FINAL REPORT

Management Options to Control Exotic Invasive Plant Species in Association with Fuel Reduction Treatments in a Wildland Urban Interface, Crooked River National Grassland

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Abstract

Social and management goals for juniper woodlands, such as reducing severe wildfire risk and sustaining and promoting biodiversity, have prompted the use of fuel reduction techniques such as mechanical thinning and burning to reduce fuels, lower stand densities, and promote historic community composition. Yet it is a significant challenge for land managers to apply thinning and burning fuel treatments in a manner that does not exacerbate existing weed and associated resource problems. The potential for weed problems is greater at the wildland urban interface (WUI), where diverse source propagules are abundant. We evaluated the effects of fuel reduction activities (thinning, slash pile burning, skid trail formation) and two native seeding treatments (cultivar and local seed) on exotic weed populations and native vegetation in an eastern Oregon juniper woodland. We focused on two disturbance types within the juniper thinning prescription (1) burned slash piles and (2) skid trails. Vegetation was measured prior to treatment, and two years after.

We found that the fuel reduction activities and post-treatment seeding introduced and spread exotic species. Data indicate that both seed mixes were successfully germinated, with an average cover of 18 – 20% for seeded species two growing seasons later. The locally derived native seed mix we used outperformed the off-the-shelf cultivar mix in some respects, but differences were very small. At a minimum, the local seed mix did not perform poorly, and based on our results would be a good option for land managers who are concerned with maintaining local genetic resources. However, neither seed mix successfully reduced exotic species cover. This may be due to do the overall high propagule pressure, aggressive nature of the exotic species present, and reduction in ecological resistance that the fuel reduction activities created. However, it is too early to determine the capacity of either seed mix in deterring the invasion of the two exotic annual grass species that are the focus of local weed management, *Taeniatherum caput-medusae* and *Ventanata dubia*. Lastly, our data indicated that pretreatment juniper abundance was positively associated with native perennial cover, and negatively associated with exotic species cover. These patterns, coupled with the impact of fuel reductions activities, suggest that reducing juniper abundance may not lead to the restoration of native plant community composition even if native treatments are used post-disturbance. Our results suggest that high rates of post fuel reduction seeding in highly invaded juniper woodlands with high propagule pressure, which might be prohibitively expensive for normal management operations, may be effective at establishing high total and native cover, but may still be ineffective at controlling exotic species in areas. However, it is much too early to tell if the treatments were successful at creating desired future conditions.

Background and Purpose

This study originally focused on examination of herbicide and native seeding management options for controlling weed establishment and spread within the Liberty WUI Fuel Reduction Project, located along the eastern slopes of the Cascades on the Cle Elum Ranger District, Okanogan-Wenatchee National Forest (hereinafter the Liberty study). The Liberty study was started in 2006 with the establishment of experimental blocks and collection of pretreatment vegetation data. In 2007, plots were remeasured, herbicide treatments applied, and soil seed bank samples were collected (seed bank component was added, costs were minimal). Unfortunately, the Cle Elum Ranger District had put the sale up for bid three times and was unable to find a bidder on the stewardship sale. In 2008, a no-cost extension and a change in study area location were requested by the PI from the JFSP. After communicating with managers about a study that was identified locally as a high priority and need, a new study plan was submitted. The Westside Wildland Urban Interface Fuel Reduction Project, located in a mixed western juniper-grassland on the Crooked River National Grassland (hereinafter the Crooked River study), offered an excellent opportunity to move the study to a new area while maintaining many of the core objectives as proposed.

Data that were collected in 2006 and 2007 as part of the Liberty study set up (weed herbicide response), along with the seed-bank study, formed the basis of a master's student thesis. These deliverables (partially funded from JFSP) are included at the end of this document. However, the majority of the funding was spent on the relocated Crooked River study and this report is focused on the results from that study.

Background and Purpose for the Crooked River Study. Decades of livestock grazing, fire suppression, and other factors such as climatic variability have created conditions that many suggest have contributed to the rapid and recent (past 100+ years) spread of western juniper (J*uniperus occidentalis*) in eastern Oregon and the Pacific Northwest (Young and Evans 1981; Eddleman 1987; Miller et al. 1987, 2005; Miller and Wigand 1994; Miller and Rose 1995). Once confined to rocky ridges and unproductive areas (Burkhardt and Tisdale, 1976; Eddleman and Miller 1992), these woodlands have spread into more productive sagebrush, riparian, and aspen sites in eastern Oregon, southwestern Idaho, and northeastern California (Figure 1) (Miller and Wigand 1994). Although western juniper is long lived, less than 3% of the woodlands in Oregon are characterized by trees >100 years old (USDI-BLM 1990). Currently, social and management goals for these forests, such as reducing severe wildfire risk and sustaining and promoting biodiversity, have prompted the use of fuel reduction techniques such as mechanical thinning and burning to reduce fuels, lower stand densities, and promote historic community composition.

The 720-acre Crooked River National Grassland Westside Wildland Urban Interface Fuel Reduction Project is located in western juniper woodland along the convergence of the Deschutes, Crooked, and Metolius Rivers on the Crooked River National Grassland (CRNG) managed by the US Forest Service (Figure 2). The 155,000-acre CRNG is one of the largest tracks of preserved grassland in the United States. The Crooked River project was designed to reduce fuels and protect adjacent homes, as well as improve wildlife habitat and move the vegetation towards a more historic community composition. The project was implemented by the Westside Stewardship Project, a collaborative group of private citizens, the National Wild Turkey Federation, the Confederated Tribes of the Warm Springs Reservation, and other groups working with the USDA Forest Service. The project consisted of cutting, piling and burning, or removing young or post-settlement western juniper. While the planned activities will reduce wildfire risk, restoration treatments may also introduce or spread exotic noxious invasive plants. The potential for weed problems is greater at the wildland urban interface (WUI), where diverse source propagules are abundant. It is a significant challenge for land managers to apply thinning and burning fuel treatments in a manner that does not exacerbate existing weed and associated resource problems. The planned area has already been invaded by noxious invasive plants, particularly invasive annual grasses such as medusahead, (*Taeniatherum caput-medusae*), cheatgrass (*Bromus tectorum*) and North Africa grass (*Ventanata dubia*).

We proposed a test of seeding treatments to suppress and control exotic weeds after fuel reduction activities and to enhance native plant diversity and community resilience. The purpose of the project was to evaluate the effects of fuel reduction activities (thinning, slash pile burning, skid trail formation) and two native seeding treatments on exotic weed populations and native vegetation.

Figure 1. Crooked River National Grassland juniper expansion: (left) 1958, (right) 2001 (Crooked River National Grassland Vegetation Management/Grazing Final Environmental Impact Statement, 2004).

Study Description and Location

The study area is in a mixed juniper-grassland; mean elevation is approximately 2700 feet. The project area is near two subdivisions, approximately 13 miles southwest of Madras, Oregon (Figure 2). Dominant understory vegetation includes Sandberg's bluegrass (*Poa secunda*), bluebunch wheatgrass (*Pseudoroegneria spicata*), bottlebrush squirreltail (*Elymus elymoides*), Thurber's needlegrass (*Achnatherum thurberianum*), mountain big sagebrush (*Artemesia tridentata*), antelope bitterbrush, (*Purshia tridentata*) and Idaho fescue (*Festuca idahoensis*).

Our study focused on two disturbance types within the juniper thinning prescription (1) burned slash piles and (2) skid trails. Within both disturbance types, the areas were examined as disturbed areas at high risk for weed invasion. Both skid trails and burn piles are common targets for seeding in an operational context, and slash piles and patches along skid trails formed our experimental units. The study was initiated in spring 2008 prior to treatment application (Table 1).

Thinning was completed by cutting all post-settlement juniper by chainsaw and removal by skid-steer within project units. Old-growth juniper trees were not cut and were identified by growth-form characteristics, such as twisted, gnarled trees, and not by size. Where slash was burned, slash was hand-piled and overwintered before burning (Table 1). See Figure 3 for pre- and post-thinning aerial photos.

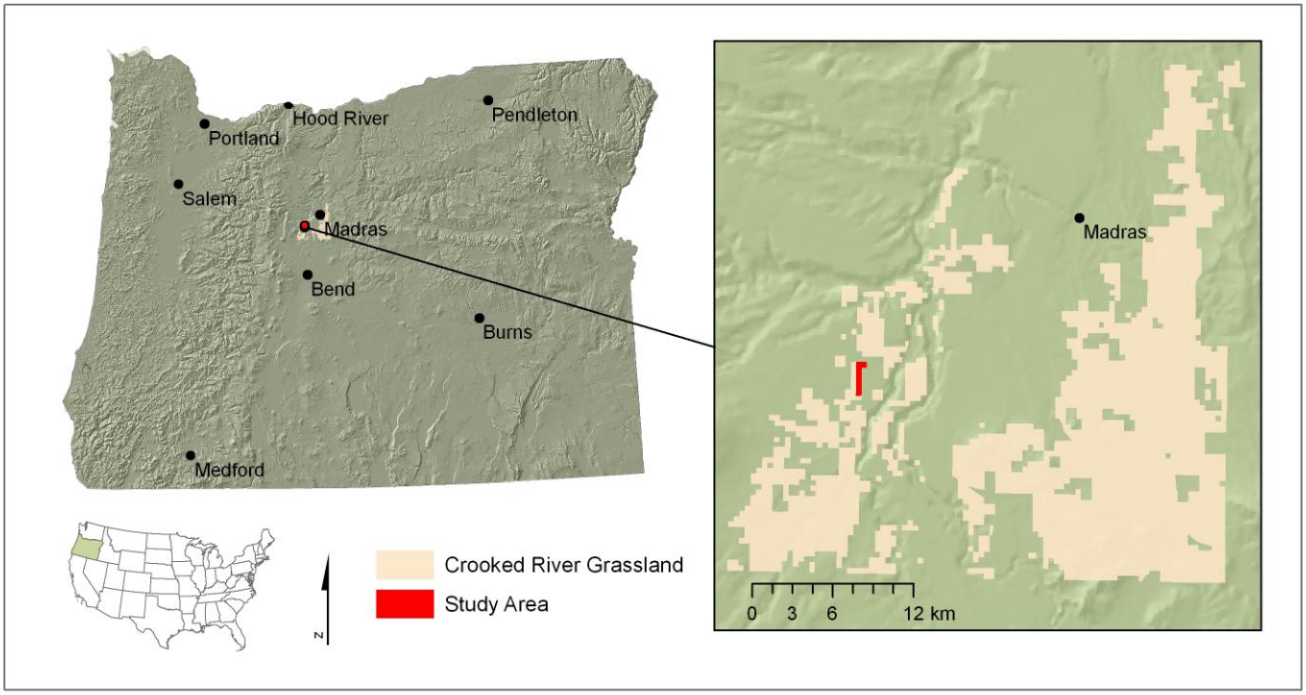


Figure 2. Crooked River study area.

To ensure statistical validity, we consulted Oregon State University statistician Manuela Huso to develop the experimental design. The study area was stratified based on high and low density juniper patches using NAIP imagery in a GIS. Within both high and low density areas, locations of slash piles were marked *prior to cutting and piling* and pre-treatment data were collected. Sixty slash piles were randomly located (30 within each density type). Seeding treatment was randomly assigned to each of the selected slash piles, replicated 10 times: (1) no seeding, (2) cultivar seed mix, and (3) native seed mix. There are an additional 20 control plots, 10 in each density type (Table 2).

Skid-trail locations could not be determined *a priori* and were determined by contractor; therefore skid-trail plots were randomly located and divided into 20 m segment lengths post-thinning. Similar to the slash pile design, 45 segments were randomly selected (10 within low density and 5 within high density) with the same seeding treatments as outlined above. Total skid-trail area within South Airpark was mostly restricted to low density juniper areas, so high density juniper skid-trail plots were established only in the northern study area unit. Areas within low density juniper patches left intact (no thinning) were randomly sampled and all high density patches were selected to provide no-thinning controls.

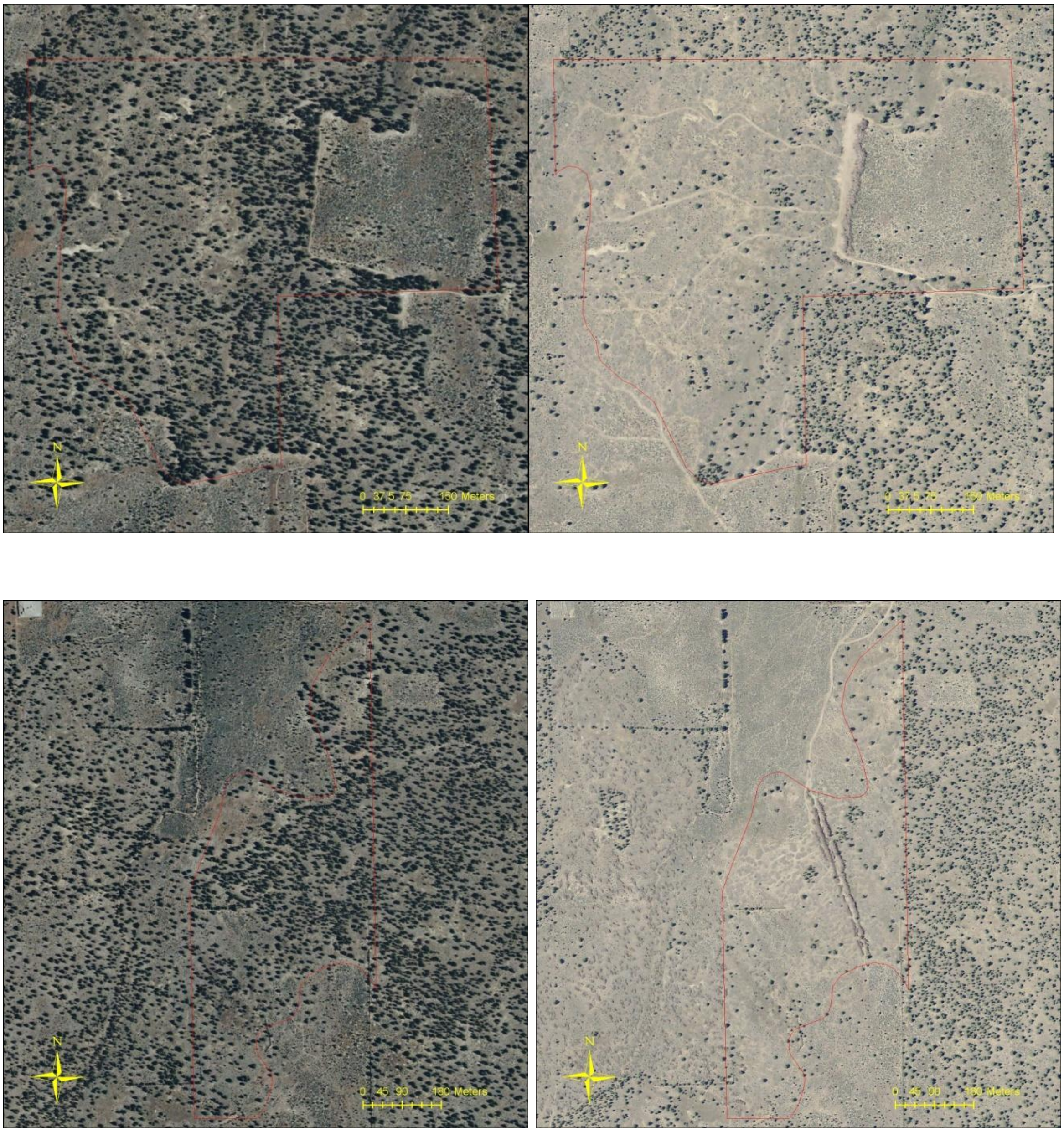


Figure 3. Northern (top) and southern (bottom) portion of study area (2005 NAIP 1-meter Imagery, left; 2009 NAIP 1-meter imagery, right).

Table 1. Crooked River Study Timeline

Activity	Date
Control units established	April 2008
Slash-pile plot locations established	April 2008
Slash-pile pretreatment data collected	Spring/Summer 2008
Transect data collected	Spring/Summer 2008
Juniper thinned	Spring - Fall 2008
Slash piled by fire crew	Fall 2008
Trees removed from site	Fall 2008 – Summer 2009
Skid trail plots established	May 2009
Piles burned	December 2009
Piles seeded	December 2009
Skid trails raked and seeded	December 2009
Post-seeding data collected	May/June 2010
First year post-treatment data collected	June/July 2011

Table 2. Sample number within disturbance type, seeding treatment and density stratification.

Disturbance Type	Experimental Treatment	High Density Juniper (n)	Low Density Juniper (n)
None	Control (no thin/no seed/no skid)	10	10
Skid Trail	Thin, No Seed	5	10
	Cultivar Seed Mix	5	10
	Native Seed Mix	5	10
Slash Pile	Thin, No Seed	10	10
	Cultivar Seed Mix	10	10
	Native Seed Mix	10	10

Seed Mixes. Species selected for seeding were done in coordination with local area managers. Aggressive early successional species offer the greatest potential to compete with weeds as they are considered functional analogs. We tested two seed mixes that were composed of the same native species, but one mix was from locally grown seed stock (hereinafter local seed), and the other was derived from widely available cultivars (hereinafter cultivar seed). A cultivar is a distinct, intentionally developed subset of a species that will behave uniformly and predictably when grown in an environment to which it is adapted. "Off-the-shelf" cultivars are often used in large quantities, often without an assessment of the consequences. While some managers suggest that cultivars are more aggressive and competitive compared to locally generated species, the material may not necessarily be optimal for all situations (Aubrey et al 2005). Species used in the seed mix were: bottlebrush squirreltail, bluebunch wheatgrass, and western yarrow (*Achillea millefolium*). Seeding rates were approximately 13 lbs PLS/acre for bluebunch wheatgrass, 10 lbs PLS/acre for squirreltail and 1 lbs PLS/acre for western yarrow. Seeding rates approximated those recommended by Sheley et al. (2008) for broadcast seeding. However, seeding rates for western yarrow were ten times higher than the recommended rate because the cultivar seed mix was already created a higher rate.

*Sampling***.** Data were collected in a series of nested plots in a similar manner in skid-trail plots, slash-pile plots and control plots. Tree, shrub and canopy cover data are collected in a 10 m radius plot; species presence/absence and regenerating juniper data are collected in a nested 5 m radius plot; and plant canopy cover data are collected in a 1x1 m quadrat at the center of the two circular plots (Figure 4 and 5).

Figure 4. Slash-pile plot nested sampling design.

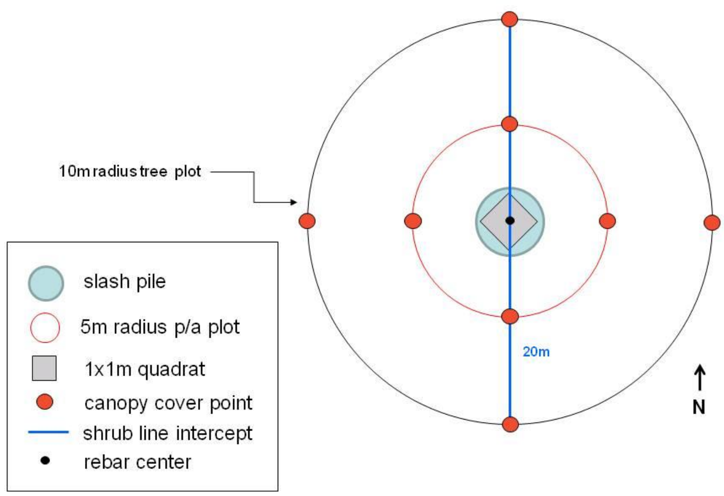
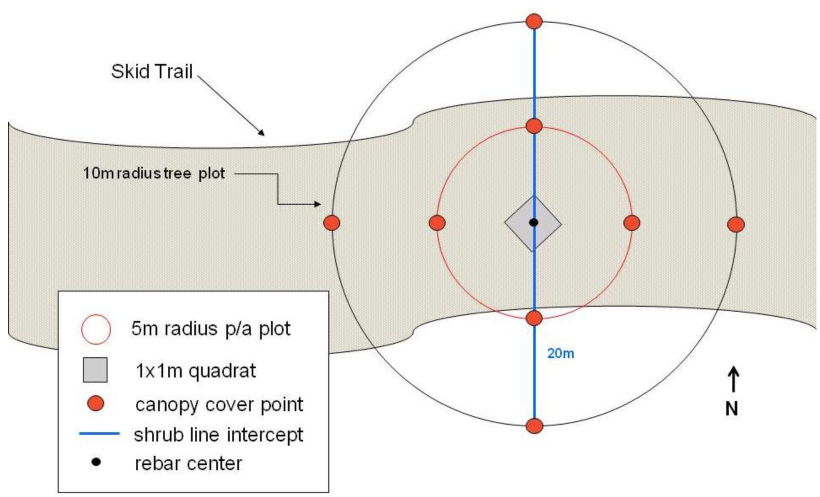


Figure 5. Skid-trail plot nested sampling design.



Data analysis. We have worked with both statisticians at Oregon State University and the Pacific Northwest Research Station during initial experimental design work and through data analysis. Data were analyzed as a completely randomized ANCOVA (analysis of covariance) design using Proc Mixed in SAS 9.2. Pretreatment juniper density was used as a covariate because juniper abundance is an important determinate of pretreatment existing differences in vegetation and potential differences in post-treatment responses due to the pre-treatment community composition. Higher density juniper areas also experienced more disturbance. Variables analyzed included: total cover, native cover, perennial native grass cover, seeded species cover, exotic cover, and exotic annual grass cover. Differences between treatments were assessed using Tukey's adjusted values, at an alpha of 0.05. We discuss statistically significant differences at alpha = 0.05 and marginally significant differences at alpha = 0.10.

Key Findings

We recorded 155 species in the study area. Dominate species (based on cover) included Thurbers needlegrass (*Achnatherum thurberianum)*, cheatgrass, Sandberg bluegrass, bluebunch wheatgrass, and several annual forbs. Prior to treatment, average understory cover of the study area was 31%. Perennial native grass cover was about 16%, and exotic species cover was 6%. Dominate exotic species were all annual species and included cheatgrass, jagged chickweed *(Holosteum umbellatum)* and spring draba (*Draba verna)*, with small pockets of medusahead (*Taeniatherum caput-medusae*). While the extensive infestation of medusahead in the study area was well known, managers were not aware that the area had also been invaded with North Africa grass (*Ventenata dubia*).

Vegetative cover in the pretreatment slash pile plots did not differ prior to treatment (Table 3). Prior to thinning juniper basal area (BA) did not significantly affect total cover, but both total exotic cover and exotic annual grass cover were influenced by basal area. Areas with higher juniper basal area had lower total exotic cover and exotic annual grass cover. Interestingly, the basal area was also significant for seeded species cover, that is, for these native perennial species, higher cover was associated with higher juniper basal area. This trend, although not significant, was also evident with perennial native grasses; higher cover was associated with higher juniper basal area.

Slash piles. We do not report results from 2010 because there was essentially little vegetative cover on the plots that were treated. Two growing season after thinning-burning (2011), total vegetation cover in the slash pile control plots increased to 56% (Table 4). This large increase in cover probably reflects both the cool and moist spring and early summer growing conditions in 2010 and 2011, and the large increase in exotic species cover. Total cover in the seeded treatments was greater than the control, although not significantly. While the cultivar and local seeding treatments were not significantly different from one another in terms of total cover, only the local seed treatment had significantly higher total cover than treated areas that were not seeded. The thinning-burning treatment significantly reduced native species cover in the absence of seeding, but areas that were seeded had higher native cover than the control, although not significantly so.

Exotic cover increased in the treated areas, but total exotic over was not significantly different than the control (Table 4). In 2011, more and new exotic species were recorded on the plots, some of

Table 3. Pretreatment (2008) cover data (%) from slash pile plots.

	Control		Cultivar		Local		No Seed			
Response Variable	**mean**	**CI**	**mean**	**CI**	**mean**	**CI**	**mean**	**CI**	***F***	***P***
Total cover	31.0	26.5 – 35.6	31.8	27.2 – 36.3	32.3	27.8 – 36.9	30.0	25.4 – 34.5	0.20	0.8963
Native cover	22.4	17.6 – 27.2	25.2	20.4 – 29.9	27.3	22.5 – 32.0	25.3	20.5 – 30.0	0.69	0.5591
Exotic cover	8.6	6.0 – 11.2	6.6	4.0 – 9.2	5.1	2.4 – 7.7	4.5	1.9 – 7.2	1.93	0.1327*
Per. native grass	15.2	10.5 – 19.9	14.6	9.8 – 19.2	17.5	12.8 – 22.2	17.7	13.0 – 22.4	0.45	0.7181
Ann. exotic grass	3.2	2.0 – 4.9	2.3	1.5 – 3.6	1.9	1.3 – 3.0	1.6	1.1 – 2.5	1.62	0.1916*

*Significant for juniper basal area, higher basal area associated with lower cover.

Table 4. Second year response (2011) in cover data (%) to juniper thinning, slash pile burning and seeding. Uppercase letters show significant contrasts based on Tukey-Kramer adjusted P-values where alpha = 0.05.

	Control		Cultivar		Local		No Seed			
Response Variable	**mean**	**CI**	**mean**	**CI**	**mean**	**CI**	**mean**	**CI**	***F***	***P***
Total cover	56.2^{AB}	44.0 – 68.4	72.6^{AB}	60.4 – 84.7	75.6^{A}	63.5 – 87.8	52.5^{B}	40.3 – 64.5	3.57	0.0178*
Native cover	28.2^{A}	21.3 – 35.0	38.9^{A}	32.1 – 45.8	34.0^{A}	27.2 – 40.9	5.2^{B}	0 – 12.0	18.85	<0.0001
Exotic cover	19.5	13.6 – 27.8	28.6	20.1 – 40.8	32.8	23.0 – 46.8	28.8	20.2 – 41.1	1.59	0.1992*
Seeded spp cover	0.3	0.1 – 1.1	17.9	5.4 – 59.8	19.9	6.0 – 66.5	0.07	0.02 – 0.3	22.19	<0.0001
Per. native grass	16.8^{A}	11.8 – 23.2	5.9^{B}	4.0 – 8.5	3.7^{B}	2.5 – 5.5	0.9^{BC}	0.6 – 1.3	41.56	<0.0001ǂ
Ann. exotic grass	15.7	9.6 – 24.5	27.7	18.0 – 40.0	31.3	20.7 – 44.2	27.3	17.7 – 39.5	2.01	0.1192*

*Significant for juniper basal area, higher basal area associated with lower cover.

ǂ Significant for juniper basal area, higher basal area associated with higher cover.

which were not observed in the area years prior (Table 5). *Poa compressa* (Table 6) was observed in both the local and cultivar seeded plots and was observed as a geminate in these plots in 2010, although it only appears as a dominant in the local seed mix. Given this species was encountered during tallies of seeded species germinants in 2010, it is likely both seed mixes were contaiminated with *Poa compressa*. Neither seeding treatment significantly reduced exotic species cover. Indeed, the seeding treatments had statistically similar exotic species cover as the areas that were not seeded (Table 4). However, the seeding treatments were somewhat successful as they significantly increased the cover of seeded species to 18 – 20%, and seeded species dominated cover in seeded plots (Table 4). In addition, seeded species plots with higher pre-treatment juniper basal area had lower total cover, exotic species cover, and exotic cover. The opposite relationship was found for perennial native cover in 2011; areas with higher pre-treatment basal area had higher cover.

Table 6. Top 5 dominate exotic species in rank order. Species that were not encountered in 2008 are indicated by **; species in the study area but not encountered on the cover plots in 2008 are indicated by *.

Exotic Group	Dominant Species Prior pretreament (2008)	Dominate species after treatment (2011)	
Annual Grasses	*Bromus tectorum*	*Bromus tectorum*	
	Taeniatherum caput-medusae	*Apera interrupta*	
	Apera interrupta	*Bromus hordeaceus*	**
	Bromus japonicus	*Taeniatherum caput-medusae*	
		Bromus sp.(unknown brome)	**
Forbs	*Holosteum umbellatum*	*Sisymbrium altissimum*	**
	Draba verna	*Holosteum umbellatum*	
		Draba verna	
		Camelina microcarpa	*
		Lactuca serriola	*

Skid trails. For skid trail areas within the thinning treatment, there was a significant interaction between seeding treatment and pretreatment juniper BA for total and native cover (Table 7). In areas of low BA, there were no differences among the treatments. In areas of high pretreatment BA, total cover was significantly higher in all seeded and not seeded treatments than in controls areas. In particular, the local seeded areas had higher native cover than in controls (Table 7). There was no interaction between seeding treatments and pretreatment juniper BA for exotic cover, exotic annual grass cover, and perennial native grass cover (Table 8). Juniper thinning and skid trail disturbance increased exotic species cover compared to control areas (Table 8), but not significantly so, regardless of pre-treatment basal area. While there was no significant response for perennial native grasses after treatments, we found that areas with higher juniper basal area had higher cover of native perennial grasses.

Regression analysis revealed that pretreatment exotic species cover was not correlated with post-treatment exotic species cover (r^2 = 0.04). In 2011, seeded species cover was also not correlated with total exotic cover (r^2 <0.001).

Table 6. Top five dominant native and exotic species by treatment in 2011 based on cover data.

	Treatment			
Group	**Control**	**Cultivar**	**Local**	**No Seed**
Native	*Achnatherum thurberianum*	*Achillea millefolium*	*Achillea millefolium*	*Achillea millefolium*
	Poa secunda	*Elymus elymoides*	*Elymus elymoides*	*Epilobium minutum*
	Vulpia microstachys	*Pseudoroegneria spicata*	*Pseudoroegneria spicata*	*Artemisia arbuscula*
	Festuca idahoensis	*Epilobium minutum*	*Epilobium minutum*	*Plagiobothrys tenellus*
	Pseudoroegneria spicata	*Artemisia arbuscula*	*Vulpia microstachys*	*Eriogonum vimineum*
Exotic	*Bromus tectorum*	*Bromus tectorum*	*Bromus tectorum*	*Bromus tectorum*
	Holosteum umbellatum	*Sisymbrium altissimum*	*Sisymbrium altissimum*	*Sisymbrium altissimum*
	Draba verna	*Holosteum umbellatum*	*Holosteum umbellatum*	*Camelina microcarpa*
	Apera interrupta	*Draba verna*	*Poa compressa*	*Bromus mollis*
	Taeniatherum caput-medusae	*Aspera interrupta*	*Draba verna*	*Draba verna*

Table 7. Second year esponse (2011) in cover data (%) to juniper thinning in skid trail plots in areas of high pre-treatment juniper basal area. Uppercase letters show significant contrasts based on Tukey-Kramer adjusted P-values where alpha = 0.05.

	Control		Cultivar		Local		No Seed	
Response Variable	**mean**	**CI**	**mean**	**CI**	**mean**	**CI**	**mean**	**CI**
Total cover	26.9^{A}	0 – 61.3	95.8^{B}	66.1 – 125	93.1^{B}	68.6 – 118	93.3^{B}	55.2 – 131
Native cover	16.9^{A}	0 – 37.8	33.6^{AB}	15.6 – 51.6	49.9^{B}	35.0 – 64.7	31.0^{AB}	7.9 – 54.1

Table 8. Second year esponse (2011) in cover data (%) to juniper thinning in skid trail plots.

	Control		Cultivar		Native		No Seed			
Response Variable	**mean**	**CI**	**mean**	**CI**	**mean**	**CI**	**mean**	**CI**	***F***	***P***
Exotic cover	32.0	17.9 – 46.1	41.3	27.4 – 55.1	42.7	28.5 – 56.9	42.8	28.9 – 56.7	0.54	0.6572
Per. native grass	18.2	10.1 – 26.3	16.1	8.1 – 24.1	14.3	6.1 – 22.5	11.7	3.7 – 19.7	0.48	0.6974 [Ŧ]
Ann. exotic grass	27.4	13.5 – 41.4	38.4	24.7 – 52.1	40.7	26.6 – 54.8	40.7	26.9 – 54.5	0.82	0.4862

[Ŧ] Significant for juniper basal area, higher basal area associated with higher cover.

Seeding treatment costs. Costs for seeding were $566/acre for cultivar seed. Costs have not been estimated for the local seed mix. Labor for the seeding treatments involved raking (skid trails only) and seeding by hand. For our study area, two people were able to rake and seed the plots in about three days. However, only plots and buffer areas were treated. Treating all of the disturbed areas would take considerably more time.

Management Implications

Fuel reduction activities and post-treatment seeding introduced and spread exotic species, and may have increased exotic species cover. Four exotic species were introduced into the plots, some of which are now dominant. While the thinning and burning treatments increased exotic species cover in all treated areas and in skid trails, we were unable to detect a statistically significant difference compared to control areas. This may simply reflect the overall high exotic cover in the area (19 – 32 % in control areas in 2011). However, given the trend in our data, we suspect that differences may emerge later if remeasurements are taken.

Seeding was expensive, but successful at establishing native perennial species, especially after slash pile burning. For thinned-burned treatments, seeding successfully increased total vegetative, native, and native perennial grass cover compared to areas that were not seeded. For skid trails, seeding increased native cover compared to control areas.

A local native seed mix rather than an "off-the-shelf" native cultivar seed mix might produce better results, but the differences were very small. At a minimum, the native seed mix did not perform poorly, and based on our results would be a good option for land managers who are concerned with maintaining local genetic resources.

At this point in time, neither seed mix significantly reduced exotic species cover compared to areas that were not seeded. This result may be due to do the overall high propagule pressure, aggressive nature of the exotic species present, and reduction in ecological resistance that the fuel reduction activities created. However, it is too early to determine the capacity of the local versus cultivar seed treatments in deterring the invasion of the two exotic annual grass species that are the focus of Grassland weed management, medusahead and North Africa grass. These species while highly invasive, occupy dense and isolated patches within the grassland, although these patches seem to have expanded since juniper thinning treatments were completed.

While the historic increase in juniper is viewed as a problem for maintaining native biodiversity, our data suggest that juniper abundance may be the solution in our study area. We found that exotic species cover was negatively associated with juniper basal area; therefore, juniper cover may be limiting exotic species establishment and spread. Moreover, we found in some cases that juniper basal area was positively associated with some native perennial species. These patterns, coupled with the impact of fuel reductions activities, suggest that reducing juniper abundance may not lead to desired future conditions. However, our current data only reflect the first two years after treatment, reflecting the early seral post-treatment environment. It is too early to tell if the treatments were successful at creating desired future conditions.

Relationships to Other Recent Findings

Despite the economic and ecological threats posed by invasive plant species, ecologists do not fully understand the mechanisms that control exotic plant invasions. Invasive species have been described as both “passengers” and “drivers” of environmental change (MacDougall and Turkington 2005). From the passenger perspective, exotic species become dominant as a result of anthropogenic or other drivers such as disturbance. The driver model infers that invasive plantss become dominant as a result of a variety of related means generally having to do with species traits, competitive interactions, and resource capture. Whether or not invasive plants are drivers or passengers of the invasion process, there is a large body of literature that suggests the successful invasion of a natural community is highly influenced by several factors such as environment, disturbance or resource availability, biotic resistance, and propagule pressure (D’Antonio et al. 2001, Davis et al. 2000, Levine et al. 2004, Eschtruth and Battles 2009, Pauchard et al. 2009).

The importance of disturbance and availability of resources as a major invasion driver has long been recognized (D’Antonio et al. 1999, Elton 1958, Hobbs and Huennke 1992). Natural and anthropogenic disturbances such as fire, landslides, volcanic activity, logging, road building, etc., alter resource availability in forests by opening canopies, reducing above- and below-ground competition, exposing mineral soil, or by directly increasing resources via geomorphic or chemical processes. Invasive plants are generally well adapted to exploit these resources. Fluctuation in resource availability, coinciding with available propagules, is a key factor for understanding the invasibility of an environment and the influx of both native and exotic invasive species associated with early secondary succession following disturbance (Davis et al. 2000; Halpern 1989, Parks et al. 2005). Of particular concern for are the effects of fire management on invasive plants (Keeley 2006). Invasion of forests and other ecosystems by invasive plants may be particularly problematic if management activities take place in areas adjacent to seed sources. Invasive annual grasses are of particular concern to land managers in the context of fire management impacts due to the potential changes in fire regimes.

Plant invasion success can be reduced by certain biotic features of the resident community. Biotic resistance has been well studied and discussed for invasive plants, and competition from resident plants is commonly assumed to regulate invasion success (Levine 2000; Seabloom et al. 2003). Typical metrics of biotic resistance for invasive plants include the plant community species richness and abundance. Application of the biotic resistance theory has promoted land managers to alter post-disturbance (logging, fire) environments to increase local site biotic resistance via seeding to lower the probability of invasive plants establishment. However, little is known about how biotic resistance interacts with propagule supply to influence plant invasions, and even if biotic resistance initially appears to be strong, it can still be overcome by high rates of propagule supply (Lonsdale 1999, D’Antonio et al. 2001).

Propagule pressure, which includes propagule sizes, propagule numbers, and temporal and spatial patterns of propagules, has been found to be an important invasion driver (perhaps the most important) in forests and other ecosystems (Colautti et al. 2006, Estruth and Battles 2009, Simberloff 2009, Tilman 1997). Yet the topic has received surprisingly little study. In addition, little is known about how resistance factors (abiotic and biotic) interact with propagule supply to influence exotic plant invasion (Lonsdale 1999, D’Antonio et al. 2001). Estruth and Battles

(2009) found that in 10 eastern hemlock forests in Pennsylvania and New Jersey (USA), overstory canopy disturbance and propagule pressure were the most important factors for predicting plant invasion.

Future Work Needed

Expansion of our study to a wider variety of sites and testing additional seed mixes would allow more options for land managers to assess. In addition, remeasurement of our sites five years or more post-treatment (in 2014 or later) would allow a meaningful assessment of the success of the seeding treatments and their capacity to deter key invasive plants. Remeasurement would also allow us to assess the potential recovery of the seeded and skid trail areas as establishment of the desired native plant community will most likely take more than two years.

Deliverables and Status

Proposed	Details	Status
Website	http://www.fs.fed.us/wwetac/projects/kerns2.html	Completed in FY 2006
Meetings with Manager	• Presentations were made in person to the leadership teams of the Cle Elum Ranger District and the Okanogon-Wenatchee National Forest at the start of the original project. • A presentation with the Crooked River managers was scheduled Spring 2010, but was cancelled by local managers due to a local conflict and budget issues. • Currently the PI is under a travel restriction, but is working to schedule a VTC with Crooked River Managers.	Partially complete: 11/6/2006
Annual progress reports	Filed on schedule	Completed annually
Technical Conference Presentations	• A presentation was made based on the pretreatments data collection for the Liberty study: Snider, G., Kerns, B.K., Buonopane, M. Community reassembly potential following proposed thinning in a mixed conifer forest: Lessons from the seedbank. Poster. Ecological Society of America Annual Meeting, Milwaukee, WI • Kerns will make a presentation to ESA in 2012 on key findings from the Crooked River study.	Completed 2008
Field Workshop	Due to increased travel restrictions, we will not be conducting a field workshop, but will hold VTC meetings with mangers (see above)	In progress
Scientific Paper(s)	Kerns is working on at least 2 scientific papers, one from work partially funded by JFSP based on the Liberty study,	FY2013

	and one from Crooked River: • Aboveground Vegetation and Viable Seed Bank of a Dry Mixed-Conifer Forest at a Wildland-Urban Interface in Washington State. • Effect of seeding treatments in exotic invasive plant patterns in a juniper woodland and the role of disturbance, resistance, and propagule pressure (this paper may end up being two papers).	
Unanticipated MS Thesis	This thesis was partially funded by JFSP, using the first years data collection from the Liberty study: Snider, Gabrielle. 2010. Aboveground vegetation and viable seed bank of a dry mixed-conifer forest at a wildland-urban interface in Washington State. Unpublished M.S. Thesis, Oregon State University.	Completed 2010
Unanticipated Peer-reviewed publication	Buonopane, M. B., Snider, G., and Kerns, B. In prep. Aboveground vegetation and viable seed bank of a dry mixed-conifer forest at a wildland-urban interface in an eastern Oregon mixed conifer forest.	In progress

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