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Recent trends in post-wildfire seeding in western US forests: costs and seed mixes

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Abstract. Broadcast seeding is one of the most commonly used post-fire rehabilitation treatments to establish ground cover for erosion control and mitigation of non-native plant species invasions. Little quantitative information is available on overall trends of post-fire seeding expenditures and seed mixes used over time in forested ecosystems in the western USA. We reviewed scientific articles, government publications and unpublished documents as well as USDA Forest Service Burned Area Reports to determine trends in post-fire seeding in forested ecosystems over time. Of 1164 USDA Forest Service Burned Area Reports, 380 contained information on seeding treatments conducted in forested ecosystems. A review of 40 papers and 67 Burned Area Reports reporting species seeded between 1970 and 2007 revealed a trend of increasing use of native species, annual cereal grains and sterile-grass hybrids, with natives dominating seed mixes. According to 380 Burned Area Reports with data on costs and area seeded, total post-fire seeding expenditures have increased substantially, averaging US$3.3 million per year spent on post-fire emergency seeding treatments in forested ecosystems that involved the Forest Service during the period 2000 to 2007 – an increase of 192% compared with the average spent during the previous 30 years. The percentage of the total burned area seeded averaged 21% in the 1970s, compared with only 4% between 2000 and 2007.

Additional keywords: annual cereal grains, Burned Area Emergency Response, native plant species.

Introduction

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

Historically, aerial broadcast seeding of grasses, typically non-native annuals or short-lived perennials, has been the most commonly used post-fire stabilisation treatment (Robichaud *et al*. 2000). According to recent post-fire seeding reviews, demand and use of native species has increased (Beyers 2004; Wolfson and Sieg, in press) with the growing recognition in recent revegetation policy of the importance of using these species during restoration and rehabilitation activities (Richards *et al*. 1998; Erickson 2008). However, high costs and restricted

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availability, especially in high-severity fire years, often limit inclusion of native plants in post-fire seeding. Instead, the recognised competitive ability of non-native and some native grass cultivars, coupled with their abundant availability and relative low costs, have resulted in continued seeding with these species (Robichaud *et al*. 2000; Beyers 2004).

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

Currently, quantitative information on overall trends of post-fire seeding expenditures and seed mixes used over time for forested ecosystems in the western USA is lacking. Robichaud *et al*. (2000) quantified USFS BAER treatment spending on aerial seeding between 1973 and 1998, which included post-fire seeding treatments occurring in both chaparral and conifer forests across the western USA. More recent reviews by Beyers (2004) and Peppin *et al*. (2010) focussed primarily on post-fire seeding effectiveness and effects on native plant communities. Trends in species used and costs of seeding reviewed by Wolfson and Sieg (in press) were limited to the south-western USA. We reviewed scientific literature, theses and government publications, as well as USFS Burned Area Reports related to post-fire seeding in specifically forested ecosystems across in the western USA to help answer: (1) what are trends in seeding of specific species, especially native species, over time; and (2) how have other post-fire seeding trends, particularly those related to costs and area seeded, changed over time?

Methods

Literature review

As part of a study reported in Peppin *et al*. (2010), we conducted a systematic review of literature on post-fire seeding. The systematic review methodology follows a rigorous, predetermined protocol to ensure that the synthesis of available literature is thorough, unbiased and evidence-based (Pullin and Stewart 2006). We searched online databases (JSTOR, Google Scholar, Forest Science Database, Ingenta, Web of Science, AGRICOLA), online government collections and electronic university libraries using combinations of key search terms: seeding AND fire; seeding AND burn; seeding AND wildfire; seeding AND erosion; and seeding AND native species. Refereed journal articles, peer-reviewed reports (such as government documents and conference proceedings), theses and unpublished literature were considered. To be included, potential studies had to meet all three of the following specified criteria:

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

Peppin *et al*. (2010) identified 94 papers meeting the above criteria to evaluate treatment effectiveness and effects on soils and plant communities. For the present study, we used only those papers containing quantitative information useful for describing trends in seeding over time: (1) area and amounts of seed used; (2) seed sources and species selected; (3) total cost of seeding; and (4) cost per hectare seeded. Both qualitative and quantitative data were extracted from the papers. We characterised the types of plant species seeded as non-native or native, in most cases following the authors' classifications from the paper. However, lack of a widely accepted definition of 'native' (Jones 2003) caused definitions to differ between papers. Ultimately, nativity was assigned according to the USDA Natural Resource Conservation Service Plants Database (NRCS 2010). When available, information about the geographic origin of seed sources used was extracted as well.

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

Forest Service Burned Area Reports

We used a database developed originally by Robichaud *et al*. (2000) containing summaries of 1164 USFS Burned Area Report (FS-2500-8) forms to obtain information on BAER treatments prescribed for fires in forested ecosystems in the western USA from 1966 to 2007. Much post-fire seeding occurs in forested areas in the western United States. Approximately half of the forested land in the West is federally managed, with the USFS as the lead management agency (Richards *et al*. 1998; Pollard *et al*. 2006). For this reason, USFS Burned Area Reports provide valuable information regarding post-fire seeding trends associated with costs and area seeded in these ecosystems. However, the dataset was missing results from several fires, particularly from the 1970s and 1980s, because the original paper records were unobtainable (Robichaud *et al*. 2000). Therefore, costs and area totals reported are minimum estimates. We limited our review to reports for projects that used seeding in forested ecosystems. Post-fire rehabilitation assessment reports from federal land-management agencies under the Department of Interior were not available in electronic format. In addition, many reports contained only information on what was planned, not what was actually implemented. Because of these complexities, burned area assessment data from these agencies were excluded. Results reported on costs and area seeded are therefore solely representative of trends occurring on lands managed by the USFS. All BAER spending and treatment costs were adjusted to constant 2009 US dollars (Federal Reserve Bank 2009).

Results and discussion

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

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

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

The most frequently used species in the 1970s were yellow sweetclover (*Melilotus officinalis* (L.) Lam.), orchardgrass (*Dactylis glomerata* L.), timothy (*Phleum pratense* L.), sheep fescue (*Festuca ovina* L.), and perennial ryegrass (*Lolium perenne* L.) (Table 1). In the 1980s, perennial grasses such as orchardgrass and smooth brome (*Bromus inermis* Leyss.) still dominated seeded mixes, but annual ryegrass (*Lolium perenne* ssp. *multiflorum* (Lam.) Husnot) was used almost as often. Use of slender wheatgrass (*Elymus trachycaulus* (Link) Gould ex Shinners), mountain brome (*Bromus marginatus* Ness ex Steud.) (both natives), cereal rye (*Secale cereal* L.) and intermediate wheatgrass (*Thinopyrum intermedium* (Host) Barkworth & D.R. Dewey, non-native) increased in this period

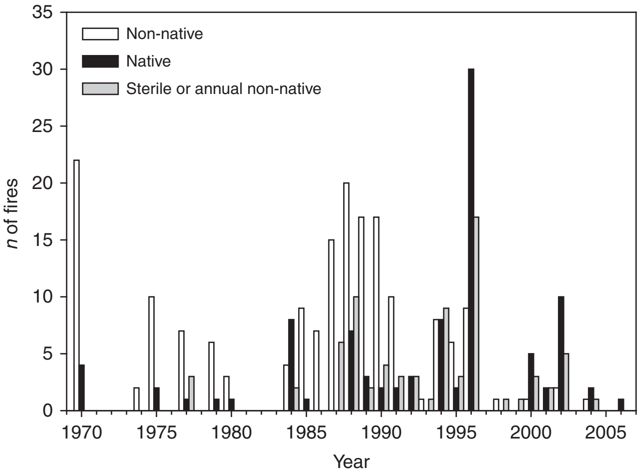

Fig. 1. Number of fires seeded with non-native, native and annual cereal grain species from 1970 to 2005. Graph shows only seeded species used on at least three fires for rehabilitation. Values for the 1970s and 1980s are minimum estimates owing to incomplete collection of Burned Area Reports from those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

as well. Slender wheatgrass continued in popularity through 2005. During the 1990s, the number of native species, annual cereal grains and sterile-grass hybrids used on burned areas increased dramatically, with the most frequently used being slender wheatgrass, mountain brome, 'Regreen' (*Triticum* × *Agropyron*) and cereal barley (*Hordeum vulgare* L.); non-native annual ryegrass continued in popularity as well, however. Between 2000 and 2006, cereal barley and slender wheatgrass continued as the most commonly seeded species, followed by mountain brome and western wheatgrass (*Pascopyrum smithii* (Rydb.) A. Löve).

Since the 1990s, use of annual non-natives, annual cereal grains and sterile-grass hybrids has increased, exceeding that of perennial non-natives in the years 2000–06. This increase is likely due to the hypothesis that annual non-native species (e.g. annual ryegrass), annual cereal grains and sterile-grass hybrids provide quick cover in the first year after fire and then die out to let native vegetation reoccupy the site in subsequent years (Beyers 2004). Some evidence demonstrates their ability to quickly increase cover. Barclay *et al*. (2004) and Keeley (2004) showed that successful exclusion of non-natives resulted when annual non-native seeded species produced high cover in the first year (Barclay *et al*. 2004; Keeley 2004). These studies and others have also shown the ability of these species to rapidly die off (Barclay *et al*. 2004; Keeley 2004; Loftin 2004; Kuenzi *et al*. 2008). However, other studies have shown that these species can persist (Conard *et al*. 1991; Sexton 1998; Schoennagel and Waller 1999), thereby leading to the ineffective recovery of native species (Conard *et al*. 1991; Sexton 1998; Schoennagel and Waller 1999) even many years after fire (Conard *et al*. 1991). These results suggest that seeding annual non-natives or sterile cereal grains may delay the recovery of native flora in some circumstances. Further research and longer-term quantitative monitoring are needed to assess more thoroughly any persistent effects seeding with annual cereal grains or sterile-grass hybrids may have on native plant recovery.

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

Life forms are: g, grass; f, forb. Life cycles are: a, annual; b, biennial; p, perennial; x, 'sterile' hybrid. Native origin of species are as per USDA Natural Resource Conservation Service (NRCS) Plants Database (http://plants.usda.gov/, accessed 14 April 2010)

Species name	Common name	Life form	Life cycle	Number of fires seeded by decade			
				1970–79	1980–89	1990–99	2000–06
Non-native							
Agropyron cristatum (L.) Gaertn.	Crested wheatgrass	g	p	2	2	1	0
Avena sativa L.	Common oat	g	a	0	1	2	1
Bromus inermis Leyss.	Smooth brome	g	p	3	11	6	0
Dactylis glomerata L.	Orchardgrass	g	p	9	16	7	0
Eragrostis curvula (Schrad.) Nees	Weeping lovegrass	g	p	0	3	2	0
Festuca brevipila Tracey	Hard fescue	g	p	2	2	0	0
F. ovina L.	Sheep fescue	g	p	4	2	3	0
Hordeum vulgare L.	Common barley	g	a	0	3	9	5
Lolium perenne L. ssp. *multiflorum* (Lam.) Husnot	Italian ryegrass or annual ryegrass	g	a or b	1	8	14	1
L. perenne L.	Perennial ryegrass	g	p	4	3	0	2
Lotus corniculatus L.	Bird's-foot trefoil	f	p	2	1	0	0
Medicago spp.	Alfalfa	f	a or p	0	1	2	0
Melilotus officinalis (L.) Lam.	Yellow sweetclover	f	a, b or p	7	8	8	1
Phleum pratense L.	Timothy	g	p	8	4	7	0
Secale cereal L.	Cereal rye	g	a	2	7	3	0
Sanguisorba minor Scop.	Small burnet	f	p	0	3	2	0
Thinopyrum intermedium (Host) Barkworth & D.R. Dewey	Intermediate wheatgrass	g	p	4	8	5	0
Trifolium hybridum L.	Alsike clover	f	p	0	0	3	0
T. repens L.	White clover	f	p	2	6	3	0
Triticum × *Agropyron*	Regreen	g	x	0	0	9	1
T. aestivum L.	Common wheat	g	a	0	2	7	4
Vulpia myuros (L.) C.C. Gmel.	Rat-tail fescue	g	a	0	4	1	0
Native							
Bouteloua curtipendula (Willd. Ex Kunth) Lag. Ex Griffiths	Sideoats grama	g	p	0	0	3	1
Bromus marginatus Nees ex Steud.	Mountain brome	g	p	0	5	8	3
Elymus glaucus Buckley	Blue wildrye	g	p	2	0	1	1
E. lanceolatus (Scribn. & J.G. Sm.) Gould	Thickspike wheatgrass	g	p	0	1	2	1
E. trachycaulus (Link) Gould ex Shinners	Slender wheatgrass	g	p	6	7	15	5
Festuca arizonica Vasey	Arizona fescue	g	p	0	0	3	2
F. idahoensis Elmer	Idaho fescue	g	p	0	0	3	2
Koeleria macrantha (Ledeb.) J.A. Schultes	Prairie junegrass	g	p	0	0	3	1
Nassella viridula (Trin.) Barkworth	Green needlegrass	g	p	0	1	2	2
Pascopyrum smithii (Rydb.) A. Löve	Western wheatgrass	g	p	0	5	3	3
Poa secunda J. Presl	Sandberg bluegrass	g	p	0	1	2	1
Sporobolus cryptandrus (Torr.) Gray	Sand dropseed	g	p	0	0	2	2

Increased demand in recent years, in large part due to stronger federal land-management policy for the use of native species (Richards *et al*. 1998; US Department of the Interior and US Department of Agriculture 2006), has led to the increased availability of many native species and lowered their cost (Erickson 2008). As a result, incorporation of native species in post-fire seeding activities has increased. Increased large-scale production and use of native species have given rise to questions as to whether many natives are genetically appropriate for areas seeded (Smith *et al*. 2007). It has been speculated that seeding with non-local genotypes of native species may have long-term genetic consequences on local plant communities due to out-breeding effects (Linhart 1995; Montalvo and Ellstrand 2001); however, there is very little quantitative information addressing these issues. Furthermore, few studies have investigated the use of native species to meet post-fire management objectives related to soil erosion and non-native species invasion (Peppin *et al*. 2010). The lack of basic information underscores the importance of further research to determine the short- and long-term effects of seeding with native species following fire. Additionally, care must be taken to ensure that seed mixes are free of non-native seed.

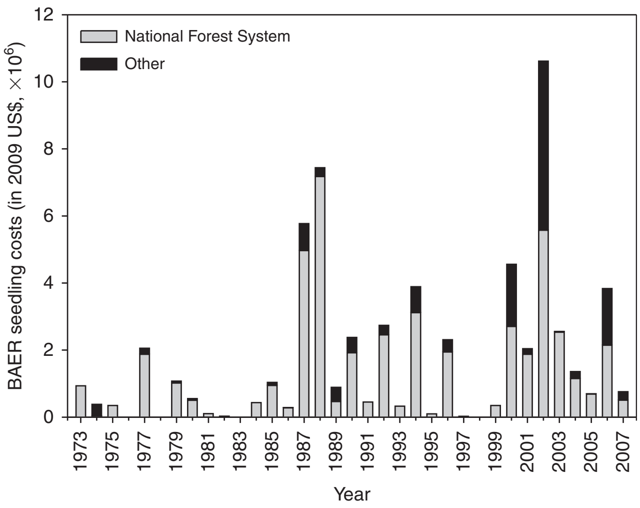

Fig. 2. Burned Area Emergency Response (BAER) seeding costs in forested ecosystems by National Forests and other lands that had some portion of National Forest lands by year in 2009 US dollars. Values for the 1970s and 1980s are minimum estimates owing to incomplete collection of Burned Area Reports from those decades.

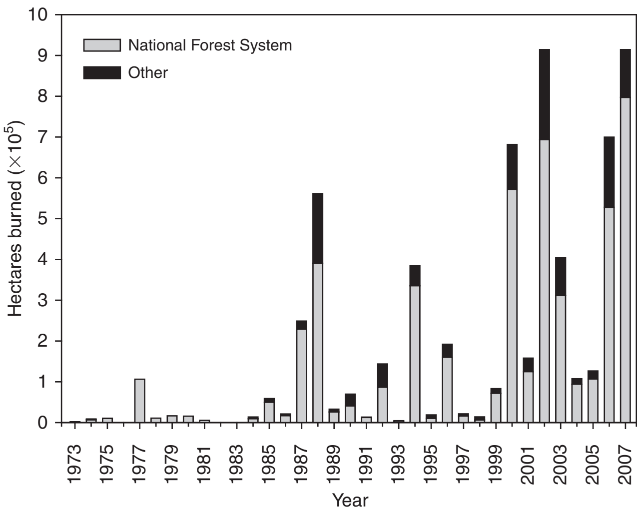

Fig. 3. Total hectares (1 ha = 2.47 acres) burned in forested ecosystems in National Forests and other lands that had some portion of National Forest lands by year from the Burned Area Reports. Values for the 1970s and 1980s are minimum estimates owing to incomplete collection of Burned Area Reports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

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

According to data from the 380 USFS Burned Area Reports, over the past four decades (1973–2007) more than US$60 million was spent on post-fire seeding in forested ecosystems involving the USFS (Fig. 2). Of that, ~78% (US$47 million) came from USFS to seed ~405 000 ha (1 million acres) of a total of 6 million hectares (15 million acres) from BAER project fires in these systems (Fig. 3). Approximately 80% (~5 million hectares (12 million acres)) of the total area burned was included in BAER project fires in forested ecosystems managed by the USFS. Since 2000, total area burned and expenditures for BAER seeding treatments have increased substantially when compared with the preceding three decades (Figs 2 and 3). For example, 66% (4 million ha (10 million acres)) of the total area burned in the last four decades burned since 2000, of which 82% occurred on National Forest System lands in forested ecosystems. However, owing to gaps in data collected, total area burned is at best a minimum estimate. From 2000 to 2007, an average of US$3.3 million per year was spent on post-fire emergency seeding treatments in forested ecosystems that involved the Forest Service – an increase of 192% compared with the average spent during the previous 30 years. Of the US$26 million spent in total on post-fire emergency seeding treatments in forested ecosystems that involved the USFS, 2000–07, approximately US$17 million came directly from the USFS, with the largest expenditure during the 2002 fire season. Rocky Mountain, Intermountain and Southwest areas (Regions 2, 3 and 4) accounted for 70% of the BAER spending on seeding from 2000–07, with the Southwest (Region 3) spending the most (32%; Fig. 4). Total area burned by year shows a trend similar to that for spending on seeding between 1973 and 2007, except in 2006 and 2007, when a greater number of hectares burned compared with amount spent on seeding.

In recent years, the percentage of burned areas seeded in forested ecosystems, including National Forests and other lands, has decreased substantially (Fig. 5). For example, an average of 21% of the total burned area was seeded across the previous three decades, with the highest percentage seeded in the 1970s (26%). This declined in the 1980s to 14% but increased to 24% in the 1990s. In the most recent period, from 2000 to 2007, the proportion of burned area seeded declined dramatically to an average of 4%.

The decline in burned area seeded may be a reflection of a change in seeding practices due to concerns raised in recent research findings regarding the effects and effectiveness of these treatments. A recent review showed that seeding success, defined as effectiveness in mitigating soil erosion, was on average not statistically distinguishable from unseeded sites (Peppin *et al.* 2010). There is discrepancy within the literature as to the effectiveness of seeding for curtailing non-native invasions (Peppin *et al.* 2010). Use of non-native annual species in seeding treatments can increase the likelihood of successful exclusion of undesirable non-natives (Schoennagel and Waller 1999; Barclay *et al.* 2004; Keeley 2004). However, these species have been shown to displace native species (Sexton 1998; Schoennagel and Waller 1999; Barclay *et al.* 2004; Keeley 2004; Logar 2006) and persist in seeded sites (Sexton 1998; Barclay *et al.* 2004; Hunter *et al.* 2006). There is much more evidence that seeding, in general, suppresses unseeded native species (Robichaud *et al.* 2000; Beyers 2004; Peppin *et al.* 2010). With increasing concerns from managers regarding the effects and effectiveness of seeding treatments, managers may be recommending seeding smaller, more targeted areas where soil erosion or threats of invasive species are most critical. Prioritising burned areas to be seeded through more thorough evaluation of immediate threats as well as potential effects and control of soil erosion and invasion of non-native species is

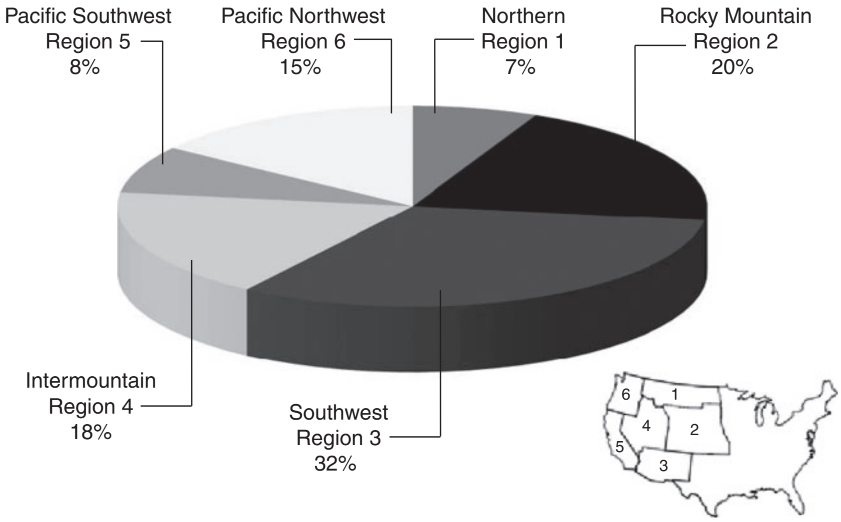

Fig. 4. Proportion of National Forest Burned Area Emergency Response (BAER) seeding costs by Region in forested ecosystems for 2000–07 from Burned Area Reports. Amounts for all years were converted to 2009 US dollars before calculation. The insert shows the western National Forest Regions used in this study.

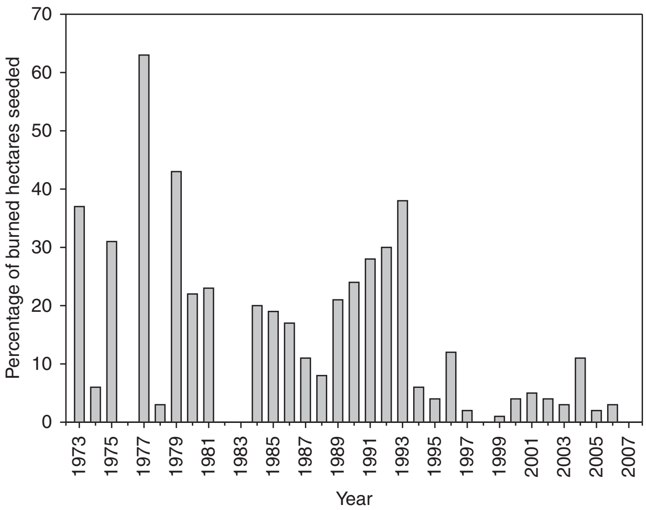

Fig. 5. Percentage of total burned hectares (1 ha = 2.47 acres) seeded 1973–2007 from Burned Area Reports.

advisable, although well-designed long-term monitoring is needed to determine any long-lasting effects seeding may have.

Conclusions and management implications

Our review of post-fire seeding practices in the western USA over the last four decades revealed a trend of increasing use of native species, annual cereal grains and sterile-grass hybrids, with native species dominating seed mixes in recent years. Cereal barley, slender wheatgrass, mountain brome and western wheatgrass were identified as the most commonly selected species for reseeding wildfires since 2000. The decline in the use of perennial non-native species is encouraging to many biologists, as those species have been shown to disrupt recovery of native plant communities. Current choices for seeding are not without concern, however. Annual cereal grains or sterile-grass hybrids, although generally short-lived, can occasionally persist into subsequent years, which may result in delayed recovery of native species. The short- and long-term effects of using native species remain uncertain. Priority should be given to research quantifying the effects of using native species, annual cereal grains and sterile-grass hybrids on burned landscapes.

Total USFS BAER seeding expenditures have increased substantially in the last decade. The expenditures approximately correlate to the increased area burned, but in fact, smaller proportions of burned areas have been seeded annually. The smaller area seeded likely reflects rising concerns over effects of seeding treatments. The success of post-fire seeding treatments in achieving specified rehabilitation objectives remains uncertain, yet millions of dollars continue to be spent annually on post-fire seeding. The ecological risks and economic costs imposed by seeding may be lessened through use of alternative rehabilitation methods shown to be more effective (e.g. mulching) and prioritisation of burned areas seeded to those immediately threatened by soil erosion and invasion of non-native species.

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