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Ecological impacts of wheat seeding after a Sierra Nevada wildfire*

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Abstract. The Highway Fire burned 1680 ha of mixed ponderosa pine–oak–chaparral in the newly created Giant Sequoia National Monument and the adjacent Sequoia National Forest of Fresno County, California in August 2001. The USDA Forest Service Burned Area Emergency Rehabilitation (BAER) program recommended that portions of the burned forest be seeded with a non-persistent variety of wheat at a density of 157 kg ha^{-1} (140 lb/ac). The present study compared the vascular plant diversity and cover in seeded and unseeded parts of this burn to evaluate the ecological impact of seeding an alien grass. In the first post-fire growing season, the natural regeneration of unseeded control sites averaged ~55% ground surface covered. Wheat seeding enhanced the ground cover, averaging 95% ground surface cover. Wheat was the dominant species on the seeded sites, comprising 67% of the total cover. Dominance–diversity curves were markedly affected by the seeding and indicated a disruption in the natural ecological structure of these communities. On seeded sites, wheat dominated and all other species were poorly represented whereas, on unseeded control sites, there was a more equitable distribution of species. Correlated with the wheat cover was a significant decrease in species richness at all scales examined. Total species richness was reduced from 152 species across all unseeded sites to 104 species on all seeded sites. Average species richness, at scales from 1 to 1000 m^2, was 30–40% lower on seeded sites. Species most strongly inhibited were post-fire endemics whose lifecycle is restricted to immediate post-fire environments. Seeded sites had fewer alien species than unseeded sites; however, this may not have any lasting effect since other studies show the primary alien threat is not in the first post-fire year. Seeding was also associated with an order of magnitude drop in *Pinus ponderosa* seedling recruitment and, coupled with the massive thatch still remaining on the site, it is likely that recruitment will be inhibited in subsequent years.

Additional keywords: BAER; biodiversity; species area curves; erosion; forest fire; non-persistent wheat; sterile wheat.

Introduction

Wildfires are a natural process in many western USA ecosystems but they often have undesirable impacts. In addition to the immediate destruction of natural and human resources, post-fire environments have the potential for increased soil erosion and hazardous flooding. To mitigate these post-fire problems, early in the 20th Century, agencies initiated programs designed to 'rehabilitate' burned watersheds through seeding of alien forbs and grasses. In recent years the federal government has formalized this process into the Burned Area Emergency Rehabilitation (BAER) program and its effectiveness at attaining the desired goals of slope stabilization and reduced soil erosion was recently reviewed (Robichaud *et al.* 2000). One of the primary concerns raised in this report was the lack of post-treatment monitoring and, as a consequence, there were data for only a small subset of all BAER projects.

It is expected that, as the concept of adaptive management becomes more instilled in resource management agencies, our database on such projects will improve with increasing awareness of the need for post-treatment monitoring. Monitoring is crucial because adaptive management is a philosophy that essentially treats land management actions as hypotheses, and this requires controlled studies to objectively evaluate treatment effectiveness and impacts.

In general, monitoring of BAER projects has focused on measurements of treatment effectiveness on reducing

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Fig. 1. Post-fire wheat dominated ponderosa pine forest reseeded after the 2001 Highway Fire, Giant Sequoia National Monument, Fresno County, CA.

sediment loss and far less attention has been paid to the negative impacts on ecological processes (Robichaud *et al.* 2000). There is good reason to be concerned because of the well-documented ability of alien grasses to competitively displace native species (e.g. Schultz *et al.* 1955; Eissenstat and Mitchell 1983; Davis and Mooney 1986; Elliott and White 1987; Wade 1989). Although not part of BAER monitoring, there are scientific studies that have demonstrated negative impacts of post-fire seeding treatments on natural revegetation in both forest and shrubland ecosystems (Anderson and Brooks 1975; Keeley *et al.* 1981; Griffin 1982; Gautier 1983; Nadkarni and Odion 1986; Barro and Conard 1987; Taskey *et al.* 1989; Conard *et al.* 1991, 1995; Geier-Hayes 1997; Keeler-Wolf 1995; Keeley 1996; Beyers *et al.* 1998).

In the summer of 2001 the Highway Fire burned through a mid-elevation mosaic of ponderosa pine, oak and chaparral in the Sequoia National Forest and newly designated Giant Sequoia National Monument. Subsequently wheat (*Triticum aestivum* L.) was seeded resulting in a dense grass cover over much of this forest and woodland (Fig. 1). The purpose of this study was to evaluate the ecological impacts of this seeding project on the natural biodiversity and first year regeneration of ponderosa pine.

Study sites and methods

The Highway Fire began on 19 August 2001 and burned 1680 ha in the Lower Fork of the Kings River Basin in Fresno County, California. The bulk of the fire burned in the Hume Lake Ranger District of the Sequoia National Forest but also included were private lands and the newly created Giant Sequoia National Monument. Within days of the fire the site was studied by a USDA Forest Service BAER team with the purpose of evaluating and recommending rehabilitation treatments (Anonymous 2001). That report noted a patchwork of low and high severity fire and recommended, among other things, hand seeding with a grass mixture at a density of 118 kg ha^{-1} (105 lb/ac). That mix was to include a ratio of 76% alien annual cereal grain (wheat or rye) and the remainder a mixture of a native and alien perennial grasses.

As is commonly the case, the recommendations were not logistically feasible and the actual application comprised pure wheat seed, hand-seeded at a density of 157 kg ha^{-1} (140 lb/ac) over 332 ha (Anonymous 2003). Roughly two-thirds of the seeded area was inside the newly designated Giant Sequoia National Monument and the remainder on National Forest land. This seed was a non-persistent variety that was to establish largely in the first post-fire year and, since wheat is an annual plant, be present mostly as thatch in subsequent years. Inspection of the sites in the second post-fire year indicated there was germination and recruitment, albeit much lower than the original seeding (Thomas McGinnis, USGS, personal observations, May 2003). This seeding density was more than an order of magnitude greater than is typically applied in rehabilitation projects that commonly utilize annual ryegrass *Lolium multiflorum* Lam. (Robichaud *et al.* 2000). This higher density was necessary to achieve a seed density comparable to other projects (Anonymous 2003); wheat seeds have 16.8 times greater mass than annual ryegrass (Dr Nancy Vivrette, Ransom Seed Lab, Carpenteria, CA, personal communication, January 2003). The estimated seed density of 393 wheat seeds m^{-2} was comparable to other BAER projects using annual ryegrass (Robichaud *et al.* 2000). Seeds were sown over a 2-week period in early November 2001. Other actions recommended by the BAER team, such as mulching and straw bales, were not considered in this study.

In spring of 2003 we selected five seeded sites and five unseeded sites in the burned area for study; dominants at the sites included (nomenclature according to Hickman 1993): ponderosa pine (*Pinus ponderosa*), black oak (*Quercus kelloggii*), manzanita (*Arctostaphylos viscida*) and flannel bush (*Fremontodendron californicum*). Sites were in a mixture of moderate to high severity burned patches, and unseeded control sites and seeded sites were matched as closely as possible with respect to fire severity and pre-fire dominants. All sites were on poorly developed decomposed-granite substrate, and control and seeded sites comprised a mixture of east-facing and north-facing slopes and the slope incline for all sites was between 10 and 15°. Each site was 20 × 50 m and subdivided into 10 contiguous 10 × 10 m plots, and within each plot were two subplots (each 1 m square) placed in opposite corners (Keeley *et al.* 1995; Schwilk *et al.* 1997). Within each subplot, density and cover were estimated for each species. Density was recorded if ≤ 5 individuals, otherwise categorized as 10, 25, 50, 75, 100, 150, 200 or nearest hundred up to 1000, then estimated to the nearest 1000. Cover was taken as the percentage of ground surface covered by the shadow of the foliage, estimated as ≤ 1, 5, 10, 25, 50, 75, 90, >95. In each of the 10 100-m^2 plots, additional species not in the subplots were recorded. Richness at the

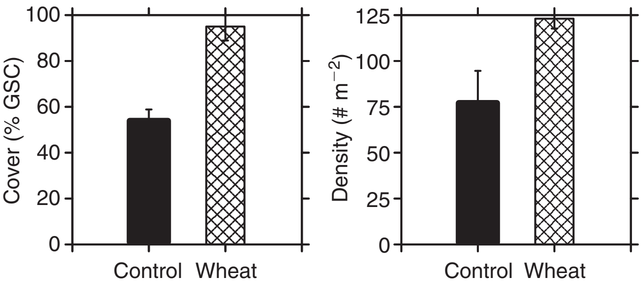

Fig. 2. Cover (± s.e. bars), expressed as percentage of ground surface covered (GSC), and density for unseeded control sites and wheat-seeded sites in the first growing season after the Highway Fire. Treatments are significantly different at $P < 0.01$, $n = 5$.

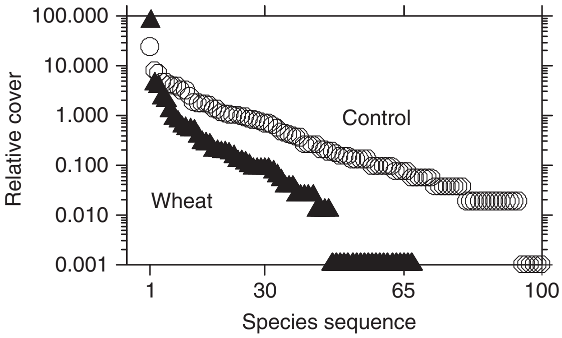

Fig. 3. Dominance–diversity curves for unseeded controls and wheat-seeded sites on the Highway Fire burn. Species are arranged in order from the most to the least dominant and the species sequences were truncated at 100.

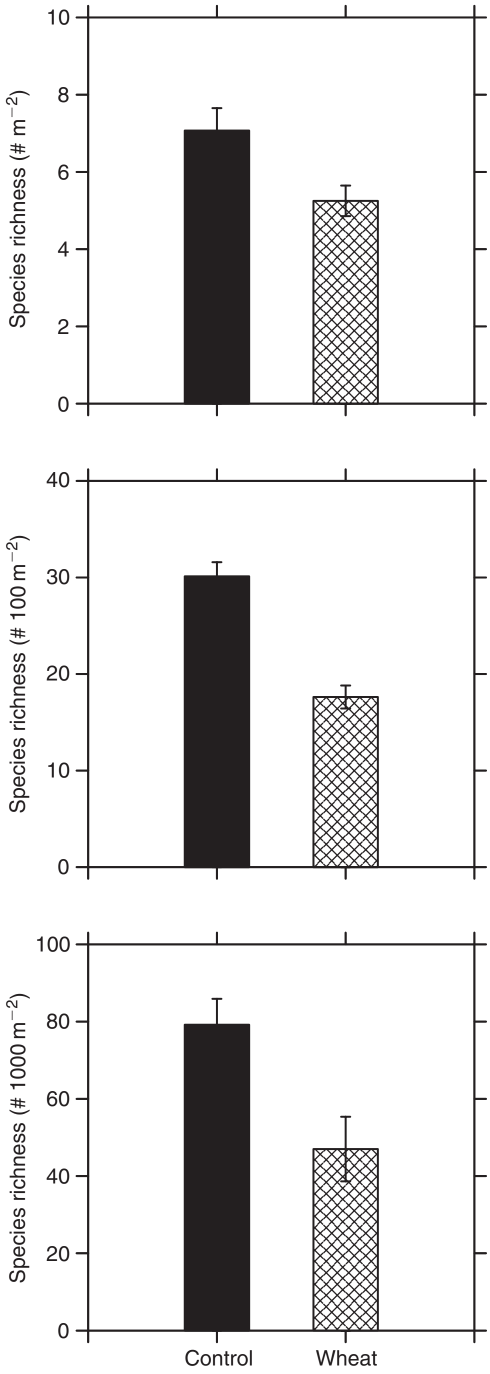

Fig. 4. Species richness (± s.e. bars) at 1, 100, and 1000 m^2 for unseeded controls and wheat-seeded sites on the Highway Fire burn. Treatments are significantly different at $P < 0.01$, $n = 5$.

1000-m^2 scale was obtained from the total species list from the 10 plots. Data were compared with the one-tailed *t*-test and displayed graphically with SYSTAT 10.0. Dominance–diversity curves were constructed as described in Whittaker (1965).

Results

Wheat-seeding treatments were effective at enhancing the plant cover, as both cover and density were over 50% greater on seeded sites than on unseeded control sites, and these differences were statistically significant (Fig. 2).

Seeding greatly altered the dominance–diversity patterns on these burned sites (Fig. 3). The seeded sites were dominated by a single species, wheat, whose cover was an order of magnitude greater than the next highest species. On the control sites the dominant, *Chamaebatia foliosa*, comprised about a fifth of the cover and the remaining species were much more equitably represented than on the seeded sites.

Wheat seeding reduced species richness at all scales. Across all five wheat seeded sites, there was a total of 104 species recorded, which was substantially less than the 152 species recorded across all of the unseeded control sites. At other scales species richness was also significantly reduced as well; (Fig. 4); at 1-m^2 $P < 0.01$, $n = 100$, at 100-m^2 $P < 0.001$, $n = 50$, at 1000-m^2 $P < 0.05$, $n = 5$. There were a number of post-fire endemic forb species (i.e. species usually restricted to post-fire conditions) recorded from these sites, most prominently *Allophyllum gilioides*, *Menzelia distans*, *Mimulus bolanderi* and *Phacelia purpurea.* On unseeded control sites these post-fire endemics constituted 15% of

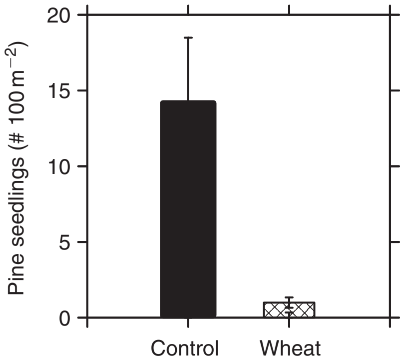

Fig. 5. *Pinus ponderosa* seedling density on unseeded controls and wheat-seeded sites on the Highway Fire burn. Treatments are significantly different at $P < 0.01$, $n = 50$.

the total cover and on seeded sites they were an order of magnitude lower.

Alien plant species comprised 19% of the flora on control sites and 17% on seeded sites, which translated into 12 more alien species on unseeded control sites. Control sites had 8% ground surface cover by aliens whereas seeded sites had 67% cover by aliens. However, if wheat were not included in this estimate, then aliens comprised less than 1% of the cover on the seeded sites. In terms of native species, control sites had 46% ground surface covered by natives in contrast to only 28% on seeded sites.

Pinus ponderosa was the primary tree in these forests and exhibited a patchwork pattern of survivorship with complete crown scorch and mortality on several of our sites. Seedling recruitment was quite variable across the area but significantly greater ($P < 0.01$) on the control sites then on seeded sites (Fig. 5).

Discussion

The objectives of the seeding component of this BAER project were several-fold (Anonymous 2001):

1. Re-establish vegetation in a timely fashion in order to eliminate threats to long-term soil productivity, water quality and ecological integrity of the watersheds;
2. Control noxious weed invasions;
3. Control erosion;
4. Restore vegetation within the Giant Sequoia National Monument; and
5. Promote the re-establishment of vigorous vegetal ground cover to protect soils and watershed values.

The initial BAER Report (Anonymous 2001) recommended post-treatment monitoring in order to evaluate the success of these objectives. Monitoring consisted of walk-through inspections of some seeded sections by the Hume Lake District Ranger and Silviculturist on separate days in April 2002 (Anonymous 2003). Inspections reported 'wheat seed germination was over 95% and coverage good. No signs of accelerated erosion were seen.'. However, there was no comparison with unseeded areas, and no formal monitoring studies incorporating comparison with control sites, thus it is not possible to determine whether or not the seeding resulted in any significant reduction in soil erosion. This is not unusual since two-thirds of the BAER monitoring reports reviewed by Robichaud *et al*. (2000) were qualitative evaluations and lacked quantitative data. Considering the limitations of the Highway Fire Monitoring report it is a matter of some concern that the walk-through monitoring on this project represented a closer look than most BAER monitoring evaluations, which are conducted by automobile (Bill Elliot, USFS, Fire Monitoring Workshop, Herndon VA, 22 April 2003). The Highway Fire BAER monitoring study (Anonymous 2003) made no mention of negative biotic impacts or attempts at evaluating alien reduction goals, and based on the review by Robichaud *et al*. (2000) of previous BAER monitoring results, it would appear that this is not uncommon. In general, BAER monitoring is highly geared towards monitoring effectiveness, and far less attention is given to negative biotic impacts.

Confirming the Highway Fire BAER monitoring report (Anonymous 2003), our observations also noted a lack of significant sediment movement; however, the majority of the seeded area comprised relatively gentle terrain with slopes between 5 and 15° (e.g. Fig. 1). We observed no obvious erosion damage associated with unseeded sites, nor was there any evidence of excessive rilling or gullying. In addition, the unseeded control sites had over 50% cover, which is near the 60% threshold where the threat of sediment loss is near zero (Robichaud *et al*. 2000). Also, an important species throughout this area was the rhizomatous subshrub *Chamaebatia foliosa*, with extensive lateral roots that are good at binding soil. The difference in soil-binding properties between this native and the shallow-rooted wheat suggests that *C. foliosa* would likely be as good as or better than wheat at reducing post-fire soil loss. However, this species comprised only 24% ground surface cover in control plots and generally sites with less than 30% cover of this species have high priority for seeding (Ruby 1989). There was storm damage to unimproved roads in the area and, although we did not conduct any serious study of this, it did not appear to be outside the range of typical storm damage observed in unburned areas, nor was it absent from the seeded areas.

Our results also confirm the BAER monitoring report (Anonymous 2003) conclusion that the seeding effort produced a dense continuous stand of wheat (Figs 1 and 2). One reason for this high cover of wheat was the extraordinarily high quantity of seed applied; 157 kg ha^{-1} (140 lb/ac) of wheat seeds, which was roughly 10 times greater than most BAER projects (Robichaud *et al*. 2000). Apparently the primary reason for this difference is that most projects use annual rye or other cereal grasses that have substantially smaller seeds, and it was intended that the main goal of the seeding operation be to produce a final seed density comparable to other projects (Anonymous 2003). Despite differences in seed size, mature wheat and annual rye are roughly of comparable size, but research is needed to determine whether seed mass or seed number is the appropriate target for BAER projects.

An important objective of this BAER project was to control noxious weed invasions and it was expected that the high density of wheat establishment would play a valuable role in inhibiting aliens (Anonymous 2001). However, the monitoring report made no evaluation of this goal (Anonymous 2003). Our study revealed that the seeding of wheat did indeed reduce the number of alien species in the treated areas. In short, there were only 18 aliens on seeded sites compared to 30 on untreated control sites and, if we don't consider wheat in our analysis, there was only ~1% alien cover in the seeded areas, compared to 8% on the control sites. It is unknown if this will have any lasting impact on reducing noxious species. One reason for concern is tied to the first year dominance of the site by non-persistent wheat. The fact that it has had such a marked inhibitory effect on the native regeneration means that in the second year there may be an ecological vacuum to be filled, and this is exactly the type of situation that promotes alien invasion (Mooney and Hobbs 2000). Thus, the BAER project aimed to reduce alien invasion in the initial post-fire year but may have made these sites more vulnerable to invasion in subsequent post-fire years. This problem needs to be looked at more closely because studies in mixed conifer forests in the adjacent Sequoia and Kings Canyon National Parks have shown that alien threats are minimal in the first post-fire year, but increase markedly in the subsequent 2–3 years due to the inability of alien propagules to survive fire and the well-developed colonizing ability of aliens (Keeley *et al*. 2004).

While the focus of the BAER project was to restore vegetation, there seems to have been limited concern for potential negative impacts on the native flora or on the ecological integrity of these communities. Our study shows that seeding reduced native cover by 40% relative to unseeded sites and reduced native plant diversity by 36 species. Reduced species diversity was apparent at all scales from the point scale of 1 m^2 to the community scale of 1000 m^2 (Fig. 4). In addition, the very strong dominance by wheat greatly altered the structure of these communities (Fig. 3). One functional group that was severely affected was the post-fire endemic species, including *Allophyllum gilioides*, *Menzelia distans*, *Mimulus bolanderi* and *Phacelia purpurea*. These annual species persist as dormant seed banks until germination is triggered by fire (Keeley and Fotheringham 2000). Seed banks of these species are not replenished during the interval between fires and thus repeated application of competing alien grasses after fires could extirpate these species from the site.

One impact of major concern is the marked reduction in pine seedling recruitment. The shallow roots of the wheat, particularly at the extraordinary density of these plantings, likely reduced soil moisture early in the year, which would compromise pine seedling survivorship (Schultz *et al*. 1955; Davis and Mooney 1986; Elliott and White 1987; Amaranthus *et al.* 1993).

It is unknown to what extent the seeding operation will have lasting impacts on this ecosystem. Although the non-persistent wheat exhibited only very localized recruitment in the second post-fire year, the dense stand of thatch persisted and could potentially inhibit future pine recruitment (Fowells 1965). In addition, depending upon patterns of decomposition, this massive input of thatch has the potential for accelerated microbial growth and immobilization of soil nitrogen (Schlesinger 1997).

One critical threat resulting from the extraordinary success of this wheat seeding treatment is that, when these dense stands of annual grass (Fig. 1) dry, they represent an increased fire hazard that has the potential for carrying a repeat fire (Zedler *et al*. 1983; Keeley 2002). This threat of repeat fire is well understood as a potential problem to seeding projects (Ruby 1989). Indeed, in early revegetation projects designed to enhance grazing potential, this was considered one of the assets of seeding with alien grasses (Hedrick 1949). In addition, due to the rapid drying of this shallow-rooted annual cereal grass, the fire season on this site began much earlier in the summer than on sites dominated by natives (Keeley, personal observations). However, this dense seeding of wheat did not promote a repeat fire in the first summer after fire, but the dense layer of thatch persists and does present a fire hazard for at least another year or two. A repeat fire this early in succession could disrupt pine regeneration and further favor alien invasion. Of course all of these negative impacts can be mitigated by further allocation of resources, such as pine seedling plantings coupled with appropriate site preparation, but they may not be the most economically desirable alternative.

The results of this investigation illustrate the complex ecological problems involved in evaluating artificial revegetation of wildland areas. Adaptive management of these landscapes will never be an effective policy until scientifically based monitoring is imposed on management activities that have had limited rigorous study.

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