Post-wildfire Seeding in Forests of the West: Trends, Costs, Effectiveness, and Use of Native Seed

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Study Design

The opening decade of the 21st century has been characterized by a sea change in the scale of severe fires, the scientific information available to support management decisions, and the choices made by managers for post-fire seeding. We conducted an evidence-based systematic review of post-fire seeding literature to examine the effectiveness and effects of post-fire seeding treatments on soil stabilization and plant community recovery in the western U.S. In addition to reviewing scientific articles, theses, and government publications, we analyzed USDA Forest Service Burned Area Reports to determine overall trends in seeding over time. We also gathered information on managers´ perspectives on post-fire seeding and native seed use; those findings are not included in this report but will be transmitted to the JFSP after review is completed. In a previous study, web-based surveys were administered to seed suppliers from both large- and small-scale seed production companies across the western U.S., Great Plains states, and other states with successful seed production companies to determine native plant material needs and concerns; because the results are informative for this project, we summarize findings from that study as well.

Key Findings

Evidence-based Systematic Review: We reviewed a total of 94 papers. As sampling designs have become more rigorous in recent years, evidence that seeding is effective in reducing erosion has decreased. Of the 27 papers evaluating soil erosion, none of the 16 papers published since 2000 concluded that seeding was effective or minimally effective in reducing erosion compared to controls, whereas 64% of 11 papers published before 2000 found seeding to be in those categories. Only 9% of earlier papers met the criteria for highest or high quality evidence, while 71% of papers since 2000 did. Seeding did not reduce erosion relative to unseeded controls in the majority (78%) of the 30 sites contained in 9 papers providing direct measures of sediment yield. Even when seeding significantly increased vegetative cover, seeded sites rarely supported sufficient plant cover to stabilize soils within the first and second year post-fire. Of the papers evaluating seeding effectiveness for curtailing invasions of non-native plant species (11 papers), an almost equal percentage found seeding treatments to be effective (54%) or ineffective (45%). However, 83% of the treatments regarded as effective used non-native species such as grasses and cereal grains. A majority (60%) of studies reported that seeding suppressed recovery of native plants, although data on long-term impacts of this reduction are limited.

Trends in Post-Wildfire Seeding: Out of 1164 USFS Burned Area Reports, 380 contained information on seeding treatments conducted in forested ecosystems specifically. Together, 40 papers and 67 Burned Area Reports reported species seeded on 122 fires across the western United States from 1970 to 2006. These data revealed a trend of increasing use of native species and annual cereal grains/hybrids, with natives dominating seed mixes rather than non-native species. According to 380 Burned Area Reports reporting seeding costs and amount area seeded, total Burned Area Emergency Response (BAER) seeding expenditures have increased substantially, reaching an average of $3.3 million per year spent on post-fire emergency seeding treatments in forested ecosystems that involved the Forest Service during the period 2000 to

2007 – an increase of 192% compared to the average spent during the previous 30 years. The percentage of total burned area that was seeded averaged 21% in the 1970s compared to only 4% between 2000 and 2007, but the cost per acre seeded has increased over time.

Survey of Seed Suppliers: Many suppliers (80%) recognize the importance of supplying local genotypes and agreed (70%) that there is a current market for an enhanced supply of native seed to meet large-scale restoration demands, specifically for grass species. However, producers stated lack of "consistent and reliable demand" (38%) from buyers was the most significant limitation to a business involved in the production of native plant materials followed by "knowledge of native plant production" (21%). These issues in combination with limitations and issues associated with harvesting and/or production, difficulties in determining what constitutes a "local genotype," and lack of funding make suppliers hesitant to further the development and production of local genotypes.

Management Implications

The scientific literature and monitoring data show that post-fire seeding is not reliably effective in protecting soil in the short term and can have negative consequences for native plant recovery, particularly woody species. Seeding with annual non-native species can be effective in curtailing invasive non-natives. However, seeding with these species is often associated with slower native plant recovery. Land managers need to be aware of these tradeoffs. Use of native seed has increased. However, limited supplies of many species cause their prices to remain high. Without substantial increase in the availability of locally-adapted native seed, post-fire stabilization and rehabilitation teams will have to continue to rely on the use of non-local sources and risk genetic contamination of local gene pools. Land managers should weigh the cost/benefit of seeding treatments and consider using alternative rehabilitation methods shown to be more effective (e.g., various types of mulch, but care must be taken to ensure that mulch is free of non-native seed). Early detection of new undesirable species invasions through monitoring post-fire environments, in combination with rapid response methods to quickly contain, deny reproduction, and eliminate these invasions, may allow better control of non-native species establishment than is typically obtained through seeding.

Increased communication and collaboration with commercial seed suppliers is necessary to develop an adequate supply of native seed that meets genetic requirements of individual agencies. Before an increased supply is developed, growers and agencies must work to find common ground on the genetic classification of local plant materials in demand so that supplies can be developed accordingly. To develop a more reliable market, utilizing contracting options may further encourage native seed market development by reducing limitations related to funding and unreliable demand.

Future Research Needs

The effectiveness and long-term effects of post-fire seeding deserve further study, particularly well-designed research experiments and rigorous quantitative monitoring. Priority should be given to research on the effects of using native and annual/hybrid cereal grain species on burned landscapes, especially studies which look at longer-term effects on native plant community recovery and possible reburning potential. Further research on the genetic implications of using non-local genotypes of native species for postfire seeding is also essential. To avoid questions of genetic contamination in seeding projects, there is a need develop strategies and techniques to enhance supplies of local genotype plant materials. Growers and agencies should work to find common ground on the genetic classification of local plant materials in demand so that supplies can be developed accordingly. Researching and establishing guidelines for appropriate seed transfer zones for species useful for post-fire stabilization and rehabilitation will help protect the genetic integrity of locally-adapted species.

CHAPTER ONE

Post-wildfire seeding in forests of the West: An evidence-based review

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Abstract

Broadcast seeding is one of the most widely used post-wildfire emergency response treatments intended to reduce soil erosion, increase vegetative ground cover, and minimize establishment and spread of non-native plant species. However, seeding treatments can also have negative effects such as competition with recovering native plant communities and inadvertent introduction of invasive species. We conducted an evidence-based review to examine the effectiveness and effects of post-fire seeding treatments on soil stabilization and plant community recovery in the western U.S. We reviewed 94 scientific papers, theses, and agency monitoring reports identified using a systematic search protocol. The majority of studies (78%) evaluating soil erosion in seeded versus unseeded controls showed that seeding did not reduce erosion relative to unseeded controls. Even when seeding significantly increased vegetative cover, seeded sites rarely supported sufficient plant cover to stabilize soils within the first and second year post-fire. A majority of studies reported that seeding suppressed recovery of native plants (60%), although data on long-term impacts of this reduction are limited. Of the papers evaluating seeding effectiveness for curtailing invasions of non-native plant species, an almost equal percentage found seeding treatments to be effective (54%) or ineffective (45%). However, 83% of the treatments regarded as effective used non-native species, potentially causing negative impacts on native communities. In addition, native species used may not be locally-adapted and genetically-appropriate (seed sources adapted to local site conditions and genetically compatible with existing plant populations) for areas seeded. The literature suggests that post-fire seeding does little to protect soil in the short-term, has equivocal effect on invasion of non-native species, and can have negative effects on native vegetation recovery with possible long-term ecological consequences.

Keywords: evidence-based systematic review, post-fire seeding, plant community recovery, soil stabilization, invasive species

1. Introduction

Land management agencies in the United States such as the USDA Forest Service, National Park Service, and Bureau of Land Management are required by federal burned area emergency rehabilitation policy to prescribe emergency watershed-rehabilitation measures when and where deemed necessary to minimize threats to life or property or to stabilize and prevent further unacceptable degradation to natural and cultural resources resulting from the effects of a fire (USDI, 2006; USDA, 2004). Historically, aerial broadcast seeding of grasses, typically non-native annuals or short-lived perennials, has been the most commonly used post-fire stabilization treatment (Robichaud et al., 2000; Beyers, 2004). Rapid vegetation establishment has been regarded as the most cost-effective method to mitigate the risks of increased runoff and soil erosion and establishment of non-native species over large areas (Beyers, 2004). Federal policy in the U.S. currently mandates use of seed from native species for post-fire rehabilitation when available and economically feasible (Richards et al., 1998). Although the use of native species has increased (Beyers 2004; Wolfson and Sieg, in press), high costs and inadequate availability often limit inclusion of native plants in post-fire seedings. Furthermore, a vague definition of the term "native" has led to inconsistent interpretations regarding the types and origins of native species used (Richards et al., 1998). Despite ongoing debates over the efficacy of post-fire seeding and potential negative impacts on natural plant community recovery, seeding remains a widely used stabilization treatment in forested ecosystems throughout the western U.S. (Robichaud et al., 2000, Beyers, 2004).

Since publication of Robichaud et al. (2000) and Beyers (2004), several developments have altered the context of post-fire seeding. These include increasing size and severity of wildfires across the western U.S. (McKenzie et al., 2004; Westerling et al., 2006; Littell et al. 2009), increased research and quantitative monitoring on post-fire seeding and plant community interactions, increased use and allocation of funds for native seed mixes (Wolfson and Sieg, in press), and stronger policy direction for the use of locally-adapted and genetically-appropriate seed sources (seed sources adapted to local site conditions and genetically compatible with existing plant populations) (GAO, 2003; Rogers and Montalvo, 2004; USDA, 2006). The time is ripe to re-examine what is known about the effectiveness and ecological impacts of post-fire seeding.

We conducted a systematic review of the scientific literature, theses, and burned area rehabilitation monitoring reports about post-fire seeding in forested ecosystems across the western U.S. We addressed three questions pertaining to post-fire seeding relative to overall treatment effectiveness and effects on soils and plant communities: 1) Does seeding after severe forest fires reduce soil erosion? 2) Is seeding effective at reducing non-native plant invasion into burned areas? and 3) Does post-fire seeding affect native plant community recovery?

2. Methods

The systematic review methodology is relatively new in natural resource disciplines but has been widely used in medical sciences (Fazey et al., 2005, Pullin and Stewart, 2006). This methodology follows a rigorous, predetermined protocol to ensure that the synthesis of available literature is thorough, unbiased, and evidence-based. We conducted our formal systematic review in stages established by Pullin and Stewart (2006): 1) question formulation, 2) protocol formation and search strategy, 3) data extraction, and 4) analysis.

For this review, we defined forested ecosystems as those dominated by coniferous and/or deciduous trees occurring at elevations above grasslands, pinyon-juniper woodlands, or chaparral vegetation in the western U.S. The review team drafted primary and secondary study questions, which were further refined by managers, scientists, and outside experts.

We produced a review protocol to guide key decisions: 1) search, inclusion, and rejection criteria; 2) extracting evidence; and 3) comparing evidence. We submitted our review to The Centre for Evidence-Based Conservation (www.cebc.bangor.ac.uk/; Systematic Review No. 60), an international organization that hosts systematic review protocols online and facilitates review by a worldwide audience, for independent review.

We searched online databases (JSTOR, Google Scholar, Forest Science Database, Ingenta, Web of Science, AGRICOLA), online government collections, and electronic university libraries using combinations of key search terms: seeding AND fire, seeding AND burn, seeding AND wildfire, seeding AND erosion, and seeding AND native species. Refereed journal articles, peer-reviewed reports (such as government documents and conference proceedings), theses, and unpublished literature were considered. Potential studies were then evaluated for inclusion using the following specific criteria:

- *Subject(s) studied* – Seeding studies conducted in forests burned by wildfire in the U.S., predominately coniferous forests in western states, since 1970. Experimental seeding studies in controlled burns, such as prescribed fires, were also included if the information was deemed relevant to post-fire seeding. Non-wildfire seeding data were summarized separately from wildfire data.
- *Treatment(s)* – Seeding herbaceous plant or shrub seed alone or in combination with other post-fire rehabilitation activities such as mulching, fertilizing, soil ripping, and log erosion barriers.
- *Outcome(s)* – Soil stabilization attributes, such as runoff, surface erosion, and sediment yield, and change in plant community attributes, such as cover, richness, diversity, biomass, and composition of native and non-native herbaceous plants, shrubs, and trees.

All potentially relevant publications were imported into a database. Those publications listed as "possibly relevant" were examined by the senior author for final inclusion decisions.

Qualitative data extracted from the reviewed papers included study design, land and fire attributes, types of treatments, study results, and conclusions. We characterized plant species seeded as non-native or native, in most cases following the author's classifications from the paper. However, lack of a widely accepted definition of "native" (Jones, 2003) caused definitions to differ between papers. Quantitative data included soil and/or plant community attributes. In cases where authors reported results from the same fire in different papers, data from each paper were extracted independently but the overlap in studies was noted.

For consistency, each paper was reviewed by two members of the review panel. Reviewers did not evaluate papers they authored. After all publications were reviewed twice we formed a master list of all publications and reviews; this list was then reviewed by the senior author to locate any inconsistencies in recorded data, which were discussed with panel members and resolved.

We assigned "quality of evidence" ratings for each study based on design and statistical robustness (Table 1). Statistically robust data from replicated randomized and controlled experiments were judged to be of "highest" quality; whereas unreplicated, uncontrolled, qualitative data had "lowest" quality of evidence. We evaluated post-fire seeding effectiveness

Table 1. Criteria for rating the quality of evidence presented in the papers reviewed and their respective categories

Study design[a] 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, prescribed burn, or slash pile burning; peer-reviewed reviews on post-fire 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 post-fire seeding (not peer-reviewed with qualitative data)	Lowest

[a]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.

based on the treatment's effectiveness in reducing: 1) erosion and sedimentation, 2) non-native species invasion, and 3) effects on native plant community recovery. Studies were examined for overall seeding treatment effectiveness or ecosystem impacts in each category (Table 2). When available, quantitative data from seeded and unseeded treatments were compared. Some studies had multiple sites; we made comparisons based on the number of sites rather than the total number of publications. Each study or individual site within a study was given an effectiveness rating (Table 3). Studies/sites rated as "no difference in effectiveness" were not statistically or perceivably different in their effectiveness, whereas those judged to be "ineffective" were counter-productive in their effectiveness to a specified impact category (e.g. effect was opposite of that intended).

We used descriptive statistics and correlation/regression to explore relationships between post-fire seeding treatments and associated variables as well as the influence of time since fire. Regression analysis was completed using an alpha level of 0.05 (JMP, 2008). We divided relevant papers into ecoregions (Bailey, 1983; Figure 1) for analysis of climatic influences.

For each review question, we drew conclusions (when possible) based on data from 1970 to 1999, including papers previously reviewed by Robichaud et al. (2000), and on data published since 2000. The latter group of papers was expected to include more studies using native species in seed mixes and addressing invasive plant control in burned forests.

Table 2. Measurements reported in papers that were used to judge overall seeding treatment effectiveness or ecosystem impacts

Category	**Measures of Effectiveness/Impacts**
Erosion Control	Decreased sediment yield, surface erosion, or runoff
Non-Native Species	Decreased cover, frequency, density, or species richness of non-native invasive plants
Effects on Plant Communities	Negative changes to plant community attributes such as cover, biomass, composition, frequency, species richness, and density

Table 3. Criteria for rating seeding treatment effectiveness and their respective categories

Criteria for rating seeding treatment effectiveness	**Effectiveness Rating**
Sufficient evidence exists to conclude that seeding was statistically or perceivably effective in decreasing erosion, increasing cover, or reducing non-native species invasions without negative effects	Effective
Sufficient evidence exists to conclude that seeding was effective under some but not all circumstances or seeding was effective, but with potentially negative ecosystem impacts	Minimal effectiveness
Sufficient information exists to conclude that seeding treatments in treated and untreated controls were not statistically or perceivably different in their effectiveness for increasing cover, reducing erosion, and/or reducing non-native species invasions	No difference in effectiveness
Sufficient evidence exists to conclude that seeding was statistically or perceivably different in effectiveness, where treatments were counter-productive in their effectiveness (e.g. effect was opposite of what was intended); potentially negative ecosystem impacts exist	Ineffective

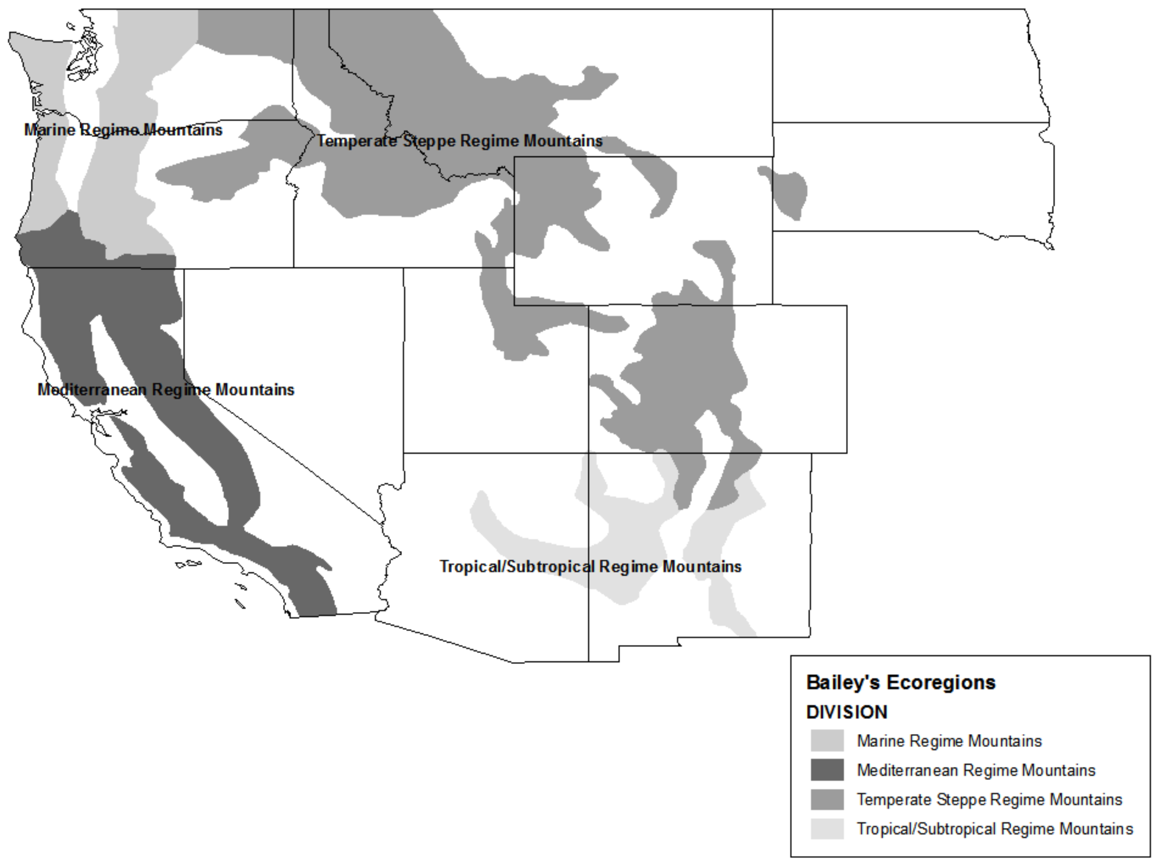

Figure 1. Map of ecoregions (Bailey 1983) containing published studies reporting measures of seeding "success" during the first 2 years following fire (Table 5).

3. Results and Discussion

Approximately 19,455 studies were identified through the literature search, of which 94 were considered relevant after applying inclusion criteria (Table 4, Appendix A). Considering the entire dataset (n = 94), replicated and randomized experiments made up the largest category (19%, Fig. 2). In the more recent period, 2000-2009 (n = 57), there was a greater proportion of replicated randomized experiments (46%), review papers (29%), and expert opinions (27%) compared to 1970-1999. Using quality of evidence criteria, during the time period between 1970 and 1999 (n = 37), 6 papers (16%) were of highest quality, 5 papers (14%) were high quality, 4 papers (11%) were medium quality, and the majority (60%) were in the low and lowest quality category (Fig. 3). The proportion of papers in these categories changed slightly for the 2000-2009 papers, with the greatest increase in the high quality of evidence category (28%); 19% were of highest quality, 11% medium, 9% low, and one-third (33%) fell into the lowest quality category (Fig. 3).

Table 4. Number of papers included at each of the systematic review stages

Systematic review stage	No. of Articles
Studies captured using search terms in electronic databases (excluding duplicates) and gray literature searches	*19,455
References remaining from electronic database and unpublished search after inclusion criteria assessment	143
Relevant studies remaining following further examination by the review coordinator	120
Relevant studies remaining subsequent to the first full review meeting search term and/or relevancy requirements	94

* Approximate figure only

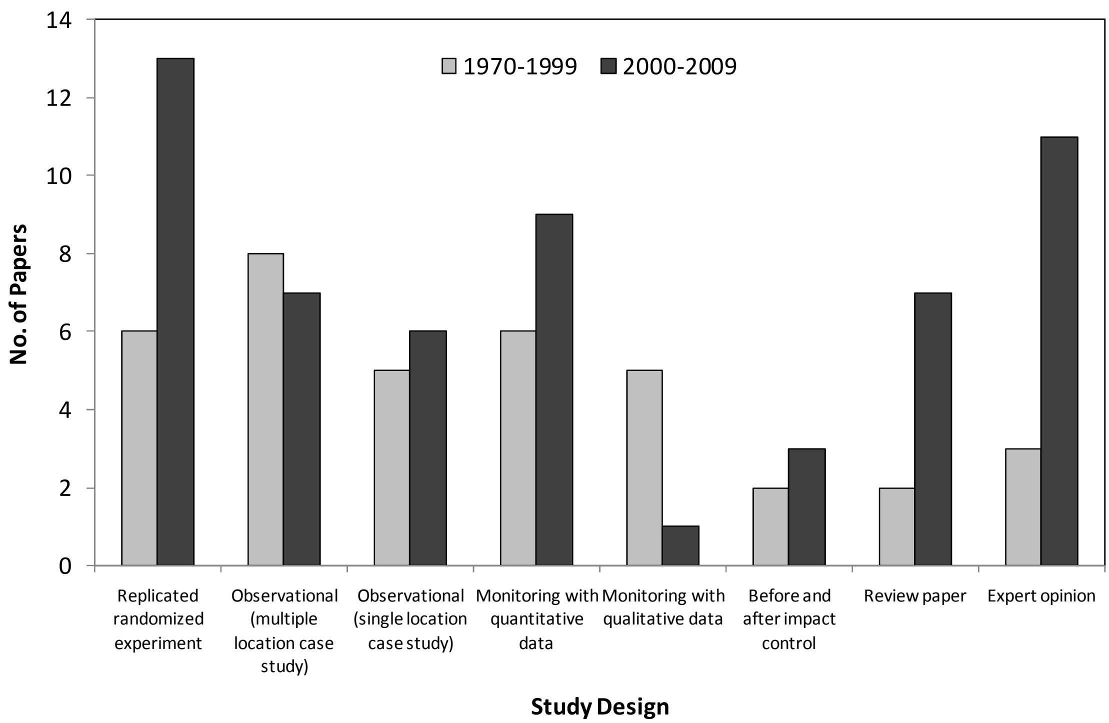

Figure 2. The number of papers by study design category for studies reviewed from 1970 to 1999 (37 papers) and those since 2000 (57 papers)

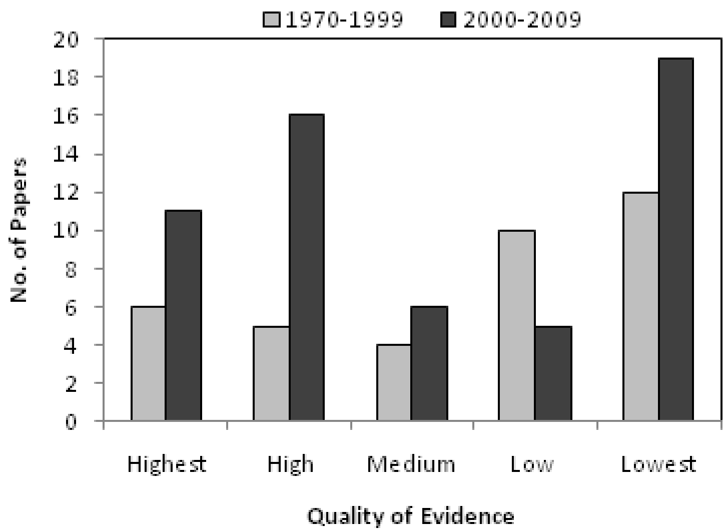

Figure 3. The number of papers by quality of evidence for studies reviewed from 1970 to 1999 (37 papers) and since 2000 (57 papers)

3.1 Does seeding after severe forest fires in the western USA reduce soil erosion?

Twenty-seven studies provided evidence regarding post-fire seeding effects on soil erosion. Authors defined erosion control in terms of decreases in sediment yield, runoff, or surface erosion. Using effectiveness ratings (Table 3), 33% of the 27 studies showed seeding to be effective, 26% showed minimal effectiveness or ineffectiveness, and 15% showed no difference in effectiveness of seeding in reducing erosion. However, the evidence for seeding effectiveness drops substantially when quality of evidence criteria (Table 1) are considered: none of the four studies with highest quality evidence found seeding to be effective or even minimally effective in reducing soil erosion when compared to unseeded control plots. For example, Robichaud et al. (2006), in a study conducted in north-central Washington, used a randomized block design of four plots with controls, replicated eight times, to compare the effects of seeding with winter wheat (*Triticum aestivum* L.) and fertilizing on post-fire erosion rates. They found no reduction in erosion rates for seeding or fertilization treatments, alone or in combination, at any time during the four-year study. Five of the eight studies with high quality evidence found seeding to be ineffective, while two reported minimal effectiveness. The remaining study reported that seeding (seeded species unknown) was effective for erosion reduction only in combination with mulching and log erosion barriers on a fire in southwestern Colorado (DeWolfe et al., 2008).

More evidence for seeding effectiveness was reported in studies with lower quality evidence. One of three medium quality studies, three of four low quality studies, and all eight lowest quality studies found seeding to be effective or minimally effective in reducing erosion. For example, in a publication considered to have lowest quality evidence, two subjectively-chosen study areas were set up within a single burned area in the Black Hills, South Dakota, each with eight plots to assess sedimentation and runoff (Orr, 1970). The study found that a mixture of seeded non-native and legume species dominated the cover at both sites throughout the study and suggested that neither site would have reached a 60% ground-cover requirement for minimum soil stability within four years without seeding; however, no unseeded sites were evaluated (Orr, 1970).

As sampling designs have become more rigorous in recent years, evidence that seeding is effective in reducing erosion has decreased. In fact, none of the 16 papers published since 2000 concluded that seeding was effective or minimally effective in reducing erosion compared to controls, whereas 64% of 11 papers published before 2000 found seeding to be in those categories. Only 9% of earlier papers met the criteria for highest or high quality evidence, while 71% of papers since 2000 did.

Only nine of the 27 studies used direct measures of sediment yield from 30 seeded and unseeded sites to assess post-fire seeding effectiveness. While seeded sites tended to produce less sediment than unseeded sites the first year after fire (Fig. 4), only 22% of the sites showed a statistically significant decrease in erosion on seeded relative to unseeded sites. This largely non-significant trend toward sediment yield reduction was less apparent in measurements from the second year post-fire and essentially disappeared by the third and subsequent years. However, by the third year post-fire most studies showed little sediment movement in either seeded or unseeded sites (Fig. 5), indicating that slopes had largely stabilized.

Sediment movement is strongly related to the amount of cover on a hillslope (Robichaud et al. 2006; Rough 2007). Because so few studies reported actual erosion measurements, we also used vegetation cover as an indicator of seeding "success" for potential erosion control effectiveness (Dadkhah and Gifford 1980; Bruggink 2007). We included studies from the first and second year after fire that compared seeded treatments to unseeded plots in this analysis. As was done in Robichaud et al. (2000) and Beyers (2004), we used two levels of cover to indicate the potential for seeding to reduce erosion. Cover > 30% was regarded as partially effective at reducing erosion, and cover > 60%, which has been found to allow negligible sediment movement (Noble 1965; Orr 1970), was considered to be effective.

Comparing cover measurements between seeded and unseeded plots from 20 studies containing a total of 29 study sites, we found that 41% of sites had significantly greater total plant cover on seeded plots by the end of the first year after fire. Fifty-five percent of the seeded sites had > 30% total plant cover in the first year after fire, compared to only 31% of the unseeded sites (Table 5). Another 14% of seeded sites had > 60% total plant cover after the first year post-fire compared to none of the unseeded sites. However, of the 12 sites where erosion was measured, none showed that seeding significantly reduced erosion in the first year after fire.

In the second year after fire, seeded sites were nearly four times more likely to be stabilized than untreated sites based on cover percentage (Table 5). Second-year seeded sites had greater total cover than did unseeded sites 39% of the time. Eighty-three percent of the seeded sites had greater than 30% cover, compared to 50% of unseeded sites. Twenty-eight percent of seeded sites had adequate cover (>60%) to reduce soil erosion to negligible amounts, compared to only 6% (1 site) of unseeded sites. Despite these cover findings, only one of the studies measuring erosion in the second year showed that seeding significantly reduced erosion. It appears that greater cover does not always produce less erosion. A main goal of post-wildfire stabilization treatments is to reduce soil erosion in the year immediately following a fire (Robichaud et al., 2000). However, seeding appears to have a low probability of effectively reducing erosion within the first year and even the second year.

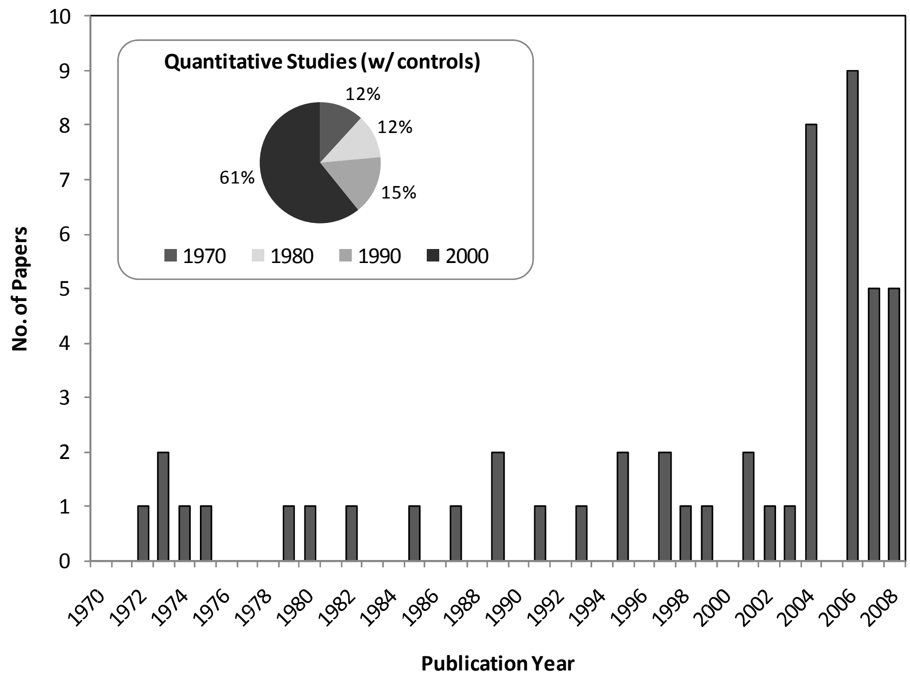

Figure 4. Number of studies reviewed with quantitative data (including controls) by publication year. The insert shows the number of quantitative studies by decade as a percent of the total.

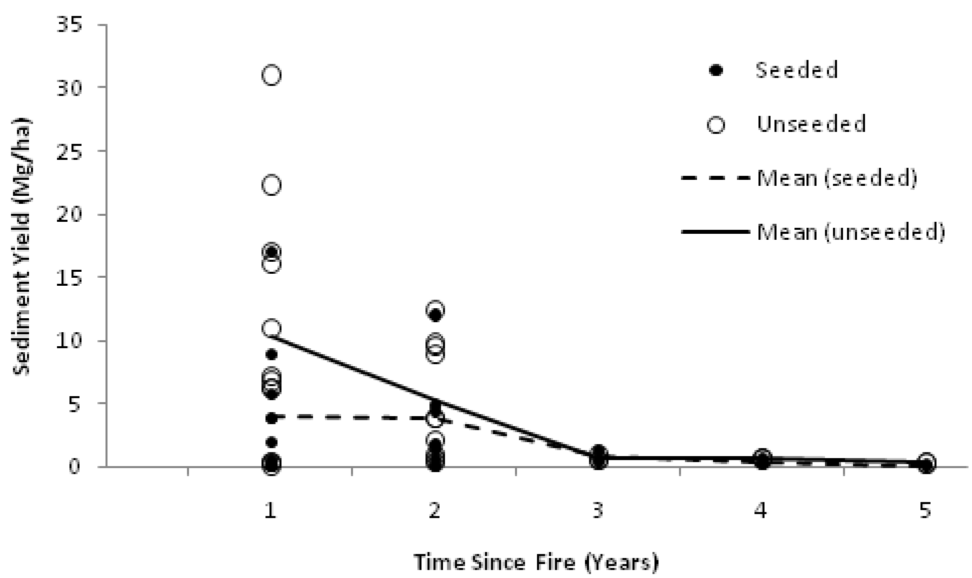

Figure 5. Amount of sediment yield versus time since fire in seeded plots and unseeded plots (data from 30 sites)

Table 5 – Number of sites in published studies reporting measures of seeding "success" by ecoregion (Bailey 1983) during the first 2 years following fire

	Sites Showing Cover Measure-ments	Those Showing Seeding Significantly Increased Cover	% of Sites Showing > 30% Cover (No. of Sites)		% of Sites Showing >60% Cover (No. of Sites)		Sites Showing Erosion Measure-ments	Those Showing Seeding Significantly Reduced Erosion
			Seeded	Unseeded	Seeded	Unseeded		
	No.		*Percent*				*No.*	
Post-fire Year One								
Marine Regime Mountains	6	3	33 (2)	17 (1)	0	0	5	0
Temperate Steppe Regime Mountains	8	0	50 (4)	50 (4)	0	0	4	0
Tropical/Subtropical Regime Mountains	3	0	100 (3)	100 (3)	0	0	0	—
Mediterranean Regime Mountains	12	9	58 (7)	8 (1)	33 (4)	0	3	0
Combined	**29**	**12**	**55**	**31**	**14**	**0**	**12**	**0**
Post-fire Year Two								
Marine Regime Mountains	4	1	100 (4)	75 (3)	0	0	5	0
Temperate Steppe Regime Mountains	7	0	71 (5)	71 (5)	0	14 (1)	5	1
Mediterranean Regime Mountains	7	6	86 (6)	14 (1)	71 (5)	0	0	0
Combined	**18**	**7**	**83**	**50**	**28**	**6**	**10**	**1**

Authors of all review papers (4) agreed that research to date has failed to show any notable relationship between establishment of vegetative cover and reduction of erosion within the first year after fire (Beschta et al., 2004; Beyers, 2004; Wolfson and Sieg, in press). This is not surprising as the majority of sediment movement often occurs before plant cover is established (Robichaud et al., 2000). However, our review suggests that seeding was more likely to increase plant cover and therefore potentially reduce soil erosion in the Marine and Mediterranean Regime Mountain ecoregions than in Temperate Steppe Regime Mountains ecoregion (Table 5; see Fig. 1 for ecoregion boundaries).

In the Intermountain West and Rocky Mountains (Temperate Steppe Regime Mountains), high-intensity short-duration rainfall events often occur shortly after severe wildfires (Robichaud et al., 2000). Watersheds within this region are therefore vulnerable to high erosion due to these storm events (Wagenbrenner et al., 2006; Kunze et al., 2006; Rough, 2007). In contrast, forests of the Mediterranean and Marine Regimes (California and the Pacific Northwest) receive most precipitation during the winter months as snow or are subjected to prolonged periods of rainfall, allowing seeded species to germinate under better conditions (Anderson and Brooks, 1975; Roby, 1989; Amaranthus et al., 1993; Robichaud et al., 2006; Peterson et al., 2007).

Several studies provide evidence that seeding for erosion control may be more effective when done in concert with other treatments (Maloney and Thornton, 1995; Meyer et al., 2001; Earles et al., 2005; DeWolfe et al., 2008), although other studies showed no reduction in erosion rates (e.g. Robichaud et al., 2006). Some studies suggest that mulch treatments alone are more effective than seeding in reducing erosion. For example, in a study conducted in northwestern Montana, Groen and Woods (2008) found straw mulch application at a rate of 2.24 Mg/ha resulted in 100% ground cover and reduced rainsplash erosion by 87% in small test plots; whereas an aerially seeded mixture of native grasses failed to provide enough ground cover to reduce the erosion rate relative to untreated plots. In studies conducted in Colorado's Front Range, MacDonald and Larson (2009) and Wagenbrenner et al. (2006) also found straw mulch to be more effective than other treatments (seeding alone, seeding and mulching, contour-felled logs, hydromulch, and polyacrylamide) for reducing soil erosion following wildfires. Seeded species in MacDonald and Larson (2009) included native cultivars and sterile cereal grains, whereas Wagenbrenner et al. (2006) tested a mixture of non-natives plus sterile and non-sterile cereal grains. In sum, seeding may be more effective when used with other erosion control measures, but mulching alone can provide as much or more cover then all other treatment combined.

3.2 Does seeding reduce non-native species invasions in severely burned forest land?

Post-fire seeding treatments are often designed to mitigate or prevent invasions of undesirable non-native species (Robichaud et al., 2000; USDA, 2004). Seeded grasses are thought to combat non-native species due to their quick growth, capturing resources ahead of invading non-native species (Robichaud et al., 2000; Grime, 2001; Beyers, 2004). In 11 papers with direct evidence regarding the role of seeding in reducing non-native species abundance, 56% (6 papers) showed seeding to be effective, whereas 45% (5 papers) showed seeding did not reduce non-native species' abundance. Considering quality of evidence (Table 1), three of five papers (60%) of highest quality showed seeding to be effective for reducing non-natives. However, two of those were conducted in prescribed burn or slash pile burned areas. Two of three papers of high quality showed seeding to be ineffective for reducing non-native species. Thus, an equal amount of papers (50% each) found seeding to be effective and ineffective. The three lower quality-of-evidence categories likewise gave mixed results.

Clearly, seeding has an equivocal record for reducing non-native species invasion. Successful exclusion of non-natives was generally reported when seeded species produced high cover (Barclay et al., 2004; Keeley, 2004), while studies where seeding was ineffective usually showed no difference in total cover on seeded and unseeded sites (Sexton, 1998; Hunter and Omi, 2006; Stella et al., in press). However, of the studies showing seeding to be effective, 83% included non-native annual species in the seeding treatments. Thus, successful suppression of non-seeded invaders appears to result from the competitive advantage of other (seeded) non-native species (Schoennagel and Waller, 1999; Barclay et al., 2004; Keeley, 2004). These same papers and others showed that successful seeded species also displaced native species (Sexton, 1998; Schoennagel and Waller, 1999; Barclay et al., 2004; Keeley, 2004; Logar, 2006). Although the non-native annual species in seed mixes are generally selected because they are expected to disappear in one year (e.g., winter wheat, annual ryegrass), they can persist beyond the first and second years post-fire (VanZuuk, 1997; Sexton, 1998; Barclay et al., 2004; Hunter et al., 2006). Two studies found that seed mixes were contaminated with exotics (Sexton, 1998;

Hunter et al., 2006). It thus appears that seeding to reduce the negative impacts of invading non-native species on post-fire vegetation recovery may end up replacing one (or more) competitive non-native species with another.

Few studies have investigated the use of native species for reducing non-native species invasion, and only one of the three using native seed was conducted after a wildfire. Stella (in press) found that non-native species richness and abundance did not differ among seeding treatments incorporating non-native and native species mixes on three high-severity wildfires in Arizona. The other studies were conducted following a prescribed burn in northwestern Arizona (Springer et al., 2001) and following slash pile burning in northern Arizona (Korb et al., 2004). Springer et al. (2001) found that seeding certified "weed-free" native seeds was ineffective in reducing non-natives, whereas Korb et al. (2004) noted that seeding native species was effective only with the addition of soil amendments.

Concerns over use of native species for post-fire seeding include the fact that some native grasses have been shown to suppress growth of conifer seedlings (Larson and Schubert, 1969; Pearson, 1972), and using non-local native seed sources may contaminate local gene pools (Huenneke, 1991; Schmid, 1994; Linhart, 1995; Hufford and Mazer, 2003; Rogers and Montalvo, 2004). Conserving local genotypes of plant populations is considered a vital mechanism by which plant communities can adapt and evolve to survive in a changing climate (Huenneke, 1991, Rogers and Montalvo, 2004).

All of the papers on the effectiveness of seeding for reducing non-native species invasion in forested ecosystems were published since 1998. This likely reflects the increased interest in this kind of treatment by land management agencies. Additional and longer-term quantitative monitoring is needed to more thoroughly assess the effectiveness of seeding to prevent non-native species invasion after fire.

3.3 Does seeding after severe forest fires in the western USA affect native plant community recovery?

There is substantial evidence in older literature that seeded species may suppress recovery of native graminoids, forbs, and shrub and tree seedlings (Beyers, 2004). In recent years, non-persistent species have been increasingly used during post-fire seeding activities in an effort to lessen inference with recovering natives (Robichaud et al., 2000; Beyers, 2004). Effects of seeding on native plant recovery are strongly influenced by which species are seeded, post-fire precipitation intensity, and time since fire (Schoennagel and Waller, 1999; Barclay et al., 2004; Robichaud and Elliot, 2006; Wagenbrenner et al., 2006; Peterson et al., 2007; Rough, 2007).

Twenty-six papers included data addressing post-fire seeding effects on native plant recovery. The majority (62%, 16 papers) showed decreased cover of native species on seeded plots compared to unseeded, while 19% (5 papers) showing greater native species cover on seeded plots. Considering quality of evidence, 50% of the highest quality papers (3 of 6) found that seeding reduced native cover, and the remaining papers showed seeding to have no effect, minimal effect, or positive effect on native cover. Two out of 5 papers with high quality evidence found seeding reduced native cover, while two stated seeding increased native cover and the other showed minimal effect. Six of seven papers (86%) rated as medium quality evidence found that seeding reduced native cover, and 63% of the eight low and lowest quality of evidence studies determined that seeding inhibited the return of native species.

Of the highest and high quality evidence studies finding a reduction of native plant cover with seeding (5 papers), three suggested that seeding could have persistent effects on post-fire vegetation recovery. For example, Stella (2009) found that annual and biennial native forbs were significantly reduced in seeded treatments compared to unseeded treatments the first year after fire; this reduction persisted into the second year even though the cover of seeded species declined. Another southwestern U.S. study found a similar effect of seeding annual ryegrass (*Lolium perenne* ssp. *multiflorum* (Lam.) Husnot) on native forbs (Barclay et al., 2004): cover of native forbs in unseeded areas increased from year one to year two, but native forb cover in seeded areas remained constant even though ryegrass cover declined. The third study, conducted in the eastern Cascades, showed a reduction of native early-successional species and fire-dependent colonizers as a result of high frequency and cover of seeded non-natives. The researchers suggested that seeding effects could therefore alter native plant communities well beyond the life of the seeded species (Schoennagel and Waller, 1999).

Two studies with highest and high quality evidence found that seeding enhanced native plant cover (Springer et al., 2001; Hunter and Omi, 2006). Hunter and Omi (2006) examined how seeded species (a mixture of native cultivars and non-native annual grasses) and native grasses responded to increased availability of soil nitrogen and light after the Cerro Grande Fire in New Mexico. They found that cover of native species (those not seeded during post-fire rehabilitation efforts) increased over a four-year period in seeded areas of low fire severity and did not differ between seeded and unseeded areas of high fire severity, although seeded grass cover remained high. However, seeding treatments did reduce native species richness, at least at small scales (Hunter and Omi, 2006).

Both seeded species and native plant cover are highly influenced by post-fire precipitation. When unfavorable conditions (e.g., low precipitation) occur, seeding often has no effect on native species cover and/or recovery (Robichaud et al., 2006; Wagenbrenner et al., 2006; Peterson et al., 2007). In contrast, under favorable conditions seeded species can rapidly dominate the post-fire environment, which in turn may lead to low first-year native plant recruitment and subsequent reductions in native species over time. However, one long-term study revealed that 31 years after a fire in north-central Washington, non-native cultivars which dominated seeded sites initially were completely replaced by a diverse mixture of native graminoids, forbs, shrubs and trees (Roche et al., 2008). This study suggests that non-native grasses seeded after wildfires do not always have persistent effects on native plant communities, but long-term datasets like this one are rare.

Seeding treatment performance and effects are related to length of time since fire (Robichaud and Elliot, 2006; Rough, 2007). Cover data from 15 studies containing 57 different study sites showed seeded cover decreased significantly relative to control plot cover with increasing time since fire (p-value = 0.0447, Fig. 6). Total cover on seeded plots was more

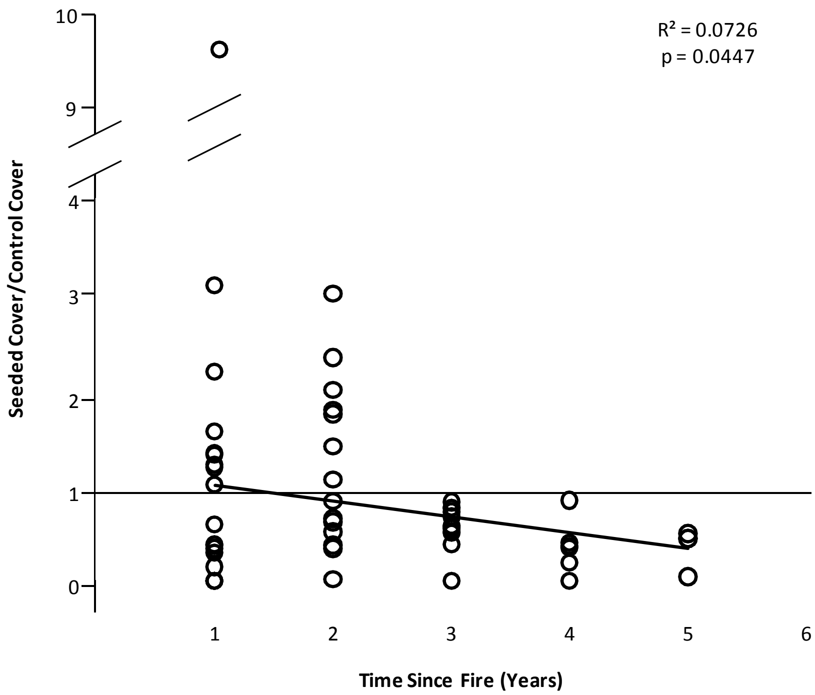

Figure 6. Ratio between seeded and control cover estimates versus time since fire in years (data from 57 sites). Ratios greater than one have greater seeded cover than control cover.

variable but only slightly higher on average than total cover on control sites for two years post-fire; after two years, control cover was consistently greater than seeded cover. However, of 13 sites with greater cover on seeded than unseeded sites in the first and/or second year post-fire, the majority (77%, 10 sites) occurred in ecoregions characterized by favorable rainfall intensity, amounts, and timing. In addition, in all of these sites annual cereal grains or non-native perennial grass species were either seeded alone (62%, 8 sites) or as a predominant proportion of a mix with natives cultivars and legumes (38%, 5 sites) (Anderson and Brooks, 1975; Griffin, 1982; Amaranthus, 1989; Amaranthus et al., 1993; Holzworth, 2003; Keeley, 2004; Logar, 2006; Roche et al., 2008). These results suggest that seeded species, in particular annual cereal grains, may exit the system quickly (Kuenzi et al. 2008) or be outcompeted by native or naturalized species after two years. However, data beyond two years from areas seeded with annual cereal grains are rare, so studies quantifying their ability for rapid die-off are limited.

Based on data from all 57 sites, by four years after fire both seeded and unseeded sites supported approximately 45% total plant cover and only 40-41% total plant cover after five year (Fig. 7). Seeded cover was relatively high for the first three years after fire (about the same as

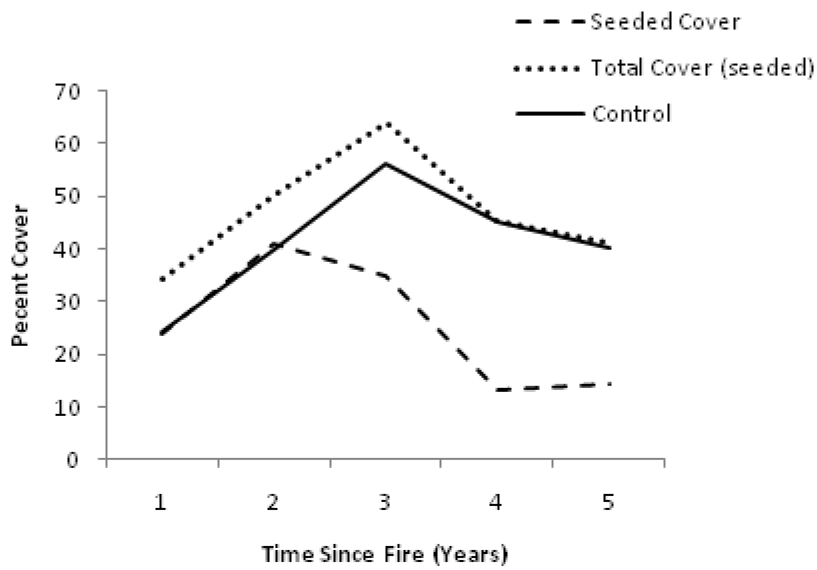

Figure 7. Average seeded cover and total cover (including seeded species) across seeded sites and total cover in control sites versus time since fire (data from 57 sites)

control cover during the first two years) but declined substantially to 13% and 14% in years four and five, respectively. The higher initial seeded cover suggests that one of the major goals of post-fire rehabilitation was being effectively met: seeded species established quickly and lasted for a few years, then decreased relative to other species. However, total cover in seeded sites and controls was nearly identical by years four and five, suggesting that the remaining seeded species were offsetting local plant species that would otherwise occupy the site. Regardless of species seeded, total cover values converged at four to five years post-fire, suggesting that ecosystems may only support a threshold level of plant cover (Connell and Slatyer, 1977; Noble and Slatyer, 1977) and post-fire seeding actually suppresses the establishment of local species after fires (Anderson and Brooks, 1975; Schoennagel and Waller, 1999; Sexton, 1998; Barclay et al., 2004; Keeley, 2004). Data from this review cannot assess the differences in vegetation composition between seeded and non-seeded sites. Longer-term monitoring results (e.g., > 5 years) are needed to assess lasting impacts of seeded species. Assessment of soil seed banks is also needed to determine whether seed of non-persistent seeded species can remain viable within the seed bank (Griffin 1982).

Seven of nine papers (78%) assessing the effect of seeding on native species richness reported negative effects, while the remaining two showed no difference in native species richness on seeded versus unseeded controls. Eighty-six percent of the papers providing highest and high quality evidence reported that seeding decreased native species richness. Two-thirds of these papers were published since 2000. Reduced native species richness is often a function of high dominance by seeded species (Conard et al., 1991; Amaranthus et al., 1993; Sexton, 1998; Schoennagel and Waller, 1999; Keeley, 2004). Authors defined seeded species dominance in terms of high cover, biomass, density, and/or frequency. In five cases, studies reported high seeded species dominance coincident with reduced native species richness. Conversely, Kruse et al. (2004) reported cereal barley (*Hordeum vulgare* L.) cover had no effect on native richness on a fire in northern California. Instead, this study linked reduced native species richness with cover of straw mulch, showing that direct competition for water or nutrients with actively growing seeded species was not the only way for a suppressive effect to occur (Kruse et al., 2004). Barclay et al. (2004) noted a reduction in native forb richness in the second year following fire in north-central New Mexico. However, this reduction coincided with low seeded annual ryegrass cover. The authors suggested that dominant ryegrass cover may have led to the suppression of native species in the first year, causing subsequent lack of reproduction of native forbs in the second year after ryegrass disappeared. However, total cover was also reported to be low; thus, the relative abundance of seeded ryegrass compared to other species may have remained high. In the two studies reporting no difference in native species richness between seeded and unseeded plots, one showed minimal cover of seeded annual species in both the first and second year post-fire in the Southwest (Stella, 2009). The other found that although seeded non-native annual and perennial grass and legume species had high dominance (cover and frequency) in seeded plots in the eastern Cascades, a native plant, pinegrass (*Calamagrostis rubescens* Buckley), also dominated the site, which may have counteracted any effects of seeded species abundance (Schoennagel, 1997).

Overall, the literature suggests that seeded species' dominance plays a critical role in determining species richness in the first and/or second year after fire. In cases where seeding is successful, reduced native species richness is likely. Mulching may also inhibit native species recovery as much as seeding (Schuman et al., 1991; Bakker et al., 2003; Kruse et al., 2004), as well having the potential to introduce non-species if the mulch used is not free of weeds (Kruse et al., 2004).

A number of studies examined competitive effects of seeded grasses on woody plant establishment. The potential for seeded grasses to compete with woody plant species can be viewed as positive or negative depending on the ecosystem or site being rehabilitated. Of 14 papers investigating post-fire seeding effects on tree seedling growth and shrub cover, the majority (79%, 11 papers) found seeding to negatively affect woody plant establishment. All studies seeded only grasses in treated plots. Half of the papers providing highest or high quality evidence (2 out of 4) found that seeding negatively affected tree seedling and/or shrub growth and survival. One paper reported seeding had no effect on the growth and survival of woody species, while the other showed seeding improved establishment. Of five studies quantifying shrub cover in sites seeded with non-native species versus unseeded controls (16 sites), shrub cover in unseeded plots was almost always higher than in seeded plots (Fig. 8).

Soil moisture likely influences establishment and survival of trees and shrubs, and soil moisture can be depleted more rapidly on seeded sites yielding high plant production, thus limiting water availability to woody plant species (Elliott and White, 1987). For example, Amaranthus et al. (1993) found that seeded annual ryegrass suppressed first-year pine seedling growth in southwestern Oregon by lowering soil moisture availability and reducing root-tip and mycorrhiza formation. In contrast, Sexton (1998) noted no difference in tree and shrub seedling establishment on plots seeded with annual ryegrass versus controls in south-central Oregon, in spite of similar soil moisture levels on seeded and control plots. A prescribed burn study in northwestern Arizona found increased shrub cover on seeded plots, but shrubs were included in the seeding treatment (Springer et al., 2001). Eight out of nine (89%) studies in the lower quality of evidence categories found reduced conifer seedlings and/or shrub growth and survival on sites dominated by seeded annual non-native species (Griffin, 1982; Conard et al., 1991; Schoennagel

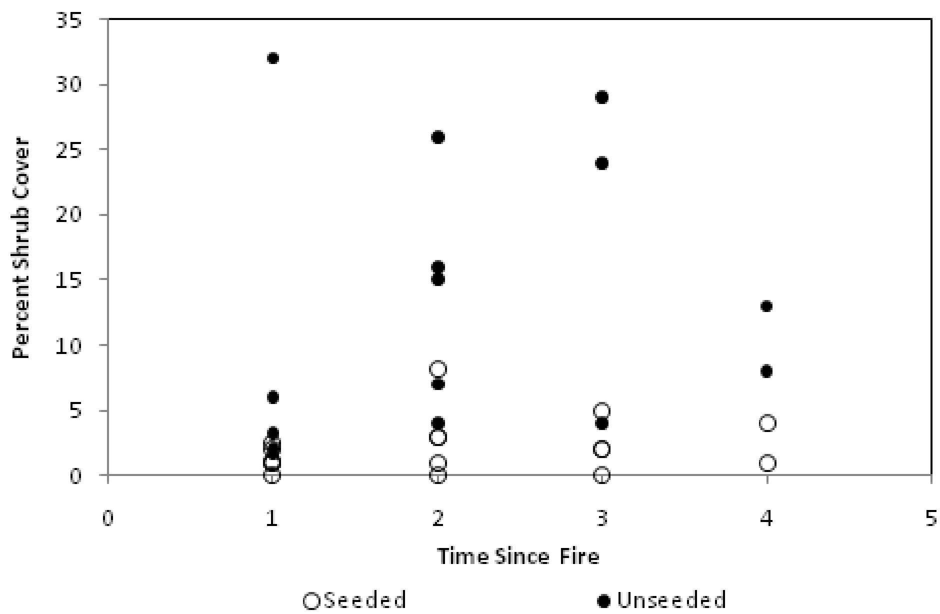

Figure 8. Percent shrub cover in seeded and unseeded sites versus time since fire in years (data from 16 sites)

and Waller, 1999; Barclay et al., 2004; Keeley, 2004; Kruse et al., 2004). These results suggest that seeding non-native annual species may negatively affect woody plant seedlings through competition for available resources (specifically soil moisture), space, and light during the first two years after fire (Beyers, 2004).

4. Conclusions

Severe wildfires can have profound effects on soils and plant communities. Over the last decade, areas of high-severity forest fires have increased by as much as an order of magnitude in the western United States (Westerling et al., 2006; Littell et al. 2009). Climate projections consistently suggest that trends of increasing size and severity of wildfires will continue (McKenzie et al., 2004). If correct, the need to rehabilitate burned areas will undoubtedly escalate. Among U.S. natural resource agencies, post-fire seeding treatments continue to be used as a first choice rehabilitation measure, although success of these treatments in achieving specified rehabilitation objectives remains highly debatable.

The scientific rigor of published evidence has increased since earlier reviews on post-fire rehabilitation identified a need for better designed studies to evaluate the effectiveness of seeding (Robichaud et al., 2000; GAO, 2003; Beyers, 2004). Evidence that seeding is often ineffective in meeting post-fire management objectives has strengthened as improved sampling designs produced more statistically robust data. The scientific literature and monitoring data show that post-fire seeding does little to protect soil in the short term and can have negative consequences for native plant recovery, particularly woody species. Erosion may be better reduced by mulching, but care must be taken to ensure that mulch is free of non-native seed. Plant community recovery may be improved with the use of locally-adapted, genetically appropriate plant materials, although more research regarding the effects and effectiveness of these species is critical. Seeding has proven to be equivocal at best for reducing non-native species spread after fire. Early detection of new undesirable species invasions through monitoring post-fire environments, in combination with rapid response methods to quickly contain, deny reproduction, and eliminate these invasions (Westbrooks, 2004), may allow better control of non-native species establishment than is typically obtained through seeding.

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CHAPTER TWO

Recent trends in post-wildfire seeding: Analysis of costs and use of native seed

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Abstract

Post-fire seeding is a widely used rehabilitation treatment in forested ecosystems throughout the West despite ongoing debates over the efficacy of these treatments. Little quantitative information is available on overall trends of post-fire seeding expenditures and use of native seed over time for the entire western U.S. We conducted a review of scientific articles, unpublished documents, and government publications as well as USDA Forest Service Burned Area Reports to determine trends in seeding over time. Out of 1164 USFS Burned Area Reports, 380 contained information on seeding treatments conducted in forested ecosystems specifically. Together, 40 papers and 67 Burned Area Reports reported species seeded on 122 fires across the western United States from 1970 to 2006. These data revealed a trend of increasing use of native species and annual cereal grains/hybrids, with natives dominating seed mixes rather than non-native species. According to 380 Burned Area Reports reporting seeding costs and amount area seeded, total post-fire seeding expenditures have increased substantially, reaching an average of $3.3 million per year spent on post-fire emergency seeding treatments in forested ecosystems that involved the Forest Service during the period 2000 to 2007 -- an increase of 192% compared to the average spent during the previous 30 years. The percentage of the total burned area seeded averaged 21% in the 1970s, compared to only 4% between 2000 and 2007, but the cost per hectare seeded has increased over time.

Additional keywords: post-fire seeding, Burn Area Emergency Response, native species, annual cereal grains

Introduction

By consuming protective vegetation and litter cover and increasing the availability of light and nutrients, high-intensity wildfires often result in increased erosion, runoff, sediment transport (Debano *et al.* 1998; Neary *et al.* 2005), and conditions favorable for non-native plant species invasions (DeBano *et al.* 1998; Crawford *et al.* 2001; Keeley *et al.* 2003; Wang and Kemball 2005; Freeman *et al.* 2007). These conditions often trigger prescription of emergency watershed rehabilitation measures required by land management agencies to minimize threats to life or property or to stabilize and prevent further degradation to natural and cultural resources resulting from the effects of wildfire (USDI and USDA 2006). Because vegetative cover acts to intercept precipitation, promote rapid infiltration, and utilize available resources, post-fire seeding treatments are recommended based on the assumption that rapidly establishing vegetative cover will minimize fire-induced effects on runoff and soil erosion (Debano *et al.* 1998; Robichaud *et al.* 2000; Benavides-Solorio and MacDonald 2001; Peterson *et al.* 2007) while curtailing invading non-native species (Robichaud *et al.* 2000; Grime 2001; Beyers 2004). Grass seeding to become one of the most commonly used methods to stabilize soils, establish ground cover for erosion control, and reduce non-native species invasions on firelines and hillslope areas that require immediate protection (Richards *et al.* 1998; Robichaud *et al.* 2000; Beyers 2004; Wolfson and Sieg, in press).

Historically, aerial broadcast seeding of grasses, typically non-native annuals or short-lived perennials, has been the most commonly used post-fire stabilization treatment (Robichaud *et al*. 2000). According to recent post-fire seeding reviews, use of native species has increased (Beyers 2004; Wolfson and Sieg, in press); however, high costs and restricted availability often limit inclusion of native plants in post-fire seedings. Instead, the recognized competitive ability of non-native and some native grass cultivars, coupled with their abundant availability and relative low costs, have resulted in continuted seeding with these species (Robichaud *et al.* 2000; Beyers 2004).

Even when low-cost seeding materials are selected, post-fire seeding activities are expensive (Robichaud *et al.* 2000). In an evaluation of U.S. Department of Agriculture Forest Service (hereafter USFS) Burned Area Emergency Response (BAER) spending on hillslope treatments in the western United States, Robichaud *et al.* (2000) identified total expenditures on aerial seeding to be the highest among post-fire rehabilitation hillslope treatments over time, although cost per unit area was considerably less than other rehabilitation treatments and total costs for seeding declined in the last years of their study. This practice remains the only method available to treat large areas at a reasonably low cost per hectare. In a more recent review of post-fire seeding practices in the southwestern U.S., Wolfson and Sieg (in press) noted that along with a decline in the area seeded, cost per hectare seeded generally increased over time.

Previous post-fire seeding reviews indicate that seeding treatments often do not result in sufficient vegetative cover to reduce erosion or invasions by undesirable non-native species (Robichaud *et al.* 2000; Beyers 2004). In addition, seeded plant species can negatively affect native plant communities through competition with recovering native species (Schoennagel and Waller 1999; Barclay 2004; Keeley 2004; Kruse *et al.* 2004), persistence of seeded non-native species (Sexton 1998; Barclay *et al*. 2004; Hunter *et al.* 2006), introduction of non-local genotypes when native species are used (Sexton 1998; Hunter *et al.* 2006), and spread of non-native invasive species through contaminated seed mixes (Barclay *et al.* 2004; Kruse *et al.* 2004). Thus, seeding may impose undesirable long-term ecological changes to ecosystem composition and structure (Beschta *et al.* 2004).

Currently, quantitative information on overall trends of post-fire seeding expenditures and use of native seed over time for the forested ecosystems in the western U.S. is lacking.

Robichaud *et al.* (2000) quantified USFS BAER treatment spending, which included post-fire seeding; however, their analysis was restricted to aerial seeding expenses between 1973 and 1998. More recent reviews by Beyers (2004) and Peppin *et al.* (in review; chapter 1 of this report) focused primarily on post-fire seeding effectiveness and impacts on native plant communities. Trends in species used and costs of seeding reviewed by Wolfson and Sieg (in press) were limited to the southwestern U.S. We reviewed scientific literature, theses, government publications, and USFS Burned Area Reports related to post-fire seeding in forested ecosystems across in the western U.S. to help answer: 1) What are trends in seeding of specific species, especially the use of native species, over time? and 2) How have other post-fire seeding trends, particularly those related to costs and area seeded, changed over time?

Methods

As part of a study reported in Peppin *et al.* (in review), we conducted a systematic review of literature on post-fire seeding. The systematic review methodology follows a rigorous, predetermined protocol to ensure that the synthesis of available literature is thorough, unbiased, and evidence-based (Pullin and Stewart 2006). We searched online databases (JSTOR, Google Scholar, Forest Science Database, Ingenta, Web of Science, AGRICOLA), online government collections, and electronic university libraries using combinations of key search terms: seeding AND fire, seeding AND burn, seeding AND wildfire, seeding AND erosion, and seeding AND native species. Refereed journal articles, peer-reviewed reports (such as government documents and conference proceedings), theses, and unpublished literature were considered. Potential studies were included based on the following specific criteria:

- *Subject(s) studied* – Seeding studies conducted in forests burned by wildfire in the U.S., predominately coniferous forests in western states, since 1970.
- *Treatment(s)* – Seeding herbaceous plant or shrub seed alone or in combination with other post-fire rehabilitation activities such as mulching, fertilizing, soil ripping, and log erosion barriers.
- *Outcome(s)* – Soil stabilization attributes, such as runoff, surface erosion, and sediment yield, and change in plant community attributes, such as cover, richness, diversity, biomass, and composition of native and non-native herbaceous plants, shrubs, and trees.

Peppin *et al.* (in review) identified 94 papers meeting the above criteria to evaluate treatment effectiveness and effects on soils and plant communities. For this study we used only those papers containing quantitative information on trends in seeding over time including: 1) area and amounts of seed used, 2) seed sources and species selected, 3) total cost of seeding, and 4) cost per hectare seeded. Both qualitative and quantitative data were extracted from the papers. We characterized the types of plant species seeded as non-native or native, in most cases following the author's classifications from the paper. However, lack of a widely accepted definition of "native" (Jones 2003) caused definitions to differ between papers. Ultimately, nativity was assigned according to the USDA Natural Resource Conservation Service Plants Database (http://plants.usda.gov/). When available, information about the geographic origin of seed sources used was extracted as well.

Both in the literature review and the analysis of USFS Burned Area Reports (below), only fires which were operationally seeded, with or without additional treatments, were used in our analysis. We excluded papers that evaluated experimental seeding treatments in the context of research studies rather than landscape-scale fire treatments. Only data obtained from seeding operations in forested ecosystems were included. We defined forested ecosystems as those dominated by coniferous and/or deciduous trees occurring at elevations above grasslands, pinyon-juniper woodlands, or chaparral vegetation in the western U.S. Only species that were seeded on at least three fires were used in our analysis.

Forest Service Burned Area Reports

We used a database developed originally by Robichaud *et al.* (2000) containing summaries of 1164 USFS Burned Area Report (FS-2500-8) forms to obtain information on BAER treatments prescribed for fires in the western U.S. from 1966 to 2007. The dataset was missing results from a number of Forest Service regions (2, 4, 5, and 6), particularly from the 1970s and 1980s, because the some of the paper records had been archived at the time of the study and were unobtainable (Robichaud *et al.* 2000). We limited our review to reports for projects which used seeding in forested ecosystems. Post-fire rehabilitation assessment reports from federal land management agencies under the Department of Interior (Bureau of Indian Affairs, National Park Service, Bureau of Land Management, and Fish and Wildlife Service) were not available in electronic format. In addition, many reports contained only information on what was planned, not what was actually implemented. Because of these complexities, burned area assessment data from these agencies were excluded. All BAER spending and treatment costs were adjusted to constant 2009 dollars (Federal Reserve Bank 2009).

Results and Discussion

What are trends in seeding of specific species, especially the use of native species, over time?

Out of the 1164 USFS Burned Area Reports, 380 contained information on seeding treatments conducted in forested ecosystems specifically, of which only 67 reported sources and species selected for seeding. Together, 40 reviewed papers and 67 Burned Area Reports provided information regarding species seeded on 122 fires across the western United States from 1970 to 2006 (Fig. 1).

According to reviewed papers and reports, 22 non-native and 12 native species have been used to seed at least three or more burned areas in the period 1970 to 2006 (Table 1). Perennial non-native species appear to be used almost exclusively from about 1970 to about the early 1980s (Fig. 1). However, many fires in California and the Pacific Northwest (for which data were missing in Burned Area Report assessment) used annual ryegrass extensively during this time period (Richards et al. 1998; Robichaud et al. 2000; Beyers 2004). During the 1980s, use of annual grasses, cereal grains, and native species increased, although perennial non-natives remained as the dominant seeded species. By 1990, the use of perennial non-natives declined as seed mixes incorporating cereal grains and/or cereal-grass hybrids and native species increased. Since the late 1990s and especially since 2000, it appears that seed mixes throughout the western U.S. have shifted to mixes consisting of native species and cereal grains and/or cereal-grass hybrids, with native species being seeded on a greater number of fires.

Table 1. Native and non-native seed species used on at least three fires for post-fire revegetation in forest lands of the western U.S. between 1970 and 2006 and the number of fires/decade on which each species was seeded .

Species Name	Common Name	Life Form[A]	Life Cycle[B]	Number of Fires Seeded by Decade			
				1970-1979	1980-1989	1990-1999	2000-2006
Non-native[C]							
Agropyron cristatum (L.) Gaertn.	crested wheatgrass	g	p	2	2	1	0
Avena sativa L.	common oat	g	a	0	1	2	1
Bromus inermis Leyss.	smooth brome	g	p	3	11	6	0
Dactylis glomerata L.	orchardgrass	g	p	9	16	7	0
Eragrostis curvula (Schrad.) Nees	weeping lovegrass	g	p	0	3	2	0
Festuca brevipila Tracey	hard fescue	g	p	2	2	0	0
Festuca ovina L.	sheep fescue	g	p	4	2	3	0
Hordeum vulgare L.	cereal barley	g	a	0	3	9	5
Lolium perenne L. ssp. *multiflorum* (Lam.) Husnot	Italian ryegrass/annual ryegrass	g	a/b	1	8	14	1
Lolium perenne L.	perennial ryegrass	g	p	4	3	0	2
Lotus corniculatus L.	bird's-foot trefoil	f	p	2	1	0	0
Medicago spp.	alfafa	f	a/p	0	1	2	0
Melilotus officinalis (L.) Lam.	yellow sweetclover	f	a/b/p	7	8	8	1
Phleum pratense L.	timothy	g	p	8	4	7	0
Secale cereal L.	cereal rye	g	a	2	7	3	0
Sanguisorba minor Scop.	small burnett	f	p	0	3	2	0
Thinopyrum intermedium (Host) Barkworth & D.R. Dewey	intermediate wheatgrass	g	p	4	8	5	0
Trifolium hybridum L.	alsike clover	f	p	0	0	3	0
Trifolium repens L.	white clover	f	p	2	6	3	0
Triticum x *Agropyron*	Regreen	g	x	0	0	9	1
Triticum aestivum L.	common wheat	g	a	0	2	7	4
Vulpia myuros (L.) C.C. Gmel.	rat-tail fescue	g	a	0	4	1	0

Table 1 (Continued)

Species Name	Common Name	Life Form[A]	Life Cycle[B]	Number of Fires Seeded by Decade			
				1970-1979	1980-1989	1990-1999	2000-2006
Native[C]							
Bouteloua curtipendula (Willd. Ex Kunth) Lag. Ex Griffiths	blue grama	g	p	0	0	3	1
Bromus marginatus Nees ex Steud.	mountain brome	g	p	0	5	8	3
Elymus glaucus Buckley	blue wildrye	g	p	2	0	1	1
Elymus lanceolatus (Scribn. & J.G. Sm.) Gould	thickspike wheatgrass	g	p	0	1	2	1
Elymus trachycaulus (Link) Gould ex Shinners	slender wheatgrass	g	p	6	7	15	5
Festuca arizonica Vasey	Arizona fescue	g	p	0	0	3	2
Festuca idahoensis Elmer	Idaho fescue	g	p	0	0	3	2
Koeleria macrantha (Ledeb.) J.A. Schultes	prairie junegrass	g	p	0	0	3	1
Nassella viridula (Trin.) Barkworth	green needlegrass	g	p	0	1	2	2
Pascopyrum smithii (Rydb.) A. Löve	western wheatgrass	g	p	0	5	3	3
Poa canbyi J. Presl	sandberg bluegrass	g	p	0	1	2	1
Sporobolus cryptandrus (Torr.) Gray	sand dropseed	g	p	0	0	2	2

[A] g = grass, f = forb
[B] a = annual, b = biennial, p = perennial, x = “sterile” hybrid

[C] Nativity per USDA NRCS Plants Database (http://plants.usda.gov/)

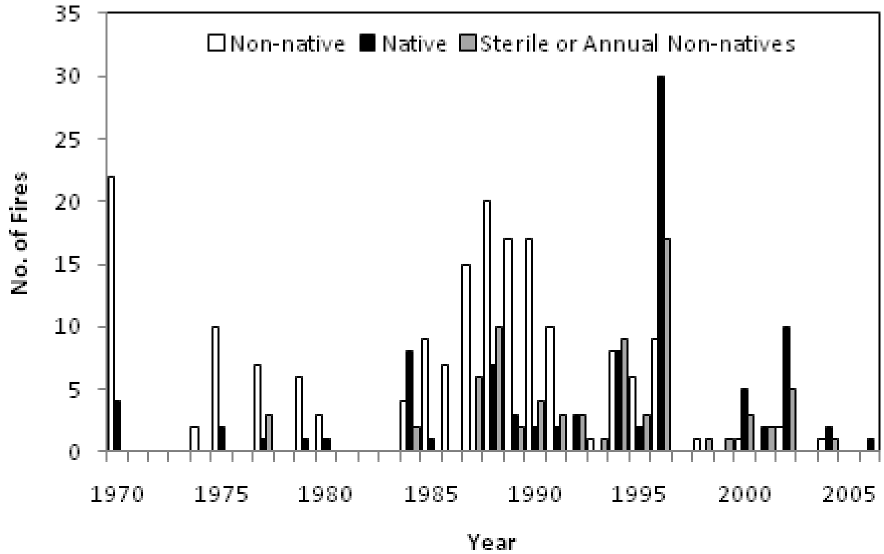

Figure 1. Number of fires seeded with non-native, native, and annual cereal grain species from 1970-2005. Graph shows only seeded species used on at least three fires for rehabilitation. Values for the 1970s and 1980s are minimum estimates due to incomplete collection of Burned Area Reports from those decades.

The most frequently used species in the 1970s were yellow sweetclover (*Melilotus officinalis* (L.) Lam), orchardgrass (*Dactylis glomerata* L.), timothy (*Phleum pratense* L.), sheep fescue (*Festuca ovina* L.), and perennial ryegrass (*Lolium perenne* L.) (Table 1). In the 1980s perennial grasses such as orchardgrass and smooth brome (*Bromus inermis* Leyss.) still dominated seeded mixes, but annual ryegrass (*Lolium perenne* spp. *multiflorum* (Lam.) Husnot) was used almost as often. Use of slender wheatgrass (*Elymus trachycaulus* (Link) Gould ex Shinners), mountain brome (*Bromus marginatus* Ness ex Steud.) (both natives), cereal rye (*Secale cereal* L.), and intermediate wheatgrass (*Thinopyrum intermedium* (Host) Barkworth & D.R. Dewey, non-native) increased in this period as well. Slender wheatgrass continued in popularity through 2005. During the 1990s, the number of native species and cereal grains and sterile hybrids used on burned areas increased dramatically, with the most frequently used being slender wheatgrass, mountain brome, “Regreen®” (*Triticum* x *Agropyron*), and cereal barley (*Hordeum vulgare* L.); non-native annual ryegrass continued in popularity as well, however. Between 2000 and 2006, cereal barley and slender wheatgrass continued as the most commonly seeded species, followed by mountain brome and western wheatgrass (*Pascopyrum smithii* (Rydb.) A. Löve).

Since the 1990s, use of annual non-natives and cereal grains or sterile cereal-grass hybrids has increased, exceeding that of perennial non-natives in the years 2000-2006. Annual non-native species (e.g., annual ryegrass) and cereal grains or sterile hybrids are expected to provide quick cover in the first year and then die out to let native vegetation reoccupy the site in subsequent years (Beyers 2004). Some evidence demonstrates this rapid die-off (Barclay *et al.* 2004; Keeley 2004; Loftin 2004; Kuenzi *et al.* 2008). However, other studies have shown that these species can persist (Conard *et al.* 1991; Sexton 1998, Schoennagel and Waller 1999).

Conard *et al.* (1991) found the greatest reduction in native species cover, relative to unseeded plots, during the second and subsequent years after fire. These results suggest that seeding non-native annual or sterile cereal grains may delay the recovery of native flora in some circumstances and therefore alter local plant diversity many years after fire.

Increased demand in recent years has lead to the increased availability of many native species and lowered their cost (Erickson 2008). Local genotype seed sources (seed of plants adapted to local site conditions and genetically compatible with existing plant populations) are required by recent policy "when possible" (Richards *et al.* 1998; USDA 2006). Inclusion of local genotypes is rare due to low availability and high costs (Beschta *et al.* 2004). Many of the native species included in post-fire seed mixes are usually not from local sources and instead came from accessions propagated in field-grown settings (Barclay *et al.* 2004; Hunter *et al.* 2006; Kuenzi *et al.* 2008; Stella 2009). Seeding with non-local genotypes of native species may have long-term genetic consequences on local plant communities due to outbreeding effects (Linhart 1995; Montalvo and Ellstrand 2001). Thus, although the use of native species has increased, use of non-native annuals continues, and there is uncertainty as to whether many natives are genetically appropriate for areas seeded.

The increasing magnitude of severe wildfires and non-native species invasions has been the impetus for government initiatives to develop and use native plant materials (Monsen and Shaw 2001). Since 2000, several interagency projects have been developed to meet the need for increased genetically appropriate plant material availability and production information (Pellant *et al.* 2004; Shaw *et al.* 2005). Most of these efforts are focused on grass- and shrublands in the Great Basin region (Monsen and Shaw 2001). Assuming trends of increased seeding of native species on forested lands continue, there is a need to enhance production and availability of locally-adapted species for these ecosystems as well.

How have other post-fire seeding trends, particularly those related to costs and area seeded, changed over time?

According to data from the 380 USFS Burned Area Reports, over the past four decades (1973-2007) more than $60 million was spent on post-fire seeding in forested ecosystems involving the USDA Forest Service (Fig. 2). Of that, about 78% ($47 million) came from National Forest Systems to seed about 405,000 hectares (1 million acres) of a total of 6 million hectares (15 million acres) from BAER project fires in these systems (Fig. 3).

About 80% (~5 million hectares [12 million acres]) of the total area burned was on National Forest System lands. Since 2000, total area burned and expenditures for BAER seeding treatments have increased substantially when compared to the preceding three decades (Figs 2 & 3). For example, 66% (4 million hectares [10 million acres]) of the total area burned in the last four decades burned since 2000, of which 82 percent occurred on National Forest System lands. However, due to gaps in data collected, total area burned is at best a minimum estimate. From 2000-2007 an average of $3.3 million per year was spent on post-fire emergency seeding treatments in forested ecosystems that involved the Forest Service -- an increase of 192% compared to the average spent during the previous 30 years. Of the $26 million spent in total on post-fire emergency seeding treatments in forested ecosystems that involved the Forest Service about $17 million came from National Forest Systems with the largest expenditure during the 2002 fire season. Regions 2, 3, and 4 accounted for 70% of the BAER spending on seeding from

2000-2007, with Region 3 spending the most (32%; Fig. 4). Total area burned by year shows a trend similar to that for spending on seeding between 1973 and 2007, except in 2006 and 2007, when a greater number of hectares burned compared to amount spent on seeding.

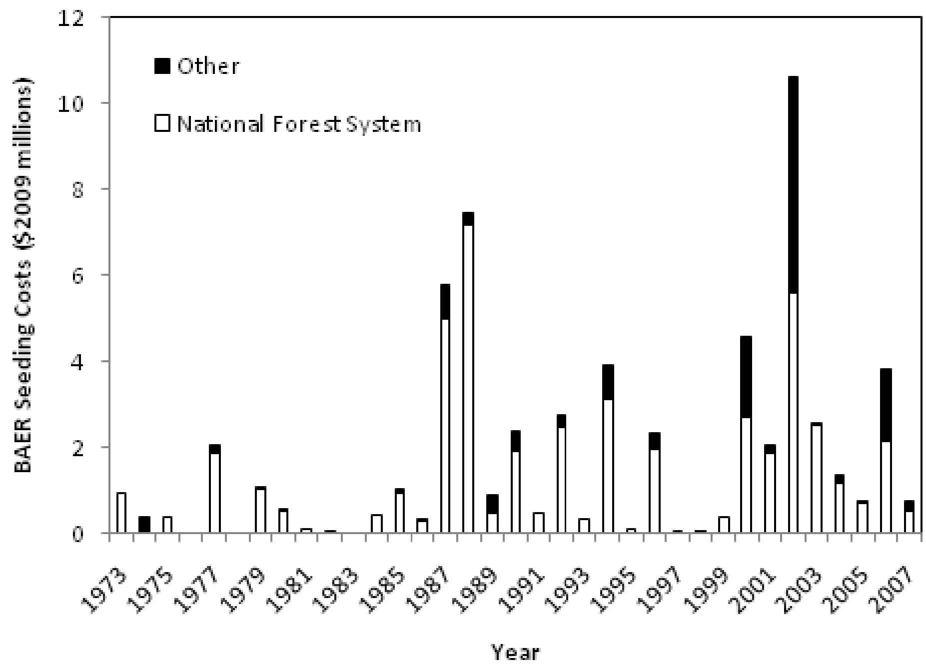

Figure 2. BAER seeding costs in forested ecosystems by National Forests and other entities that include National Forests by year in 2009 dollars. Values for the 1970s and 1980s are minimum estimates due to incomplete collection of Burned Area Reports from those decades.

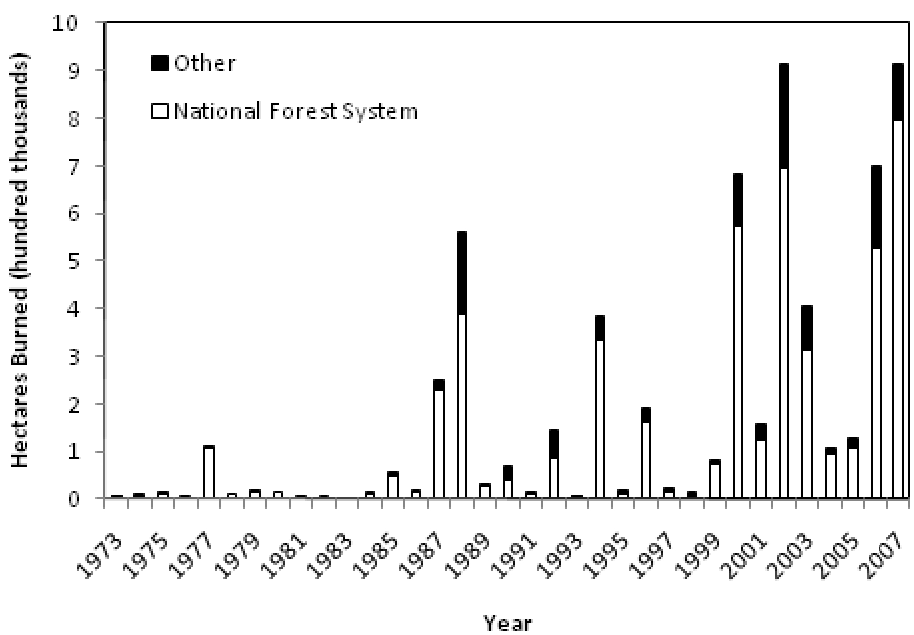

Figure 3. Total hectares (1 hectare = 2.47 acres) burned in forested ecosystems in National Forests and other lands that had some portion of National Forest lands by year from the Burned Area Reports. Values for the 1970s and 1980s are minimum estimates due to incomplete collection of Burned Area Reports from those decades.

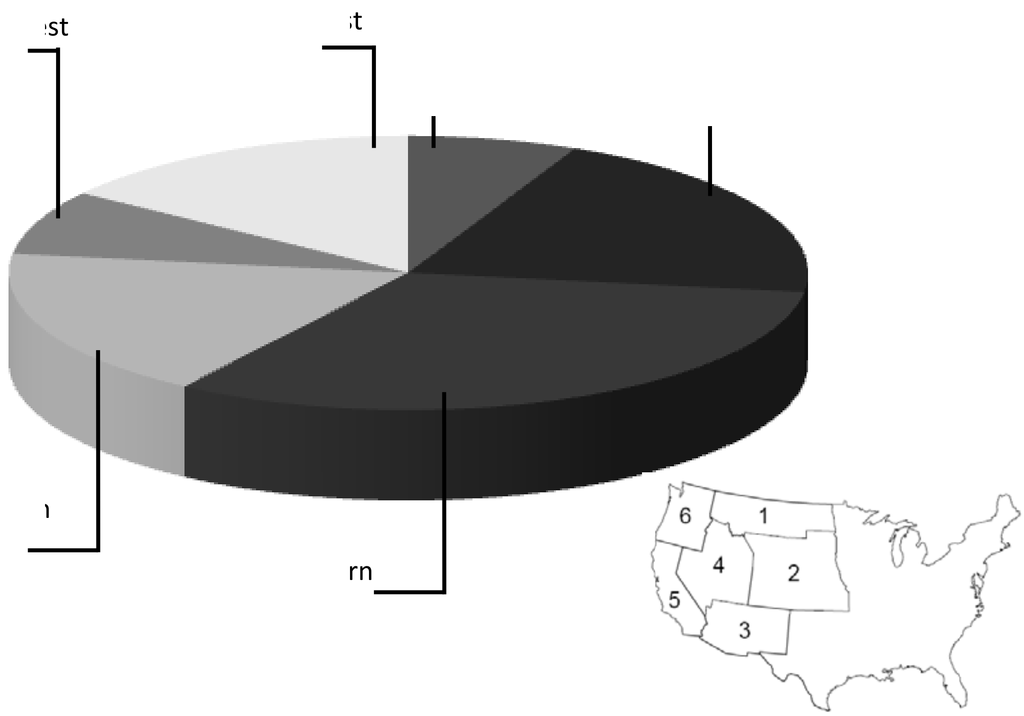

Figure 4. Proportion of National Forest BAER seeding costs by Region in forested ecosystems for 2000-2007 from Burned Area Reports. Amounts for all years were converted to 2009 dollars before calculation. The insert shows the western National Forest Regions used in this study.

In recent years, the percentage of burned areas seeded in forested ecosystems, including National Forests and other lands, has decreased substantially (Fig. 5). For example, an average of 21% of the total burned area was seeded across the previous three decades, with the highest percentage seeded in the 1970s (26%). This declined in the 1980s to 14% but increased to 24% in the 1990s. In the most recent period, from 2000-2007, the proportion of burned area seeded declined dramatically to an average of 4%. The average annual cost per hectare seeded generally increased over time (p-value = 0.016, Fig. 6). As BAER teams seeded smaller portions of burned areas, more money was being spent on seeding treatments per hectare. The elevated cost of seeding is likely a reflection of increased use of native species and sterile hybrids like Regreen®. In recent years, additional treatments such as fertilizer and/or mulch have been used in conjunction with seeding to improve treatment success rates (increased cover), but these additions are expensive to apply (Robichaud *et al.* 2000). It is likely that high costs associated with fertilizing and mulching have contributed to higher total cost of post-fire seeding treatments.

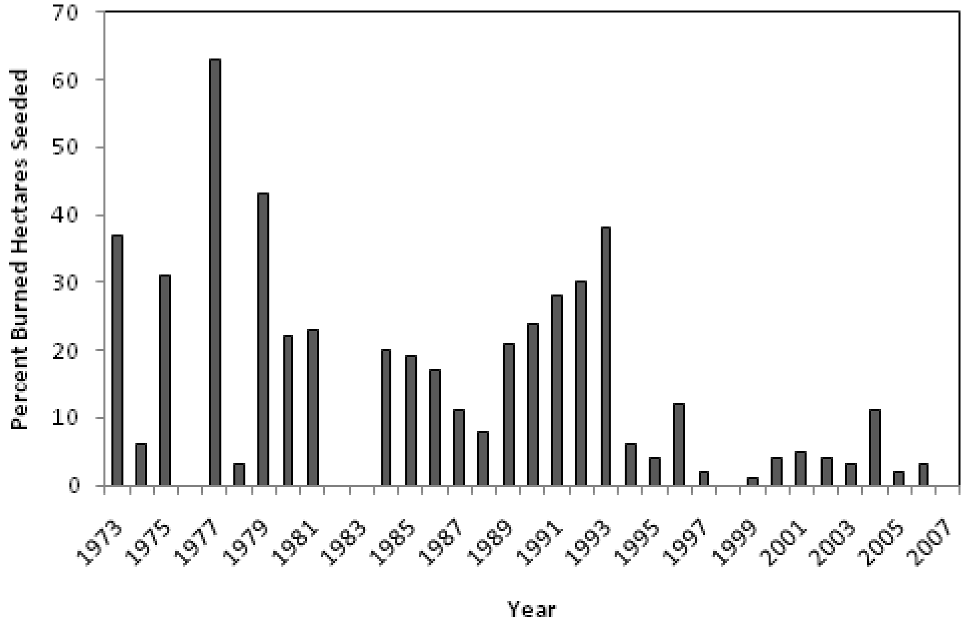

Figure 5. Percentage of total burned hectares (1 hectare = 2.47 acres) seeded 1973-2007 from Burned Area Reports.

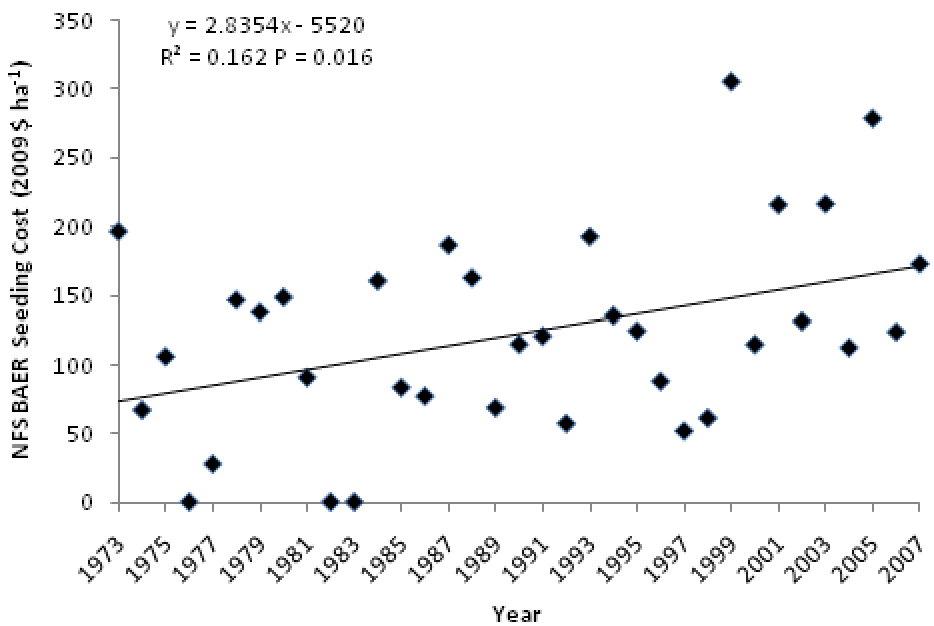

Figure 6. National Forest BAER seeding cost per hectare (1 hectare = 2.47 acres) burned in forested ecosystems by year from Burned Area Reports.

Conclusions and Management Implications

Our review of post-fire seeding practices in the western U.S. over the last four decades revealed a trend of increasing use of native species and annual cereal grains or sterile hybrids, with native species dominating seed mixes in recent years. Total USFS BAER seeding expenditures have increased substantially in the last decade. The expenditures roughly track the increased area burned, but in fact smaller proportions of burned areas have been seeded annually at higher cost per seeded hectare, likely due to increased use of costlier native species. Cereal barley, slender wheatgrass, mountain brome, and western wheatgrass were identified as the most commonly selected species for reseeding wildfires since 2000. The decline in the use of perennial non-native species is encouraging to many biologists, as those species have been shown to disrupt recovery of native plant communities. Current choices for seeding are not without concern, however. Cereal grains or sterile cereal/grass hybrids, while generally short-lived, can occasionally persist into subsequent years, which may result in delayed recovery of native species. Use of non-local genotypes of native species does occur, and this may result in alteration of the diversity and genetic composition of locally occurring species (Lynch 1991; Hufford and Mazer 2003).

The success of post-fire seeding treatments in achieving specified rehabilitation objectives remains debatable (Peppin *et al.* in review). Before spending public funds on seeding, land managers should weigh the cost/benefit of these treatments and consider using alternative rehabilitation methods shown to be more effective (e.g., mulching). Where seeding with natives continues, the use of locally-adapted and genetically-appropriate seed sources should be promoted. Until seed transfer zones of species used during post-fire seeding are defined, however, land managers may want to consider limiting use of non-local (or unknown) genotypes. Priority should be given to research quantifying the effects of using native species and cereal grains or cereal/grass hybrids on burned landscapes.

Acknowledgments

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CHAPTER THREE

Summary of information from web-based surveys with seed suppliers contained in "Market perceptions and opportunities for native plant production on the southern Colorado Plateau"

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Reference: Peppin, D.L., P.Z. Fulè, J.C. Lynn, A.L. Motteck-Lucas, and C.H. Sieg. *In press.* Market perceptions and opportunities for native plant production on the southern Colorado Plateau. *Restoration Ecology.*

Abstract

We summarize findings from web-based surveys with seed suppliers investigating perceptions and the potential for the initiation of a native plant market in the southern Colorado Plateau region. Due to a lack of seed suppliers within the region, web-based surveys were administered to both large and small-scale seed production companies in Arizona, New Mexico, nearby western and Great Plains states, and other successful seed production companies. The information gained from this study relates widely to seed producers across to the western United States. Many suppliers (80%) recognize the importance of supplying local genotypes and agreed (70%) that there is a current market for an enhanced supply of native seed to meet large-scale restoration demands, specifically of grass species. However, producers stated lack of "consistent and reliable demand" (38%) from buyers was the most significant limitation to a business involved in the production of native plant materials followed by "knowledge of native plant production" (21%). These issues in combination with limitations and issues associated with harvesting and/or production, difficulties in determining what constitutes a "local genotype," and lack of funding make suppliers hesitant in furthering the development and production of local genotypes. Increased communication and collaboration with commercial seed suppliers is necessary to develop an adequate supply of native seed. To develop a more reliable market, utilizing contracting options may further encourage native seed market development by reducing limitations related to funding and unreliable demand.

Introduction

Land management agencies such as the U.S. Forest Service (USFS) and U.S. Bureau of Land Management (BLM) are required to prescribe emergency watershed-rehabilitation measures when and where deemed necessary to (1) stabilize soil; (2) control water, sediment, and debris movement; (3) prevent ecosystem degradation; and (4) to minimize threats to human life or property. In the U.S. Southwest, seed used for post-fire seeding has shifted from mixes dominated by perennial non-native species to mixes incorporating more native species (Wolfson & Sieg, in press), although non-natives are still used. Beyond post-wildfire rehabilitation, revegetation is an integral component of other land management practices in the region including invasive species management, livestock grazing, wildlife habitat management, roadside rehabilitation, mine reclamation, and recreational use. Agency revegetation policies increasingly stress using native plant materials (NPM) and recognize the importance of using locally-adapted NPM during restoration and rehabilitation activities (Richards et al. 1998; Erickson 2008). In the Great Basin, interagency projects have been developed to meet the need for increased NPM availability (Pellant et al. 2004; Shaw et al. 2005). However, in the Southwest, federal, state, tribal, nonprofit, and private entities presently purchase restoration materials primarily from distant sources. Thus, regional projects continually incorporate non-local genetic materials, which may be more susceptible to the effects of changing environments (Huenneke 1991; Schmid 1994; Rogers & Montalvo 2004) and may threaten the long-term sustainability of restored sites (Lynch 1991; Hufford & Mazer 2003) as well as local populations with which they may interbreed (Linhart 1995; Montalvo & Ellstrand 2001). We addressed two questions: 1) What are the needs and concerns of supply stakeholders involved with NPM? 2) What factors limit the initiation of a NPM market in the southern Colorado Plateau?

Methods

A web-based survey was developed to assess current native plant market perceptions. A supply survey was administered to a targeted group of individuals from both large and small-scale seed production companies in Arizona, New Mexico, nearby western and Great Plains states, and other successful seed production companies (Table 1).

We developed 37 questions for the supply survey based on preliminary information from interviews and current literature (Richards et al. 1998; Soller 2003; Hooper 2003). Each survey question was arranged into a series of related survey questions and placed within five thematic areas pertaining to native plant materials: 1) policy and regulation; 2) issues and concerns; 3) purchasing and expenditures; 4) future use and needs; and 5) collaboration and funding. Thirty-nine finalized supply surveys were created and administered online (Andrews et al. 2003; Kaplowitz et al. 2004) using the web tool SurveyMonkey (www.surveymonkey.com).

Analysis of final survey response datasets was completed using Statistical Package for the Social Sciences (SPSS) software (SPSS 2007). Survey answer frequencies (n) and valid percents of respondent participation were calculated for each question. Survey responses “Don’t know” and “Decline to answer” were not included in the valid percent calculations. For questions that offered multiple responses, total percentages could exceed 100. Percents were rounded, which could cause totals to be slightly greater or less than 100%.

Table 1. Location and total number of potential commercial seed company respondents

State	Number of Supply Participants
Arizona	4
California	4
Colorado	7
Idaho	2
Montana	1
Nevada	2
New Mexico	4
Oregon	2
Utah	5
Washington	3
Wyoming	1
Other (OK, MN, NE, WI)	4
Total	**39**

Results and Discussion

Seed producers and distributors completed 33 web-based surveys (85% response rate) from the targeted sample group (n=39). Here we summarize findings and discuss information obtained from the surveys in the context of this JFSP project. Due to non-random sample selection and a small sample size (n=39), extrapolation of results and conclusions to a larger population should be considered cautiously (Babbie 2004).

Communication and collaboration with commercial seed suppliers will be necessary to develop an adequate supply of native seed and, more specifically, improve availability of genetic sources that meet agency requirements. Of the suppliers surveyed, most (32%) sold “seeds” and, more specifically, several species of wheatgrass, a common species used during post-fire seeding actitivies (see Chapter 2 of this report). The majority of suppliers (80%) indicated that producing local genotypes was “very important” to “somewhat important” (33% and 47%, respectively) to their organization. Moreover, the majority (70%) agreed that there is a current market for an enhanced supply of native seed, specifically of grass species, to meet large-scale restoration demands. Increased importance by federal agencies for the use of native species for seeding has contributed to the recognition by seed suppliers for the need to enhance native seed supply. Moreover, implementation of stronger native plant policies has stimulated the development of new certified seed categories that accommodate the use of native plant germplasm (Jones & Young 2005). These categories provide accurate documentation of collection sites and/or cultivated production to buyers seeking site-appropriate native plant materials (AOSCA 2003). According to recent literature, suppliers are beginning to offer certified native seed as the demand for it has increased (Loftin 2004; Jones & Young 2005). Supply survey respondents noted that decisions to sell certified seed are strongly influenced by both their own ecological ethics (27%) and federal and state policy (22% and 27%, respectively); however, it appears that increases in demand often overshadow seed source concerns.

Lack of “consistent and reliable demand” from buyers (38%) and “knowledge of native plant production” (21%) (Fig. 1) make suppliers hesitant in furthering the development of local genotype plant materials. These limitations are compounded by difficulties associated with high costs, complications during the harvesting and/or production of NPM, and difficulties in determining what constitutes a “local genotype.” Fluctuating requests for species, types of genetic material, and amounts needed make suppliers hesitant to further the development and production of local genotypes. Uncertainty about these factors creates dilemmas for suppliers faced with deciding what types and how much material to produce and market (Hooper 2003).

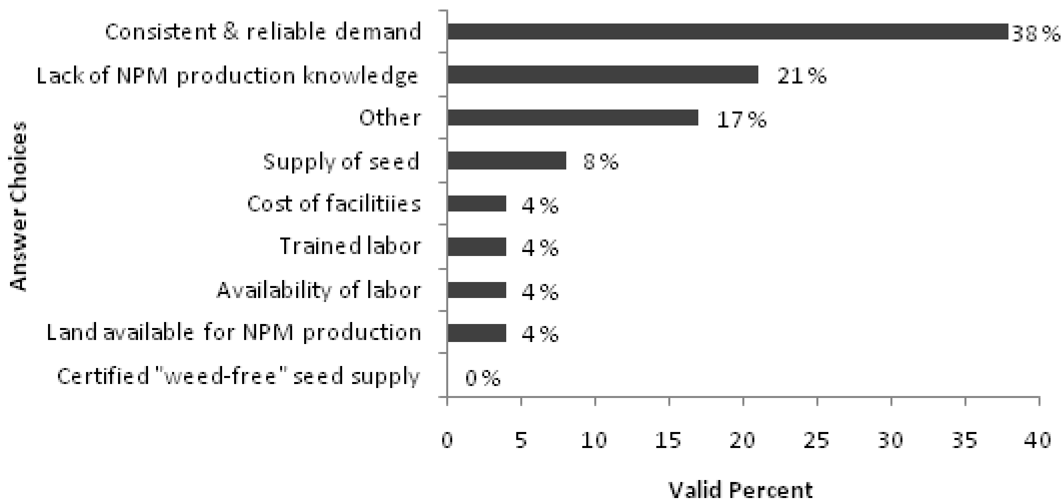

Figure 1. What is the most significant limitation to a business involved in the production of native plant materials (plants and/or seeds)?

Over the years a wealth of information has accumulated regarding NPM production (Pellant et al. 2004; Shaw et al. 2005). Increased communication and information transfer regarding available production guidelines (Potts et al. 2002) would further encourage potential suppliers to grow needed NPM. Greater information sharing may also help to lower NPM costs by providing suppliers with cost-effective production techniques. Finding common ground on the genetic classification of local plant materials in demand will be critical to effectively develop increased local genotype plant materials sold in commercial seed markets. Forms of contracting, such as stewardship contracting and indefinite-delivery/indefinite-quantity contracts, are available and have been used by federal entities to provide market incentives to further encourage partnerships with the private sector (Erickson 2008; US GAO 2008). Utilizing contracting options may further encourage native seed market development by reducing limitations related to funding and unreliable demand. Ideally, a major goal would be to develop regionally specific markets with enough seed suppliers to produce sufficient quantities of local-genotype seed to meet current restoration demands.

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DELIVERABLE CROSS-WALK TABLE

Proposed	**Delivered**	**Status**
Referred or peer-reviewed technical publications	Peppin, D.L., Fulé, P.Z., Sieg, C.H., Hunter, M.E., Beyers, J.L. Post-fire seeding in forests of the West: An evidence-based review. *In review* Peppin, D.L., Fulé, P.Z., Sieg, C.H., Hunter, M.E., Beyers, J.L., Robichaud, P.R. Post-wildfire seeding in forests of the West: trends, costs, effects, and use of native seed. *In prep.* Information on managers´ perceptions of post-fire seeding and native seed use: information collected, results are in internal review and will be communicated to JFSP when complete.	In review with *Forest Ecology and Management*, posted on Centre for Evidence-Based Conservation website To be submitted to *International Journal of Wildland Fire* In revision; paper on managers' perceptions of seeding will be submitted to the *Journal of Forestry* after revisions and review are completed.
Searchable multimedia DVD	Documents on DVD includes full written report, full index of citations usded (in a varied of formats downloadable into online citation managers (RefWorks, ProCite, EndNote, etc.)),	Completed, submission of hard copy to JFSP
Project Website	http://www.eri.nau.edu/en/arizona/post-wildfire_seeding_review-jfsp-report http://www.environmentalevidence.org/SR60.html	Updated as needed
In-person presentation of findings	Post-wildfire seeding in forests and rangelands of the West: trends, costs, effects, and use of native seed. 2009. Association for Fire Ecology - 4th International Fire Ecology and Management Congress, November 30 –December 4, 2009. Savannah, Georgia Invited speaker and panelist. 2009. Joint Fire Science Program special session - Association for Fire Ecology – 4th International Fire Ecology and Management Congress, November 30 – December 4, 2009. Savannah, Georgia Post-wildfire seeding in forests on federal lands: Trends, costs, effectiveness, and use of native seed. 2008. Wildfires and Invasive Plants in American Deserts Conference and Workshop. December 9-11, 2008. Reno, Nevada 2010 SWSAF Spring Meeting – "Merging Science and Management," April 9, 2010. Flagstaff, Arizona	Completed Completed Completed Completed

Appendix A: Evidence-Based Review References (w/ quality of evidence ratings [Table 1; page 9 in Chapter 1 of this report])

Abbreviated Description of Quality of Evidence Ratings:

***Highest* –** replicated, controlled, statistically robust;
High – unreplicated, controlled, observational (multiple sites), quantitative;
***Medium* –** unreplicated, controlled, observational (single location), quantitative;
Low – unreplicated, uncontrolled, quantitative;
***Lowest* –** unreplicated, uncontrolled, qualitative

Amaranthus, M. P. 1989. Effect of grass seeding and fertilizing on surface erosion in two intensely burned sites in southwest Oregon. In: Berg, Neil H., tech. coord. Proceedings of the symposium on fire and watershed management, October 26-28, 1988, Sacramento, California. Gen. Tech. Rep. PSW-109. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station: 148-149.
Quality of Evidence Rating: *Highest*

Amaranthus, M. P., J. M. Trappe, D. A. Perry. 1993. Soil Moisture, native revegetation, and *Pinus lambertiana* seedling survival, growth, and mycorrhiza formation following wildfire and grass seeding. Restoration Ecology 1:188-95.
Quality of Evidence Rating: *Highest*

Anderson, W.E., and L.E. Brooks. 1975. Reducing erosion hazard on a burned forest in Oregon by seeding. Journal of Range Management. 28:394-398.
Quality of Evidence Rating: *Medium*

Barclay, A.D., J.L. Betancourt, C.D. Allen. 2004. Effects of seeding ryegrass (*Lolium multiflorum*) on vegetation recovery following fire in a ponderosa pine (*Pinus ponderosa*) forest. International Journal of Wildland Fire 13:183-194.
Quality of Evidence Rating: *Highest*

Becker, R. 2001. Effective aerial reseeding methods: Market search report. USDA Forest Service 5100 - Fire Management, 0151 1204 - San Dimas Technology & Development Center, San Dimas, CA.
Quality of Evidence Rating: *Lowest*

Beschta, R.L., J.J. Rhodes, J.B. Kauffman, R.E. Gresswell, G.W. Minshall, J.R. Karr, D.A.Perry, F.R. Hauer, C.A. Frissell. 2003. Postfire management of forested public lands of the western United States. Conservation Biology 18:957-967.
Quality of Evidence Rating: *High*

Beyers, J.L. 2004. Post-fire seeding for erosion control: effectiveness and impacts on native plant communities. Conservation Biology 18:947-956.
Quality of Evidence Rating: *High*

Bruggink, J. 2007. Long term ecological changes with post-fire emergency seeding. Advancing the Fundamental Sciences: Proceedings of the Forest Service National Earth Sciences Conference, PNWGTR-689, San Diego, CA. 20-26.
Quality of Evidence Rating: ***Low***

Buckley, K. J., J. Walterscheid, S. Loftin, G. Kuyumjian. 2002. Progress report on Los Alamos National Laboratory Cerro Grande fire rehabilitation activities one year after burned area rehabilitation. Los Alamos National Laboratory Report LA-UR-02-4921, Los Alamos, NM.
Quality of Evidence Rating: ***Low***

Buckley, K. J., J. Walterscheid, S. Loftin, G. Kuyumjian. 2003. Progress report on Los Alamos National Laboratory Cerro Grande fire rehabilitation activities: Status of burned area rehabilitation two years postfire. Los Alamos National Laboratory Report LA-UR-03-5196, Los Alamos, NM.
Quality of Evidence Rating: ***Low***

Callahan, K., and B. Baker. 1997. Crystal burn analysis. Postfire succession and seeding monitoring: year three. Unpublished report on file at: U.S. Department of Agriculture, Forst Service, Tahoe National Forest, CA. 23 p.
Quality of Evidence Rating: ***Low***

Christensen, M. D., J. A. Young, R.A. Evans. 1974. Control of annual grasses and revegetation in ponderosa pine woodlands. Journal of Range Management 27:143-145.
Quality of Evidence Rating: ***Highest***

Clark, J.T, and G.A. Kuyumjian. 2006. Landscape-scale postfire vegetative condition monitoring using multi-temporal landsat imagery on the Cerro Grande fire. Online at: http://www.fws.gov/fire/ifcc/esr/Library/Library.htm.
Quality of Evidence Rating: ***Medium***

Cline, G.G., and W.M. Brooks. 1979. Effect of light seed and fertilizer application in steep landscapes with infertile soils after fire. Northern Region Soil, Air, Water Notes 72, 6 p.
Quality of Evidence Rating: ***Highest***

Conard, S. G., J. C. Regelbrugge, R.D. Wills. 1991. Preliminary effects of ryegrass seeding on postfire establishment of natural vegetation in two California ecosystems. Proceedings of the 11th conference on fire and forest meteorology. Society of American Foresters, Missoula Montana. 16-19.
Quality of Evidence Rating: ***Low***

Dellasala, D. A., J. E. Williams, C.D. Williams, J.F. Franklin. 2004. Beyond smoke and mirrors: A synthesis of fire policy and science. Conservation Biology 18:976-986.
Quality of Evidence Rating: ***Lowest***

DeWolfe, V.G., P.M. Santi, J. Ey, J.E. Gartner. 2008. Effective mitigation of debris flows at Lemon Dam, La Plata County, Colorado. Geomorphology 96:366-377.
Quality of Evidence Rating: *High*

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