FINAL REPORT

Synthesis of Current Knowledge on Post-fire Seeding for Soil Stabilization and Invasive Species Control

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Abstract

The General Accounting Office has identified a need for better information on the effectiveness of post-fire emergency stabilization and rehabilitation methods used by the U.S. Forest Service and Department of Interior (DOI) agencies. Since reviews were published on treatment effectiveness in the early 2000s, treatment choices have changed and increased monitoring has been done. Greater use of native species has added substantially to burned area emergency response (BAER) treatment costs, for example, but quantitative data on this treatment were scarce in earlier reviews. We synthesized current information on the effectiveness of post-fire seeding for both soil stabilization and for prevention of the spread of invasive species in rangelands. We reviewed published literature (peer-reviewed and “gray”) and agency monitoring reports, as well as compiled and analyzed quantitative data in agency files. Products of this review include a web-accessible database of monitoring reports and published information, a scientific journal paper summarizing findings of scientific studies, an annotated bibliography of peer-reviewed papers, a summary report published as a General Technical Report that will be available online (in progress), and presentations to scientific meetings and BAER/ESR team training sessions and workshops. By combining results from studies done by Forest Service and DOI agency personnel with research studies published since the initial reviews, we presented a comprehensive synthesis of seeding effectiveness knowledge that complements the review of other hillslope treatments published by other researchers. This information will help federal land managers make more cost-effective decisions on post-fire stabilization and rehabilitation treatments.

Background and Purpose

The General Accounting Office (GAO) identified a need for better information on the effectiveness of post-fire emergency stabilization and rehabilitation methods used by the U.S. Department of Agriculture (USDA) Forest Service and Department of Interior (DOI) agencies (GAO 2003), based in large part on reviews by Robichaud et al. (2000) for the Forest Service and Pyke and McArthur (2002) for the Bureau of Land Management (BLM). The most widely used post-fire treatment is seeding, primarily with native or non-native grasses, on which there has been considerable research and continued debate over effectiveness and ecosystem impacts (Beyers 2004). The success of seeding depends on many factors, including species selection, climate, terrain, competition with other species, seedbed preparation, and post-seeding management (Monsen et al. 2004). Beyers (2004) pointed out a lack of data on then-emerging seeding practices, especially increased use of native species and sterile cereal grains for erosion control as well as seeding to prevent spread of invasive non-native plants. The GAO report and the published reviews have sparked an upsurge in research on seeding effectiveness and agency monitoring of post-fire treatments. This new information is scattered and largely unavailable to burned area assessment teams on tight timelines to recommend stabilization measures.

Study Description and Location

Part 1, Literature Review (Pyke et al. 2013)

This review was conducted using methods described in Pullin and Stewart (2006). We searched for literature dealing with postfire seeding of rangelands worldwide. Literature databases searched included SCOPUS, Dissertation Abstracts, Forest Science, Treesearch, 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 1519. 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). Based on titles and abstracts, a list of 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 the quality of evidence following Peppin et al. (2010) (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. 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.

Statistical analysis of the effect of postfire seeding on invasives was performed by breaking seedings into "cases" within each paper. 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. Significance for grouping was determined by the individual article's definition and analysis. In some cases, these were statistical tests while others were comparisons among confidence levels. 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 (Neutral/Increase) while the other category consisted of those that had significant declines in invasives with seedings (Decreased). All cases were tallied and included in a 2 by 2 contingency table and tested using Fisher's exact test (SAS Institute, Inc. 2011), which calculates the cell probabilities based on the row and column totals (which were fixed by design).

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. 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, BACI, review paper, and expert opinion.

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

Part 2, Review of BLM Monitoring Reports (in preparation for publication)

We reviewed BLM monitoring reports of post-fire seedings that occurred from 2001 through 2006. We found 220 reports describing 327 treatments that could be assigned a success rating based upon visual observations, or qualitative or quantitative data. Two reviewers read each report and agreed on a consensus success rating (good, fair, poor, or failure) for each treatment. Reports and treatments that could not be assigned a success rating were excluded. Because monitoring reports did not consistently observe or report the same parameters or use the same objectives or methods, success ratings were necessarily subjective (Zedler 2007); however, attempts were made to standardize this by using agreed-upon terms that would relate to the success rating (Table 2).

To determine the importance of treatment type and year on success rating, we used a log linear model for three-way tables. A hierarchical selection procedure using a three-way contingency table with seeding type (aerial or drill), success rating (good, fair, poor, fail), and year (2001, 2002, 2003, 2005, and 2006) was used. There were not enough reports from 2004 to be included in the analysis. We began with a saturated model and progressively dropped interaction terms until the simplest best fit model for the data emerged (Fienberg 1980). When information on the species sown at each project was available, we examined the trends in the numbers of native and non-native species used over the time period covered by the monitoring reports.

Table 2. Criteria for rating monitoring reports and relevant key words found within the reports to justify the rating given.

Rating	Criteria	Key Words found in reports to describe success
Good	Narrative or data reflected widespread establishment of most seeded species.	"Fully successful", "good", "excellent", "fantastic"
Fair	Narrative or data reflected some species establishing well and not others, or patchy distributions of species establishment.	"Partially", "somewhat", or "marginal success", "fair", "patchy"
Poor	Narrative or data described very little establishment or only some establishment of a minority of species from the seed mix.	"poor", "low density", "limited", "minimal", "sparse"
Failure	The narrative or data showed none or an extremely small amount of establishment	"Not successful", "failure", "no establishment from seeding"

Fire perimeter shapefiles were obtained for as many projects as possible that were detailed in the third year closeout reports. Mean elevation for each project was calculated using USGS Digital Elevation Models (90 m resolution). Thirty year (1971-2000) average and first through third year precipitation after fire were calculated for the critical October through June time period (hereafter CP) (PRISM Climate Group 2010). In order to investigate causal factors of effectiveness, treatment success ratings were converted into a binary variable, with good and fair success given a numerical rating of 1 and poor and failing success ratings given a numerical rating of 0. Separate regressions were performed for each treatment type (drill and aerial). Only independent seeding projects were included, meaning a maximum of one seeding of each type was used for each fire perimeter. In cases with multiple seedings within the same fire perimeter, all treatments were removed if they had different ratings while one was retained if the treatments had the same rating. This was because treatments with different results would be associated with the same precipitation and elevation data, thereby confounding the analysis.

Key Findings

Part 1, Literature Review (Pyke et al. 2013)

Nineteen published studies specifically measured the abundance of invasive plant species following postfire seeding, and eight measured soil erosion. All these studies were at least medium quality, i.e., had adequate unseeded controls. Effects of seeding on postfire erosion in chaparral were summarized by Robichaud et al. (2000) and Beyers (2004); we found no new studies regarding post-fire seedings in chaparral published after these two reviews.

Of the 19 studies examining seeding effects on invasive species in sagebrush rangelands, 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. Confounding factors that eliminated papers from the analysis included herbicide application, short monitoring periods after seeding (less than 1 year), and aggregating results for multiple plant communities. Within these 13 studies, there were 18 cases of postfire reseeding, including 9 aerial/broadcast and 9 drill seedings (Table 3). 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 33% for aerial and drill seedings, respectively). Across both treatments, 28% reduced, 67% were neutral, and 5% increased the cover, frequency, or density of invasive species (primarily *Bromus tectorum*) after seeding. New seedings (measured ≤ 3 years after treatment) decreased invasives in 16.7% of the cases ($n = 12$) while older seedings (measured > 3 years after treatment) decreased invasives in 50% of the cases ($n = 6$).

Seeding perennial grasses after fire to reduce erosion provided mixed results 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 vs. 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 USA 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 to 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), resulting in no difference in erosion rates between seeded and control plots when tested 9 months after burning.

Table 3. Articles and cases used for examining effects of postfire seeding on invasive plant species in arid and semiarid shrublands and grasslands in the USA.

Aerial Seedings	Study Quality	Plant Community	Species	Effect on Invasive	Years Since fire
Getz & Baker (2008)	Medium	Pinyon-Juniper, CO	*B. 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 & 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 & Rooks (1999)	Medium	Pinyon-juniper, UT	*Carduus nutans Circium arvense*	Decrease	6
Drill Seedings					
Jessop & Anderson (2007)	Highest	Black Sagebrush , UT	*B. tectorum*	No effect	3
Jessop & Anderson (2007)	Highest	Greasewood/shadscale, UT	*B. tectorum*	No effect	3
Lynch (2003)	High	Sagebrush, NV	*B. tectorum*	No effect	3
Ratzlaff & Anderson (1995)	High	Sagebrush, ID	*B. tectorum*	No effect	3
Sheley et al. (2007)	Highest	Medusahead, OR	*Taeniatherum caput-medusae*	No effect	2
Wirth & Pyke (2009)	High	Sagebrush, OR	*B. tectorum*	No effect	3
Clary & 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

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 the study, there was no plant establishment from the seeding treatments, but all study plots had vegetation cover from annual plants (mostly non-native cheatgrass). 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).

Results from this review suggest that 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 from the fire or are established due to seeding. Ecosystems that need seedings to attain erosion protection or to resist invasive species require time to reach these goals. 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). It is apparent that seeding will have little effect on decreasing erosion due to wind or water when the risk is greatest – immediately after fire.

Part 2, Review of BLM Monitoring Reports

Of the 220 monitoring reports examined, 43% of the fires occurred in the 2001-2002 and 50% occurred in 2005-2006. Most of the fires occurred in Idaho (38%), Nevada (31%), Utah (15%), and Oregon (12%). Of the 327 treatments, 214 were aerial and 113 were drill seedings. Treatments assessed within these reports accounted for 400,943 ha (990,752 ac) of public lands treated from 2001 to 2006 (Table 4). Aerial seedings composed approximately 75% of the acreage treated, while drill seedings accounted 25%.

Out of all 327 seedings, 33.0% were rated as failures, 26.1% as poor, and 20.3% each for fair and good success. Aerial and drill seedings were significantly different in their success ratings (Fisher's Exact Test $\chi^2 = 19.38$ df=3, $p > 0.001$), with drill seeding rated good success more often than aerial (Table 4). When both treatment and year data were included (Table 5), the best-fit log-linear model included interaction terms between success ratings and seeding treatment (aerial vs. drill, $p < 0.001$) and success rating and year (2001-2003 and 2005-2006, $p < 0.001$), but not year-by-seeding ($\chi^2 = 25.40$, df = 16, $p = 0.06$, n = 324). This means that the success ratings were different for the two seeding types (aerial and drill), and that the frequencies of seedings within the success categories were different in different years.

Table 4. Number of projects of each treatment and percentage of total for which a determination of success was made.

Treatment	# of projects	Hectares (Acres)	Good (%)	Fair (%)	Poor (%)	Fail (%)
Aerial Seeding	214	304,097 (751,440)	29 (13.6)	39 (18.3)	63 (29.6)	83 (38.5)
Drill Seeding	113	96,339 (238,060)	34 (30.1)	28 (24.8)	26 (23.0)	25 (22.1)
Total	**327**	**400,943 (990,752)**	**63 (20.3)**	**67 (20.3)**	**89 (26.1)**	**108 (33.0)**

There were 139 aerial and 89 drill seedings for which both fire perimeter data and ratings on seeding success were available. Critical period (CP) precipitation at these sites was generally below average in the first year after the fires (84.2 and 90.9% of the 30-year average for the aerial and drill seedings, respectively). Only 7.2% of aerial and 17.9% of drill seedings received above-average CP precipitation (>120% of the 30-year CP average) in the first year after treatment.

For aerial seedings, treatments rated “good” were located on sites that received 6.8 cm higher average CP precipitation and were 295 m higher than those that failed. From 2001 to 2006, the majority of the aerial seedings were rated as failing or poor (71.9%). Of the aerially seeded projects that were sown during "average" precipitation years (first year post-fire CP precipitation between 80 and 120% of 30-year average), 82.1% were rated as poor or failing (n=56), while only 40.0% of projects implemented in years with above-average CP precipitation (>120% of 30-year average) were rated poor or failing (n=10).

Drill seedings rated good were on sites that received an average 3.8 cm greater 30-year average CP precipitation and were 284 m higher in elevation than those that failed. Average CP precipitation during the first year after fire was 6.9 cm higher in treatments rated good than in those rated as failure. Nearly half (46%) of all drill seedings experienced less than 80% of their sites’ 30-year average CP precipitation in the first year after fire. However, the percentages of drill seedings in the poor or failing categories were fairly consistent despite differences in precipitation: the percentage rated as poor or failing were 48.0, 40.1, and 43.8% for those receiving below, normal, and above normal precipitation, respectively.

Table 5. Number (% in parentheses) of projects stratified by success ratings, year and treatment. Three treatments from 2004 are not included. Percentages in a column may not add up to 100 due to rounding.

	2001		**2002**		**2003**		**2005**		**2006**	
	Drill	**Aerial**	**Drill**	**Aerial**	**Drill**	**Aerial**	**Drill**	**Aerial**	**Drill**	**Aerial**
Good	3 (12)	3 (6)	7 (44)	5 (14)	0 (0)	3 (33)	9 (43)	6 (55)	15 (33)	12 (11)
Fair	3 (12)	3 (6)	6 (38)	9 (25)	2 (50)	1 (11)	5 (24)	2 (18)	11 (24)	24 (22)
Poor	8 (32)	14 (29)	2 (13)	7 (19)	1 (25)	1 (11)	2 (10)	1 (9)	13 (28)	40 (37)
Failure	11 (44)	28 (58)	1 (6)	15 (42)	1 (25)	4 (44)	5 (24)	2 (18)	7 (15)	32 (30)
Total	25	48	16	36	4	9	21	11	46	108

Results of this analysis have shown some trends that were suspected to occur but had not been quantitatively analyzed to date. Examining the frequencies of effectiveness ratings for aerial seedings by year reveal that different years result in different frequencies of good, fair, poor, and failing seeding projects, particularly for aerial seedings. Aerial seedings showed a greater percentage of failures after three years than drill seedings and could be partially explained by environmental factors. Drill seedings showed a more even distribution among the four success categories with different environmental factors, resulting in only elevation being useful for predicting drill seeding success. Projects that received less than 80% of the 30-year average precipitation in the first year after fire had reduced success relative to other years. Drill seedings showed less variation in success than aerial seedings in this regard, with high percentages of treatments being rated as good and fair even in some years of low precipitation.

The probability of an aerial seeding being rated good or fair increased with mean elevation, average precipitation (generally correlated with elevation), and precipitation received in the first and third year critical periods after seeding. Significance of third year precipitation may be due to the large number of treatments that occurred in 2006 and were monitored for closeout reports in 2009, which was a relatively wet year in many places and was preceded by 2 years of relative drought. The contrast between the years may have led observers to rate seedings as more successful based on the increased production of all plants at the treatments in 2009.

Management Implications

- Significant reductions in erosion due to seeding are unlikely in the first years after seeding. 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 since the fire-induced reduction of weeds may have been eliminated.
- Tracking success of post-fire seeding projects alone is a valuable source of information for land managers. The current level of reporting within BLM is enough to make some preliminary conclusions regarding the frequency of qualitative success ratings within the Intermountain West (but see recommendations below).

Relationship to other Recent Findings and Ongoing Work on this Topic

Recent reviews have assessed the effectiveness of seeding for reducing water-borne soil erosion in the short term (mostly 1-2 years post-seeding) after fires in chaparral and forested ecosystems (Beyers et al. 1998, Robichaud et al. 2000, Beyers 200, 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 the seeded plants becoming successfully established. Peppin et al. (2010) found few studies in forested ecosystems that documented reduced erosion in the first or second year following fire. They concluded that seeding to reduce water erosion was largely ineffective in the short term until established plants can provide adequate cover. 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).

Effectiveness of post-fire seedings in establishing adequate cover to protect sites from erosion and invasive species as interpreted by BLM's own reports appears to coincide with Knutson et al. (2013). Aerial seedings were more problematic than drill seedings, and sites located at higher elevations were most likely to be found effective. These results also support the perceptions regarding the likelihood of restoration success relative to sites with greater productivity or greater resilience to disturbance and resistance to invasive species (Chambers et al. 2014).

Future Work Needed

Because the papers we reviewed essentially amounted to unique case studies generally after single fires and single seedings 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. 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 time 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.

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. Including additional information such as covariate factors (soil type, fire intensity, etc.) could improve these analyses and eventually form the basis of a decision support system for potential treatments. Periodic re-evaluation of a large number of projects could be undertaken to identify trends of post-fire rehabilitation effectiveness over the Intermountain West to help account for fluctuations in project locations and climate.

Deliverables Crosswalk Table

Planned Deliverable	Status	Product
Web-accessible database of sources used	In progress, USGS	Draft USGS Data Series publication with metadata
General Technical Report of findings	Replaced by journal article; could still be produced	Possible report on BLM monitoring report analysis, FY16 (in preparation)
Annotated bibliography	Completed	Supplement to Restoration Ecology article (available online)
Fire Science Brief	Completed	After The Fire Is Out
Powerpoint presentations	Several completed, including joint presentation with Fulé project	Peppin & Beyers, 2009 Systematic Review of Post-wildfire Grass Seeding, AFE
Journal article on findings	Completed	Pyke et al. 2013, Restoration Ecology 21:415-421

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