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Native plant regeneration and introduction of non-natives following post-fire rehabilitation with straw mulch and barley seeding

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Abstract

To reduce soil erosion after fires, forest managers commonly employ rehabilitation treatments, including application of grass seed or mulching with straw. In 1999 the Megram fire burned 24,000 ha of mixed conifer/tanoak forest in northern California, USA. In the subsequent year, some areas were aerially seeded with barley and others were mulched with rice straw; some areas received both treatments. We investigated how these treatments affected these aspects of ecological recovery: (a) the introduction of non-native plants, (b) percent vegetative cover, (c) the diversity and density of regenerating native plants, and (d) the density and frequency of conifer seedlings. We found that mulched quadrats had a significantly higher occurrence of non-native species than untreated quadrats did. In addition, we found little evidence that mulching or mulching + seeding facilitated recovery of the native plant community. Percent vegetative cover was no higher in treated quadrats than in untreated quadrats. While annuals were present in significantly higher densities in the mulched + seeded quadrats compared to the other treatments, perennial density and overall plant density were not affected by treatment. Mulching and mulching + seeding significantly reduced the density and frequency of conifer seedlings. While we found similar native species richness on a per-quadrat basis for all three treatments, the cumulative number of native species in untreated quadrats taken as a whole exceeded the numbers found in mulched-only and mulched + seeded quadrats. We recommend that managers take steps to assure that mulch is free of non-native seed, and that further efforts be made to investigate systematically aspects of ecological recovery after the application of rehabilitation treatments.
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Keywords: BAER; Ecological recovery; Emergency stabilization; ESR; Fire, mulching; Native plant regeneration; Non-native species; Post-fire rehabilitation; Seeding

1. Introduction

A century of fire suppression in the forests of the Western United States has created conditions of high susceptibility to catastrophic wildfires (Agee, 1993). By completely removing the understory vegetation and accumulated organic material, such high-severity fires can have particularly serious consequences for forest soils and waterways. Forest managers responsible for these lands often practice emergency stabilization and rehabilitation treatments designed to reduce these consequences. To this end, the federal agencies that manage wildlands in the United States

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(US Department of Agriculture Forest Service (USFS); US Department of the Interior (USDI) Bureau of Land Management; National Park Service; USDI Fish and Wildlife Service; Bureau of Indian Affairs) employ a range of treatments known variously as Burned Area Emergency Rehabilitation (BAER) or Emergency Stabilization and Rehabilitation (ESR). BAER/ESR treatments (hereafter designated as BAER) are intended to minimize post-fire damage to private property that could occur via flooding and debris flows, to reduce loss of soil and soil productivity, to decrease the risk of flooding, and to protect water quality (Robichaud et al., 2000).

Reduction of hillslope erosion is a main target of the BAER program (Robichaud et al., 2000). The three most commonly used hillslope treatments, in decreasing order, are: (1) aerial seeding with grass species, sometimes mixed with legumes, to rapidly re-establish root systems, which promote water infiltration and hold soil in place; (2) felling of logs on burned hillsides so that when arranged along the slope contour they serve as a mechanical barrier to water and sediment movement; and (3) mulching of mineral soil with organic material such as paper, jute, or straw, to reduce raindrop impact and decrease speed of water/sediment flows (Robichaud et al., 2000). In this paper we examine the roles of two of these treatments, aerial seeding and mulching, in ecological recovery.

BAER treatments focus on providing control of water and soil erosion in the year or two immediately following a fire. In addition, they are designed to work in conjunction with (or at least to not inhibit) ecological recovery (US Department of Agriculture Forest Service, 1995) because over the long-term it is the re-establishment of the native plant community that accomplishes BAER's primary goals. By reducing soil erosion, seeding and/or mulching could speed the recovery of the native plant community, or at least stabilize the soil until native species can become established (Taskey et al., 1989). However, these treatments could hinder rather than help native plant regeneration, including that of conifer seedlings, in two ways. First, seeding could delay or prevent native plant regeneration through direct competition for water, nutrients, and light by the seeded plants (Taskey et al., 1989; Harrod and Reichard, 2001). Competition from seeded grasses has been observed to displace the regeneration of native species in general (Taskey et al., 1989; Amaranthus et al., 1993; Geier-Hayes, 1997; Schoennagel and Waller, 1999; Keeley, 2004) and of conifer seedlings in particular (Amaranthus et al., 1993; Schoennagel and Waller, 1999; Keeley, 2004). Though perhaps beneficial for short-term erosion control, seeding could interfere with long-term watershed protection if it delays the regeneration of deep-rooted native perennials (Taskey et al., 1989). While the impact of mulching on native species regeneration has not been studied in forest ecosystems, the results of greenhouse experiments have demonstrated negative effects of mulch on seedling emergence and survival (Bergelson, 1990).

Secondly, native species regeneration could be hindered because high-severity fires can create disturbed, low-competition habitats that are readily invaded by exotic species, if an exotic seed source is available (Harrod and Reichard, 2001). Stabilization treatments like seeding are intended in part to reduce the likelihood of alien invasions, and Keeley (2004) has investigated seeding's ability to do so. However, if either the seed stocks used for seeding or the material used for mulching are contaminated by weed seeds, these treatments could have a negative effect, acting as avenues for the introduction of exotic invasives. The ecological risks (Vitousek et al., 1996; Wilcove et al., 1998) and economic costs (Pimentel et al., 2000) posed by invasive species are well known and there is increasing recognition of the hazards inherent in the invasion of forest lands by exotic species (Harrod, 2001; Harrod and Reichard, 2001). No systematic investigations of the potential of seeding or of straw mulch to introduce exotic species unintentionally have been published in peer-reviewed form.

In this study, we investigate the effects of mulching and aerial seeding with barley on two aspects of ecological recovery after fire, non-native species introduction and native species regeneration. Specifically, we ask: (1) Do areas mulched with straw after a high-intensity fire have a higher incidence of non-native species than comparable unmulched areas? (2) Do mulched areas differ from unmulched areas in their density or diversity of native species? (3) Does the addition of barley seed to mulched areas affect the density or diversity of either native or non-native species? (4) Do either of these treatments affect the occurrence of conifer seedlings? (5) Do annuals and perennials respond differently to these treatments?

2. Study area and treatments

We conducted this study in northern California, USA (Lower Trinity Ranger District, Six Rivers National Forest), where the Megram fire burned 24,000 ha in the fall of 1999. This site, which ranges in elevation from ~900 to ~1500 m, includes conifer and mixed conifer/hardwood second growth forests dominated by Douglas-fir (*Pseudotsuga menziesii*), White fir (*Abies concolor*), Red fir (*Abies magnifica*), and Tanoak (*Lithocarpus densiflorus*) (US Department of Agriculture Forest Service, 2000). The BAER treatments and our study occurred in the following temporal sequence (Lee Morgan, personal communication): In winter/spring 2000, approximately 1012 ha of high-intensity burn (i.e. experiencing nearly 100% vegetative cover loss; US Department of Agriculture Forest Service, 1995) were aerially seeded with annual barley. In summer 2000, 500 ha of high-intensity burn were spread manually with 19,000 bales of rice straw (Six Rivers National Forest, 2000). Sites chosen to receive straw mulch were either unseeded or were places where the barley that had been seeded seemed to have low germination. Thus, some areas received both treatments. We conducted our study in June and July 2001, 1 year after the straw mulch was applied. We had no difficulty identifying treated sites, because dry barley stems (as well as some living ones) were still evident in all seeded areas that had successful germination, and the straw mulch was still conspicuous.

3. Methods

We first selected a series of plots within high-intensity burn areas that had been seeded and/or mulched or left untreated. Each plot was at least 1000 m^2, but their areas varied depending on how the treatments had been applied. Within each plot we sampled a group of 1 m^2 quadrats, the number depending on the area of each plot. We selected plots to be as similar as possible to one another except for the treatment each received. Accordingly, all plots were within 50 m of USFS roads, and on one side (downhill) of the road, since mulch was only applied close to roads; all were in second growth stands with trees roughly 30 years of age at the time of the fire; and all had fully burned canopies. In two of our mulched plots, salvage logging had begun earlier that year, but we never sampled within areas affected by this activity. Ultimately we identified 17 plots that matched our criteria, representing three treatments (see Fig. 1): mulched-only (four plots), mulched + seeded (four plots), and untreated (nine plots). Because we found only one unmulched plot seeded with barley within 50 m of a road, we were unable to analyze the effects of seeding alone (Hurlbert, 1984). To situate sampling quadrats within each plot, we ran transects perpendicular to the road every 10 m and placed one quadrat (using a random number table) along each transect. No quadrat was placed less than 10 m from a plot boundary or less than 1 m from a road. Each of the plots contained between three and 19 quadrats.

In each quadrat we estimated the percent cover of green plant material (excluding barley) and of straw mulch to the nearest 5%. We recorded all the plant species present in each quadrat, and censused the density of each by counting numbers of individuals. No plant was more than 2 years old, so the range in plant sizes was small. Individuals included both annuals and perennials, some of which were probably resprouted from underground rootstocks that survived the fire. For each quadrat we computed: total native plant density (pooling individuals of all native species), densities of native annuals, densities of native perennials, percent cover of plant material, and native species richness (number of species). We examined the effects of: (a) mulching and (b) mulching + seeding on these measures, as well as on the occurrence of each of the non-native species and of conifer seedlings (Douglas-fir and true firs combined). To control for any confounding of the mulching and seeding treatments with environmental variables that could affect a quadrat's suitability for seed germination and establishment, we recorded each quadrat's distance from the nearest stream, its slope, and its aspect. We estimated the distance from each quadrat to the nearest area with unburned ground cover, because the proximity to a native seed source could affect a quadrat's native species richness.

We compared the percent cover of straw mulch in the two mulching treatments using a mixed-model nested ANOVA, with treatment as a fixed effect and plot nested within treatment as a random effect. The treatment effect was tested over the plot term; the plot

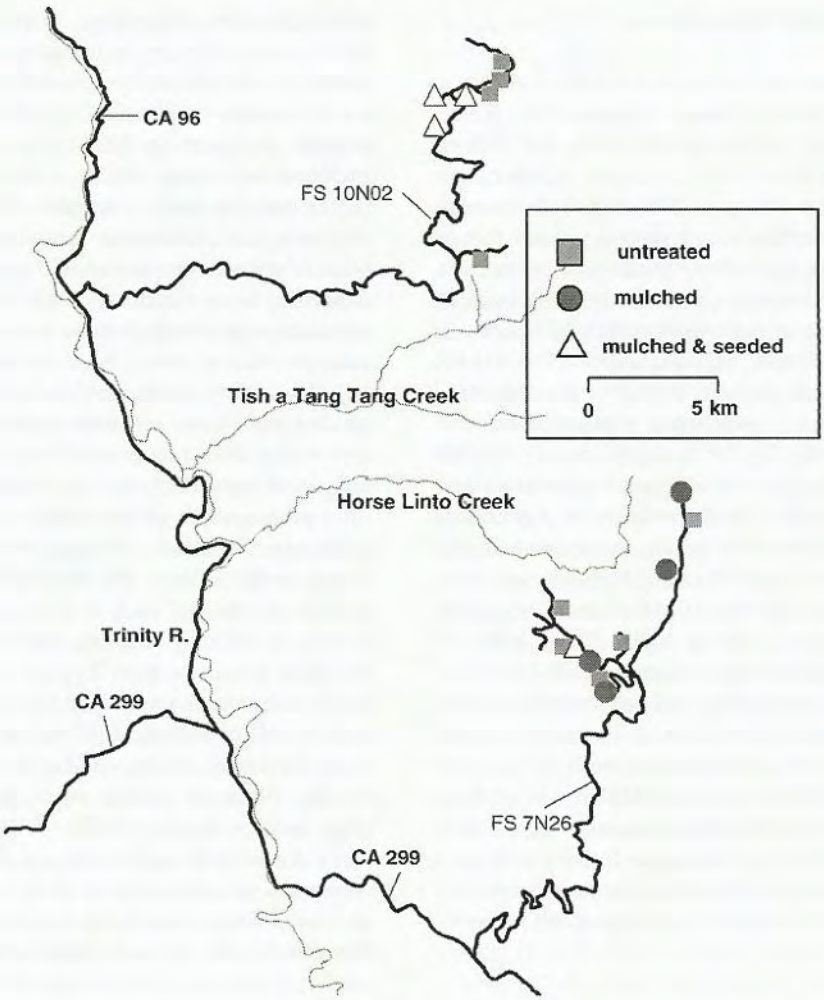

Fig. 1. Map of quadrat locations.

effect was tested over the error term. Residuals were examined and variables were transformed to achieve normality of residuals when necessary. We tested for a treatment effect in quadrat aspect with the Watson and Williams test for circular statistics (Batschelet, 1981). We examined relationships between possible confounding environmental variables (distance to stream, distance to unburned area, slope, aspect) and native community characteristics with parametric correlation tests, using a Bonferroni correction. We again used a mixed-model nested ANOVA to analyze treatment effects on these variables. For variables with significant treatment effects, we used Tukey's test to compare individual treatments. To examine the effect of possible confounding environmental variables on the numbers of non-native species and of fir seedlings per quadrat, whose distributions were highly skewed, we used non-parametric correlation tests, applying a Bonferroni correction. To examine treatment effects for these response variables, we used Wilcoxon tests. Finally, we compared the frequency of quadrats that contained fir seedlings in the different treatments using log-likelihood tests. These analyses were all performed using JMP statistical software (SAS Institute, Version 5.0.1a, Cary, North Carolina). We also compared species accumulation curves for the three

treatments. These curves were created by a randomization process in which quadrats were randomly selected and the total number of species computed for one quadrat, for groups of two quadrats, for groups of three, etc. until all quadrats had been drawn without replacement from the pool. We performed 100 randomizations for each treatment, using EstimateS Version 5 (Colwell, 1997).

4. Results

There were two unexpected differences between the treatments. First, we observed significantly more straw cover ($\bar{x} = 35.8\%$) in the mulched-only quadrats than in the mulched + seeded ones ($\bar{x} = 14.8\%$) (Table 1). Second, the Watson–Williams test indicated that the treatments differed significantly in aspect ($F = 18.79$, $v_1 = 2$, $v_2 = 127$, $P < 0.05$). However, an examination of these data shows that the aspect readings for each treatment were multimodal; multimodality causes differences between groups to be significant (Batschelet, 1981). The wide range of aspect values within each of the different treatment groups (spanning 180° or more) makes it unlikely that differences in aspect can explain the differences we observe below.

4.1. Non-native species introduction

The number of non-native individuals/m^2 was not significantly correlated with a quadrat's slope, aspect, its distance to a creek, or its distance to an unburned area. To assess the effect of mulching on the occurrence of non-native species, we considered only those quadrats that had not been seeded. We identified 54 species (see Table 2), one of which was not native: *Cirsium vulgare* (bull thistle). Only one of 54 unmulched quadrats (1.8%) contained *C. vulgare* (Fig. 2), and it had only one individual. By contrast, the percent of mulched quadrats containing *C. vulgare* was nearly seven times greater (11.8% of 34 quadrats), and we observed as many as nine individuals in a single mulched quadrat. Mulching significantly increased the probability that a quadrat contained this non-native species (Wilcoxon test, $n_1 = 54$, $n_2 = 34$, tied $P = 0.05$). We found *C. vulgare* in two different mulched plots located 7.5 km apart.

Table 1
Results of ANOVAs for effect of treatment on response variables

	d.f.	F	$P > F$
Native species richness			
Treatment	2	1.26	0.287
Plot nested within treatment	13	2.51	0.005
Error	114		
Straw mulch			
Treatment	1	9.28	0.003
Plot nested within treatment	6	1.68	0.140
Error	68		
Square root (percent cover plant material)			
Treatment	2	3.97	0.022
Plot nested within treatment	13	1.04	0.422
Error	114		
Square root (total native density)			
Treatment	2	0.15	0.864
Plot nested within treatment	13	2.07	0.021
Error	114		
Square root (annual density)			
Treatment	2	4.64	0.012
Plot nested within treatment	13	2.50	0.005
Error	114		
Square root (perennial density)			
Treatment	2	0.22	0.807
Plot nested within treatment	13	1.78	0.055
Error	114		

Mulched + seeded quadrats contained two additional non-native species: *Cichorium intybus* (chicory) and *Sonchus asper* (sow thistle) (Fig. 2). We observed only a single individual of each of these species. This increase in the incidence of non-natives in mulched + seeded quadrats compared to mulched-only quadrats was not significant (Wilcoxon test, $n_1 = 34$, $n_2 = 42$, $P = 0.76$).

4.2. Native species regeneration

Total native density (individuals/m^2) was not significantly correlated with a quadrat's slope, aspect, its distance to a creek, or its distance to an unburned area. Plot explained a significant amount of the variation in

Table 2
Species observed

Species	Native/non-native	Annual/perennial
Abies spp., *Pseudotsuga* spp. (seedlings)	Native	Perennial
Achlys spp.	Native	Perennial
Agoseris spp.	Native	Annual/perennial
Alnus incana (L.) Moench subsp. *tenuifolia* (Nutt.) Breitung	Native	Perennial
Apocynum androsaemifolium L.	Native	Perennial
Arabis spp.	Native	Perennial
Arnica latifolia Bong.	Native	Perennial
Asarum caudatum Lindl.	Native	Perennial
Asarum hartwegii S. Watson	Native	Perennial
Berberis aquifolium Pursh	Native	Perennial
Campanula prenanthoides Durand	Native	Perennial
Ceanothus velutinus Dougl.	Native	Perennial
Chimaphila menziesii (D. Don) Sprengel	Native	Perennial
Chimaphila spp.	Native	Perennial
Cichorium intybus L.	Non-native	Perennial
Cirsium vulgare (Savi) Ten.	Non-native	Perennial
Claytonia perfoliata Willd.	Native	Perennial
Claytonia rubra (Howell) Tidestrom	Native	Perennial
Claytonia spp.	Native	Perennial
Clintonia uniflora (Schult.) Kunth	Native	Perennial
Collomia heterophylla Hook.	Native	Annual
Cornus nuttallii Audubon	Native	Perennial
Cryptantha spp.	Native	Annual/perennial
Disporum hookeri (Torrey) G. Nicholson	Native	Perennial
Epilobium angustifolium L. subsp. *circumvagum* Mosq.	Native	Perennial
Fragaria spp.	Native	Perennial
Galium triflorum Michx.	Native	Perennial
Gayophytum spp.	Native	Annual
Gnaphalium canescens DC.	Native	Perennial
Hieracium albiflorum Hook.	Native	Perennial
Holodiscus discolor (Pursh) Maxim.	Native	Perennial
Hordeum sp.	Non-native	Annual
Lilium washingtonianum Kellogg ssp. *purpurascens* (Stearn) M. Skinner	Native	Perennial
Linnaea borealis L. var. *longiflora* Torrey	Native	Perennial
Lithocarpus densiflorus (Hook. & Arn.) Rehder	Native	Perennial
Lotus aboriginus Jeps.	Native	Perennial
Lupinus spp.	Native	Annual/perennial
Madia elegans Lindl.	Native	Annual
Moehringia macrophylla (Hook.) Fenzl	Native	Perennial
Nemophila spp.	Native	annual
Penstemon anguineus Eastw.	Native	Perennial
Phacelia cicutaria Greene	Native	Annual
Pteridium aquilinum (L.) Kuhn var. *pubescens*	Native	Perennial
Pyrola picta Sm.	Native	Perennial
Ribes lobbii A. Gray	Native	Perennial
Ribes sp.	Native	Perennial
Rosa nutkana C. *Presl* var. *nutkana*	Native	Perennial
Rubus parviflorus Nutt.	Native	Perennial
Rubus ursinus Cham. & Schldl.	Native	Perennial
Rumex salicifolius J.A. Weinm.	Native	Perennial
Salix spp.	Native	Perennial
Sambucus racemosa L.	Native	Perennial

Table 2 (*Continued*)

Species	Native/non-native	Annual/perennial
Senecio sp.	Unknown	Annual/perennial
Smilacina racemosa (L.) Link	Native	Perennial
Smilacina stellata (L.) Desf.	Native	Perennial
Solanum parishii A. Heller	Native	Perennial
Sonchus asper (L.) Hill ssp. *Asper*	Non-native	Annual
Symphoricarpos mollis Nutt.	Native	Perennial
Thuja spp. (seedlings)	Native	Perennial
Trientalis latifolia Hook.	Native	Perennial
Vancouveria hexandra (Hook.) Morren & Decne.	Native	Perennial
Vicia americana Willd. Var. *americana*	Native	Perennial
Viola glabella Nutt.	Native	Perennial
Viola spp.	Native	Perennial
Whipplea modesta Torrey	Native	Perennial

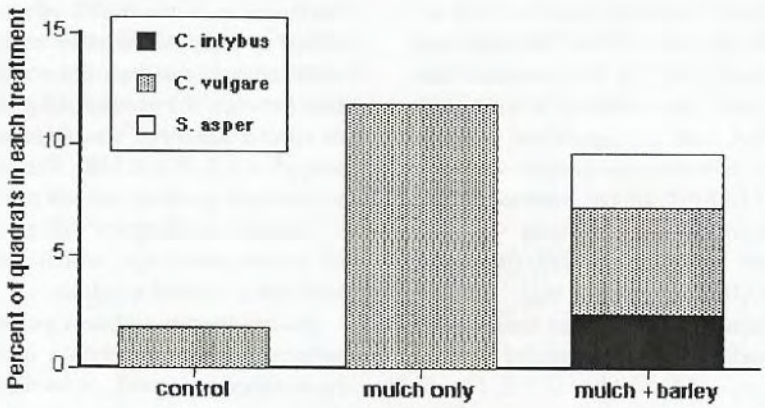

Fig. 2. Percentage of quadrats in each treatment containing at least one individual of a non-native species. $n = 54$ for untreated quadrats, $n = 34$ for mulched-only quadrats, and $n = 42$ for mulched + seeded quadrats. Bars with the same letter are not significantly different at $P = 0.05$.

native individuals/m^2, but treatment had no effect (Table 1, Fig. 3).

However, we did see a significant treatment effect for percent cover of green vegetation (Table 1). Vegetative cover was significantly higher in the mulched + seeded quadrats ($\bar{x} = 31.1\%$) than in the mulched-only quadrats ($\bar{x} = 17.2\%$, Fig. 4). The percent vegetative cover of the untreated quadrats (24.3%) was intermediate and not significantly different from either of the others.

Annual and perennial species displayed different responses to the treatments. For annual density/m^2, we observed a significant effect of plot and of treatment (Table 1); there was a significantly higher density of

Fig. 3. Mean number of native individuals/m^2, +1 S.E. of the mean. Sample sizes same as in Fig. 2.

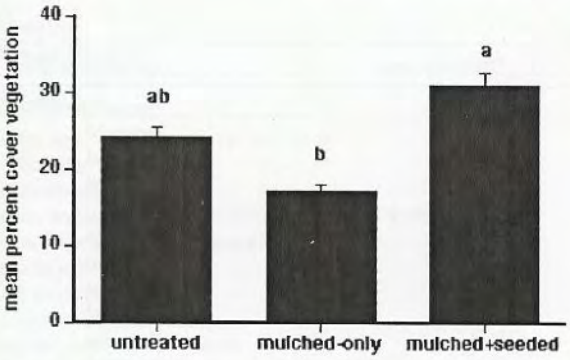

Fig. 4. Mean percent cover of living vegetation for each treatment. Means with the same letter are not significantly different at $P = 0.05$. Sample sizes as in Fig. 2.

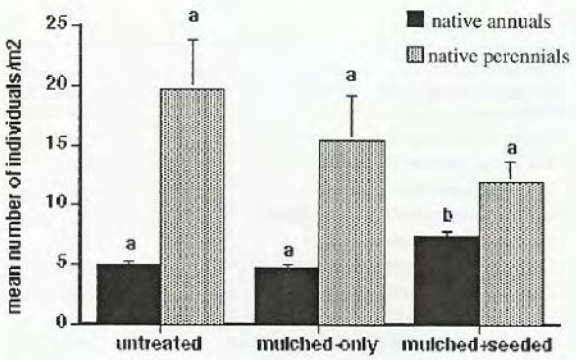

Fig. 5. Mean number of annual and perennial individuals/m^2 in each treatment, +1 S.E. of the mean. Means with the same letter are not significantly different at $P = 0.05$. Sample sizes same as in Fig. 2.

annuals in the mulched + seeded treatment (7.5 m^2) than in either of the other two (5.0 m^2 for untreated, 4.8 m^2 for mulched-only, Fig. 5). For perennial density, on the other hand, we observed a marginally significant plot effect, and no significant effect of treatment (Table 1). However, perennials tended to be most abundant (19.7 m^2) in the untreated quadrats, less abundant in the mulched-only treatment (15.5 m^2), and least abundant in the mulched + seeded treatment (12.0 m^2).

We found significantly fewer conifer seedlings/m^2 in mulched-only quadrats than in untreated quadrats (Wilcoxon test, $n_1, n_2 = 54, 34$; $P = 0.012$; Fig. 6). Furthermore, while 66.7% of untreated quadrats contained at least one conifer seedling, only 41.2% of mulched-only quadrats did so (Fig. 6). This association between the absence of mulch and the presence of conifer seedlings was significant (likelihood ratio test, $\chi^2 = 5.5$, $P = 0.019$). The addition of barley seed to mulched quadrats did not affect either the number of conifer seedlings/m^2 (Fig. 6) or the incidence of conifer seedlings, which occurred in 40.5% of mulched + seeded quadrats.

Native species richness per quadrat was not significantly correlated with a quadrat's slope, aspect, its distance to a creek, or its distance to an unburned

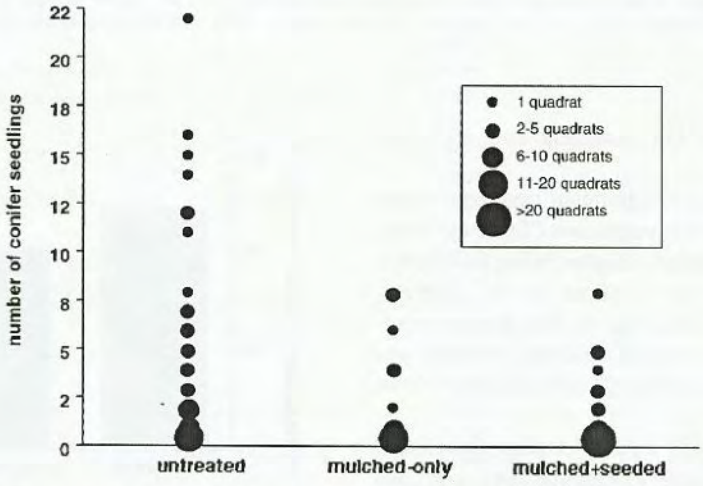

Fig. 6. Distribution of numbers of conifer seedlings/m^2 in each treatment. The size of each point represents the number of 1 m^2 quadrats observed with a particular number of conifer seedlings (see legend). Sample sizes same as in Fig. 2.

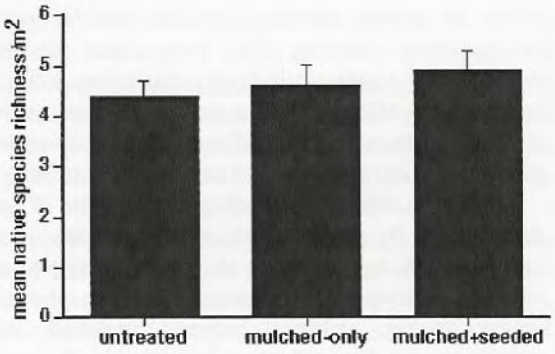

Fig. 7. Mean number of native plant species (species richness)/m^2, +1 S.E. of the mean. Sample sizes same as in Fig. 2.

area. Plot explained a significant amount of the variation in native species richness per quadrat, but treatment had no effect (Table 1, Fig. 7). These per-quadrat means, however, provide no information about how many total species we observed within each treatment, nor about how different quadrats in the same treatment differed from one another. To answer these questions, we compared species accumulation curves (using only native species) for each treatment (Fig. 8). Untreated quadrats, taken as a whole, had higher numbers of native species than the mulched-only quadrats, even when we account for the effect of differing sample size. Because these two treatments had similar mean species richness/m^2 (Fig. 7), this difference reflects the fact that individual untreated quadrats were more different from one another in their species composition than were mulched-only quadrats. The mulched + seeding quadrats had significantly greater total native species present, compared to mulched-only quadrats (Fig. 8), but the curve still lies below that for untreated quadrats. None of these three curves has yet reached its asymptote, indicating that our censuses did not capture all of the species likely to have been present in these treatments.

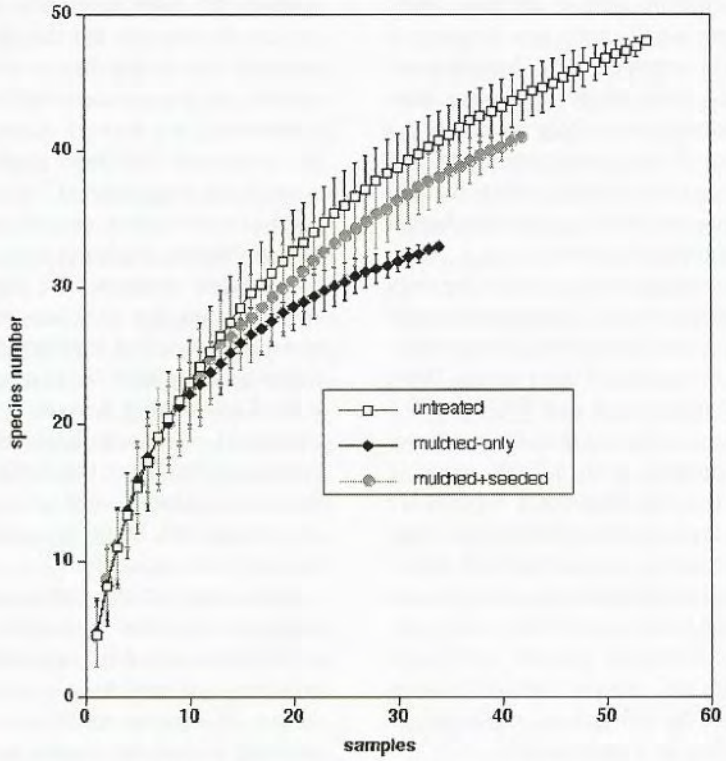

Fig. 8. Species accumulation curves for each of the three treatments. Each point represents the mean cumulative number of native species as a function of number of quadrats drawn from the total pool, ±1 S.D., from 100 runs of EstimateS.

5. Discussion

Following fires, long-term stabilization of forest soils and protection of streams from siltation requires re-establishment of the native plant community. In this study we investigated the effect of two BAER hillslope treatments, mulching and seeding with barley, on the early stages of native community re-establishment. The results of our investigation provide little evidence that either mulching or mulching + seeding promoted more rapid recovery of natural vegetation than what would have occurred naturally. Further, some of our findings indicate that rehabilitation treatments hindered native regeneration.

Species accumulation curves show that 18 months after the Megram Fire more native plant species had re-established themselves in untreated areas than in comparable mulched + seeded or mulched-only areas. Treated quadrats had no greater species richness and no greater density of native perennials than those in untreated areas. The percent cover of living plants was no higher in treated quadrats than in untreated ones. Conifer seedlings were significantly less frequent in treated quadrats than in untreated ones. Treated quadrats were significantly more likely to contain alien weeds than were untreated ones. Only for annuals, a relatively small subset of the plant community, and one with little ability to provide long-term soil stabilization, did treated quadrats have significantly higher plant densities than untreated quadrats.

Our finding that mulching does not benefit the early stages of native plant community regeneration parallels reports that seeding with non-native grasses delays the re-establishment of natives (Taskey et al., 1989; Geier-Hayes, 1997; Schoennagel and Waller, 1999; Keeley, 2004). Our results suggest that direct competition for water or nutrients with actively growing seeded plants is not the only way for a suppressive effect to occur; this is the first demonstration that straw mulch can also serve as a "competitor" of native species in forests. The mechanism by which mulch suppresses regeneration is not known, but it may block sunlight to emerging seedlings, provide a physical barrier to their emergence, prevent contact between newly arrived seeds and the soil surface, and/or reduce soil nitrogen availability as it decomposes.

Species accumulation curves suggested that both mulching and mulching + seeding had negative effects on species richness. The fact that the curve for mulching + seeding lies above that for the mulched-only treatment indicates that either seeding had a positive effect on native species richness, counteracting the negative effect of mulch, or that a smaller quantity of mulch had less of an inhibitory effect.

Our results differed depending on the scale of our observations. By contrast to the species accumulation curves, which are based on all the quadrats pooled together, analyses on a per-quadrat basis showed similar species richness between mulched and untreated areas. This difference is the result of greater heterogeneity in native species composition among quadrats in the untreated plots than in the treated areas, and perhaps implies that mulching homogenizes the environment, favoring only those native species able to tolerate the conditions it creates. However, such a result would also be observed if the mulched plots represented only a subset of all the available habitat types in the study area. It should be noted that the mulched-only plots were all in one drainage system, whereas the other treatments spanned both areas, so we should not rule out this possibility (Fig. 1). We selected sites so that they would be comparable in the amount of pre-treatment habitat heterogeneity they represented, but because our study was initiated after the treatments had been applied, perfectly matched control and experimental areas could not be found.

Percent live cover, an indicator of plant vigor, was not significantly higher in either of the treatments than in untreated quadrats. The significant difference we saw between the mulched-only treatment and the mulching + seeding treatment is difficult to interpret. Either seeding itself facilitates plant recovery (which is hard to establish because we had no seeding-only treatment), or straw mulch is inhibitory, but only when thickly applied (since the mulched + seeded treatment had lower percent cover of straw than the mulched-only treatment). Some interaction between these two factors is also possible.

One subset of the native plant community is of particular economic interest in the process of forest regeneration after fires: tree seedlings. Our finding that mulching and mulching + seeding reduced both the density of conifer seedlings and the percentage of quadrats containing conifer seedlings, the first such published report, is similar to results reported for the effect of seeding alone. Schoennagel and Waller

(1999) found that seeding reduced the density of conifer seedlings to a degree similar to the reduction we observed associated with mulching. Keeley (2004) found that seeded plots contained an order of magnitude fewer *Pinus ponderosa* seedlings than control plots did. However, when assessing all of these results it is important to consider that self-thinning is expected to take place among young stands of trees, and that the reductions in occurrence of seedlings may have no effect on forest development if lower starting densities are accompanied by correspondingly lower thinning rates. Thus it is important to monitor control and treated areas over considerable periods of time; such results have so far not been reported.

Until now, only Keeley (2004) had investigated the effect of BAER treatments on the occurrence of alien species. Keeley found that seeding with wheat reduced the percent cover of alien species in the mixed forest-chaparral area he studied. By contrast, we found that mulching was associated with an increase in alien species, although whether this finding should be cause for concern can only be established upon further study.

Two of the weed species we found were observed only once (*C. intybus*, *S. asper*) and are not considered noxious. However, the alien we observed most commonly, *Cirsium vulgare*, has been placed on the California Invasive Plant Council's (2004) 'B' list (invasive, but spreading less rapidly than plants on list 'A'). It is restricted, prohibited, or considered noxious in 10 US states and two Canadian provinces (Zouhar, 2002). *C. vulgare* is usually found in disturbed sites such as pastures, overgrazed areas, forest clearcuts and waste places. It is at least partially self-compatible, can produce up to 300 seeds per flower (Zouhar, 2002), and is a biennial. It is important to learn whether, over time, this small population will go extinct naturally (as R. Harrod (personal communication) reports is usually the fate of this species in the Pacific Northwest), or whether it will serve as the nucleus of a new invasion.

Straw mulch is considered unlikely to serve as a medium for the introduction of noxious exotics because the straw is usually derived from rice, which is grown in moist habitats (Robichaud et al., 2000). The assumption has been that successful weeds in rice fields are unlikely to germinate, mature, or spread in dry forestland. However, because weeds are known to have wide ecological amplitude (Baker, 1974), this assumption should be tested carefully by monitoring sites of invasion over time. Because prevention is the most important (and cost-effective) way to manage exotic species invasions (Harrod, 1994), Asher et al. (2001) recommend that all seed and mulch used for rehabilitation of burned areas be free of weeds.

Schoennagel and Waller (1999) note that post-fire rehabilitation treatments are rarely applied as experiments, with explicitly designated control areas, and that it is often difficult to find treated and untreated areas that are alike in all other respects. Our study was no exception. The mulch applied after the Megram fire was restricted to areas near roads, and because we found only one area matching our criteria that had been seeded but unmulched, we were unable to analyze the effect of seeding alone, or of any possible interaction between mulching and seeding. Our study is also limited in its spatial extent and temporal duration; in order to overcome these limitations, a study would need to monitor many different burned areas for several years.

In spite of the shortcomings of this and other studies, evidence is mounting that these BAER treatments do little to facilitate ecological recovery, and may even delay the development of the native plant community, interfere with tree regeneration, and/or introduce noxious aliens. Still, these treatments may have sufficient value for short-term erosion control, their intended purpose, to justify their use. However, Robichaud et al. (2000) report that our understanding of these treatments' effectiveness is limited by the fact that their application is rarely followed by monitoring, and that when such monitoring occurs, it is rarely quantitative and often does not include untreated control areas. The questions about ecological recovery raised by this study and others suggest that further research based on careful experimental design is warranted. Only well-designed long-term studies that focus on ecological recovery as well as short-term erosion control will provide the information necessary for a rigorous cost–benefit assessment of BAER treatments.

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