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RESEARCH ARTICLE

Does Seeding After Wildfires in Rangelands Reduce Erosion or Invasive Species?

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Abstract

Mitigation of ecological damage caused by rangeland wildfires has historically been an issue restricted to the western United States. It has focused on conservation of ecosystem function through reducing soil erosion and spread of invasive plants. Effectiveness of mitigation treatments has been debated recently. We reviewed recent literature to conduct a meta-analysis of seeding after wildfires to determine if seedings may (1) protect ecosystems against soil erosion and (2) reduce invasion or abundance of undesirable nonnative plant species. Effectiveness of postfire seedings was examined in 8 erosion and 19 invasive species cases. Seeding has little effect on erosion during the first year after fire and is highly dependent upon initial establishment and coverage of species in successive years. Among all seeding cases, 28% reduced, 67% were neutral, and 5% increased invasive species abundance. Older seedings were more likely to show reductions in invasives than younger seedings. Seedings with high plant establishment were more likely to reduce invasives than those with low establishment. Studies are needed that examine (1) frequency of adequate establishment of postfire seedings and causal factors of success or failure, (2) long-term impacts of seeding along a range of initial establishment and concomitant plant coverage over time as it relates to erosion and abundance of invasive plant species, and (3) auxiliary treatments designed to increase likelihood of germination and establishment given the inevitable variability of environmental conditions. These studies would aid land managers in deciding when postfire treatments are required and their likely level of success.

Key words: **aerial seeding, *Bromus tectorum*, drill seeding, erosion, pinyon-juniper, sagebrush.**

Introduction

Wildfires create disturbances that remove vegetation and litter, making soils vulnerable to both wind and water erosion and leaving gaps within vegetation that are susceptible to invasive species. The level of an ecosystem's resilience determines its ability and length of time to recover from disturbances and to resist invasions, in part depending on an adequate presence of resident species (Peterson et al. 1998). Postfire rangeland landscapes vary considerably in slope, slope length, aspect, soil type, surface roughness, water repellency, burn severity, vegetation cover, and plant height, and receive highly variable precipitation, resulting in a wide range of spatial and temporal susceptibility to both water and wind erosion (Pierson et al. 2002; Sankey et al. 2009) and to colonization, establishment, and dominance of invasive species (Allington et al. 2013).

Burned areas at risk of erosion are often identified as critical areas for revegetation (Robichaud et al. 2000). The amount of time required for a site to recover to prefire levels of water-induced erosion in rangeland systems has been estimated at 3–4 years (Wright et al. 1982; Pierson et al. 2008).

Studies of wind erosion in shrublands have not been conducted for long enough or in enough ecosystems to adequately evaluate recovery times; however, lower erosion rates have been noted within two postfire growing seasons in semiarid communities (Sankey et al. 2009; Miller et al. 2012). Within more mesic grasslands, such as the Great Plains, wind erosion may approach prefire levels within the first growing season (Stout & Zobeck 1998; Vermeire et al. 2005). However, wind erosion is affected by many site-specific factors (e.g. soil type) and can be expected to vary considerably (Wiggs et al. 1995; Whicker et al. 2002).

Recovery of both plant cover and height contributes to lower potential for wind and water erosion after fires in shrublands and grasslands (Zobeck et al. 1989; Whicker et al. 2002; Vermeire et al. 2005; Sankey et al. 2009). Vegetation cover values between 40 and 72% have been cited as being required for erosion to reach prefire levels (Wright et al. 1982; Robichaud et al. 2000; Pierson et al. 2010). Postfire seedings that result in either reduced times to reach these levels or higher maximum cover values than would be obtained without seeding should reduce losses of soil resources.

Introductions of fire-resilient weedy plants have created a new threat to rangeland ecosystems through changes in fire

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frequency (Miller et al. 2011). These species take advantage of the postfire landscape and of ecosystems with lower levels of resistance to invasion (e.g. less productive or sites with available niches for invaders; Chambers et al. 2007; Allington et al. 2013) where reduced native plant density, increased soil nutrients (Rew & Johnson 2010), and increased bare ground are associated with invasive plant establishment and growth (Reisner 2010).

Revegetation as a mitigation after wildfires has become a common practice in the United States, but only recently has it become more frequent in other nations (Bennett et al. 2000; Lamond 2009). These actions have met with various levels of success. Overall effectiveness of postfire seeding has been debated during the last decade (Robichaud et al. 2000; Beyers 2004; Keeley 2006). Reviews of postfire seeding and other stabilization treatment effectiveness on forested lands have been published (Robichaud et al. 2000, Peppin et al. 2010, Robichaud et al. 2010) but to our knowledge no analysis has focused on seeding arid shrublands or grasslands (hereafter called rangelands).

Postfire seedings are typically sown using either drill or aerial methods. Aerial seeding is considered less effective than drill seeding for degraded rangelands (Clary 1988) unless it is followed immediately with a soil disturbance (e.g. dragging a harrow or anchor chain) to allow soil to cover seeds (Monsen & Stevens 2004). However, aerial seeding is often the only option for burned areas with complex topography (e.g. steep slopes or stony soils) or where policies will not allow motorized equipment (e.g. wilderness areas). In these situations, managers may not be able to cover seeds and typically increase seeding rates by 20–100% to compensate for potential seed losses (Monsen & Stevens 2004). In contrast, seed drills facilitate seed burial, soil-to-seed contact, and protection from desiccation and seed predators by opening soil and placing seeds at appropriate depths. Effectiveness of aerial versus drill seeding methods has never been compared across a wide set of rangeland conditions.

The purpose of this study was to institute a systematic review of the literature (Centre for Evidence-based Conservation—Protocol CEE 08-022; http://www.environmentalevidence.org/Documents/Final_protocols/Protocol59.pdf, accessed 10 September 2012) to determine if seeding after wildfires in rangelands helps to (1) protect ecosystems against soil erosion and (2) reduce invasion or abundance of undesirable nonnative plant species (hereafter called invasives).

Methods

This review was conducted using methods described in Pullin & Stewart (2006). We searched for literature on postfire seeding of rangelands worldwide. Literature databases searched included SCOPUS, Dissertation Abstracts, Forest Science, Tree search, Web of Science, Google Scholar, and science.gov.

Search terms within publications included fire or wildfire in combination with seeding, rehabilitation, restoration, revegetation, stabilization, chaining, disking, drilling, invasives, weeds, cheatgrass, medusahead, sagebrush, rangeland, or grassland. The initial pool of potentially relevant articles numbered 1,519. Abstracts of all papers were reviewed. This pool included many papers not directly relevant to our review, including different ecosystems and different issues associated with wildfire (e.g. air pollution or property damage). On the basis of titles and abstracts, 126 potentially relevant papers were reviewed by at least two investigators. Upon further evaluation, some papers either did not pertain to our focal ecosystems or did not address aspects of soil erosion or invasive species. Of those that remained as potential studies, each article was rated for quality of evidence (Table 1). We included only papers that were rated as medium or higher quality that specifically addressed invasives or soil erosion after a postfire seeding. We selected medium quality as an inclusion cutoff to ensure postfire seeding treatments were compared against unseeded controls. Confounding factors that eliminated papers from the analysis included herbicide application, short monitoring periods after seeding (<1 year), and aggregating results for

Table 1. Studies in this review were rated and grouped into these five levels of quality of evidence that are defined by their level of study design and statistical robustness.

Study Design and Statistical Robustness	*Quality of Evidence*
Statistically robust evidence obtained from replicated randomized and controlled experiments with sampling occurring after seeding treatments in areas burned by wildfire, prescribed burn, or slash pile burning	Highest
Unreplicated, controlled, observational, or monitoring report (multiple locations); Before After Control Impact study (BACI) with reliable quantitative data from sampling occurring after seeding treatments in areas burned by wildfire, or prescribed fire; peer-reviewed reviews on postfire seeding	High
Unreplicated, controlled, observational, or monitoring report (single location) with reliable quantitative data	Medium
Unreplicated, uncontrolled, observational, or monitoring report; quantitative data	Low
Unreplicated, uncontrolled, qualitative data; anecdotal observation; expert opinion; or review of postfire seeding (not peer-reviewed with qualitative data)	Lowest

Major study design categories included: replicated randomized experiment, observational (multiple location case study), observational (single location case study), monitoring report with quantitative data, monitoring report with qualitative data, review paper, and expert opinion.

multiple plant communities. For purposes of this review, erosion is defined as loss of soil from a site and invasive plants were species that were not native locally, but once they colonize a site have the potential for dominating that site even if disturbances are removed. An annotated bibliography of the papers used in this document is available as supporting information (Appendix S1).

Statistical analysis of the effect of postfire seeding on erosion was not conducted due to the low number of studies but analysis of invasives was performed by breaking seedings into "cases" within articles. If only one treatment in one location was evaluated in a particular study, that was counted as one case. If two separate treatments were evaluated, these were considered two cases (e.g. both a drill and an aerial seeding conducted on the burned land, but done separately). If multiple treatments used similar techniques (e.g. all seedings were drilled but had minor differences in species mixture), treatments were grouped together into a single case. Each case was scored as significantly reducing, increasing, or having no effect on invasives based on the individual article's definition of significance. We tested the null hypothesis that seeding methods (aerial vs. drill) did not significantly reduce invasive species. We compared two categories: one category combined cases that showed increases in invasives with those that were neutral relative to controls while the other category consisted of those that had significant declines in invasives with seedings. All cases were tallied and included in a two-by-two contingency table and tested using Fisher's exact test (R Development Core Team 2012), which calculates cell probabilities based on row and column totals that were fixed by design.

Results

Nineteen published studies measured abundance of invasive plant species following postfire seeding and eight measured soil erosion. Effects of seeding on postfire erosion in chaparral were summarized by Robichaud et al. (2000) and Beyers (2004); we found no new studies regarding effects of postfire seedings on erosion or invasive species in chaparral published after these two reviews.

Does Seeding Perennial Grasses After Wildfires Reduce Soil Erosion in Rangelands?

Seeding perennial grasses after fire provided mixed results on erosion relative to untreated areas. Seeded species establishment, seeding rate, and seeding application method appear to contribute to effective erosion control. Wright et al. (1982) found reductions in cumulative soil loss on seeded versus unseeded burned watersheds in central Texas; however, burns were conducted in different years and only burn pile scars were seeded, not entire slopes. Brown et al. (1985) found no difference between sediment load on burned and drill-seeded compared to burned-only plots in the first year after seeding. However, they did find increased infiltration rates and less runoff due to surface roughness created by furrows from drill seeding.

In two related studies from Spain, sites were burned and hand-sown the following year with a mixture of grasses and forbs to attain a total seeding rate of 30 g seeds/m^2 (Badía & Martí 2000; Badía et al. 2008). Using rainfall simulators, they demonstrated a reduction in soil erosion during the first growing season after the fire. We compared their seeding rate to those used in the Great Basin area of the United States by converting seed mass to seed numbers using plant characteristic data from the PLANTS database (http://plants.usda.gov, accessed 7 September 2012) for each species. Their seed rate was approximately 35-fold higher (17,000 seeds/m^2) than the highest recommended seed rates for the Great Basin (approximately 225–450 seeds/m^2: Monsen & Stevens 2004). Another study from NW Spain using similar high seeding rates found that seeded plots had approximately 85% less erosion than unseeded plots over a 20-month period (Pinaya et al. 2000). However, Fernández et al. (2012) saw no increase in vegetation cover due to seeding (no establishment), but significant cover due to recovering vegetation, resulting in no difference in erosion rates between seeded and control plots when tested 9 months after burning.

There can also be secondary effects on erosion from seedings. Pierson et al. (2007) found that soil erosion increased with the amount of soil disturbance associated with three seeding practices (disc-chain plus land imprinter > minimum-till drill > broadcast). In their study, there was no plant establishment from seeding treatments, but all study plots had vegetation cover from annual plants (mostly nonnative *Bromus tectorum*). Miller et al. (2012) found an increase in wind erosion due to drill seeding as opposed to controls in an area in Utah that was highly susceptible to wind erosion. They attributed the increase to soil disturbance caused by the treatments (chaining after broadcast seeding or drill seeding).

Does Seeding Perennial Plants After Wildfires Reduce Invasion and Dominance of Nonnative Invasive Species?

Of the 19 studies on invasive species, 13 contained sufficient information on abundance of an invasive species between burned-seeded and burned-unseeded locations without confounding factors to include in a statistical analysis. Within these 13 studies, there were 19 cases of postfire reseeding, including 9 aerial/broadcast and 10 drill seedings (Table 2). There was no significant difference between aerial and drill seedings in the frequency with which they reduced invasive species (Fisher's exact test, $p = 1.00$, 22 and 30% for aerial and drill seedings, respectively). Across both treatments, 26% reduced, 68% were neutral, and 5% increased the cover, frequency, or density of invasive species (primarily *B. tectorum*) after seeding. New seedings (measured ≤ 3 years after treatment) decreased invasives in 15% of the cases ($n = 13$) while older seedings (measured > 3 years after treatment) decreased invasives in 50% of the cases ($n = 6$).

Table 2. Articles and cases used in this review for examining effects of postfire seeding types (aerial vs. drill) on invasive plant species in arid and semiarid shrublands and grasslands in the United States.

	Study Quality	Plant Community, State	Invasive Species	Effect on Invasive	Years Since Fire
Aerial seedings					
Getz and Baker (2008)	Medium	Pinyon-Juniper, CO	*Bromus tectorum*	Increase	2
Beyers et al. (1995)	Medium	Coastal Sage Scrub, CA	*Erodium, Hirschfeldia, Bromus, Centaurea*	No effect	1
Conard et al. (1995)	Highest	Chaparral, CA	*Bromus* sp., *Hirschfeldia incana*	No effect	1–5
Floyd et al. (2006)	High	Pinyon-Juniper, CO	*B. tectorum*	No effect	7
Goodrich and Rooks (1999)	Medium	Pinyon-Juniper, UT	*B. tectorum*	No effect	6
Lynch (2003)	High	Sagebrush, NV	*B. tectorum*	No effect	3
Thompson et al. (2006)	Highest	Pinyon-Juniper, UT	*B. tectorum*	No effect	3
Floyd et al. (2006)	High	Pinyon-Juniper, CO	*Carduus nutans*	Decrease	7
Goodrich and Rooks (1999)	Medium	Pinyon-Juniper, UT	*C. nutans*	Decrease	6
Drill seedings					
Jessop and Anderson (2007)	Highest	Black Sagebrush, UT	*B. tectorum*	No effect	3
Jessop and Anderson (2007)	Highest	Greasewood/Shadscale, UT	*B. tectorum*	No effect	3
Lynch (2003)	High	Sagebrush, NV	*B. tectorum*	No effect	3
Pierson et al. (2007)	Highest	Sagebrush, ID	*B. tectorum*	No effect	3
Ratzlaff and Anderson (1995)	High	Sagebrush, ID	*B. tectorum*	No effect	3
Sheley et al. (2007)	Highest	Sagebrush, OR	*Taeniatherum caput-medusae*	No effect	2
Wirth and Pyke (2009)	High	Sagebrush, OR	*B. tectorum*	No effect	3
Clary and Wagstaff (1987)	Medium	Pinyon-Juniper, UT	*B. tectorum*	Decrease	3
Hilty et al. (2004)	Highest	Sagebrush, ID	*B. tectorum*	Decrease	10
Thompson et al. (2006)	Highest	Sagebrush, UT	*B. tectorum*	Decrease	3

Within a seeding type, studies are organized by effect on invasive (increase, no effect, or decrease).

Among studies reviewed, there was considerable variation in biotic and abiotic components examined. Plant communities included chaparral, coastal sage scrub, big sagebrush, salt desert scrub, and pinyon-juniper. Elevations ranged from 332 to 2,484 m (1,089–8,150 feet), while average annual precipitation ranged from 15.2 to 45.7 cm (6–18 inches). Treatment types also varied, particularly among aerial seedings within pinyon-juniper woodlands. Pinyon-juniper woodland treatments included aerial seeding alone, aerial seeding with chaining, or aerial seeding with imprinting. Further variation was due to residual plants, timing of seeding, species seeded (native, nonnative, annual, perennial), environmental conditions, and age of seeding at the time of monitoring. Therefore, each case was a unique combination of these factors.

Of the 19 cases, 12 were in shrubland ecosystems (Table 2). Three of these were aerially or broadcast seeded, and none found a reduction of invasives due to seeding. The remaining nine cases were drill seeded, of which two found a decrease in invasives in seeded versus control areas while the rest found no effect.

Seven cases were located in pinyon-juniper woodlands. Of the six aerial seedings, two cases resulted in decreases in invasive thistles after seeding (Goodrich & Rooks 1999; Floyd et al. 2006), and the only drill seeding showed a reduction in *B. tectorum* (Clary & Wagstaff 1987). Three cases showed no decrease in *B. tectorum* (Goodrich & Rooks 1999; Floyd et al. 2006; Thompson et al. 2006), while one reported an increase (Getz & Baker 2008).

Most cases that documented no effect also reported low establishment of seeded species (Beyers et al. 1995; Conard et al. 1995; Ratzlaff & Anderson 1995; Jessop & Anderson 2007 greasewood site; Pierson et al. 2007; Sheley et al. 2007; Wirth & Pyke 2009), although not all studies reported seeded plant establishment. One study showed no effect with good establishment of seeded species (Jessop & Anderson 2007, black sagebrush site). Only two cases within shrublands evaluated seedings more than 3 years after treatment (Table 2).

There were seven studies without direct comparisons between seeded and unseeded areas. Shinneman & Baker (2009) examined 19 fires in big sagebrush and pinyon-juniper in the Colorado Plateau and found no overall differences in *B. tectorum* cover between burned and seeded versus burned and unseeded treatments, but they did not distinguish between aerial and drill seeding. For seeded treatments, they found that lower pretreatment cover of biological soil crusts (BSC) and lower than normal pretreatment precipitation along with higher prefire cover of native annual forbs were associated with higher cover of *B. tectorum* after fire. Kulpa et al. (2012) found higher densities of *B. tectorum* on south facing slopes as compared to flat or north slopes at five separate postfire drill seedings in northern Nevada. A few studies found that aerial seeding followed by soil disturbance to provide greater soil-to-seed contact did improve desired plant establishment over those without soil disturbance, which in turn may have reduced invasive annual grasses, but these studies did not test this using unseeded controls (Haferkamp et al. 1987; Clary 1988; Ott et al. 2003). Eiswerth & Shonkwiler (2006) examined 62 postfire sites in northern Nevada and concluded that grazing was associated with increased *B. tectorum* density, although *B. tectorum* density was very low overall. Also, regeneration of native species surviving the fire can be negatively affected by successful establishment of seeded species (Waitman et al. 2009).

Discussion

Reduction of both erosion and weed abundance due to postfire seeding is highly variable but ultimately dependent on the cover of desirable species that either recover after fire or are established due to seeding. Seeding success is dependent on conditions for germination and establishment followed by time for adequate growth to attain sufficient cover or provide adequate competition (Hardegree et al. 2011). Wildfire rehabilitation techniques often take advantage of the fire-induced reduction in seed banks to control invasive species and save the cost of herbicides, but these may not be adequate to control all invasive species and may only provide a short window of opportunity (Pyke et al. 2010). We did not examine effectiveness of adding herbicide applications to the seeding process since so few wildfire rehabilitation studies have examined this combination, but general rangeland improvement studies indicate that appropriate weed control treatments can increase establishment and growth of desired vegetation (Hardegree et al. 2011). Clearly, more research on postwildfire integrated weed management techniques that include seedings is necessary.

Ecosystem theories regarding erosional resilience following wildfires and resistance to invasion after wildfires project quicker recoveries and less invasion in more mesic than arid rangelands (Chambers et al. 2007; Davies et al. 2007). Time to recovery will likely be longer in less productive, more arid environments. Wildfire rehabilitation projects therefore may in many rangeland environments take more than 3 years (the funding period of U.S. federal wildfire rehabilitation; U.S. General Accountability Office 2006) to show trends in effectiveness. Long-term (>3 years) studies of effectiveness are required, but few have been conducted.

Very little literature is available for assessing effects of seeding on erosion after fire in rangelands of the intermountain United States. Clearly, there is a need for additional studies regarding seedings and erosional processes, especially wind erosion. However, recent reviews have assessed effectiveness of seedings for reducing water-borne soil erosion in the short term (mostly 1–2 years postseeding) after fires in chaparral and forested ecosystems (Beyers et al. 1998; Robichaud et al. 2000; Beyers 2004; Peppin et al. 2010). Robichaud et al. (2000) found that seeding slopes with annual or perennial grasses could reduce erosion, but only after sufficient cover was produced, which usually only occurred in the second year or longer following fire and was dependent on successful establishment of seeded plants. Peppin et al. (2010) concluded that seeding to reduce water erosion was largely ineffective in the short term. By the time seeded plants provided enough cover to reduce erosion, the peak period of erosion risk was past.

On the basis of current literature, and extrapolating information from forested systems, it is apparent that seeding in rangelands will have little effect on decreasing wind- or water-borne erosion when the risk is greatest, immediately after fire. In addition, the scale of the study is critical in evaluating results. Small plots with high establishment may not reflect hillslopes with variable establishment. Landscape-scale studies are necessary to reflect operational scale results of such treatments. Soil disturbance created by some treatments may even make erosion worse. Very little information is available about the magnitude of erosion in successive years after fires in rangelands; however, erosion risk is likely to decrease with increasing time after the fire and is highly dependent upon soil type and establishing/recovering vegetation if we can accept results from forested ecosystem as pertaining to rangelands (Robichaud et al. 2000, 2010).

There is some evidence to suggest that seeding may, in certain instances, reduce invasion and abundance of nonnative annual weeds after fire; however, this is dependent on the level of establishment (success) and size (age) of both seeded and residual plants. Most cases that showed low establishment also showed no effect on invasives, while older seedings had a higher frequency of reductions in invasives than younger seedings. In addition, some studies may show no difference in invasive species between seeded and unseeded controls when propagule pressure of invasives was initially low. In these cases, determining effectiveness of a seeding based on invasive species abundance is not appropriate. Therefore, effectiveness monitoring should include separate measures of dominance for invasive plants, seeded plants and residual perennial plants.

Climatic variability is a well-recognized factor in seeding failure, postfire or otherwise (Hardegree et al. 2011). Variability in seedling establishment has hampered our ability to quantify the degree to which seedings may reduce invasives. Provided a seeding establishes successfully at levels necessary to fill available niches, rehabilitation will likely lead to erosional resilience and invasive plant-resistant ecosystems. This will most likely occur in more mesic and productive communities. Because papers we reviewed essentially amounted to unique case studies, generally involving single fires and single seeding projects, more information from a wide range of treatments, locations, and years will be required to generate an accurate, replicated assessment of the effect of postfire rangeland seeding on invasives.

The perceived emergency nature of a burned landscape leads to quick decisions that may not always be well-informed. Generating a significant body of knowledge regarding which treatments have the greatest likelihood of success would aid land managers when decisions are required. This would include studies that examine (1) the rate of establishment of postfire seedings and the causal factors of success or failure, (2) the relationship between level of establishment of seedings and the abundance of invasive plant species over a longer period (>3 years), and (3) types of auxiliary treatments that could increase the likelihood of seeded species establishment given the inevitable variability of environmental conditions, particularly precipitation. These experiments can be difficult to conduct given multiple confounding factors, but this information will be valuable in assessing the need for and improving the utility of seeding treatments after wildfires.

Implications for Practice

- Significant reductions in erosion due to seeding are unlikely in the first year after fire. Potential long-term reductions due to seeding are likely to be site-specific and variable. Where postfire erosion is a significant threat to resources, other treatments, such as mulching, should probably be considered.
- Postfire seedings must result in successful establishment to reduce weed expansion and spread; therefore, reapplication of seedings in successive years may be necessary if weed control is the goal. However, other forms of weed control may be required in conjunction with reapplication, because the fire-induced reduction of weeds may no longer exist.
- Future monitoring and research should track abundance of invasives and establishment of both seeded and residual plants to enable analysis of these factors on postfire plant communities and to provide guidance for adaptive management.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Effectiveness of post-fire rehabilitation seeding on abundance of invasive 1 annual weeds and erosion: an annotated bibliography.