Research Article

Vegetation Response after Post-Fire Mulching and Native Grass Seeding

Penelope Morgan[1,*], Marshell Moy[1,3], Christine A. Droske[1,4], Leigh B. Lentile[1,5], Sarah A. Lewis[2], Peter R. Robichaud[2], and Andrew T. Hudak[2]

[1] Department of Forest, Rangeland, and Fire Sciences, University of Idaho, 875 Perimeter Drive MS 1133, Moscow, Idaho 83844, USA

[2] US Department of Agriculture, Forest Service, Rocky Mountain Research Station, 1221 South Main Street, Moscow, Idaho 83843, USA

[3] Current address: US Department of Agriculture, Forest Service, Payette National Forest, 800 West Lakeside Avenue, McCall, Idaho 83638, USA

[4] Current address: US Department of Agriculture, Forest Service, Salmon-Challis National Forest, 1206 South Challis Street, Salmon, Idaho 83467, USA

[5] Current address: Department of Forestry and Geology, University of the South, 735 University Avenue, Sewanee, Tennessee 37375, USA

[*]Corresponding author: Tel.: +1-208-885-7507; e-mail: pmorgan@uidaho.edu

ABSTRACT

Post-fire mulch and seeding treatments, often applied on steep, severely burned slopes immediately after large wildfires, are meant to reduce the potential of erosion and establishment of invasive plants, especially non-native plants, that could threaten values at risk. However, the effects of these treatments on native vegetation response post fire are little studied, especially beyond one to two years. We compared species richness, diversity, and percent canopy cover of understory plants one, two, three, four, and six years after immediate post-fire application of wood strand mulch, agricultural wheat straw mulch, hydromulch + seed with locally adapted native grasses, seed only with locally adapted native grasses with no mulch, and untreated (no mulch or grass seeding)

RESUMEN

Los tratamientos post-fuego de mulch y siembra, aplicados inmediatamente después de grandes incendios sobre pendientes escarpadas y severamente quemadas, se realizan para reducir el potencial de erosión y el establecimiento de plantas exóticas invasoras que podrían poner en riesgo otros valores. Sin embargo, los efectos de estos tratamientos post-fuego sobre la vegetación nativa están poco estudiados, especialmente después de uno o dos años de aplicados. Nosotros comparamos la riqueza de especies, la diversidad y el porcentaje de la cubierta del dosel de las plantas del sotobosque, uno, dos, tres, cuatro y seis años después del fuego mediante la aplicación de mulch de madera, mulch de paja de trigo, hidromulch más semillas de gramíneas nativas adaptadas al lugar, semillas de gramíneas nativas adaptadas sin mulch, y sin tratamiento (sin mulch ni semillas de gramíneas), luego del incendio de School Fire en 2005, en Washington, EEUU. Para los trataafter the 2005 School Fire in Washington, USA. For wood strand mulch treatments, mean canopy cover of grasses and forbs was low, varying from 3% to 20% in post-fire years two through six; whereas wheat straw mulch had the lowest mean cover of grasses, <1%, and the highest canopy cover of both forbs and shrubs, each >29% in post-fire years two through six. Plots hydromulched and seeded with grass, and those seeded with grass but not mulched, tended to have higher grass cover than other treatments and untreated plots over the six years. Species richness and diversity was highest for the hydromulch + seed treatment. Ten non-native species were found, but never with more than 2% canopy cover, each. Although the inference of our small-plot work is limited, our results suggest that post-fire rehabilitation treatments apparently altered the abundance and diversity of native perennial understory plants for one to six years post fire—effects that could persist for decades.

mientos con mulch de madera, la cobertura del dosel de gramíneas y hierbas fue baja, variando entre el 3% y 20% a los dos y seis años después del fuego, mientras que el mulch de paja del trigo obtuvo el promedio más bajo de cobertura de gramíneas, <1%, y la más alta cobertura del dosel de herbáceas y arbustos, cada una >29% a dos y seis años después del fuego. Las parcelas con hidromulch más semillas de gramíneas, y aquéllas con gramíneas pero sin mulch, tendieron a tener una cobertura más alta de gramíneas que los otros tratamientos y que las parcelas sin tratar, por más de seis años. La riqueza de especies y la diversidad fueron más altas para el tratamiento de hidromulch con las semillas de gramíneas nativas. Diez especies exóticas fueron encontradas, pero nunca con más del 2% de cobertura del dosel cada una. A pesar de que la inferencia de nuestro trabajo está limitada por el pequeño tamaño de las parcelas, nuestros resultados sugieren que los tratamientos de rehabilitación post-fuego aparentemente alteraron la abundancia y diversidad de plantas nativas perennes bajo dosel por uno a seis años después del fuego, pudiendo estos efectos persistir por décadas.

Keywords: burned area emergency response, hydromulch, invasive species, post-fire rehabilitation, seeding, species diversity, wheat straw mulch, wood strand mulch

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INTRODUCTION

Extensive wildfires and lengthened fire seasons in recent years (Westerling *et al.* 2006), and concerns about the potential for post-fire erosion and non-native species establishment post fire have led to increased investment in post-fire rehabilitation to protect values at risk (Robichaud *et al.* 2009, 2010). These treatments, often applied on steep, severely burned slopes immediately after large wildfires, are meant to reduce the potential of erosion and establishment of plants, especially non-native plants, that could threaten values at risk (Beyers 2004; Robichaud 2009; Robichaud *et al.* 2000, 2009, 2010, 2013*a, b*). Treatments include aerial seeding with native or non-native grasses and mulching with agricultural wheat straw, wood strands or shreds, and hydromulch (Robichaud *et al.* 2009). Wood strand and agricultural straw mulches can increase soil infiltration and reduce soil erosion (Bautista *et al.* 2009, Robichaud *et al.* 2013*a, b*), retain soil moisture (Rhoades *et al.*

2012), alter nutrient cycling (Baer *et al.* 2003, Rhoades *et al.* 2012), and cover bare mineral soil and change soil temperature—all of which can alter the environment for vegetation establishment and growth (Bautista *et al.* 2009). Further, non-native species may be inadvertently introduced through mulch treatments or from nearby roads and trails (Beyers 2004). The effects of seeding on vegetation response are well studied, but not the effects of seeding with native grass (Peppin *et al*. 2010). Post-fire rehabilitation treatments, specifically mulching treatments, are designed to stabilize soils (Robichaud *et al.* 2010) until plants can reestablish (Taskey *et al.* 1989, Kruse *et al.* 2004), but their influence on vegetation response for more than one or two years post fire is largely unknown (Robichaud *et al.* 2003, 2009).

Mulch consists of materials that have been shown to slow hillslope erosion (Robichaud *et al.* 2000, 2010, 2013*a*) or mimic natural erosion deterrents found on site, such as pine needles (Pannkuk and Robichaud 2003). Wheat straw mulch is generally inexpensive, but can introduce non-native seeds (this is possible but less likely if mulch is certified to be weed-free) and is prone to clumping during dispersal (Robichaud *et al.* 2009). Wood strand mulch is commercially made and transported to the site (Foltz and Copeland 2008), whereas wood shred mulch is produced locally with mastication or other equipment (Robichaud *et al*. 2013*b*). Wood mulch is heavy to apply and slowly decomposes on site, thus providing ground cover longer than other mulches (Robichaud *et al.* 2013*b*). Hydromulch is a mixture of wood fiber, paper, water and a tackifier to adhere the treatment to soils. Hydromulch may also contain seeds and a mycorrhizal inoculant (Robichaud *et al.* 2010). Seeding is one of the most common post-fire rehabilitation techniques (Beyers 2004; Robichaud *et al.* 2000, 2009; Peppin *et al.* 2010), largely due to its perceived success in post-fire erosion mitigation and low cost, but resulting plant cover is highly variable, and purposely seeded and non-native species inadvertently introduced as part of the seed mixture can compete with native vegetation (Robichaud *et al.* 2000, Beyers 2004, Peppin *et al.* 2010). Mulch treatments likely alter vegetation response with potentially long-term but unknown implications for vegetation response. Post-fire seeding treatments often result in high canopy cover that often increases competition with native plants for light, nutrients, and space, thereby affecting native species diversity (Peppin *et al.* 2010). Rhoades *et al.* (2012) found that mulch from masticated wood had high carbon to nitrogen ratios that influenced nutrient cycling, which would likely affect vegetation response. The plants that establish immediately post fire often persist to shape subsequent vegetation trajectories (Lyon and Stickney 1976). Altered vegetation response is an important potential but poorly understood consequence of post-fire rehabilitation treatments. Long-term monitoring is important because species diversity may change post fire as plants resprout and germinate from seed and competition occurs (Lyon and Stickney 1976).

Our objective was to evaluate understory plant species richness, diversity, and abundance one, two, three, four, and six years after seeding and mulch treatments on steep hillslopes (50% to 70% slope) that burned at high severity during the 2005 School Fire. We hypothesized: 1) that mulch treatments, especially those that decompose slowly (wood strand and agricultural wheat straw), would have lower species richness and diversity than plots treated with mulches that decompose quickly after application (hydromulch + seed with native grasses) or plots without mulch (native grass seeding only and untreated); 2) that in comparison to untreated plots, all treated plots would have greater species richness of non-native species because of the additional disturbance and potential to introduce non-native plants from seed mixes (alternatively the mulch could reduce species diversity by posing a physical barrier to seed establishment); and 3) that plots seeded with native grasses (hydromulch + seed and seed only) would have reduced abundance of forbs, shrubs, and tree seedlings due to competition from grasses. Understanding the implications of widespread post-fire rehabilitation treatments on native species response, including richness and diversity, is important to managers charged with the conservation of biological diversity and effective post-fire vegetation management.

METHODS

Study Area

The School Fire burned approximately 21 000 ha of mixed-ownership forest and grassland south of Pomeroy, Washington, USA, during July and August 2005. This area contains high plateaus deeply cut by an intricate system of steep-walled, rim-rock canyons (ranging from flat to over 100 % slope and 870 m to 1680 m in elevation). The fire burned rapidly due to extremely dry fuels, high temperatures, and strong winds in rugged terrain. Fifty-six percent of the burned area was under federal management, and most (83 %) was classified as ponderosa pine (*Pinus ponderosa* Lawson and C. Lawson) or mixed-conifer forest before the fire.

The study area encompasses mixed-conifer forest dominated by Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), grand fir (*Abies grandis* [Douglas ex D. Don] Lindl.), and lodgepole pine (*Pinus contorta* Douglas ex Loudon var. *latifolia* Engelm. ex S. Watson) on ridges and plateaus, and by ponderosa pine on the more xeric, low elevations. We do not have pre-fire vegetation composition for our plots, but common species in the area include shrubs such as Scouler's willow (*Salix scouleriana* Baratt ex Hook.), white spiraea (*Spiraea betulifolia* Pall.), common snowberry (*Symphoricarpos albus* [L.] S.F. Blake), thinleaf huckleberry (*Vaccinium membranaceum* Douglas ex Torr), and currant (*Ribes* L.) species. Forbs are also abundant in the area including heartleaf arnica (*Arnica cordifolia* Hook.), fireweed (*Chamerion angustifolium* [L.] Holub), Piper's anemone (*Anemone piperi* Britton ex Rydb.), and common yarrow (*Achillea millefolium* L.). The dominant soil is an ashy loamy sand (Klicker-like; a Loamy-skeletal, isotic, frigid Vitrandic Argixeroll) derived from basalt (http://websoilsurvey.nrcs.usda.gov/app/, accessed 13 Apr 2013).

Average annual precipitation for the sampling years (2005 to 2011) was 1460 mm, while average annual daily maximum and minimum temperatures were 10.6 °C and 2.1 °C (data from nearest weather station, 21 km from study site: Touchet SNOTEL 1686 station, latitude 46° 6' 36" longitude −117° 51' 0", elevation 1681 m). This period was slightly wetter than the average precipitation of 1434 mm and nearly the same average annual daily maximum and minimum temperatures of 10.1 °C and 1.5 °C during the period of 1989 to 2010. Annual precipitation at the SNOTEL site was 1135 mm in 2005, 1671 mm in 2006, 1285 mm in 2007, 1631 mm in 2008, 1572 mm in 2009, 1455 mm in 2010, and 1473 mm in 2011.

Data Collection

We monitored vegetation on steep hillsides (51 % to 70 % slope), all burned with high severity (>70 % tree mortality, >50 % bare mineral soil exposure) above the Tucannon River, that were selected by Robichaud *et al.* (2013*a, b*) for monitoring the effects of each of five different post-fire treatments on erosion as part of an ongoing analysis of post-fire treatment effectiveness. The treatments included: 1) native grass seeding only, 2) hydromulch with grass seeding (we refer to this as hydromulch + seed in this paper), 3) wheat straw mulch, 4) wood strand (WoodStraw®, Forest Concepts, Federal Way, Washington, USA[1]) mulch, and 5) untreated (Table 1, Figure 1). Each treat-

[1] Trade names are provided for the benefit of the reader and do not imply endorsement by the University of Idaho or US Department of Agriculture.

Table 1. Mulch and seed treatments applied by helicopter in fall 2005 on the School Fire. All treatments were limited to large patches of high severity burns on steep slopes.

Treatment	Application rate	Ground covered (%)	Area treated (ha)
Hydromulch + seed, native grasses	1.1 Mg ha^{-1} (1000 lbs ac^{-1}) wood fiber mulch with 90 kg ha^{-1} (80 lbs ac^{-1}) guar tackifier and 11.3 kg ha^{-1} (10 lbs ac^{-1}) pure live grass seed, locally sourced	56	20
Wheat straw mulch	2.2 Mg ha^{-1} (1 t ac^{-1}), certified weed-free straw	57	32
WoodStraw® mulch	4.5 Mg ha^{-1} (2 t ac^{-1})	54	10
Seed only, native grasses	11.3 kg ha^{-1} (10 lbs ac^{-1}) pure live seed, locally sourced		712
Untreated	None		Extensive

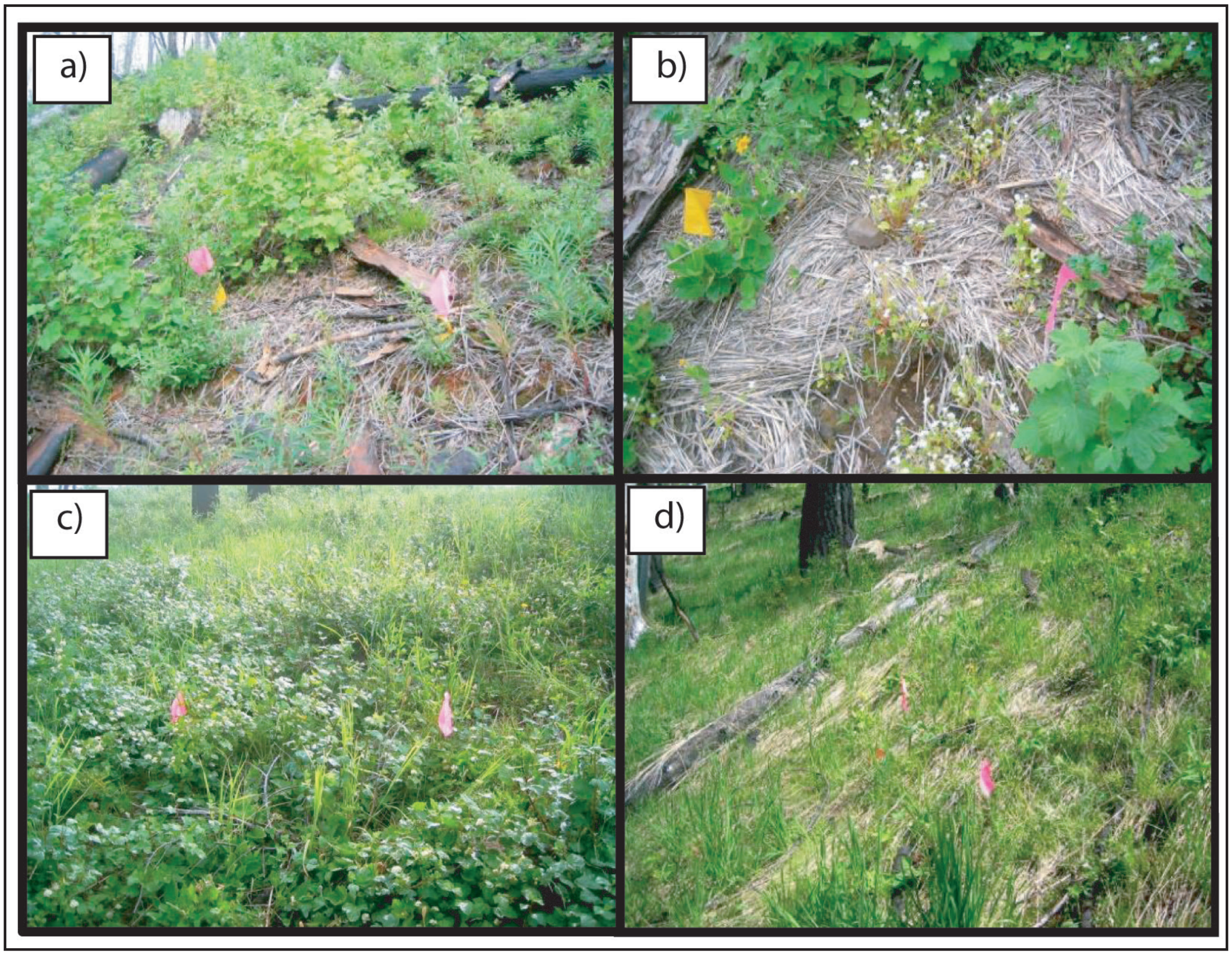

Figure 1. Contrasting vegetation response three years after each of four post-fire rehabilitation treatments were applied to plots on the 2005 School Fire, Washington, USA. Treatments included a) wheat straw mulch, b) wood strand mulch, c) grass seed only (no mulch), and d) hydromulch + seed with grass (untreated not shown). Note the persistence of the wheat straw and wood strand mulch and the visible differences apparent in the plant communities.

ment was confined to one of five hillslopes (Table 1), and each hillslope had seven plots. Each of the five hillslope sites had had similar forest structure and composition before all the trees died in the fire, with similar elevation (1457 m to 1547 m) and aspect (W- to NE-facing), and all were located within 3 km of each other. We measured vegetation abundance by species on three permanently located 1 m × 1 m subplots systematically placed with one in the upper, one in the middle and one in the lower portion of larger, 147 m^2 to 331 m^2 plots bordered by silt fences (after Robichaud and Brown 2002). Data were aggregated for the three subplots within each of the seven plots per treatment. The Umatilla National Forest has a long-standing protocol of applying stored native grass seed grown from locally adapted seed sources to disturbed areas in order to mitigate both erosion and spread of non-native species. The seed mix for the hydromulch + seed and seed-only treatments included Idaho fescue (*Festuca idahoensis* Elmer), California brome (*Bromus carinatus* Hook. & Arn.), blue wildrye (*Elymus glaucus* Buckley), and Sandberg bluegrass (*Poa secunda* J. Presl.). All mulch and seed treatments were aerially applied with a helicopter during the fall of 2005. Moisture content of the mulch and the heavier weight of the wood strands initially made applying treatments evenly and consistently challenging, so mulch coverage was clumpy. Because this was the first post-fire application of wood strands with a helicopter, it took several trials to improve uniformity by increasing the helicopter speed and releasing the cargo net at high altitude.

We sampled during the height of the growing season in late June and early July, one to six years post fire (in each of the years from 2006 to 2009, and again in 2011). We identified all plant species present on the subplots and made ocular estimates of percent canopy cover by species. We verified all plant species in the Stillinger Herbarium at the University of Idaho, Moscow, USA, and we used nomenclature following the USDA Plants Database (http://plants.usda.gov/). In the years immediately post fire, plants were generally very small and species identification was often difficult. In order to provide consistent and detailed data, we compared subplot-level species lists between years to identify unknown species whenever possible. We had no data on the plant composition on these plots prior to the fire.

Data Analysis

We calculated species richness and Shannon-Wiener diversity for each plot by year (mean of three subplots per plot, seven plots per treatment). We calculated the Shannon-Wiener diversity by

$$H' = \sum (p_i \ln(p_i)) \ , \qquad (1)$$

where p_i = the proportion of canopy cover for an individual species to the total canopy cover of all species found in that plot. To calculate the average percent canopy cover by plant form (grass, forb, or shrub), we averaged observed values on the three 1 m × 1 m subplots for each of seven plots per treatment for each year.

We display the findings as boxed plots and use the overlap among them to discuss differences. Given the pseudoreplication, with each treatment applied once to a different hillslope, our findings are not well suited to statistical analysis.

RESULTS

Species Richness and Diversity Varied with Treatment

We found 96 different tree, forb, shrub, and grass species. Ten species were non-native (Table 2), but none had cover values exceeding 2%. Note that, although we found tree seedlings in our plots, they were few in number (average less than 1 m^{-2}, data not

Table 2. Graminoid, forb, and shrub species listed with scientific names, common names, and whether native (N) or non-native (I, introduced). All nomenclature and nativity is consistent with the USDA Plants Database (http://plants.usda.gov/). Seeded species are marked with an asterisk (*), and species designated as "noxious" in one or more states or Canadian provinces (invader.dbs.umt.edu/Noxious_Weeds/noxlist.asp) are marked with the dagger symbol (†).

Scientific name	Common name	Native (N) or introduced (I)
Graminoids		
Agrostis scabra Willd.	rough bentgrass	N
Alopecurus sp. L.	foxtail	N
Bromus carinatus Hook. & Arn.*	California brome	N
Bromus spp. L.	brome	N, I
Bromus tectorum L. †	cheatgrass	I
Calamagrostis canadensis (Michx.) P. Beauv.	bluejoint	N
Calamagrostis rubescens Buckley	pinegrass	N
Carex geyeri Boott	Geyer's sedge	N
Carex rossii Boott	Ross' sedge	N
Dactylis glomerata L. †	orchardgrass	I
Elymus glaucus Buckley *	blue wildrye	N
Festuca idahoensis Elmer *	Idaho fescue	N
Poa secunda J. Presl. *	Sandberg bluegrass	N
Pseudoroegneria spicata (Pursh) Á. Löve	bluebunch wheatgrass	N
Triticum aestivum L.	common wheat	I
Forbs		
Achillea millefolium L.	common yarrow	N
Actaea rubra (Aiton) Willd.	red bane berry	N
Agastache urticifolia (Benth.) Kuntze	nettleleaf giant hyssop	N
Allium spp. L.	onion	N
Anaphalis margaritacea (L.) Benth.	western pearly everlasting	N
Anemone piperi Britton ex Rydb.	Piper's anemone	N
Antennaria spp. Gaertn.	pussytoes	N
Arnica cordifolia Hook.	heartleaf arnica	N
Astragalus spp. L.	milkvetch	N
Calochortus apiculatus Baker	pointedtip mariposa lily	N
Capsella bursa-pastoris (L.) Medik. †	shepherd's purse	I
Chamerion angustifolium (L.) Holub	fireweed	N
Cirsium arvense (L.) Scop. †	Canada thistle	I
Cirsium spp. Mill.	thistle	N, I
Cirsium vulgare (Savi) Ten. †	bull thistle	I
Claytonia perfoliata Donn ex Willd.	miner's lettuce	N
Collinsia grandiflora Lindl.	giant blue eyed Mary	N
Collomia linearis Nutt.	tiny trumpet	N
Crepis elegans Hook.	elegant hawksbeard	N
Delphinium bicolor Nutt.	little larkspur	N
Epilobium spp. L.	willowherb	N
Erythronium grandiflorum Pursh	yellow avalanche-lily	N
Eurybia conspicua (Lindl.) G.L. Nesom	western showy aster	N
Fragaria vesca L.	woodland strawberry	N
Galium boreale L.	northern bedstraw	N
Galium triflorum Michx.	fragrant bedstraw	N
Hackelia spp. Opiz	stickseed	N
Heuchera spp. L.	alumroot	N
Hieracium scouleri Hook. var. *albertinum* (Farr) G.W. Douglas & G.A. Allen	Scouler's woollyweed	N
Hieracium albiflorum Hook.	white hawkweed	N
Hydrophyllum capitatum Douglas ex Benth.	ballhead waterleaf	N

Table 2 continued next page.

Table 2, continued.

Scientific name	Common name	Native (N) or introduced (I)
Forbs, continued		
Iliamna rivularis (Douglas ex Hook.) Greene	streambank wild hollyhock	N
Lactuca serriola L. †	prickly lettuce	I
Lithophragma parviflorum (Hook.) Nutt. Ex Torr. & A. Gray	smallflower woodland-star	N
Lupinus spp. L.	lupine	N
Maianthemum stellatum (L.) Link	starry false lily of the valley	N
Mitella breweri A. Gray	Brewer's miterwort	N
Mitella stauropetala Piper	smallflower miterwort	N
Moehringia lateriflora (L.) Fenzl	bluntleaf sandwort	N
Nothocalais troximoides (A. Gray) Greene	sagebrush false dandelion	N
Osmorhiza berteroi DC.	sweetcicely	N
Packera spp. Á. Löve & D. Löve	ragwort	N
Penstemon spp. Schmidel	beardtongue	N
Penstemon glandulosus Douglas	stickystem penstemon	N
Petasites frigidus (L.) Fr.	arctic sweet coltsfoot	N
Phacelia spp. Juss.	phacelia	N
Polemonium pulcherrimum Hook.	Jacob's-ladder	N
Polygonum douglasii Greene	Douglas' knotweed	N
Ranunculus uncinatus D. Don ex G. Don	woodland buttercup	N
Rudbeckia alpicola Piper	showy coneflower	N
Sedum stenopetalum Pursh	wormleaf stonecrop	N
Stellaria spp. L.	starwort	N
Stellaria media (L.) Vill.	common chickweed	N
Taraxacum officinale F.H. Wigg. †	common dandelion	I
Thalictrum occidentale A. Gray	western meadow-rue	N
Tragopogon dubius Scop.	yellow salsify	I
Trautvetteria caroliniensis (Walter) Vail	Carolina bugbane	N
Trifolium repens L.	white clover	I
Triteleia grandiflora Lindl.	largeflower triteleia	N
Valeriana occidentalis A. Heller	western valerian	N
Viola spp. L.	violet	N
Zizia aptera (A. Gray) Fernald	meadow zizia	N
Shrubs		
Acer glabrum Torr.	Rocky Mountain maple	N
Amelanchier alnifolia (Nutt.) Nutt. ex M. Roem.	Saskatoon serviceberry	N
Ceanothus velutinus Douglas ex Hook.	snowbrush ceanothus	N
Physocarpus malvaceus (Greene) Kuntze	mallow ninebark	N
Prunus emarginata (Douglas ex Hook.) D. Dietr.	bitter cherry	N
Ribes spp. L.	currant	N
Rosa spp. L.	rose	N
Rubus parviflorus Nutt.	thimbleberry	N
Salix scouleriana Barratt ex Hook.	Scouler's willow	N
Sambucus racemosa L.	red elderberry	N
Spiraea betulifolia Pall.	white spirea	N
Symphoricarpos albus (L.) S.F. Blake	common snowberry	N
Vaccinium membranaceum Douglas ex Torr	thinleaf huckleberry	N
Trees		
Abies grandis (Douglas ex D. Don) Lindl.	grand fir	N
Larix occidentalis Nutt.	western larch	N
Picea engelmannii Parry ex Engelm.	Engelmann spruce	N
Pinus contorta Douglas ex Loudon var. *latifolia* Engelm. ex S. Watson	lodgepole pine	N
Pinus ponderosa Lawson and C. Lawson	ponderosa pine	N
Pseudotsuga menziesii (Mirb.) Franco	Douglas-fir	N

shown). All large trees had been killed by the fire and live trees were usually more than 100 m away from the plots.

Species richness tended to be higher on plots treated with hydromulch + seed compared to untreated plots in all years, and higher on wheat straw mulched plots for the first three years (Figure 2). For all treatments, species richness increased from years one to three post fire, then remained similar for years four and six (Figure 2). Species diversity was variable and did not differ much among treatments (Figure 3). The highest species diversity values were on hydromulch + seed plots in year three. In the sixth year post fire, we found greater species diversity on the hydromulch +

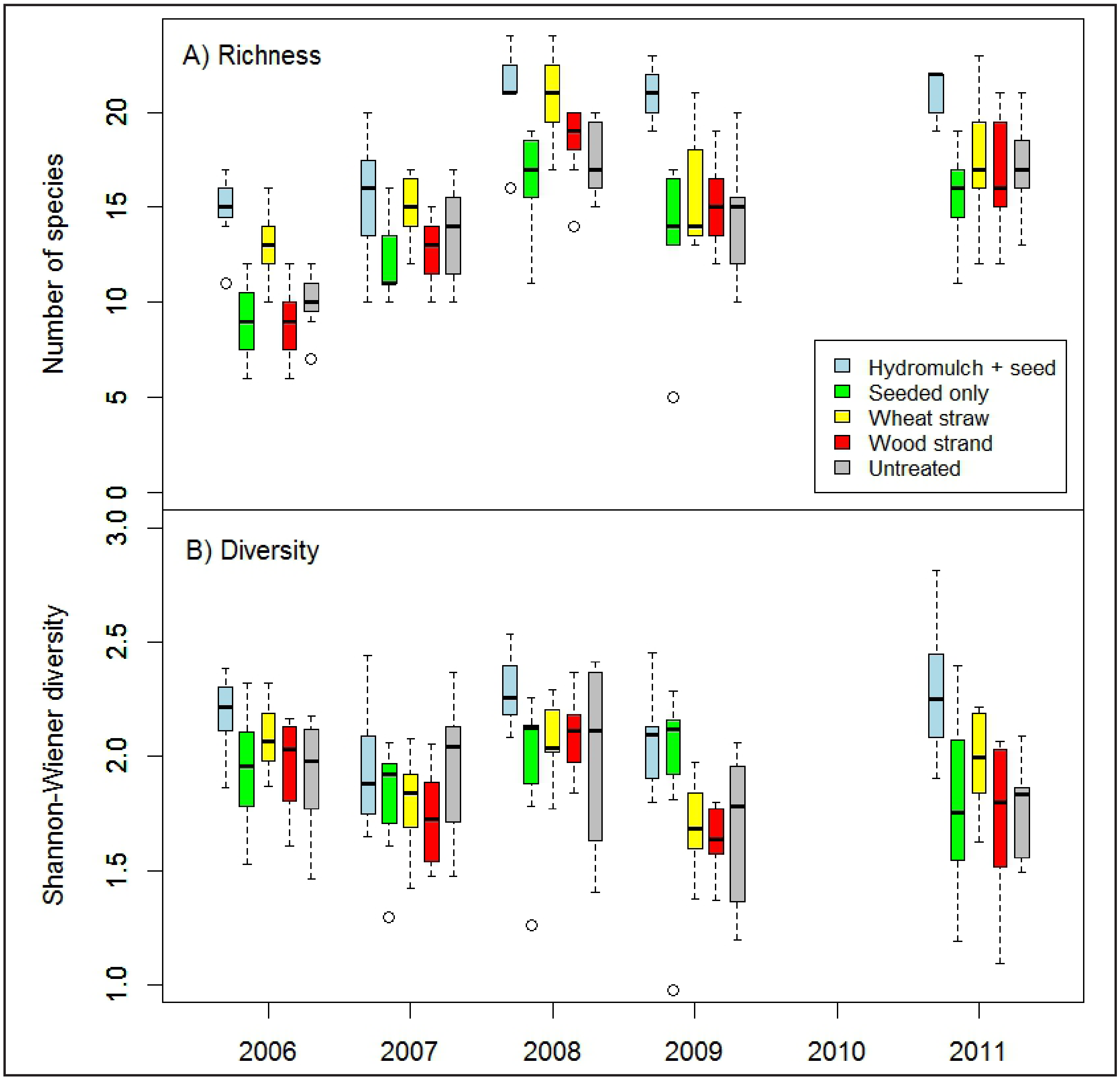

Figure 2. Species richness and diversity for four post-fire rehabilitation treatments and a similar but untreated area for comparison for 2006 through 2011 (we did not sample in 2010), one to six years after mulch treatments were applied in fall 2005 on the School Fire, Washington, USA. Data are shown as box plots with median and 25th and 75th percentiles. The same seven plots in each treatment were sampled each year.

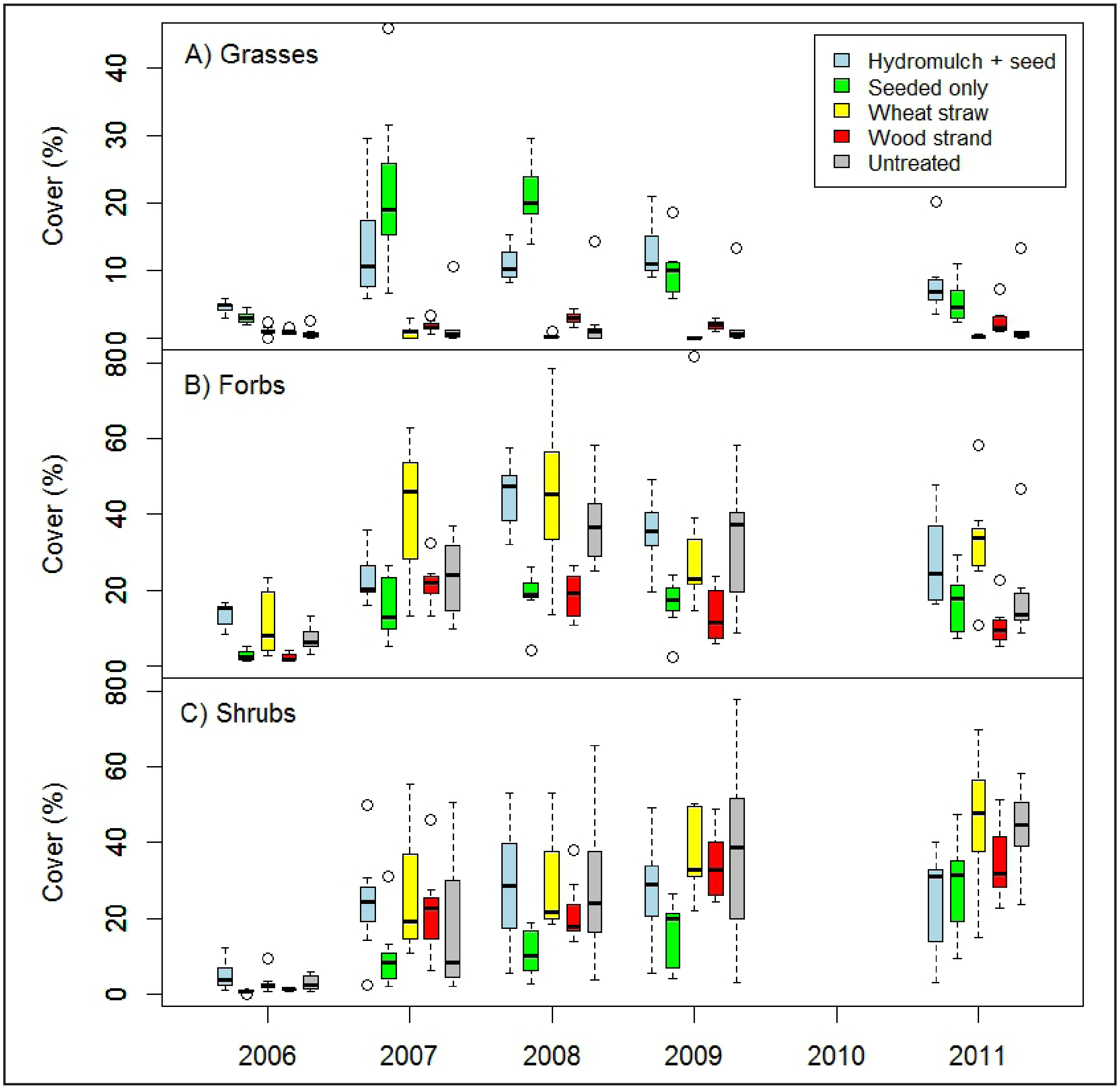

Figure 3. Canopy cover (%) of grasses, forbs, and shrubs for four post-fire rehabilitation treatments and untreated plots for 2006 through 2011 (no samples were collected in 2010), one to six years after mulch treatments were applied on the 2005 School Fire, Washington, USA. Data are shown as box plots with median and 25th and 75th percentiles. The same seven plots in each treatment were sampled each year.

seed plots compared to the plots of other treatments and untreated plots, which were similar to each other (Figure 3). This was contrary to our expectation that grass seeding would result in lower species diversity compared to other treatments. Although the wood straw and wheat straw persisted (it was still abundant in the third year post fire; Figure 1), vegetation diversity was similar to untreated plots. Species richness and diversity did not decline after the first few years, although we had expected to find a number of species that survived the fire but didn't thrive post fire.

Response of Shrubs, Grasses, and Forbs Varied with Mulch and Seeding Treatment

Plots seeded with native grasses (seed only and hydromulch + seed) had at least twice the percent canopy cover of grass compared to plots of other treatments in every year sampled (Figure 3). We found low grass cover on wood straw plots, wheat straw plots, and untreated plots, suggesting very little natural grass regeneration. The native grass species that were in the seed mix dominated on both seeded and non-seeded plots. The same graminoid species were found on all plots, whether those plots had been seeded or not (data not shown).

Forb cover was low for all treatments in year one post fire, but was higher in years two, three, and four, with median values greater than 40% canopy cover for treatments and years (Figure 3). Forbs were present even where grass was abundant (Figure 3). In the third year post fire, forbs were least abundant on the seed-only plots and wood strand plots, and in years four and six post fire, forb cover was lowest on the plots treated with wood strand compared to all other plots. Even as grasses declined and shrubs increased, by year six, forbs were consistently abundant.

Shrub cover increased on plots of all treatments in year two and slowly increased thereafter (Figure 3). Seed-only plots tended to have lower shrub cover in years two, three, and four. In year one, shrub cover was higher on hydromulch + seed plots than for plots of all the other treatments, but by year six, shrub cover on hydromulch + seed plots and seed-only plots were lower or similar to plots of other treatments. In year four post fire, seed-only plots had less than half of the canopy cover of shrubs than plots mulched with wheat straw.

DISCUSSION

Post-fire rehabilitation treatments matter. Mulch and seeding apparently influenced plant cover and diversity, not just in the first two years post fire as others have found (Beyers 2004, Kruse *et al.* 2004, Dodson and Peterson 2010, Rhoades *et al.* 2012), but also for up to six years later. Vegetation responded quickly post fire, as was found on other fires (Lentile *et al.* 2007, Robichaud *et al.* 2013*a*). Robichaud *et al.* (2013*a*) reported that vegetation alone was insufficient to reduce erosion potential in the first year here and at other western USA locations, and that for several years post fire, the combined cover of wheat straw or wood strand mulch plus vegetation cover exceeded the 60% cover needed to protect the soil surface (Pannkuk and Robichaud 2003). Dodson and Peterson (2010) found that, one year after straw mulch was applied on the 2006 Tripod Fire in eastern Washington, vegetation cover was greater than on untreated areas, whereas our results were more variable. Mulch helps to retain soil moisture, but that was likely less important on our sites where moisture from spring rains were sufficient to wet soil and support vegetation recovery yet not cause erosion in the first year post fire (Robichaud *et al.* 2013*a*). The year of the fire and the second post-fire year were dry, while post-fire years one, three, four, and six had above average precipitation.

Others found that initially high post-fire species diversity declined with time since fire (Rundel and Parsons 1980). Dodson and Peterson (2010) found that species richness was higher in sites mulched with straw relative to other sites similarly burned but not treated with mulch.

Seeding with locally adapted native species, at a high application rate, with gentle, relatively frequent rains during the first growing season was so successful that it likely reduced the abundance of forbs and shrubs. Droske (2012) found significantly fewer ponderosa pine tree seedlings growing on areas that were seeded compared to those that were neither seeded with grass nor planted with tree seedlings following high burn severity elsewhere on the School Fire. Grass seeding has been more successful in the northwestern US than elsewhere (Peppin *et al.* 2010, Stella *et al.* 2010), with variable effects on post-fire vegetation response (Peppin *et al.* 2010). Schoennagel and Waller (1999) found lower cover of native species in the eastern Cascades of Washington, while Fernández *et al.* (2012) observed that, in northwestern Spain, richness increased in seeded areas.

There are several potential explanations for the results we observed, but the pseudoreplicated design of this experiment makes it difficult to differentiate between them. First, as plants resprouted or established from seeds in the soil, or regenerated from off-site seed, pre-fire differences in vegetation surely influenced vegetation present after fire. Because each treatment was applied to a different hillslope, the pre-fire vegetation could have influenced post-fire response, but we don't know the vegetation composition before fire. Second, mulch could be a physical barrier to establishment. This could explain why the hydromulch + seed, where the hydromulch was not evident in the first growing season after the fire, had the highest species richness and diversity. Species that resprouted from surviving below-ground materials were able to quickly regenerate and persist even where mulch from treatments remained on site for extended time periods. Third, mulching alters soil nutrient availability and moisture (Rhoades *et al.* 2012), depending on decomposition rates and nutrient content. Berryman *et al.* (2014) concluded from sampling soil and plants on these plots four years post fire that total soil nitrogen was 40% higher on plots mulched with wood straw or with wheat straw than untreated plots. Further, they measured nitrogen reductase activity in heartleaf arnica as a measure of nitrogen availability to plants and found that it was 30% higher on the wood strand plots than on either the wheat straw or unmulched plots. Berryman *et al.* (2014) concluded that mulch applications after fires may enhance nitrogen availability by adding nitrogen and increasing microbial mineralization of nitrogen because of the higher soil moisture under mulch. They thought this could explain the differences in vegetation responses we observed in this study.

A strength of our study is that we have data through six years, not just one or two post-fire years. If we had only monitored in the first one or two years as others have done, we would have concluded more pronounced differences than we found six years post fire. While shrubs increased across all treated and untreated plots from year one to six, grass and forb cover increased and then declined. Most monitoring is concentrated in those first two years, but there is little information and much concern and speculation about the longer-term consequences of these treatments. However, the differences we found between treatment types and vegetation response are worth documenting as there are few other studies that address the effects of mulch treatments on post-fire vegetation trajectories. Burned Area Emergency Rehabilitation (BAER) teams and land managers need a full suite of information to best determine which mulching treatments to apply, the mitigating effects of the treatments, and the potential drawbacks.

Mulch application and seed treatments can change vegetation response with potentially long-term implications well beyond the six years we sampled, especially when the abundance of long-lived perennial shrubs and grasses is influenced by treatments. Understanding how mulch presence and decomposition influences ecosystem recovery, including vegetation and soil processes, is important to strategically determine effective post-fire rehabilitation without delaying native vegetation recovery. Well designed, replicated studies are needed across multiple sites that include known levels of consistently applied (non-clumped) mulch and seed while also monitoring soil moisture and nutrient effects. Additional observational and experimental studies that help us understand the complexities associated with fire and post-fire treatments will assist in providing clear and science-based directions for forest managers tasked with managing post-fire landscapes.

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