Collaboration for Environmental Evidence
Library

CEE review 08-023

DOES SEEDING AFTER SEVERE FOREST FIRES IN WESTERN USA MITIGATE IMPACTS ON SOILS AND PLANT COMMUNITIES?

Systematic Review

FULÉ, P., BEYERS, J., SIEG, C., HUNTER, M. AND PEPPIN, D.

Northern Arizona University - P.O. Box 15018 - Flagstaff - AZ 86011 - USA

Correspondence: *Pete.Fule@nau.edu*
Telephone: 00+1+928-523-6906

Protocol published on website: 6 January 2009 - Draft review published on website: 03 August 2010 – Final review posted on website: 16 February 2011

Cite as: Peppin, D. Fulé, P., Beyers, J., Sieg, C., Hunter, M. 2011. Does seeding after severe forest fires in western USA mitigate negative impacts on soils and plant communities? CEE review 08-023 (SR60). Collaboration for Environmental Evidence: www.environmentalevidence.org/SR60.html.

Summary

1. Background

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. 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. In 2000, Robichaud et al. reviewed the effectiveness and impacts of the entire suite of burned area rehabilitation treatments used on U.S. Forest Service land, including post-fire seeding. Beyers (2004) published a review specific to post-wildfire seeding, but a good part of the conclusions were drawn from studies occurring in chaparral. Since publication of Robichaud et al. (2000) and Beyers (2004), several developments have altered the context of post-fire seeding. These include: 1) increasing size and severity of wildfires across the western U.S., 2) increased research and quantitative monitoring on post-fire seeding and plant community interactions, 3) increased use, availability, and allocation of funds for native seed mixes, and 4) 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). With the last review occurring in 2004 there is a need to re-examine what is known about the effectiveness and ecological impacts of post-fire seeding specific to forested ecosystems across the western U.S.

2. Objectives

Primary objective: To systematically collect and synthesize the available published and unpublished evidence in order to answer the question "Does seeding after severe forest fires mitigate negative impacts on soils and plant communities?"

Secondary objective(s): Summarize the evidence available to address three questions pertaining to post-wildfire seeding treatment effectiveness and effects: (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-wildfire seeding affect native plant community recovery?

3. Methods

To identify studies relevant to our review, we searched databases supported by Northern Arizona University during July-November 2008, using a defined combination of search terms. We then eliminated papers, first based on title, then abstract, then full text, based on a set of criteria that specified the review subjects (seeding in western USA forests burned by severe wildfire), intervention (seeding herbaceous plant or shrub seed alone or in combination with other post-fire rehabilitation activities), and outcome (soil stabilization attributes and changes to plant community attributes). We assessed study quality based on study design and statistical robustness, and applied a weight ((highest, high, medium, low, lowest) to each study design category (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)) with the greatest weight given to replicated randomized experiments and less to observational and opinion studies. We evaluated post-fire seeding effectiveness based on seeding treatment effectiveness in reducing erosion, non-native species invasions, and effects on native plant community recovery. When available, quantitative data from seeded and unseeded treatments were compared. Each study or individual study unit was given an effectiveness rating (effective, minimal effectiveness, ineffective, negative effect). We used descriptive statistics to explore relationships between post-fire seeding treatments and associated variables.

4. Main Results

Our review produced 94 relevant studies. Considering the entire dataset (n = 94), replicated and randomized experiments made up the largest study design category. Using quality of evidence criteria, the number of studies of quantitative experimental nature increased from the time period 2000-2009 compared to those studies in 1970-1999. Twenty-three [1]studies provided evidence regarding post-fire seeding effects on soil erosion. As sampling designs have become more rigorous in recent years, evidence that seeding is effective in reducing erosion has decreased.

Of highest and high quality studies evaluating soil erosion, 89% (8 of 9) were published since 2000, only one of which showed an effective result as a result of additional treatments. Before 2000, the majority of the studies (70%) fell into the lowest quality categories, of which, 71% showed seeding to be effective. A main goal of post-wildfire stabilization treatments is to reduce soil erosion in the year immediately following a fire; however, the majority of studies (7 of 11, 64%[2]) evaluating soil erosion in seeded versus unseeded controls showed that seeding did not reduce erosion relative to unseeded controls. Comparing cover measurements between seeded and unseeded plots from 20 studies containing a total of 29 study sites, we found that even when study results showed that 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 11 papers providing direct evidence regarding the role of seeding in reducing non-native species abundance, an almost equal percentage found seeding treatments to be effective (54%, 6 studies) or having a negative effect (45%, 5 studies). However, the majority of effective treatments and those which had a negative effect (83% and 80%, respectively) used non-native species. A majority of studies reported that seeding suppressed recovery of native plants (16 studies, 62%). However, data on long-term impacts of this reduction are limited. Cover data from 15 studies containing 57 different study sites showed decreased seeded cover relative to control plot cover with

[1] The value of 23 was erroneously given as 27 in Peppin et al. 2010.
[2] The value of 64% was erroneously given as 78% in Peppin et al. 2010.

increasing time since fire. Based on cover data from all 57 sites, total plant cover in seeded sites and controls was nearly identical by years 4 and 5 post-wildfire. A seeding treatment's ability to reduce soil erosion and/or affect native plant community recovery appears to be strongly driven by amount and timing of precipitation.

5. Conclusions

This review 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. Erosion may be better reduced by mulching, but care must be taken to ensure that mulch is free of non-native seed. 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, may allow better control of non-native species establishment than is typically obtained through seeding. 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.

A version of the systematic review has been published: Peppin, D., P.Z. Fulé, C.H. Sieg, J.L. Beyers, and M.E. Hunter. 2010. Post-wildfire seeding in forests of the western United States: An evidence-based review. Forest Ecology and Management 260:573–586.

Main Text

1.Background

By consuming protective vegetation and litter cover, high-intensity wildfires frequently result in greatly increased erosion, runoff, and sediment transport that can threaten downstream resources and infrastructure (Debano et al., 1998; Neary et al., 2005). The increased availability of light and nutrients after wildfire also creates conditions favourable for invasion of non-native plant species (DeBano et al., 1998; Crawford et al., 2001; Keeley et al., 2003; Wang and Kemball, 2005; Freeman et al., 2007). 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 (USDA, 2004; USDI, 2006). 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 and availability of many native species has increased (Beyers, 2004; Smith et al., 2007; Wolfson and Sieg, in press), high costs and inadequate availability often limit inclusion locally-adapted, regionally-appropriate plant materials in post-fire seedings (Wolfson and Sieg, in press). 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).

In 2000, Robichaud et al. reviewed the effectiveness and impacts of the entire suite of burned area rehabilitation treatments used on U.S. Forest Service land, including post-fire seeding. Beyers (2004) published a review specific to post-wildfire seeding, but a good part of the conclusions were drawn from studies occurring in chaparral. Almost all of the seeding projects reviewed in these two publications used non-native species. Since these reviews appeared, several developments have altered the context of post-wildfire seeding in the western U.S. . 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, availability, and allocation of funds for native seed mixes (Smith et al., 2007; 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. Objectives

2.1 Primary objective:

Systematically collect and synthesize the available published and unpublished evidence in order to answer the primary question:

- "Does seeding after severe forest fires mitigate negative impacts on soils and plant communities?"
-

2.2 Secondary objective(s):

Summarize the evidence available to address three questions pertaining to post-wildfire seeding treatment effectiveness and effects:

- Does seeding after severe forest fires reduce soil erosion?
- Is seeding effective at reducing non-native plant invasion into burned areas?
- Does post-wildfire seeding affect native plant community recovery?

3. Methods

3.1 Question formulation

The review team developed primary and secondary study questions, which were further refined by managers, scientists, and outside experts in the field. We defined "forests" as those dominated by tall-stature coniferous and/or deciduous trees occurring at elevations above grasslands, pinyon-juniper woodlands, or chaparral vegetation in the western U.S.

3.2 Search strategy

We searched databases supported by Northern Arizona University during July 2008 through May 2009 (using a defined combination of search terms) which included:

- IngentaConnect
- Forest Science Database (Ovid)
- JSTOR
- ISI Web of Science
- Agricola
- Google Scholar
- U.S. government database (USDA Forest Service TreeSearch, Ecological Restoration Institute library, National Park Service library)
- University libraries (M.S. theses and Ph.D. dissertations)

All the following combinations of search terms were used in each database search:

- seeding AND fire
- seeding AND wildfire
- seeding AND burn
- seeding AND native species
- seeding AND erosion

3.3 Study inclusion criteria

Potential studies were then evaluated for inclusion using the following specific criteria:

- **Relevant subject(s):** forests of the USA, predominantly coniferous forests of the West but information from any burned forests will be included. Experimental data from less severe burns, such as prescribed fires, will be assessed for relevance. Non-wildfire seeding data were summarized separately from wildfire data.
- **Timeframe:** All relevant studies from 1970-present will be included as appropriate. However, there are multiple timeframes to consider. First, studies since the review by Robichaud et al. (2000) will be exhaustively assessed for inclusion (2000-present). Second, any relevant studies from 1970-1999 will be included as appropriate, regardless of being previously reviewed. References that appear in the literature to relevant earlier research will be tracked down.
- **Types of intervention:**
    - Seeding of herbaceous plants
    - Seeding of shrubs
    - Combinations of seeding in conjunction with other post-fire rehabilitation activities such as mulching, water-bars, tree-felling on terrain contours, etc.
    - Methods and timing of seed delivery
- **Types of comparator:**
    - Replicated randomized experiments
    - Before-after control-impact (BACI) studies
    - Observational studies
    - Expert opinion

- **Types of outcome:**
    - Cover and biomass of herbaceous plants
    - Cover and biomass of shrubs
    - Cover and biomass of invasive non-native plants
    - Plant community composition: nativity, richness, diversity
    - Species selected for seeding (non-native and native)
    - Soil stabilization variables
- **Types of study:**
    - Studies investigating effects of seeding after severe forest fires

There is substantial heterogeneity in the forests of the USA, even among the western forests where the greatest amount of information is likely to be found. This heterogeneity is associated with the latitudinal and elevational gradients where these forests occur and ecotones with adjacent ecosystems. Wildfires burn heterogeneously as well and important post-fire effects can have a stochastic component (e.g., erosion is not a simple function of terrain and fire severity, but also of the chance of a strong rainstorm occurring soon after the fire). There is heterogeneity in pre-existing propagule sources (seed bank) and nearby sources. Finally, management interventions vary widely in terms of the species selected for seeding and the timing and methods of seed delivery.

We considered all types of studies, including 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 papers, and expert opinions. All potentially relevant publications were imported into a RefWorks reference manager database (www.refworks.com). Those publications listed as "possibly relevant" were examined by the senior author for final inclusion decisions.

3.4 Study quality assessment

We assigned "quality of evidence" ratings for each study based on design and statistical robustness (Table 1). Statistically robust data (statistical results that are not affected by (small) changes in the assumptions used to obtain those results) from replicated randomized and controlled experiments were judged to be of "highest" quality evidence; whereas unreplicated, uncontrolled, qualitative data had "lowest" quality of evidence.

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 (one monitoring location), controlled experiments; observational or monitoring report (multiple fires or plots stratified within a single fire by vegetation type, fire severity, drainage, or treatment); 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-wildfire seeding	High
Unreplicated (one monitoring location), controlled, observational or monitoring report (single location) with quantitative data	Medium
Unreplicated, uncontrolled, observational or monitoring report; quantitative data	Low
Unreplicated, uncontrolled, qualitative data; anecdotal observation; expert opinion; or review of post-wildfire seeding (not peer-reviewed)	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.

We evaluated post-wildfire seeding effectiveness 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). Only papers providing direct data in each category were evaluated (ie., review papers were excluded)

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

When available, quantitative data from seeded and unseeded treatments were compared. All data were taken from original publications. 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 "ineffective" were not statistically different or stated by the author as having no difference in their effectiveness, whereas those showing a "negative effect" were counter-productive in their effectiveness to a specified impact category (e.g., effect was opposite of that intended).

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 stated by the author to be 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 stated by the author to be different in their effectiveness for increasing cover, reducing erosion, and/or reducing non-native species invasions	Ineffective
Sufficient evidence exists to conclude that seeding was statistically or stated by the author to be 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	Negative effect

3.5 Data extraction

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.

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.

3.6 Data synthesis

For this review, we used descriptive statistics to explore relationships between post-wildfire seeding treatments and associated variables as well as the influence of time since fire. We divided relevant papers into ecoregions (Bailey, 1983; Fig. 1) for analysis of climatic influences.

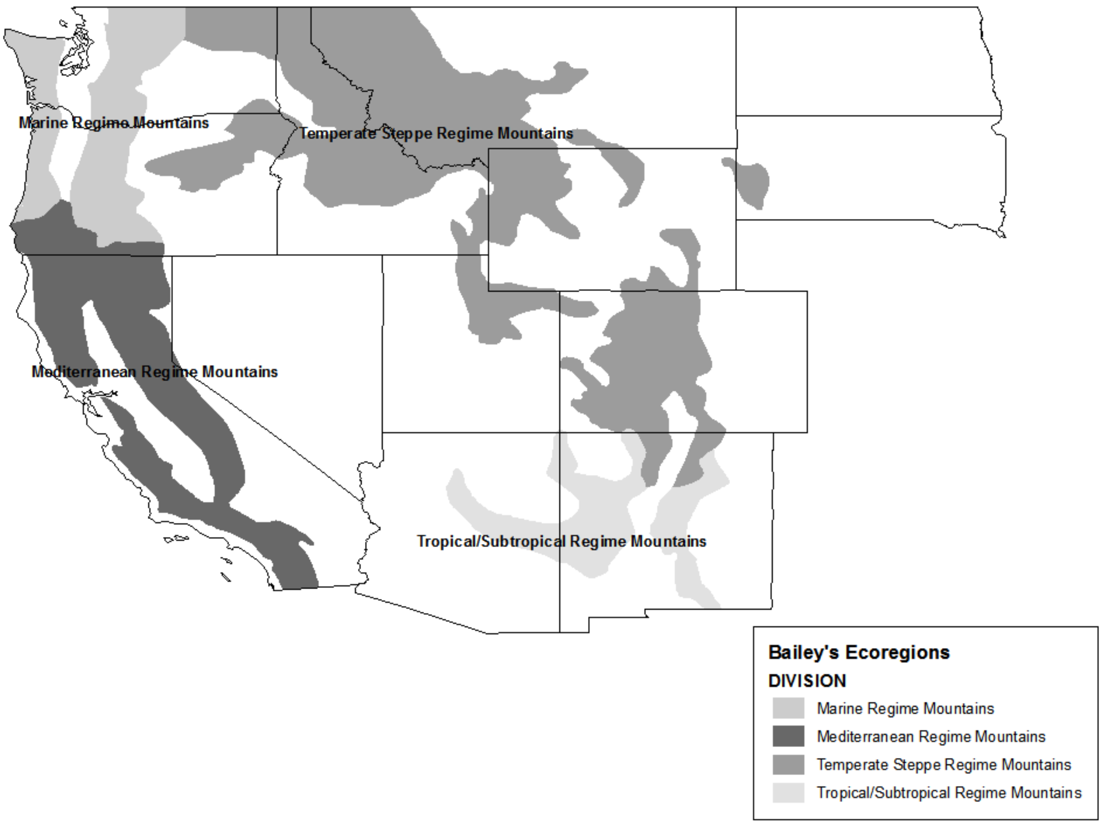

Figure 1. Map of ecoregions (Bailey 1983) containing published studies reporting measures of seeding "success" during the first 2 years following fire (Table 5).

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. For papers falling under the "review paper" category, assessment was completed independently and noted directly in the text.

4. Results

4.1 Review statistics

Approximately 19,455 studies were identified through the literature search. The primary reviewer and search assistants narrowed down the number of relevant papers using specified inclusion criteria (Section 3.3), which produced 143 studies (Table 4). Studies were imported into RefWorks and ranked based on overall relevancy (1 = relevant, 2 = possibly relevant). Those publications listed as "possibly relevant" were examined by the review coordinator for further inclusion decisions. We identified 120 studies after the review coordinator examination.

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

We then read the remaining full text articles, and used our data extraction database to determine if the studies were appropriate for the qualitative or quantitative analysis. A total of 26 studies were removed at this stage as being inappropriate or duplicative.

4.2 Description of studies

Our review produced 94 relevant papers. Considering the entire dataset (*n* = 94) and specified study design categories, 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 (*n* = 37).

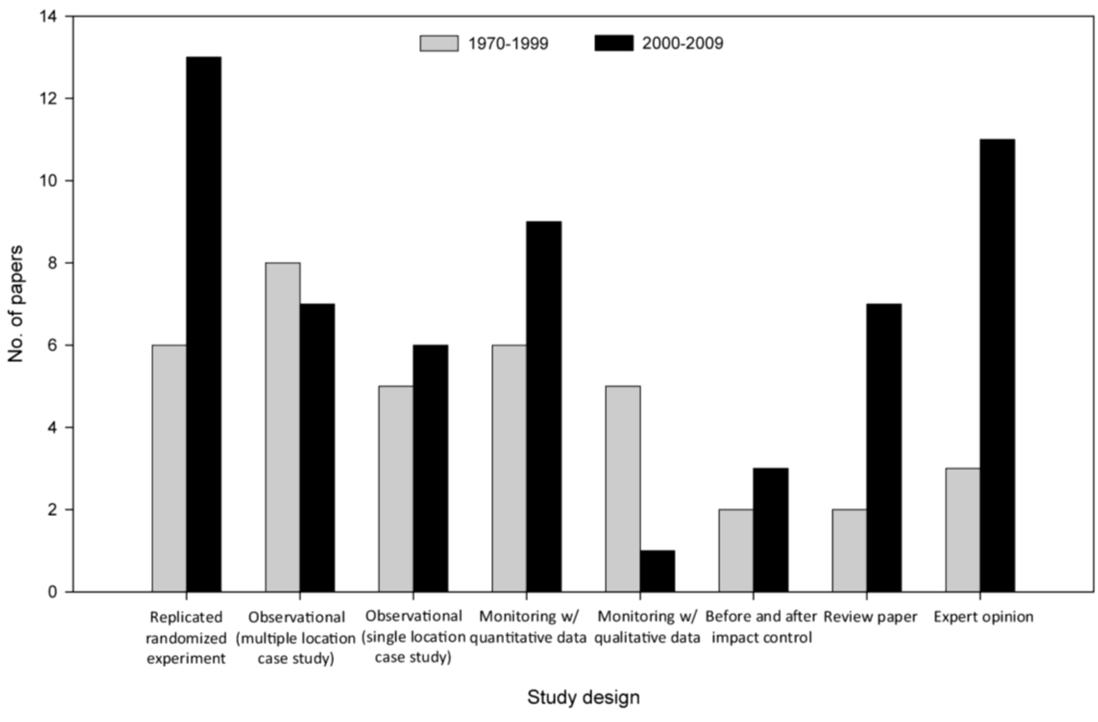

Figure 2. The number of papers by study design category for studies reviewed from 1970 to 1999 (37 papers) and those since 2000 (57 papers).

Of the 94 relevant papers, 23[3] papers provided primary evidence regarding post-fire seeding effects on soil erosion, 12 papers provided direct evidence regarding the role of seeding in reducing non-native species, and 26 papers included data addressing post-fire seeding effects on native plant recovery. The remaining 33[4] papers were considered review papers or expert opinions.

4.3 Study quality assessment

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).

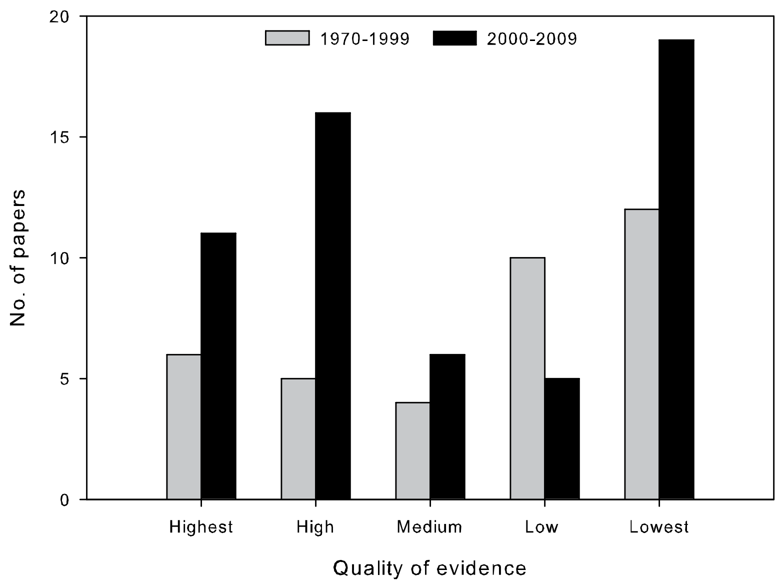

Figure 3. The number of papers by quality of evidence for studies reviewed from 1970 to 1999 (37 papers) and since 2000 (57 papers).

In the overall set of papers, a majority of information on seeding comes from well designed experimental studies. However, in more recent years there has been greater emphasis on study designs of quantitative experimental nature (Fig. 4).

[3] The value of 23 was erroneously given as 27 in Peppin et al. 2010.
[4] The value of 33 was erroneously given as 29 in Peppin et al. 2010.

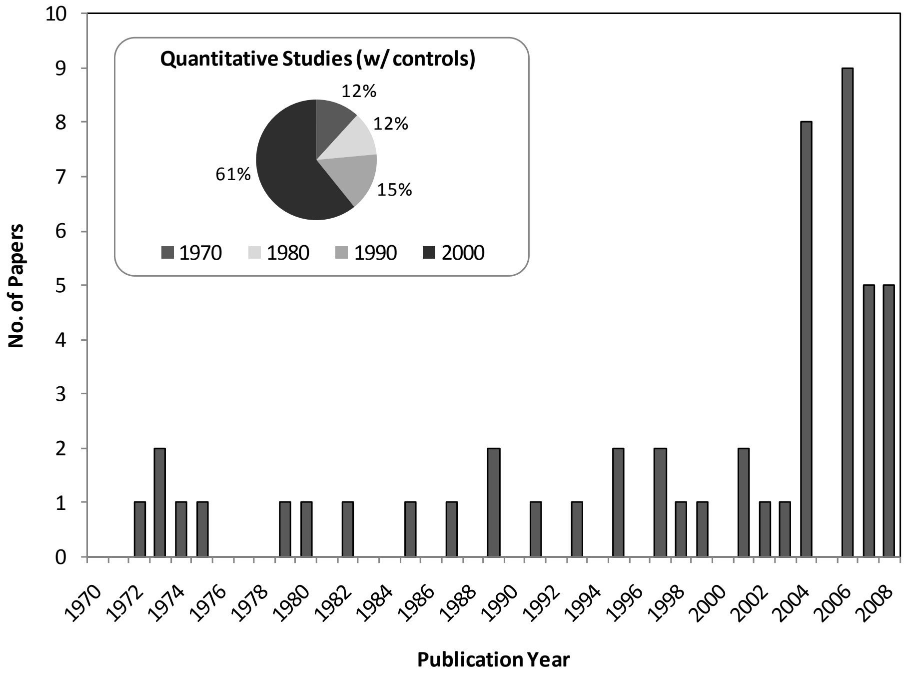

Figure 4. Number of studies reviewed with quantitative data (including controls) by publication year. The insert shows the number of quantitative studies by decade as a percent of the total.

4.4 Qualitative synthesis

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

Using effectiveness ratings (Table 3), 9 of the 23studies (39%) [5]showed seeding to be effective, an equal number of papers (5, 22% each)[6] showed minimal effectiveness or a negative effect, and 4 (17%[7]) were ineffective in reducing erosion. However, the evidence for seeding effectiveness drops substantially when quality of evidence criteria (Table 1) are considered: two of the four studies with highest quality evidence found seeding to have a negative effect while the other half were ineffective 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. Three of the five[8] studies with high quality evidence found seeding to have a negative effect, while one[9] reported minimal effectiveness. The remaining

[5] The value of “9 of the 23 studies (39%)” was erroneously given as “33% of the 27 studies” in Peppin et al. 2010.
[6] The statement “an equal amount of papers (5, 22% each)” was erroneously given as 26% in Peppin et al. 2010.
[7] The value of 17% was erroneously given as 15% in Peppin et al. 2010.
[8] The value of “Three out of five” was erroneously given as “Five out of eight” in Peppin et al. 2010.
[9] The value of one was erroneously given as two in Peppin et al. 2010.

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 seven[10] 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).

None of the 13[11] papers published since 2000 concluded that seeding was effective or minimally effective in reducing erosion compared to controls, whereas seven of 10 papers (70%)[12] published before 2000 found seeding to be in those categories. Only one (1%[13]) of the earlier papers met the criteria for highest or high quality evidence, while 8 papers (61%[14]) since 2000 did.

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.

---

[10] The value of seven was erroneously given as eight in Peppin et al. 2010.
[11] The value of 13 was erroneously given as 16 in Peppin et al. 2010.
[12] The statement "seven of 10 papers (70%)" was erroneously given as "64% of 11 papers" in Peppin et al. 2010.
[13] The value of 1% was erroneously given as 9% in Peppin et al. 2010.
[14] The value of 61% was erroneously given as 71% in Peppin et al. 2010.

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

Eleven papers provided direct evidence regarding the role of seeding in reducing non-native species abundance. Out of the 11 papers, 56% (6 papers) showed seeding to be effective, whereas 45% (5 papers) showed seeding to have a negative effect. 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. Only one of three papers [15]of high quality showed seeding to be effective for reducing non-native species.

Of the six studies showing seeding to be effective, 83% (5 papers) included non-native annual species in the seeding treatments. Eighty percent treatments showing a negative effect (4 papers) seeded non-native species, of which 60% seeded non-persistent species which persisted beyond the 1st year post-fire and 40% (2 papers) found that seed mixes were contaminated with undesirable non-native species (Sexton, 1998; Hunter et al., 2006). 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).

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.

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

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.

[15] The value of "one of three papers" was erroneously given as "two of three papers" in Peppin et al. 2010.

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.

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. Six studies (86%) 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). 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).

A number of studies examined competitive effects of seeded grasses on woody plant establishment. 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 of these studies seeded only grasses in treated plots. Three of the five [16] papers providing highest and high quality evidence (60%) found that seeding negatively affected tree seedling and/or shrub growth and survival. One of the three studies seeded include planting of native tree and shrub seedlings, the rest seeded strictly grasses. One paper reported seeding annual non-native grasses had no effect on the growth and survival of woody species. The remaining paper showed seeding improved establishment, but stated that seeding with shrub species appeared to be effective for increased shrub establishment. 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 and Waller, 1999; Barclay et al., 2004; Keeley, 2004; Kruse et al., 2004). The remaining study showed seeding to be ineffective as a result of seeding cereal barley (Hanes and Callahan, 1995).

4.5 Quantitative synthesis

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

Only nine of the 23[17] studies used direct measures of sediment yield used to assess post-wildfire seeding effectiveness. These studies provided measurements from 12 seeded and unseeded sites in the first year, 10 seeded and unseeded sites in the

[16] The value of "Three of the five" was erroneously given as "(2 out of 4)" in Peppin et al. 2010.
[17] The value of 23 was erroneously given as 27 in Peppin et al. 2010.

second year, 3 seeded and unseeded sites in the third year, 3 seeded and unseeded sites in the fourth year, and 2 seeded and unseeded sites in the fifth year (30 sites total)While seeded sites tended to produce less sediment than unseeded sites the first year after fire (Fig. 5), only 22% (7 sites) of the sites showed a statistically significant decrease in erosion on seeded relative to unseeded sites. This 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.

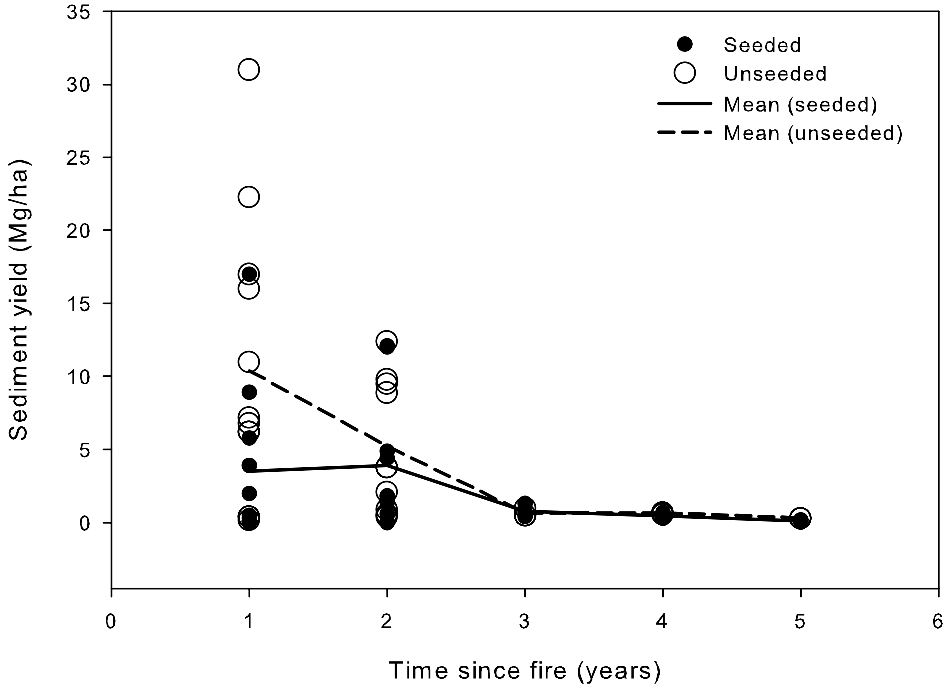

Figure 5. Amount of sediment yield versus time since fire in seeded plots and unseeded plots (data from 30 sites).

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 effective or partly effective reduce erosion. Based on previous work, we regarded cover between 30 and 60% as partially effective at reducing erosion, and > 60% cover to be effective at reducing sediment movement to negligible amounts (Noble 1965; Orr 1970).

Comparing cover measurements between seeded and unseeded plots from 20 studies containing a total of 29 study sites, we found that 12 sites (41%) had significantly greater total plant cover on seeded plots by the end of the first year after fire. Sixteen seeded sites (55%) had between 30 and 60%% total plant cover in the first year after fire, compared to only nine unseeded sites (31%; Table 5). Another four seeded sites (14%) 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.

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 Measurements	Those Showing Seeding Significantly Increased Cover	% of Sites Showing 30-60% Cover (No. of Sites)		% of Sites Showing > 60% Cover (No. of Sites)		Sites Showing Erosion Measurements	Those Showing Seeding Significantly Reduced Erosion
		Seeded	Unseeded	Seeded	Unseeded		
———No. ———		———Percent———				———No. ———	
		Post-wildfire 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 (16)**	**31 (9)**	**14 (4)**	**0**	**12**	**0**
		Post-wildfire 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 (15)**	**50 (9)**	**28 (5)**	**6 (1)**	**10**	**1**

In the second year after fire, seeded sites were nearly four times more likely to be stabilized than untreated sites based on cover percentage of greater than 60% (Table 5). Second-year seeded sites had greater total cover than did unseeded sites 39% of the cases. Fifteen seeded sites (83%) had between 30 and 60% cover, compared to only half (9 sites). Five seeded sties (28%) had adequate cover (>60%) to reduce soil erosion to negligible amounts, compared to only one unseeded site (6%) (. Despite these cover findings, only one of the 10 studies measuring erosion in the second year showed that seeding significantly reduced erosion. 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 (MacDonald, 1989; Beschta et al., 2004; Beyers, 2004; Wolfson and Sieg, in press).

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

Quantitative analysis was not completed for this question due to limited and variable quantitative data available.

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

Cover data from 15 studies containing a total of 57 study sites (19 sites in the first year, 14 sites in year two, 13 sites in year three, 7 sites in year four, and 4 sites in year five) showed decreased seeded cover relative to control plot cover with increasing time since fire (Fig. 6). Total cover on seeded plots was more 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. Of the 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).

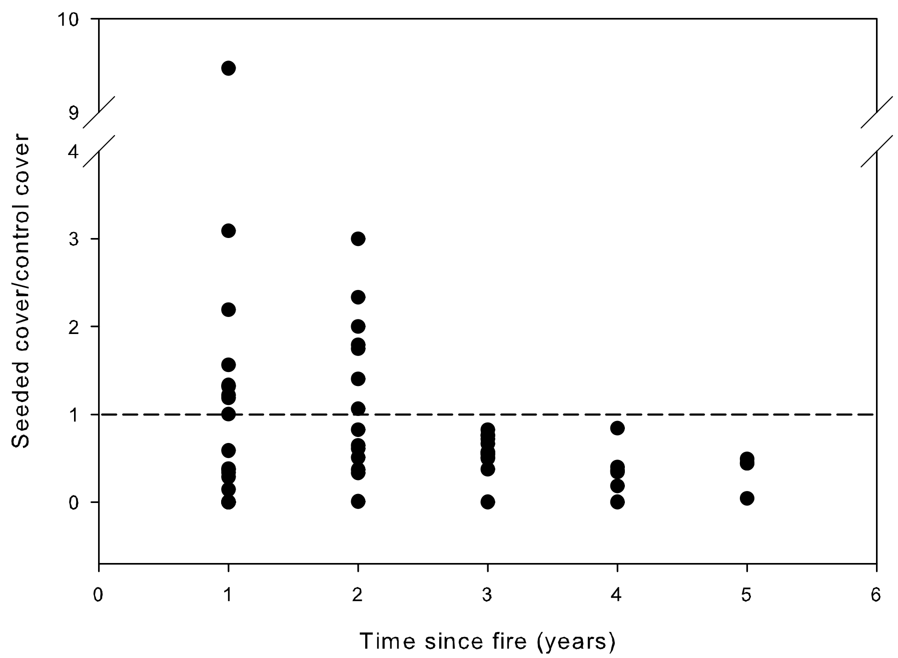

Figure 6. Ratio between seeded and control cover estimates versus time since fire in years (data from 57 sites). Ratios greater than one have greater seeded cover than control cover.

Based on data from a total of 57 sites, by four years after fire both seeded and unseeded sites supported approximately 45% total plant cover (seeded + unseeded species)and only 40% total plant cover after five years (Fig. 7). Seeded cover (seeded species only) was relatively high for the first three years after fire (about the same as control cover during the first two years) but declined substantially to 13% and 14% in years four and five, respectively.

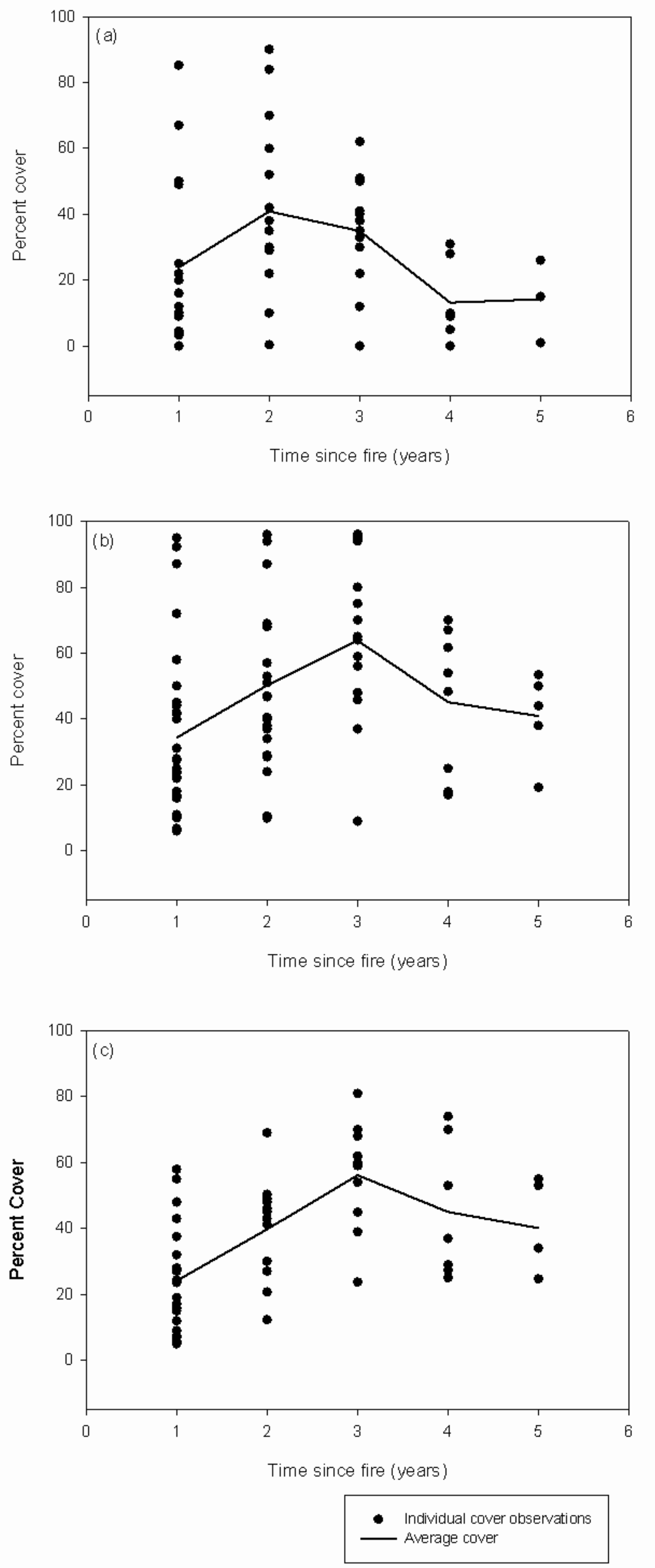

Figure 7. Average (a) seeded cover (seeded species only), (b) total cover (seeded + unseeded species), and (c) total control cover (unseeded) versus time since fire (data from 57 sites contained in 15 studies assessing post-wildfire seeding treatment performance in forested ecosystems in the western U.S.)

Of five studies quantifying shrub cover in sites seeded with non-native species versus unseeded controls (16 sites: 6 in year 1, 5 in year 2, 3 in year 3, and 2 in year 4)), shrub cover in unseeded plots was higher than in seeded plots 94% of the time (Fig. 8).

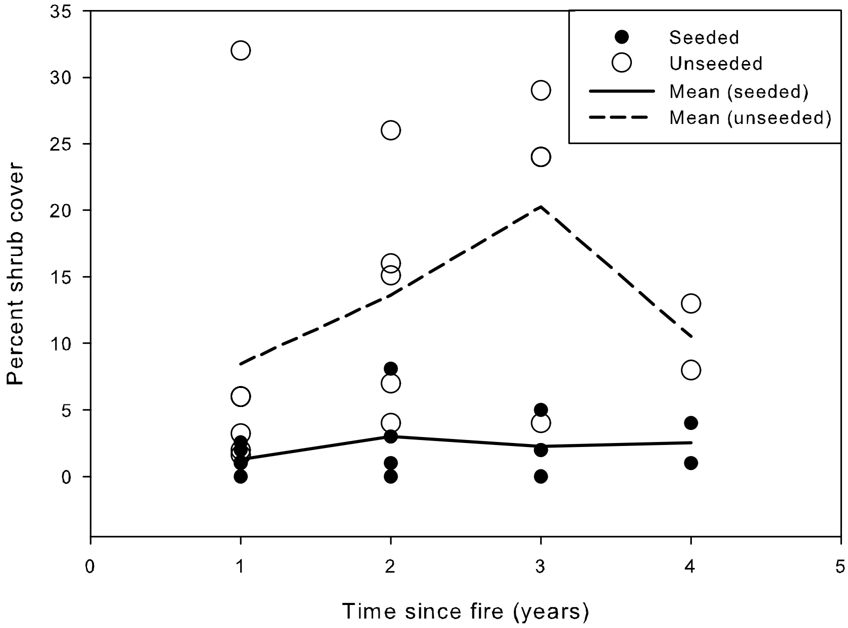

Figure 8. Percent shrub cover in seeded and unseeded sites versus time since fire in years (data from 16 sites).

4.6 Outcome of the review

Our qualitative assessment revealed that seeding is largely ineffective in reducing soil erosion. Quantitative analysis elucidated that seeding has the ability to decrease sediment yield on seeded sites compared to unseeded sites in the first year, although few sites showed a statistically significant decrease in erosion on seeded relative to unseeded sites.However, this decrease diminished with time since fire. In addition, seeding has the ability to increase cover but this increase does not ensure reduced erosion.

Regarding seeding effects on native plant communities, qualitative and quantitative analysis each revealed unique information. Qualitatively, papers showed a decreased in cover of native species on seeded plots compared to unseeded plots. Seeding treatments also showed decreased native species richness, negative effects on woody plant establishment, and persistent effects on native plant community recovery, although long-term data is lacking. Quantitatively, like soil erosion data, data regarding seeding effects on native plant communities revealed that seeded cover decreased significantly relative to control plots with increasing time since fire. However, seeded and unseeded sites supported essentially the same percent cover after five years. Seeded species increased in the first couple of years after fire but declined in subsequent years.

Only qualitative evidence was gathered regarding seeding effectiveness in curtailing non-native species invasion. This analysis showed that seeding has equivocal effectiveness in mitigating non-natives species. However, of effective treatments and those showing a negative effect, the majority included non-native annual species in the seeding, many of which are seeded non-persistent species that actually persisted beyond the first-year after fire or were contaminated with undesirable species.

5. Discussion

5.1 Evidence of effectiveness

The systematic review approaches used worked well for summarizing both qualitative and quantitative data while reducing review bias. Qualitative and quantitative analysis elucidated differing but equally important information regarding each review question and the soil and plant community attributes assessed. Conclusions draw across qualitative and quantitative analysis were similar.

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

Qualitative analysis of soil erosion papers revealed that as sampling designs have become more rigorous in recent years, evidence that seeding is effective in reducing erosion has decreased. In addition, 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. Quantitatively, it appears that greater cover does not always produce less erosion. Rather, the ability of seeding to effectively reduce erosion within the first and even second year post-wildfire depends largely of amount and timing of precipitation, not percent cover, as shown by minimal support for the cover thresholds currently used. Our data suggest 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 heavy erosion immediately following fire (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). 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.

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

Qualitatively, it appears that 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). 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).

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). In addition, it 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.

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.

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

Seeding treatment performance and effects are related to length of time since fire (Robichaud and Elliot, 2006; Rough, 2007). Quantitative analysis of cover data from 15 studies containing 57 different study sites suggests 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.

The higher initial seeded cover in the analysis of cover data from 57 sites 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).

Overall, both qualitative and quantitative data from the literature suggests that seeded species' dominance plays a critical role in determining species richness in the first and/or second year after fire. Our review further suggests that 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).

Overall, both qualitative and quantitative results on seeding effects on woody plant establishment 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).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).

5.2 Reasons for variation in effectiveness

Results obtained from qualitative and quantitative analysis did not vary so much as provided unique information which we used to make overall conclusions regarding each review question. The qualitative analysis used less rigorous statistical methods; thus the quantitative analysis produced more reliable conclusions. However, we feel that both analyses were equally important in determining the overall effects and effectiveness of post-fire seeding practices on soils and plant communities in forested ecosystems in the western USA.

5.3 Review limitations

A systematic review may become a statistically rigorous ‘‘meta-analysis’’ if data can be analyzed as ‘‘effect sizes’’ (Gates, 2002). However, measurements taken across studies relevant to soil and/or plant community attributes varied widely therefore a meta-analyses for the data obtained was not possible with the questions we addressed. In addition, due to the variation in data measures across papers, data gathered often yielded small sample sizes. Thus, conclusions drawn from both qualitative and quantitative analyses, in these cases, must be considered cautiously.

Finally, we did not complete a ‘kappa’ analysis of agreement between reviewers as to the inclusion of studies within the review. Two persons were involved in this process and worked to an agreed set of papers. The inability to quote a kappa statistic weakens the review as the selection of studies for inclusion is a potential source of unquantifiable bias.

6. Reviewers’ Conclusions

6.1 Implications for management / policy / conservation

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 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. 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.

6.2 Implications for research

The effectiveness and long-term effects of post-fire seeding deserve further study, particularly well-designed research experiments and rigorous quantitative monitoring to evaluate seeding success. Studies assessing the use of native species to combat non-native species invasions in burned areas are almost non-existent. Taking a closer look at the use of native species to reduce non-natives would be valuable.

Further quantitative research on the effects of mulching after wildfire is also essential. Although seeding with non-local genotypes of native plants has been identified as a concern, we found no studies that addressed genetic consequences of post-wildfire native seeding. Given ongoing debates about seeding, additional research on the long-term effects of seeding with both native and non-native species on natural vegetation recovery and the genetic integrity of native populations is essential.

7. Acknowledgements

We thank the students of the Ecological Restoration Institute at Northern Arizona University who helped establish the publication database of relevant post-fire seeding publications to synthesize.

8. Potential Conflicts of Interest and Sources of Support

The review is led by researchers from Northern Arizona University and the USDA Forest Service who have contributed to the literature on this topic. We will address the possibility of conflict of interest by following the review process through CEBC and additional reviews solicited from scientists who are not on the review panel and not affiliated with the lead institutions.This research was supported by a grant from Joint Fire Science Program (JFSP Project # 08-2-1-11).

9. References

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. U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station, Berkeley, CA, pp. 148-149.

Amaranthus, M. P., Trappe, J. M., Perry, D. A., 1993. Soil moisture, native revegetation, and *Pinus lambertiana* seedling survival, growth, and mycorrhiza formation following wildfire and grass seeding. Restor. Ecol. 1, 188-195.

Anderson, W.E., Brooks, L.E., 1975. Reducing erosion hazard on a burned forest in Oregon by seeding. J. Range Manage. 28, 394-398.

Bailey, R. G., 1983. Delineation of ecosystem regions. Environ. Manage. 7, 365-373.

Bakker, J.B., Wilson, S.D., Christian, J.M., Xingdong, L., Ambrose, L.G., Waddington, J., 2003. Contingency of grassland restoration on year, site, and competition from introduced grasses. Ecol. Appl. 10, 1400-1413.

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

Beschta, R.L., Rhodes, J.J., Kauffman, J.B., Gresswell, R.E., Minshall, G.W., Karr, J.R., Perry D.A. , Hauer F.R., Frissell C.A., 2004. Postfire management of forested public lands of the western United States. Conserv. Biol. 18, 957-967.

Beyers, J.L., 2004. Post-fire seeding for erosion control: effectiveness and impacts on native plant communities. Conserv. Biol. 18, 947-956.

Bruggink, J., 2007. Long term ecological changes with post-fire emergency seeding. In: Furniss, M., Clifton, C., Ronnenberg, K. (Eds.), Advancing the Fundamental Sciences: Proceedings of the Forest Service National Earth Sciences Conference, San Diego, CA, 18-22 October 2004**.** Gen. Tech. Rep. PNW-GTR-689. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR, pp. 20-26.

Conard, S. G., Regelbrugge, J. C., Wills R.D., 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 MT, pp. 16-19.

Connell, J.H., Slatyer, R.O., 1977. Mechanisms of succession in natural communities and their role in community stability and organization. Am. Nat. 111, 1119-1144.

Dadkhah, M., Gifford, G.F., 1980. Influence of vegetation, rock cover and trampling on infiltration rates and sediment production. Water Resour. Bul. 16, 979-986.

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

Earles, T.A., Foster, P., Ey, J., Wright, K.R., 2005. Missionary Ridge wildfire rehabilitation. Proceedings of the 2005 Watershed Management Conference, Williamsburg, VA. pp. 1-14.

Elliott, K.J., White A.S., 1987. Competitive effects of various grasses and forbs on ponderosa pine seedlings. For. Sci. 33, 356-366.

GAO (General Accounting Office), 2003. Wildland fires: Better information needed on effectiveness of emergency stabilization and rehabilitation treatments. GAO-03-430.

Gates, S., 2002. Review of methodology of quantitative reviews using meta-analysis in ecology. J. Anim. Ecol. 71, 547–557.

Griffin, J. R., 1982. Pine seedling, native ground cover and *Lolium multiflorum* on the Marble-Cone Burn, Santa Lucia Range, California. Madroño 29, 177-188.

Groen, A.H., Woods, S.W., 2008. Effectiveness of aerial seeding and straw mulch for reducing post-wildfire erosion, north-western Montana, USA. Int. J. Wildland Fire 17, 559-571.

Holzworth, L. K., Hunter, H.E., Winslow, S.R., 2003. Disturbed forestland revegetation effectiveness monitoring: Results of 30 years. 2003 National Meeting of the American Society of Mining and Reclamation and the 9th Billings Land Reclamation Symposium, Billings, MT, June 3-6.

Hanes, R., Callahan, K., 1996. Crystal burn analysis. post-fire succession and seeding monitoring: Year two. Unpublished Report on File at: U.S. Department of Agriculture, Forest Service, Tahoe National Forest, CA.

Huenneke, L.F., 1991. Ecological implications of genetic variation in plant populations. In: Falk, D.A., Holsinger, K.E. [eds.], Genetics and conservation of rare plants. Oxford University Press, New York, NY, pp. 31-44.

Hufford, K.M., Mazer, S.J., 2003. Plant ecotypes: genetic differentiation in the age of ecological restoration. Trends Ecol. Evol. 18, 147-155.

Hunter, M.E., Omi, P.N., 2006. Response of native and exotic grasses to increased soil nitrogen and recovery in a postfire environment. Restor. Ecol. 14, 587-594.

Hunter, M.E., Omi, P.N., Martinson, E.J., Chong, G.W., 2006. Establishment of non-native plant species after wildfires: Effects of fuel treatments, abiotic and biotic factors, and post- fire grass seeding treatment. Int. J. Wildland Fire 15, 271-281.

Jones, T.A., 2003. The restoration gene pool concept: Beyond the native versus non-native debate. Restor. Ecol. 11, 281-290.

JMP, Version 8. 2008. SAS Institute Inc., Cary, NC.

Keeley, J.E., 2004. Ecological impacts of wheat seeding after a Sierra Nevada wildfire. Int. J. Wildland Fire 13, 73-78.

Korb, J. E., Johnson, N.C., Covington, W.W., 2004. Slash pile burning effects on soil biotic and chemical properties and plant establishment: Recommendations for amelioration. Restor. Ecol. 12, 52-62.

Kruse, R., Bend, E., Bierzychudek P., 2004. Native plant regeneration and introduction of non- natives following post-fire rehabilitation with straw mulch and barley seeding. Forest Ecol. Manage. 196, 299-310.

Kuenzi, A.M., Fulé, P.Z., Sieg, C.H. 2008. Effects of fire severity and pre-fire stand treatment on plant community recovery after a large wildfire. Forest Ecol. Manage. 255, 855-865.

Larson, M.M., Schubert, G.H., 1969. Root competition between ponderosa pine seedlings and grass. General Technical Report RM-54. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

Linhart, Y. B., 1995. Restoration, revegetation, and the importance of genetic and evolutionary perspectives. In Roundy, B.A., McArthur, E.D., Haley, J.S., Mann, D.K. (Eds.), Proceedings of the Wildland Shrub and Arid Land Restoration Symposium; 19–21 October 1993, Las Vegas, Nevada. Gen. Tech. Rep. INT-GTR-315. U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Ogden, Utah, pp. 271–287.

Littell, J.S., McKenzie D., Peterson, D.L., Westerling, A.L., 2009. Climate and wildfire area burned in western U.S. ecoprovinces, 1916–2003. Ecol. Appl. 19, 1003-1021.

Logar, R., 2006. Results of reseeding a fire impacted watershed in south central Montana. USDA NRCS Forestry Technical Note no. MT-28.

MacDonald, L.H., Larsen, I.J., 2009. Effects of forest fires and post-fire rehabilitation: A Colorado, USA case study. In Cerdà, A., Robichaud, P.R. (Eds.), Fire Effects on Soils and Restoration Strategies. Science Publishers, Enfield, NH, 589 p.

Maloney, P.C., Thornton, J.L., John, L., 1995. Implementation and effectiveness monitoring of best management practices and soil and water protection measures within the Foothills fire salvage logging area 1992-1995. Unpublished Report on File at: USDA Forest Service, Boise National Forest. 51 p.

Meyer, V., Redente, E., Barbarick, K., Brobst, R., 2001. Biosolids applications affect runoff water quality following forest fire. J. Environ. Qual. 30, 1528-1532.

McKenzie, D., Gedalof, Z., Peterson, D.L., Mote, P., 2004. Climatic change, wildfire, and conservation. Conserv. Biol. 18, 890-902.

Noble, E.L., 1965. Sediment reduction through watershed rehabilitation. In: Proceedings of the federal inter-agency sedimentation conference 1963. U.S. Department of Agriculture, Misc. Publ. 970, Washington, DC, pp. 114-123.

Noble, I.R., Slatyer, R.O., 1977. Post fire succession of plants in Mediterranean ecosystems. In: Mooney, H.A., Conrad, C.E. (Eds.), Proceedings of the Symposium on Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems. Gen. Tech. Rep. WO-3. U.S. Department of Agriculture, Forest Service, Washington, DC, pp. 27-36.

Orr, H.K., 1970. Runoff and erosion control by seeded and native vegetation on a forest burn: Black Hills, South Dakota. Research Paper RM-60. U.S.

Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO. 12 p.

Pearson, H.A., Davis, J.R., Schubert, G.H., 1972. Effects of wildfire on timber and forage production in Arizona. J. Range Manage. 25, 250-253.

Peppin, D.L., Fulé, P.Z., Sieg, C.H., Beyers, J.L., Hunter, M.E., 2010. Post-wildfire seeding in forests of the western United States: An evidence-based review. Forest Ecol. Manage. 260, 573-586.

Peterson, D.W., Dodson, E.K., Harrod, R.J., 2007. Assessing the effectiveness of seeding and fertilization treatments for reducing erosion potential following severe wildfires. In: Butler, B.W., Cook, W. (Comps.), The fire environment – innovations, management, and policy; Conference proceedings 26-30 March 2007, Destin, FL. Proceedings RMRS-P-46CD. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO. 662 p.

Richards, R.T., Chambers, J.C., Ross, C., 1998. Use of native plants on federal lands: policy and practice. J. Range Manage. 51, 625-632.

Robichaud, P.R., Beyers, J.L., Neary, D.G., 2000. Evaluating the effectiveness of post-fire rehabilitation treatments. Gen. Tech. Rep. RMRS-GTR-63. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO.

Robichaud, P.R., Brown, R.E., 2005. Postfire rehabilitation treatments: Are we learning what works? In: Moglen, Glenn E., Ed. Managing Watersheds for Human and Natural Impacts: Engineering, Ecological, and Economic Challenges: Proceedings of the 2005 Watershed Management Conference, July 19-22, 2005, Williamsburg, VA, 12 p.

Robichaud, P.R., Lillybridge, T.R., Wagenbrenner, J.W., 2006. Effects of postfire seeding and fertilizing on hillslope erosion in north-central Washington, USA. Catena 67, 56-67.

Robichaud, P.R., Elliot W.J., 2006. Protection from erosion following wildfire. Report. Paper No. 068009. ASABE. MI, US.

Roche, C.T., Sheley, R.L., Korfhage, R.C., 2008. Native species replace introduced grass cultivars seeded following wildfire. Ecol. Restor. 26, 321-330.

Rogers, D.L., Montalvo, A.M., 2004. Genetically appropriate choices for plant materials to maintain biological diversity. Report to the USDA Forest Service, Rocky Mountain Region, Lakewood, CO. University of California. Davis, CA.

Rough, D., 2007. Effectiveness of rehabilitation treatments in reducing post-fire erosion after the Hayman and Schoonover fires, Colorado Front Range. M.S. Thesis, Colorado State University.

Schmid, B., 1994. Effects of genetic diversity in experimental stands of *Solidago altissima*: evidence for the potential role of pathogens as selective agents in plant populations. J. Ecol. 82, 165-175.

Schoennagel, T., 1997. Native plant response to high intensity fire and seeding of non-native grasses in an *Abies grandis* forest on the Leavenworth district of the Wenatchee National Forest. M.S. Thesis, University of Wisconsin-Madison.

Schoennagel, T.L., Waller, D.M., 1999. Understory responses to fire and artificial seeding in an eastern Cascades *Abies grandis* forest, U.S.A. Can. J. Forest Res. 29, 1390-1401.

Schuman, G.E., Tayor, E.M, Rauzi, F., 1991. Forage production of reclaimed mined lands as influenced by nitrogen fertilization and mulching practice. J. Range Manage. 44, 382-384.

Sexton, T.O., 1998. Ecological effect of post-wildfire management activities (salvage-logging and grass-seeding) on vegetation composition, diversity, biomass, and growth and survival of *Pinus ponderosa* and *Purshia tridentata*. M.S. Thesis, Oregon State University.

Smith, S.A., Sher, A., Grant, T.A., 2007. Genetic diversity in restoration materials and the impacts of seed collection in Colorado's restoration plant production industry. Restor. Ecol. 15, 369–374

Springer, J. D., Waltz, A.E.M., Fulè, P.Z., Moore, M.M., Covington, W.W., 2001. Seeding versus natural regeneration: A comparison of vegetation change following thinning and burning in ponderosa pine. USDA Forest Service, Rocky Mountain Research Station Proceedings RMRS-P-22.

Stella, K.A., 2009. Effects and effectiveness of seeding following high-severity wildfires in northern Arizona ponderosa pine forests. M.S. Thesis, Northern Arizona University.

Stella, K.A., Sieg, C.H., Fulé, P.Z., In press. Minimal effectiveness of native and non-native seeding following three high severity wildfires. Int. J. Wildland Fire.

U.S. Department of the Interior, 2006. Interagency Burn Area Rehabilitation Guidebook. Interpretation of Department of the Interior 620 DM 3. For the Burned Area Rehabilitation of Federal and Tribal Trust Lands. Version 1.3. October 2006. Washington, D.C.

U.S. Department of Agriculture, Forest Service, 2006. Notice of Proposed Native Plant Material Policy, Forest Service Manual (FSM) 2070. 26 May 2006. 71 Federal Register 102: 30375.

U.S. Department of Agriculture, Forest Service. 2004. Burned Area Emergency Rehabilitation handbook. FSH 2509.13.

VanZuuk, K. 1997. Memo, Crystal Burn monitoring. Unpublished Report on File at: U.S. Department of Agriculture, Forest Service, Tahoe National Forest, Nevada City, CA.

Wagenbrenner, J.W., MacDonald, L.H., Rough, D., 2006. Effectiveness of three post-fire rehabilitation treatments in the Colorado Front Range. Hydrol. Process. 20, 2989-3006.

Westerling, A.L., Hidalgo, H.G., Cayan, D.R., Swetnam, T.W., 2006. Warming and earlier spring increase western U.S. forest wildfire activity. Science 313, 940-943.

Wolfson, B.A.S., Sieg, C.H., In Press. 40-year post fire seeding trends in Arizona and New Mexico. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO.

10. Appendices

Appendix 1. References included in the review (w/ quality of evidence ratings)

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. U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station, Berkeley, CA, pp. 148-149.
Quality of Evidence Rating: *Highest*

Amaranthus, M. P., Trappe, J. M., Perry, D. A., 1993. Soil moisture, native revegetation, and *Pinus lambertiana* seedling survival, growth, and mycorrhiza formation following wildfire and grass seeding. Restor. Ecol. 1, 188-195.
Quality of Evidence Rating: *Highest*

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

Barclay, A.D., Betancourt, J.L., Allen, C.D., 2004. Effects of seeding ryegrass (*Lolium multiflorum*) on vegetation recovery following fire in a ponderosa pine (*Pinus ponderosa*) forest. Int. J. 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., Rhodes, J.J., Kauffman, J.B., Gresswell, R.E., Minshall, G.W., Karr, J.R., Perry D.A., Hauer F.R., Frissell C.A., 2003. Postfire management of forested public lands of the western United States. Conserv. Biol. 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. Conserv. Biol. 18, 947-956.
Quality of Evidence Rating: *High*

Bruggink, J., 2007. Long term ecological changes with post-fire emergency seeding. In: Furniss, M., Clifton, C., Ronnenberg, K. (Eds.), Advancing the Fundamental Sciences: Proceedings of the Forest Service National Earth Sciences Conference, San Diego, CA, 18-22 October 2004. Gen. Tech. Rep. PNW-GTR-689. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR, pp. 20-26.
Quality of Evidence Rating: *Low*

Buckley, K.J., Walterscheid, J., Loftin, S., Kuyumjian, G., 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., Walterscheid, J., Loftin, S., Kuyumjian, G., 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., Baker, B., 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., Young, J.A., Evans, R.A., 1974. Control of annual grasses and revegetation in ponderosa pine woodlands. J. Range Manage. 27, 143-145.
Quality of Evidence Rating: ***Highest***

Clark, J.T, Kuyumjian, G.A., 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., Brooks, W.M., 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., Regelbrugge, J.C., Wills, R.D., 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., Williams, J.E., Williams, C.D., Franklin, J.F., 2004. Beyond smoke and mirrors: A synthesis of fire policy and science. Conserv. Biol. 18, 976-986.
Quality of Evidence Rating: ***Lowest***

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

Earles, T.A., Foster, P., Ey, J., Wright, K.R., 2005. Missionary Ridge wildfire rehabilitation. Proceedings of the 2005 Watershed Management Conference,Williamsburg,VA.1-14.
Quality of Evidence Rating: *Lowest*

Elliott, K.J., White, A.S., 1987. Competitive effects of various grasses and forbs on ponderosa pine seedlings. For. Sci. 33, 356-366.
Quality of Evidence Rating: *Highest*

Field, D., 1991. Grass seeding for wildfire rehabilitation: Science and policy. M.S. Thesis. University of Montana.
Quality of Evidence Rating: *Low*

GAO (General Accounting Office), 2003. Wildland fires: Better information needed on effectiveness of emergency stabilization and rehabilitation treatments. GAO-03-430.
Quality of Evidence Rating: *Lowest*

Griffin, J.R., 1982. Pine seedling, native ground cover and *lolium multifolium* on the Marble-Cone Burn, Santa Lucia Range, California. Madroño 29, 177-188.
Quality of Evidence Rating: *Medium*

Griffith, R.W, 1998. Burned area emergency rehabilitation. Proceedings, Nineteenth Annual Forest Vegetation Management Conference: Wildfire Rehabilitation: January 20-22, 1998, Redding, CA. 4-7.
Quality of Evidence Rating: *Low*

Groen, A.H., Woods, S.W., 2008. Effectiveness of aerial seeding and straw mulch for reducing post-wildfire erosion, north-western Montana, USA. Int. J. Wildland Fire 17, 559-571.
Quality of Evidence Rating: *Highest*

Gross, E., Steinblums, I., Ralston, C., Jubas, H., 1989. Emergency watershed treatments on burned lands in southwestern Oregon. Proceedings of the Symposium on Fire and Watershed Management: October 26-28, 1988, Sacramento, California. Gen. Tech. Rep. PSW-109. 109-114.
Quality of Evidence Rating: *Low*

Habitats, A., 2006. Fire, watershed resources, and aquatic ecosystems. Fire inCalifornia's Ecosystems. University of California Press.
Quality of Evidence Rating: *Lowest*

Haire, S.L., McGarigal, K., 2008. Inhabitants of landscape scars: Succession of woody plants after large, severe forest fires in Arizona and New Mexico. Southwestern Nat. 53, 146-161.
Quality of Evidence Rating: *Lowest*

Hanes, R., Callahan, K., 1995. Crystal burn analysis: Summary of first monitoring. Unpublished Report on File at: US Department of Agriculture, Forest Service, Tahoe National Forest, CA.
Quality of Evidence Rating: *Low*

Hanes, R., Callahan, K., 1996. Crystal burn analysis. post-fire succession and seeding monitoring: Year two. Unpublished Report on File at: U.S. Department of Agriculture, Forest Service, Tahoe National Forest, CA.
Quality of Evidence Rating: *Low*

Helvey, J.D., 1980. Effects of north central Washington wildfire on runoff and sediment production. J. Am. Water Resour. As. 16, 627-634.
Quality of Evidence Rating: *Low*

Holzworth, L.K., Hunter, H.E., Winslow, S.R., 2003. Disturbed forestland revegetation effectiveness monitoring: Results of 30 years. 2003 National Meeting of the American Society of Mining and Reclamation and the 9th Billings Land Reclamation Symposium, Billings, MT, June 3-6.
Quality of Evidence Rating: *High*

Hughes, L.E., 2004. Ponderosa pine undergrowth restoration on the Arizona Strip. Rangelands 26, 23-27.
Quality of Evidence Rating: *High*

Hunter, M.E., 2004. Post-fire grass seeding for rehabilitation and erosion control: Implications for native plant recovery and exotic species establishment. Ph.D. Dissertation Colorado State University
Quality of Evidence Rating: *Highest*

Hunter, M.E., Omi, P.N., 2006. Response of native and exotic grasses to increased soil nitrogen and recovery in a postfire environment. Restor. Ecol. 14, 587-594.
Quality of Evidence Rating: *Highest*

Hunter, M.E., Omi, P.N., 2006. Seed supply of native and cultivated grasses in pine forests of the southwestern United States and the potential for vegetation recovery following wildfire. Plant Ecol. 183, 1-8.
Quality of Evidence Rating: *High*

Hunter, M.E., Omi, P.N., Martinson, E.J., Chong, G.W., 2006. Establishment of non-native plant species after wildfires: Effects of fuel treatments, abiotic and biotic factors, and post-fire grass seeding treatment. Int. J. Wildland Fire 15, 271-281.
Quality of Evidence Rating: *High*

Johnson, M., Rew, L.J., Maxwell, B.D., Sutherland, S., 2006. The role of wildfire in the establishment and range expansion of nonnative plant species into natural areas. Bozeman, MT: Montana State University Center for Invasive Plant Management.
Quality of Evidence Rating: *Lowest*

Keeley, J.E., 2004. Ecological impacts of wheat seeding after a Sierra Nevada wildfire. Int. J. Wildland Fire 13, 73-78.
Quality of Evidence Rating: ***Medium***

Keeley, J. E., Allen, C.D., Betancourt, J., Chong, G.W., Fotheringham, C.J., Safford, H.D., 2006. A 21st century perspective on postfire seeding. J. Forest. 104, 1-2.
Quality of Evidence Rating: ***Lowest***

Keeley, J.E., 2006. Fire management impacts on invasive plants in the western United States. Conserv. Biol. 20, 375-384.
Quality of Evidence Rating: ***High***

Klock, G.O., Tiedemann, A.R., Lopushinsk, W., 1975. Seeding recommendations for disturbed mountain slopes in north central Washington. USDA Forest Service Research Note PNW-244 8 p.
Quality of Evidence Rating: ***Lowest***

Korb, J. E., Johnson, N.C., Covington, W.W., 2004. Slash pile burning effects on soil biotic and chemical properties and plant establishment: Recommendations for amelioration. Restor. Ecol. 12, 52-62.
Quality of Evidence Rating: ***Highest***

Kruse, R., Bend, E., Bierzychudek, P., 2004. Native plant regeneration and introduction of non-natives following post-fire rehabilitation with straw mulch and barley seeding. Forest Ecol. Manage. 196, 299-310.
Quality of Evidence Rating: ***Medium***

Kuenzi, A.M., 2006. Pre-fire treatment effects and understory plant community response on the Rodeo-Chediski fire, Arizona. M.S. Thesis Northern Arizona University.
Quality of Evidence Rating: ***High***

Kuenzi, A.M., Fulé, P.Z., Sieg, C.H., 2008. Effects of fire severity and pre-fire stand treatment on plant community recovery after a large wildfire. Forest Ecol. Manage. 255, 855-865.
Quality of Evidence Rating: ***Medium***

Kunze, M.D., Stednick, J.D., 2006. Streamflow and suspended sediment yield following the 2000 Bobcat fire, Colorado. Hydrol. Process. 20, 1661-1681.
Quality of Evidence Rating: ***High***

Law, D.J., Kolb, P.F., 2007. The effects of forest residual debris disposal on perennial grass emergence, growth, and survival in a ponderosa pine ecotone. Rangeland Ecol. Manage. 60, 632-643.
Quality of Evidence Rating: ***Highest***

Leege, T., Godbolt, G., 1985. Herbaceous response following prescribed burning and seeding of elk range in Idaho. Northwest Sci. 59,134-143.
Quality of Evidence Rating: *High*

Loftin, S., Fletcher, R., Luehring, P., 1998. Disturbed area rehabilitation review report. Unpublished Report on File at: U.S. Department of Agriculture, Forest Service, Southwestern Region, Albuquerque, NM.
Quality of Evidence Rating: *Lowest*

Loftin, S.R., 2004. Post-fire seeding for hydrologic recovery. Southwest Hydrol. 3, 26-27.
Quality of Evidence Rating: *Lowest*

Logar, R., 2006. Results of reseeding a fire impacted watershed in south central Montana. USDA NRCS Forestry Technical Note No. MT-28
Quality of Evidence Rating: *Low*

MacDonald, L.H, Robichaud, P.R., 2007. Postfire erosion and the effectiveness of emergency rehabilitation treatments over time. Joint Fire Science Project Final Report No. 03-2-3-22.
Quality of Evidence Rating: *High*

MacDonald, L.H., 1989. Rehabilitation and recovery following wildfires: A synthesis. In: Berg, Neil H., tech. coords. 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: 141-144.
Quality of Evidence Rating: *Lowest*

MacDonald, L.H., Larsen, I.J., 2009. Effects of forest fires and post-fire rehabilitation: A Colorado, USA case study. In Cerdà, A., Robichaud, P.R. (Eds.), Fire Effects on Soils and Restoration Strategies. Science Publishers, Enfield, NH, 589 p.
Quality of Evidence Rating: *High*

Maloney, P.C., Thornton, J.L., John L., 1995. Implementation and effectiveness monitoring of best management practices and soil and water protection measures within the Foothills fire salvage logging area 1992-1995. Unpublished Report on File at: U.S. Forest Service, Boise National Forest. 51 p.
Quality of Evidence Rating: *Lowest*

Meyer, V., Redente, E., Barbarick, K., Brobst, R.. 2001. Biosolids applications affect runoff water quality following forest fire. J. Environ. Qual. 30, 1528-1532.
Quality of Evidence Rating: *Highest*

Meyer, V., Redente, E., Barbarick, K., Brobst, R., Paschke, M., Miller, A., 2004. Plant and soil responses to biosolids application following forest fire. . J. Environ. Qual. 33, 799-804.
Quality of Evidence Rating: *High*

Miles, S.R., Haskins, D.M., Ranken, D.W., 1989. Emergency burn rehabilitation: Cost, risk, and effectiveness. In: Berg, Neil H., tech. coords. 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, 97-102.
Quality of Evidence Rating: *Low*

Minard, A.E., 2003. Limiting damage to forest soils during restoration. Ecological Restoration Institute, Northern Arizona University: Working Paper 05, 5p.
Quality of Evidence Rating: *Lowest*

Monsen, S.B., Shaw, N.L., 2000. Development and use of plant resources for western wildlands. McArthur, E. Durant; Fairbanks, Daniel J., comps. Shrubland Ecosystem Genetics and Biodiversity: Proceedings. RMRS-P-21, 13-15.
Quality of Evidence Rating: *Lowest*

Noss, R.F., Franklin, J.F., Baker, W.L., 2006. Ecology and management of fire-prone forests of the western United States. Society for Conservation Biology Scientific Panel on Fire in Western US Forests.Society for Conservation Biology, North American Section, Arlington, Virginia. Online at: http://www.conbio.org/sections/namerica/napolicy.cfm.
Quality of Evidence Rating: *Lowest*

Orr, H.K., 1970. Runoff and erosion control by seeded and native vegetation on a forest burn: Black Hills, South Dakota. Research Paper RM-60. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.12 p.
Quality of Evidence Rating: *Lowest*

Pearson, H.A., Davis, J.R., Schubert, G.H., 1972. Effects of wildfire on timber and forage production in Arizona. J. Range Manage. 25, 250-253.
Quality of Evidence Rating: *High*

Peterson, D.W., Dodson, E.K., Harrod, R.J., 2007. Assessing the effectiveness of seeding and fertilization treatments for reducing erosion potential following severe wildfires. In: Butler, B.W., Cook, W. (Comps.), The fire environment – innovations, management, and policy; Conference proceedings 26-30 March 2007, Destin, FL. Proceedings RMRS-P-46CD. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO. 662p.
Quality of Evidence Rating: *Highest*

Ratliff, R.D., McDonald, P.M., 1987. Postfire grass and legume seeding: What to seed and potential impacts on reforestation. Proceedings, Ninth Annual Forest Vegetation Management Conference. November 3-5, 1987, Redding, California. 3-5.
Quality of Evidence Rating: ***Lowest***

Regelbrugge, J.C., 1990. Effects of fire intensity, rock type and seeding on vegetation recovery following the 1987 Stanslaus Complex fires in California, USA. Bull. Ecol. Soc. Am.71, 297.
Quality of Evidence Rating: ***Lowest***

Richards, R.T., Chambers, J.C., Ross, C., 1998. Use of native plants on federal lands: policy and practice. J. Range Manage. 51, 625-632.
Quality of Evidence Rating: ***Lowest***

Robichaud, P.R., Brown, R.E., 2005. Postfire rehabilitation treatments: Are we learning what works? In: Moglen, Glenn E., Ed. Managing Watersheds for Human and Natural Impacts: Engineering, Ecological, and Economic Challenges: Proceedings of the 2005 Watershed Management Conference, July 19-22, 2005, Williamsburg, VA, 12 p.
Quality of Evidence Rating: ***Lowest***

Robichaud, P.R., 2005. Measurement of post-fire hillslope erosion to evaluate and model rehabilitation treatment effectiveness and recovery. Int. J. Wildland Fire 14, 475-485.
Quality of Evidence Rating: ***Lowest***

Robichaud,P., MacDonald, L., Freeouf, J., Neary, D., Martin, D., Ashmun, L., 2003. Postfire rehabilitation of the Hayman fire. USDA Forest Service Gen Tech Rep RMRS-GTR-114, US Department of Agriculture Forest Service, Rocky Mountain Research Station, Fort Collins, Colorado. 293-313.
Quality of Evidence Rating: ***Lowest***

Robichaud, P.R., Beyers, J.L., Neary, D.G., 2000. Evaluating the effectiveness of post-fire rehabilitation treatments. Gen. Tech. Rep. RMRS-GTR-63. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO.
Quality of Evidence Rating: ***High***

Robichaud, P. R., T.R. Lillybridge, and J.W. Wagenbrenner. 2006. Effects of postfire seeding and fertilizing on hillslope erosion in north-central Washington, USA. Catena 67, 56-67.
Quality of Evidence Rating: ***Highest***

Robichaud, P.R., Elliot, W.J. 2006. Protection from erosion following wildfire. Report. Paper No. 068009. ASABE. MI, US.
Quality of Evidence Rating: ***Lowest***

Roby, K.B., 1989. Watershed response and recovery from the will fire: Ten years of observation. In Berg, N.H. (tech. coord.), Proceedings of the Symposium on Fire and Watershed Management, Sacramento, CA. Gen. Tech. Rep. PSW-109. U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station, Berkeley, CA, pp. 131-136.
Quality of Evidence Rating: *Medium*

Roche, C.T., Sheley, R.L., Korfhage, R.C., 2008. Native species replace introduced grass cultivars seeded following wildfire. Ecol. Restor. 26, 321-330.
Quality of Evidence Rating: *Medium*

Rough, D., 2007. Effectiveness of rehabilitation treatments in reducing post-fire erosion after the Hayman and Schoonover fires, Colorado Front Range. M.S. Thesis Colorado State University.
Quality of Evidence Rating: *Highest*

Ruby, E.C., 1989. Rationale for seeding grass on the Stanislaus Complex burnt. In: Berg, Neil H., tech. coords. 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, 125-130.
Quality of Evidence Rating: *Lowest*

Schoennagel, T., 1997. Native plant response to high intensity fire and seeding of non-native grasses in an *Abies grandis* forest on the Leavenworth district of the Wenatchee National Forest. M.S. Thesis Univeristy of Wisconsin-Madison.
Quality of Evidence Rating: *High*

Schoennagel, T.L., Waller, D.M., 1999. Understory responses to fire and artificial seeding in an eastern Cascades *Abies grandis* forest, U.S.A. Can. J. Forest Res. 29, 1390-1401.
Quality of Evidence Rating: *High*

Sexton, T.O., 1998. Ecological effect of post-wildfire management activities (salvage-logging and grass-seeding) on vegetation composition, diversity, biomass, and growth and survival of *Pinus ponderosa* and *Purshia tridentata*. M.S. Thesis Oregon State University.
Quality of Evidence Rating: *Highest*

Sirucek, D., 1987. The north hills fire-erosion event. Proceedings of XVIII International Erosion Control Conference, February 26-27, 1987, Reno, NV. 199-202.
Quality of Evidence Rating: *Lowest*

Springer, J.D., 2007. Understory seeding in southwestern forests following wildfire and ecological restoration treatments. Northern Arizona University: Working Paper 19, 8p.
Quality of Evidence Rating: *Lowest*

Springer, J.D., Waltz, A.E.M., Fulè, P.Z., Moore, M.M., Covington, W.W., 2001. Seeding versus natural regeneration: A comparison of vegetation change following thinning and burning in ponderosa pine. USDA Forest Service, Rocky Mountain Research Station Proceedings RMRS-P-22.
Quality of Evidence Rating: *High*

Stella, K.A., 2009. Effects and effectiveness of seeding following high-severity wildfires in northern Arizona ponderosa pine forests. M.S. Thesis. Northern Arizona University.
Quality of Evidence Rating: *Highest*

Stewart, W.L., 1973. Emergency rehabilitation of watersheds denuded by wildfire in the ponderosa pine and douglas-fir zones of north-central Washington. M.S. Thesis. Washington State University.
Quality of Evidence Rating: *Medium*

Story, M.T., Kracht, R., 1989. Memo: Emergency watershed stabilization, BMP implementation review storm creek fire. Unpublished Report on File at: U.S. Department of Agriculture, Forest Service, Gallatin National Forest, MT.
Quality of Evidence Rating: *Lowest*

Sullivan, J., Omi, P.N., Dyer, A.A., Gonzales-Caben, A., 1987. Evaluating the economics efficiency of wildfire rehabilitation treatments. West. J. Appl. For. 2, 58-61.
Quality of Evidence Rating: *Low*

Tiedmann, A.R., Klock, G.O., 1973. First-year vegetation after fire, reseeding, and fertilization on the Entiat Experimental Forest. Research Note PNW-195, 23 p.
Quality of Evidence Rating: *High*

U.S. Department of the Interior and U.S. Department of Agriculture. 2006.Interagency Burn Area Emergency Response Guidebook. Interpretation of Department of the Interior 620 DM 3 and USDA Forest Service Manual 2523. Version 4.0. February 2006. Washington, D.C.
Quality of Evidence Rating: *Lowest*

VanZuuk, K., 1997. Memo, Crystal Burn monitoring. Unpublished Report on File at: U.S. Department of Agriculture, Forest Service, Tahoe National Forest, Nevada City, CA.
Quality of Evidence Rating: *Lowest*

Wagenbrenner, J.W., MacDonald, L.H., Rough, D., 2006. Effectiveness of three post-fire rehabilitation treatments in the Colorado Front Range. Hydrol. Process. 20, 2989-3006.
Quality of Evidence Rating: *High*

Weigel, T.J., 2007. Assessing post-fire reseeding potential using Bureau of Land Management criteria in northeastern Nevada: A spatial modelling appoarch. M.S. Thesis University of Nevada, Reno.
Quality of Evidence Rating: *Low*

Wolfson, B.A.S., Sieg, C.H., In Press. 40-year post fire seeding trends in Arizona and New Mexico. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO.
Quality of Evidence Rating: *High*

Woodsmith, R.D., Vache, K.B., McDonnell, J.J., Helvey, J.D., 2004. Entiat experimental forest: Catchment-scale runoff data before and after a 1970 wildfire. Water Resour. Res. 40, 5p.
Quality of Evidence Rating: *High*

Appendix 2. Data extraction form

Data Type	**Values**
Refworks ID	#
Reviewer	Name
Paper	Authors, title of Publication, year
Study location	Place name
Length of study	dd/mm/yy-dd/mm/yy (year minimum)
Fire	Name(s)
Fire acreage/hectares	#
Date of fire	dd/mm/yy-dd/mm/yy (ignition to time of control)
Fire severity	High, moderate, low (where treatments occurred
Plant community type	Type name (e.g. Ponderosa pine, pinion-juniper, chaparral, grassland, mixed-conifer, etc.)
Elevation (range)	#
Slope (range)	%
Aspect	Degrees
Precipitation	Amount measured during study
Hypothesis	As stated by the author
Major study design category	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, or expert opinion
Experimental design	Major design category used (e.g. BACI, stratified, etc.)
Plot design	Layout (number of plots, plot size, length apart, etc.)
Number of replicated	#
Number of plots per replicate	#
Seeding treatment	Method of delivery, location seeded, acres seeded, type of seed applied (e.g. native, non-native, perennial, annual, grass, forbs, shrubs, etc.)
Seeding rate	# per unit
Species seeded	Common and scientific
Seeding treatment results	Major results related to this study, as stated by author
Additional Treatments	Details and results
Cost of treatment(s)	$ (per unit if possible)
Monitoring	Yes, no (if yes, state methods)
Overall conclusions	As stated by author
Expert opinion	Additional opinions not based from data