality requirements
- All comparisons were made with a mixed effects model using repeated measures
- Mean comparisons were made by looking at the differences of the least square means between treatments

Methods – Statistical Analysis

- Linear regressions using Pearson's R-values were used to determine if any variables were significantly related ($p<0.05$) to reduced *B. tectorum* and/or exotic annual cover
- Regressions were performed on:
  - 2008 & 2009 separately, sites pooled
  - 2008 & 2009 separately, sites separately
  - 2008 & 2009 pooled, sites pooled
  - 2008 & 2009 pooled, sites separately
- These regressions examined all possible correlations between every measured variable

Results

Results – Seedbank Study

- Number of species:
  - Craters: 2 Twin Falls: 2 Dinosaur: 9 DeBeque: 7

Table 3. Species germinated from seedbank samples (collected at study sites) to determine species composition and the number of individuals per m^{-2}

Site	Species	# Germ.	Density
Craters	unidentified forb species	1	1.25
	unidentified forb species	1	1.25
Twin Falls	unidentified forb species	3	3.75
	unidentified forb species	1	1.25
Dinosaur	*Bromus tectorum*	44	55
	Vulpia octoflora	7	8.75
	Sisymbrium altissimum	6	7.5
	Plantago patagonica	1	1.25
	Alyssum parviflorum	1	1.25
	unidentified forb species	1	1.25
	unidentified forb species	1	1.25
	unidentified forb species	1	1.25
	unidentified forb species	1	1.25
DeBeque	*Bromus tectorum*	1	1.25
	Vulpia octoflora	2	2.5
	Oenothera pallida	1	1.25
	Descurania pinnata	2	2.5
	unidentified forb species	1	1.25
	unidentified forb species	1	1.25
	unidentified forb species	1	1.25

Note: Density is: # germ. / $(0.2m^2*4)$

Results - Craters

- There were no differences between treatments observed during 2008
- In 2009, there was significantly less exotic annual cover in the perennial treatments compared to the control

Table 4. Mean (standard error) percent total plant cover, relative exotic annual cover, relative native perennial cover, relative seeded annual cover, and relative seeded perennial cover in the four seeding treatments at each site for 2008 and 2009. Lowercase letters represent significant differences (p<0.05) within sampling years.

	Treatment	Craters		Twin Falls		Dinosaur		DeBeque	
		2008	2009	2008	2009	2008	2009	2008	2009
Total Plant Cover	Annual	38.90 (4.55)	65.65 (4.73)	33.28 (3.06)	59.50 (3.21)	71.90 (2.04)	71.37 (3.62)**a**	44.61 (4.92)**a**	58.09 (4.99)**a**
	Perennial	40.02 (5.16)	70.76 (3.04)	42.41 (2.94)	68.17 (5.41)	72.48 (3.10)	85.51 (4.15)**b**	32.96 (3.54)**b**	81.72 (2.37)**b**
	Mixed	35.32 (3.30)	63.24 (3.09)	41.58 (4.04)	61.19 (3.82)	72.69 (3.21)	77.87 (2.63)**ab**	42.60 (4.45)**ab**	64.94 (3.93)**a**
	Control	38.66 (5.47)	73.35 (3.51)	37.33 (5.75)	66.49 (5.46)	68.07 (3.51)	83.16 (3.12)**b**	45.16 (4.88)**a**	81.58 (4.24)**b**
Exotic Annuals	Annual	2.00 (0.91)	5.81 (1.35)**ab**	13.11 (3.78)	31.23 (5.72)**a**	63.36 (2.47)	59.32 (3.57)**a**	30.89 (6.01)**a**	59.32 (4.81)**a**
	Perennial	2.02 (0.83)	3.71 (1.36)**a**	13.81 (4.24)	26.41 (7.24)**a**	66.18 (2.91)	78.02 (1.67)**b**	28.94 (3.36)**a**	78.02 (2.49)**b**
	Mixed	2.60 (0.67)	3.58 (1.48)**ab**	5.81 (2.20)	10.96 (3.93)**b**	64.87 (4.31)	70.58 (3.18)**b**	31.82 (3.71)**ab**	70.58 (4.57)**ab**
	Control	4.02 (1.03)	12.16 (5.34)**b**	13.27 (4.37)	26.13 (4.92)**a**	59.64 (5.52)	70.20 (3.82)**b**	42.86 (5.33)**b**	70.20 (4.10)**b**
Native Perennials	Annual	26.58 (4.22)	55.51 (6.66)	2.91 (1.42)	9.58 (4.85)	5.27 (1.36)	10.87 (3.35)	0.00 (0.00)	0.07 (0.07)
	Perennial	30.12 (4.89)	60.36 (5.99)	5.73 (2.27)	12.22 (4.74)	3.52 (0.83)	6.22 (1.73)	2.38 (0.61)**a**	0. 30 (0.15)
	Mixed	24.38 (3.26)	53.64 (4.59)	11.33 (4.61)	18.65 (7.19)	3.05 (1.19)	6.77 (2.36)	0.75 (0.22)**b**	0.67 (0.05)
	Control	26.99 (5.73)	50.27 (5.05)	2.89 (1.22)	9.58 (3.76)	5.22 (1.59)	11.53 (0.30)	0.00 (0.00)	0.00 (0.00)
Seeded Annuals	Annual	2.76 (0.91)**a**	0.37 (0.25)	0.44 (0.29)**a**	0.37 (0.15)**a**	0.96 (0.40)**a**	0.22 (0.10)	11.86 (1.49)**a**	0.52 (0.20)
	Perennial	0.53 (0.31)**bc**	1.19 (0.46)	0.00 (0.00)**b**	0.00 (0.00)**b**	0.00 (0.00)**b**	0.00 (0.00)	0.37 (0.25)**b**	0.89 (0.48)
	Mixed	1.19 (0.33)**ab**	1.34 (0.74)	0.07 (0.07)**ab**	0.52 (0.25)**a**	0.82 (0.85)**a**	0.00 (0.00)	9.29 (1.92)**a**	0.37 (0.15)
	Control	0.30 (0.22)**c**	0.37 (0.15)	0.00 (0.00)**b**	0.07 (0.07)**ab**	0.07 (0.07)**b**	0.00 (0.00)	0.22 (0.15)**b**	0.29 (0.29)
Seeded Perennials	Annual	2.97 (1.54)	4.10 (0.72)	0.60 (0.60)	1.12 (1.03)	0.74 (0.49)	1.41 (1.17)	0.00 (0.00)**a**	0.07 (0.07)**ab**
	Perennial	1.85 (0.58)	4.16 (1.18)	0.75 (0.58)	1.64 (1.39)	1.05 (0.51)	2.47 (1.65)	2.38 (0.61)**c**	0.30 (0.15)**ab**
	Mixed	2.54 (0.99)	3.72 (1.17)	0.45 (0.37)	0.45 (0.45)	1.12 (0.80)	2.45 (1.29)	0.75 (0.22)**b**	0.67 (0.50)**b**
	Control	2.90 (0.87)	5.23 (1.81)	1.27 (0.91)	2.70 (2.37)	0.97 (0.50)	4.18 (3.19)	0.00 (0.00)**a**	0.00 (0.00)**a**

Results – Twin Falls

- There were no treatment differences in 2008
- In 2009, exotic annual cover was significantly lower in the mixed seeding treatment compared to all other treatments

- Note: High winds during treatment application may have influenced results at this site due to seeds lost

Table 4. Mean (standard error) percent total plant cover, relative exotic annual cover, relative native perennial cover, relative seeded annual cover, and relative seeded perennial cover in the four seeding treatments at each site for 2008 and 2009. Lowercase letters represent significant differences (p<0.05) within sampling years.

	Treatment	Craters		Twin Falls		Dinosaur		DeBeque	
		2008	2009	2008	2009	2008	2009	2008	2009
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	Perennial	40.02 (5.16)	70.76 (3.04)	42.41 (2.94)	68.17 (5.41)	72.48 (3.10)	85.51 (4.15)**b**	32.96 (3.54)**b**	81.72 (2.37)**b**
	Mixed	35.32 (3.30)	63.24 (3.09)	41.58 (4.04)	61.19 (3.82)	72.69 (3.21)	77.87 (2.63)**ab**	42.60 (4.45)**ab**	64.94 (3.93)**a**
	Control	38.66 (5.47)	73.35 (3.51)	37.33 (5.75)	66.49 (5.46)	68.07 (3.51)	83.16 (3.12)**b**	45.16 (4.88)**a**	81.58 (4.24)**b**
Exotic Annuals	Annual	2.00 (0.91)	5.81 (1.35)**ab**	13.11 (3.78)	31.23 (5.72)**a**	63.36 (2.47)	59.32 (3.57)**a**	30.89 (6.01)**a**	59.32 (4.81)**a**
	Perennial	2.02 (0.83)	3.71 (1.36)**a**	13.81 (4.24)	26.41 (7.24)**a**	66.18 (2.91)	78.02 (1.67)**b**	28.94 (3.36)**a**	78.02 (2.49)**b**
	Mixed	2.60 (0.67)	3.58 (1.48)**ab**	5.81 (2.20)	10.96 (3.93)**b**	64.87 (4.31)	70.58 (3.18)**b**	31.82 (3.71)**ab**	70.58 (4.57)**ab**
	Control	4.02 (1.03)	12.16 (5.34)**b**	13.27 (4.37)	26.13 (4.92)**a**	59.64 (5.52)	70.20 (3.82)**b**	42.86 (5.33)**b**	70.20 (4.10)**b**
Native Perennials	Annual	26.58 (4.22)	55.51 (6.66)	2.91 (1.42)	9.58 (4.85)	5.27 (1.36)	10.87 (3.35)	0.00 (0.00)	0.07 (0.07)
	Perennial	30.12 (4.89)	60.36 (5.99)	5.73 (2.27)	12.22 (4.74)	3.52 (0.83)	6.22 (1.73)	2.38 (0.61)**a**	0. 30 (0.15)
	Mixed	24.38 (3.26)	53.64 (4.59)	11.33 (4.61)	18.65 (7.19)	3.05 (1.19)	6.77 (2.36)	0.75 (0.22)**b**	0.67 (0.05)
	Control	26.99 (5.73)	50.27 (5.05)	2.89 (1.22)	9.58 (3.76)	5.22 (1.59)	11.53 (0.30)	0.00 (0.00)	0.00 (0.00)
Seeded Annuals	Annual	2.76 (0.91)**a**	0.37 (0.25)	0.44 (0.29)**a**	0.37 (0.15)**a**	0.96 (0.40)**a**	0.22 (0.10)	11.86 (1.49)**a**	0.52 (0.20)
	Perennial	0.53 (0.31)**bc**	1.19 (0.46)	0.00 (0.00)**b**	0.00 (0.00)**b**	0.00 (0.00)**b**	0.00 (0.00)	0.37 (0.25)**b**	0.89 (0.48)
	Mixed	1.19 (0.33)**ab**	1.34 (0.74)	0.07 (0.07)**ab**	0.52 (0.25)**a**	0.82 (0.85)**a**	0.00 (0.00)	9.29 (1.92)**a**	0.37 (0.15)
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Seeded Perennials	Annual	2.97 (1.54)	4.10 (0.72)	0.60 (0.60)	1.12 (1.03)	0.74 (0.49)	1.41 (1.17)	0.00 (0.00)**a**	0.07 (0.07)**ab**
	Perennial	1.85 (0.58)	4.16 (1.18)	0.75 (0.58)	1.64 (1.39)	1.05 (0.51)	2.47 (1.65)	2.38 (0.61)**c**	0.30 (0.15)**ab**
	Mixed	2.54 (0.99)	3.72 (1.17)	0.45 (0.37)	0.45 (0.45)	1.12 (0.80)	2.45 (1.29)	0.75 (0.22)**b**	0.67 (0.50)**b**
	Control	2.90 (0.87)	5.23 (1.81)	1.27 (0.91)	2.70 (2.37)	0.97 (0.50)	4.18 (3.19)	0.00 (0.00)**a**	0.00 (0.00)**a**

Results - Dinosaur

- This site had the highest levels of total plant cover, also of exotic annuals
- There were no treatment differences observed during 2008
- In 2009 there was significantly less total plant cover in the native annual treatment, compared to the perennial and control treatments
- Also in 2009, there was significantly less exotic annual cover in the annual treatment, compared to all other treatments
- There were slight negative correlations at this site between native annual forb cover and *B. tectorum* (R^2=-0.28, $p<0.0001$) and native annual forb cover and exotic annual cover (R^2=-0.21, $p=0.0004$)

Table 4. Mean (standard error) percent total plant cover, relative exotic annual cover, relative native perennial cover, relative seeded annual cover, and relative seeded perennial cover in the four seeding treatments at each site for 2008 and 2009. Lowercase letters represent significant differences (p<0.05) within sampling years.

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	Perennial	40.02 (5.16)	70.76 (3.04)	42.41 (2.94)	68.17 (5.41)	72.48 (3.10)	85.51 (4.15)**b**	32.96 (3.54)**b**	81.72 (2.37)**b**
	Mixed	35.32 (3.30)	63.24 (3.09)	41.58 (4.04)	61.19 (3.82)	72.69 (3.21)	77.87 (2.63)**ab**	42.60 (4.45)**ab**	64.94 (3.93)**a**
	Control	38.66 (5.47)	73.35 (3.51)	37.33 (5.75)	66.49 (5.46)	68.07 (3.51)	83.16 (3.12)**b**	45.16 (4.88)**a**	81.58 (4.24)**b**
Exotic Annuals	Annual	2.00 (0.91)	5.81 (1.35)**ab**	13.11 (3.78)	31.23 (5.72)**a**	63.36 (2.47)	59.32 (3.57)**a**	30.89 (6.01)**a**	59.32 (4.81)**a**
	Perennial	2.02 (0.83)	3.71 (1.36)**a**	13.81 (4.24)	26.41 (7.24)**a**	66.18 (2.91)	78.02 (1.67)**b**	28.94 (3.36)**a**	78.02 (2.49)**b**
	Mixed	2.60 (0.67)	3.58 (1.48)**ab**	5.81 (2.20)	10.96 (3.93)**b**	64.87 (4.31)	70.58 (3.18)**b**	31.82 (3.71)**ab**	70.58 (4.57)**ab**
	Control	4.02 (1.03)	12.16 (5.34)**b**	13.27 (4.37)	26.13 (4.92)**a**	59.64 (5.52)	70.20 (3.82)**b**	42.86 (5.33)**b**	70.20 (4.10)**b**
Native Perennials	Annual	26.58 (4.22)	55.51 (6.66)	2.91 (1.42)	9.58 (4.85)	5.27 (1.36)	10.87 (3.35)	0.00 (0.00)	0.07 (0.07)
	Perennial	30.12 (4.89)	60.36 (5.99)	5.73 (2.27)	12.22 (4.74)	3.52 (0.83)	6.22 (1.73)	2.38 (0.61)**a**	0. 30 (0.15)
	Mixed	24.38 (3.26)	53.64 (4.59)	11.33 (4.61)	18.65 (7.19)	3.05 (1.19)	6.77 (2.36)	0.75 (0.22)**b**	0.67 (0.05)
	Control	26.99 (5.73)	50.27 (5.05)	2.89 (1.22)	9.58 (3.76)	5.22 (1.59)	11.53 (0.30)	0.00 (0.00)	0.00 (0.00)
Seeded Annuals	Annual	2.76 (0.91)**a**	0.37 (0.25)	0.44 (0.29)**a**	0.37 (0.15)**a**	0.96 (0.40)**a**	0.22 (0.10)	11.86 (1.49)**a**	0.52 (0.20)
	Perennial	0.53 (0.31)**bc**	1.19 (0.46)	0.00 (0.00)**b**	0.00 (0.00)**b**	0.00 (0.00)**b**	0.00 (0.00)	0.37 (0.25)**b**	0.89 (0.48)
	Mixed	1.19 (0.33)**ab**	1.34 (0.74)	0.07 (0.07)**ab**	0.52 (0.25)**a**	0.82 (0.85)**a**	0.00 (0.00)	9.29 (1.92)**a**	0.37 (0.15)
	Control	0.30 (0.22)**c**	0.37 (0.15)	0.00 (0.00)**b**	0.07 (0.07)**ab**	0.07 (0.07)**b**	0.00 (0.00)	0.22 (0.15)**b**	0.29 (0.29)
Seeded Perennials	Annual	2.97 (1.54)	4.10 (0.72)	0.60 (0.60)	1.12 (1.03)	0.74 (0.49)	1.41 (1.17)	0.00 (0.00)**a**	0.07 (0.07)**ab**
	Perennial	1.85 (0.58)	4.16 (1.18)	0.75 (0.58)	1.64 (1.39)	1.05 (0.51)	2.47 (1.65)	2.38 (0.61)**c**	0.30 (0.15)**ab**
	Mixed	2.54 (0.99)	3.72 (1.17)	0.45 (0.37)	0.45 (0.45)	1.12 (0.80)	2.45 (1.29)	0.75 (0.22)**b**	0.67 (0.50)**b**
	Control	2.90 (0.87)	5.23 (1.81)	1.27 (0.91)	2.70 (2.37)	0.97 (0.50)	4.18 (3.19)	0.00 (0.00)**a**	0.00 (0.00)**a**

Results - DeBeque

- In 2008, there was significantly less exotic annual cover in the native annual treatment compared to the control
- Also in 2008, there was significantly greater total plant cover in the native annual treatment compared to the perennial treatment
- In 2009, there was significantly less exotic annual cover in the native annual treatment compared to the perennial and control treatments
- Also in 2009, there was significantly less total plant cover in the native annual treatment compared to the perennial treatment
- At this site there was a weak negative correlation between seeded species cover and exotic annual cover ($R^2=-0.29$, $p<0.0001$)

Table 4. Mean (standard error) percent total plant cover, relative exotic annual cover, relative native perennial cover, relative seeded annual cover, and relative seeded perennial cover in the four seeding treatments at each site for 2008 and 2009. Lowercase letters represent significant differences ($p<0.05$) within sampling years.

	Treatment	Craters		Twin Falls		Dinosaur		DeBeque	
		2008	2009	2008	2009	2008	2009	2008	2009
Total Plant Cover	Annual	38.90 (4.55)	65.65 (4.73)	33.28 (3.06)	59.50 (3.21)	71.90 (2.04)	71.37 (3.62)**a**	44.61 (4.92)**a**	58.09 (4.99)**a**
	Perennial	40.02 (5.16)	70.76 (3.04)	42.41 (2.94)	68.17 (5.41)	72.48 (3.10)	85.51 (4.15)**b**	32.96 (3.54)**b**	81.72 (2.37)**b**
	Mixed	35.32 (3.30)	63.24 (3.09)	41.58 (4.04)	61.19 (3.82)	72.69 (3.21)	77.87 (2.63)**ab**	42.60 (4.45)**ab**	64.94 (3.93)**a**
	Control	38.66 (5.47)	73.35 (3.51)	37.33 (5.75)	66.49 (5.46)	68.07 (3.51)	83.16 (3.12)**b**	45.16 (4.88)**a**	81.58 (4.24)**b**
Exotic Annuals	Annual	2.00 (0.91)	5.81 (1.35)**ab**	13.11 (3.78)	31.23 (5.72)**a**	63.36 (2.47)	59.32 (3.57)**a**	30.89 (6.01)**a**	59.32 (4.81)**a**
	Perennial	2.02 (0.83)	3.71 (1.36)**a**	13.81 (4.24)	26.41 (7.24)**a**	66.18 (2.91)	78.02 (1.67)**b**	28.94 (3.36)**a**	78.02 (2.49)**b**
	Mixed	2.60 (0.67)	3.58 (1.48)**ab**	5.81 (2.20)	10.96 (3.93)**b**	64.87 (4.31)	70.58 (3.18)**b**	31.82 (3.71)**ab**	70.58 (4.57)**ab**
	Control	4.02 (1.03)	12.16 (5.34)**b**	13.27 (4.37)	26.13 (4.92)**a**	59.64 (5.52)	70.20 (3.82)**b**	42.86 (5.33)**b**	70.20 (4.10)**b**
Native Perennials	Annual	26.58 (4.22)	55.51 (6.66)	2.91 (1.42)	9.58 (4.85)	5.27 (1.36)	10.87 (3.35)	0.00 (0.00)	0.07 (0.07)
	Perennial	30.12 (4.89)	60.36 (5.99)	5.73 (2.27)	12.22 (4.74)	3.52 (0.83)	6.22 (1.73)	2.38 (0.61)**a**	0. 30 (0.15)
	Mixed	24.38 (3.26)	53.64 (4.59)	11.33 (4.61)	18.65 (7.19)	3.05 (1.19)	6.77 (2.36)	0.75 (0.22)**b**	0.67 (0.05)
	Control	26.99 (5.73)	50.27 (5.05)	2.89 (1.22)	9.58 (3.76)	5.22 (1.59)	11.53 (0.30)	0.00 (0.00)	0.00 (0.00)
Seeded Annuals	Annual	2.76 (0.91)**a**	0.37 (0.25)	0.44 (0.29)**a**	0.37 (0.15)**a**	0.96 (0.40)**a**	0.22 (0.10)	11.86 (1.49)**a**	0.52 (0.20)
	Perennial	0.53 (0.31)**bc**	1.19 (0.46)	0.00 (0.00)**b**	0.00 (0.00)**b**	0.00 (0.00)**b**	0.00 (0.00)	0.37 (0.25)**b**	0.89 (0.48)
	Mixed	1.19 (0.33)**ab**	1.34 (0.74)	0.07 (0.07)**ab**	0.52 (0.25)**a**	0.82 (0.85)**a**	0.00 (0.00)	9.29 (1.92)**a**	0.37 (0.15)
	Control	0.30 (0.22)**c**	0.37 (0.15)	0.00 (0.00)**b**	0.07 (0.07)**ab**	0.07 (0.07)**b**	0.00 (0.00)	0.22 (0.15)**b**	0.29 (0.29)
Seeded Perennials	Annual	2.97 (1.54)	4.10 (0.72)	0.60 (0.60)	1.12 (1.03)	0.74 (0.49)	1.41 (1.17)	0.00 (0.00)**a**	0.07 (0.07)**ab**
	Perennial	1.85 (0.58)	4.16 (1.18)	0.75 (0.58)	1.64 (1.39)	1.05 (0.51)	2.47 (1.65)	2.38 (0.61)**c**	0.30 (0.15)**ab**
	Mixed	2.54 (0.99)	3.72 (1.17)	0.45 (0.37)	0.45 (0.45)	1.12 (0.80)	2.45 (1.29)	0.75 (0.22)**b**	0.67 (0.50)**b**
	Control	2.90 (0.87)	5.23 (1.81)	1.27 (0.91)	2.70 (2.37)	0.97 (0.50)	4.18 (3.19)	0.00 (0.00)**a**	0.00 (0.00)**a**

Discussion

Discussion – Site Differences

- Each site had unique environmental conditions that likely played a role in the resulting vegetation
- The seedbanks and initial plant assemblages may also help explain the observed results
- Treatment effects at the Idaho sites may not have been discernable due to a lack of exotic annuals
- The Colorado sites had much greater exotic annual cover which could be why we observed significant treatment effects

Discussion – Seedbank Study

- Idaho study sites expressed lower species richness and densities of seeds post-fire
- It is possible that the more severe fires at these sites were responsible for the depauperate seedbanks
- The Colorado study sites expressed higher species richness and densities
- Low severity fires have been shown to yield higher native establishment (23)

Discussion – Native Annual Plant Species for Improved Initial Plant Cover (H1)

- Only the DeBeque site (2008) supported this hypothesis
- All other sites showed no significant difference between initial plant cover in native annual and native perennial treatments
- This indicates that the native annual treatment should be just as effective at providing initial plant cover

Discussion – Native Annual Plant Species to Suppress Exotic Annuals (H2)

- 2009 yielded results in support of H2
- Each Colorado site had significantly less exotic annual cover in the native annual treatments
- Linear regression indicated that native annual forbs had a weak correlation with *B. tectorum* (R^2=-0.21, p=0.01) at DeBeque in 2009
- The Dinosaur site had a weak correlation between the density of *Helianthus annuus* and exotic annuals (R^2=-0.28, p=0.02) in 2009

Discussion – H2

- The large native annual forbs (*Cleome & Helianthus*) could have been capable of effectively competing for soil and light resources
- Previous studies (64,45,44) have indicated that annual forbs may be effective competitors with *B. tectorum* for resources
- In addition, during 2009 the DeBeque site showed a significant correlation between exotic annual forbs and *B. tectorum* (R^2=-0.37, p=0.0006)

Discussion – H2

- Annual forb species, native and exotic, obviously played a role in suppressing *B. tectorum*
- Even if the exotic annual forbs were responsible for some suppression of *B. tectorum* there was still significantly less exotic annual cover in the native annual treatments

Discussion – H2

- Another potential factor of the successful native annual treatments at the Colorado sites might be fall flushes of the native annuals
- At the time of sampling in 2009, there were skeletons of *Cleome* and *Helianthus* that were not present during the 2008 sampling timeframe
- Since exotic annuals are capable of fall flushes, the native annual forbs may have presented additional competitive pressure during this timeframe when perennials might not have

Discussion – H2

- Although there is no direct evidence that the native annual grasses played a role in suppressing exotic annuals, they were present and could have been responsible for some level of competition
- The two *Vulpia* species that were used were not as robust as *B. tectorum*

Discussion – H2

- The Idaho sites did not support our second hypothesis
- There was much less exotic annual cover at each Idaho site compared to the Colorado sites
- Even though the Idaho seedbanks had very low species richness there were perennial grasses that survived and resprouted from the root crowns

Discussion – H2

- It is also possible that the post-fire soil conditions at the sites affected the results
- If the soils at the Idaho sites were nutrient poor, the perennial vegetation would have been favored over the annual vegetation
- Conversely, if the soils at the Colorado sites were nutrient rich they may have favored the annuals over the perennials
- This would agree with previous plant community assembly research (56,3,42)

Management Considerations

Management Considerations

- Using native annual species to combat exotic annual species in post-fire habitats represents a unique and promising management approach
- The mixed seeding treatment appeared to have stronger effects against exotic annuals at the Twin Falls site
- The native annual treatment had stronger effects against exotic annuals at the Colorado sites

Management Considerations

- An addition of native annual species, especially native annual forbs, to any post-fire seed mix would be a simple modification and provide more competition for exotic annuals
- Research has indicated that including multiple functional guilds in restoration seed mixes may increase community competitiveness and provide a buffer against exotic plant invasions (6)

Management Considerations

- A limitation to this approach is the lack of commercially available native annual seed
- Using native annual seed in post-fire management may be effective because of their tendency to grow in early-seral conditions and compete with exotic annuals at the phenological level (9)
- An advantage to using native annuals is that they are broadly adapted with broad ranges (2)
- Ruderal annual species, especially forbs, have been shown to have superior establishment success (46,52)

Management Considerations

- Land managers should take into consideration the post-fire soil characteristics
- The native annual treatment may not perform as well in nutrient poor soils
- A landscape scale fire-risk analysis may provide insight as to where nutrients could be cycled or volatilized, based on the fuel model and the atmospheric conditions during a fire

Future Research Needed

Further Research

- There should be further research with the use of native annual forbs
- Native annual grasses should be further investigated as well
- Field or greenhouse studies comparing similar treatments under known soil nutrient conditions could provide valuable insight into the role of soil nutrients and native annual treatment success

Questions???

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