Invasive Species Response to Fire and Post-fire Rehabilitation Following the 2005 School Fire, Umatilla National Forest: A Rapid Response Project

(JFSP # 06-1-02-03)

Principal Investigator: Peter Robichaud
Co- Principal Investigators: Andrew Hudak, Leigh Lentile, Sarah Lewis, Penelope Morgan
Additional Federal Collaborators: Debbie Page-Dumroese, Craig Busskohl, Caty Clifton, Ray Kokaly
Additional Co-authors: Marshell Moy, Maike Holthuijzen, Erin Berryman

Project Title: Invasive Species Response to Fire and Post-fire Rehabilitation Following the 2005 School Fire, Umatilla National Forest: A Rapid Response Project (JFSP # 06-1-02-03)
Principal Investigator: [1]Peter Robichaud
Co- Principal Investigators: [1]Andrew Hudak, [2]Leigh Lentile, [1]Sarah Lewis, [2]Penelope Morgan
Additional Federal Collaborators: [1]Debbie Page-Dumroese, [3]Craig Busskohl, [3]Caty Clifton, [4]Ray Kokaly
Additional Co-authors: [2]Marshell Moy, [2]Maike Holthuijzen, [1]Erin Berryman
Affiliations: [1]USDA Forest Service, Rocky Mountain Research Station, Moscow, ID; [2]University of Idaho, Moscow, ID; [3]USDA Forest Service, Umatilla National Forest, Pendleton, OR; [4]USGS Spectroscopy Laboratory, Denver, CO

I. Abstract

Invasive species are spreading rapidly on rangelands and in dry forests and pose serious ecological and economic threats to our environment. Managers were very concerned about weed spread following the 2005 School Fire that burned 21,000 ha of state, private and Umatilla National Forest lands in southeast Washington. Severely burned areas within the fire were treated with a combination of seeding with and without wood straw, wheat straw, and hydromulch treatments to control erosion and improve native re-vegetation. In this project, we monitored vegetation response in areas burned with low, moderate, and high severity across the range of pre-fire tree densities, including high severity areas that received the previously described rehabilitation treatments and in burned areas where post-fire salvage tree harvests occurred, as well as in adjacent sites that were identified as control sites.

Vegetation recovery was rapid, aided by rain in 2006. Total plant cover was lowest immediately after the fire but increased over time on all plots, with significant differences by burn severity, year and their interaction. Total plant cover was highest on low burn severity sites, but the difference between plant cover on low and high burn severity sites decreased over time. Plant cover was lower on salvaged than unsalvaged sites, but the effects of delayed salvage harvest confound interpretation of data from salvaged sites. Plant species diversity was significantly higher on low and moderate severity sites. Forbs had the highest cover on all plots (except those seeded with native grasses) over all years. Shrub cover increased with time, especially on high severity sites. On all unseeded sites, grass and tree seedling cover remained negligible over time. Non-native plant species occurred more often in sites burned severely, but with a maximum percent canopy cover of 2%. Non-native plant species were absent in unburned plots.

Plant established in abundance on all erosion mitigation treatment and their counterpart control sites following the first growing season post-fire. Total live canopy cover during the first growing season post-fire was generally low in all treatments, including the control, indicating that treatments would have been necessary to stabilize hillsides from potential erosion events. However, because no intense precipitation events occurred in the first three years following fire, there was very little soil erosion on any treatment or control. Plant cover in treated areas, particularly on seeded only and seeded and hydromulch sites often exceeded that of the control sites, indicating that treatments were beneficial. It appears that very few, if any, non-native species were introduced via erosion control treatments.

Multitemporal Landsat images (24 July 2005 and 25 Aug 2005) were used to map burn severity and guide the location of monitoring sites. We confirmed that 1) the dNBR derived BARC map is more likely to capture fire effects on tree crowns than on the ground, and 2) that the burn severity map correctly classified ~80% of our field plots.

Numerous presentations, field trips, Burned Area Emergency Response (BAER) trainings and manuscripts are providing much-needed information about the effectiveness of pre-fire fuels and post-fire rehabilitation treatments to mitigate fire effects and weed response and will help managers make better post-fire forest management decisions in the future.

II. Background and Purpose

Wildland managers and Burned Area Emergency Response (BAER) teams need more information on the implications of pre- and post-fire management and no-management options to mitigate critical issues such as fire hazard, spread of invasive species, and erosion and sedimentation. Little information exists on the efficacy of post-fire treatments, such as seeding, salvage, and post-fire rehabilitation treatments for native and non-native plant response (Beyers 2004). Non-native plant species may increase following reduction in tree canopy cover and density and burning associated with fuels treatments as well as wildfires (Crawford et al. 2001; Wienk et al. 2004). Replacement of native plant communities with invasive species may increase fuel flammability and alter fire regimes (D'Antonio and Vitousek 1992). In the Selway-Bitterroot Wilderness in Idaho and Montana, spotted knapweed frequently becomes the dominant plant after fires. In the BLM Sand Butte and adjoining Wilderness Study Areas in Idaho, an area burned twice by wildfire in one decade has resulted in a 24,000 ha area that now has significant rush skeletonweed infestations. The efficacy of post-fire rehabilitation treatments needs to be determined. Some seed mixes contain annual grasses to provide quick cover; however, when non-native species persist, recovery rates and diversity of native flora may be reduced (Robichaud et al. 2000). Kruse et al. (2004) found little evidence that mulching or mulching plus seeding facilitated recovery of native plant community as evidenced by higher non-native species occurrence compared with untreated areas following wildfire in California. Clearly, more monitoring is needed to better understand the direct and secondary effects of treating burned areas following fire (Beyers 2004).

An important result of wildfires is the reduction of organic matter pools in woody debris, forest floor detritus, and possibly surface mineral soil, which are essential for maintaining ecosystem function and forest productivity (Powers et al. 1998). Fire and subsequent amelioration techniques such as mulching also affect organic matter decomposition rates through changes in soil temperature, moisture, nutrients, pH, and the quality and quantity of plant residues, which should be considered when evaluating any major site disturbance (Harvey et al. 1994; Grigal and Vance 2000). Many studies have investigated the effects of fire on soil organic matter after timber harvesting (e.g., Johnson and Curtis 2001). Organic matter loss can affect soil erosion, nutrient supply, and long-term forest productivity (Jurgensen et al. 2006; Grigal and Vance 2000; Neary et al. 1999). In contrast, comparably less is known on the impact of straw mulch, wood straw and hydromulch applications after fire on soil biological processes and organic matter decomposition (Marshall 2000).

Several studies have reported on the effectiveness of post-fire mitigation treatments to reduce erosion (Robichaud et al. 2000; Robichaud 2005; Robichaud et al. 2009; Cerda and Robichaud 2009); however, monitoring is necessary to understand the longer-term impacts on soil and vegetation response of these well-intended treatments. Previous work found that ground cover treatments (e.g., straw mulch) were more effective than barrier-type treatments (contour-felled logs) at reducing erosion Robichaud et al. 2009). However the greater the rainfall intensity the less effective any treatment will be at reducing erosion. Work in Colorado on the Hayman Fire indicates that some BAER treatments have long-term soil effects. For instance, straw mulch seems to last longer on plots once vegetation becomes established. This longevity affects decay rate (faster decay at the surface where fine roots are active). Preliminary information indicates that relatively expensive hydromulch (on steep, erodable surfaces) does not last long and affects belowground processes much the same way as no mulch treatments. Additional treatment monitoring is necessary to determine the longer-term implications for weed and subsequent vegetation dynamics.

III. Study Description and Location

Study Site

The School Fire burned within ~21,000 ha of mixed ownership forest and grassland ~13-26 km south of Pomeroy, Washington. Much of this mountainous area contains high plateaus, deeply cut by an intricate system of steep-walled, rim-rock canyons. This fire burned rapidly due to extremely dry fuels, high temperatures and strong winds in rugged terrain. The fire pushed up drainages on multiple fronts and long-range spotting was observed up to a 1 km from the main fire. Fifty-six percent of the burned area was under federal management. Of that, 83% was classed as ponderosa pine or mixed-conifer forest before the fire. Of this forested area, 37% had been harvested or partially cut before the School Fire. An additional 10% of the burned area had received fuels treatments in the form of mechanical thinning and/or prescribed fire. Noxious weed populations were concentrated along roadsides on ~300 ha throughout the burned area.

The study area spanned mixed-conifer forest dominated by Douglas-fir (*Pseudotsuga menziesii*) and lodgepole pine (*Pinus contorta*) on ridges and plateaus to the more xeric, low elevation ponderosa pine (*Pinus ponderosa*) at the Tucannon River bottom. Major understory shrubs species included Scouler willow (*Salix scouleriana),* spiraea (*Spiraea betulifolia)*, snowberry (*Symphoricarpos albus)*, huckleberry (*Vaccinium membranaceum)*, and currant (*Ribes)* species. Primary forb species included heart-leaf arnica (*Arnica cordifolia)*, chickweed (*Stellaria)* species, fireweed (*Epilobium angustifolium)*, Piper's anemone (*Anemone piperi)*, and yarrow (*Achillea millefolium)*. Soil conditions also vary dramatically with topography. Slopes greater than 55 % tend towards more shallow soils, increasing in stability and depth towards ridgetop plateaus. Soils were generally moderate in texture, but were increasingly variable with increasing slope. Soils are composed of basaltic base layers, overlain by loess deposits and volcanic ash (Bassett et al. 2002, USDA 2006).

Climate patterns highly influence overall vegetation composition, but yearly weather variations and patterns often dictate the seasonal differences in the growing season and subsequently, the vegetation found on each site during sampling. Weather observations were gathered from two SNOTEL sites located in close proximity to the study area (Alder Ridge N46.27, W-117.54 and

Spruce Springs N46.18, W-117.54). Vegetation sampling generally began the second week of June, unless weather conditions dictated a later start date, and lasted into the first week of July. Temperatures were relatively consistent throughout all four years of sampling, 2006-2009. Precipitation was high in 2006, including a slow-melting deep snowpack and several low-intensity rainstorms. In 2007, less precipitation fell than in other years, and snow melted completely by May. In 2008, a late season snowstorm delayed sampling until the second week of July.

Data Collection and Sampling

Rapid response of scientific personnel allowed for preliminary plot selection and initial assessment of burn severity and vegetation response immediately after the fire. With funding from JFSP, additional plots were sampled in 2006. Seventy-nine, randomly selected, permanent plots were stratified by burn severity (low, moderate, and high) and pre-burn tree density classes (low, moderate, and high). Sampling sites were at least 50 m from roads as measured perpendicular to the slope direction. Where possible, sampling was replicated across the range of pre- and post-fire conditions with more plots in areas burned with moderate and low burn severity because our experience is that vegetation response is more variable there (Lentile et al. 2007).

Burn severity was initially assessed using a Burned Area Response Classification (BARC) map produced by the Remote Sensing Applications Center (RSAC). Pre- and post-fire Landsat 5 (TM) images (24 July 2005 and 25 Aug 2005) were utilized to calculate the delta Normalized Burn Ratio (dNBR) for burn severity comparisons. Burn severity classes inferred from satellite imagery calculations were ground validated using CBI (Composite Burn Index) during the first two years of sampling (Key and Benson 2006). We confirmed that 1) the dNBR derived BARC map is more likely to capture fire effects on tree crowns than on the ground, and 2) that the burn severity map correctly classified ~80% of our field plots.

Half of the plots in each burn severity category (low, moderate, and high) were placed in locations where post-fire salvage logging was planned. Sample plots were also randomly located on a subset of high severity sites that were seeded with native grasses following the fire. The Umatilla National Forest (UNF) has a long-standing policy of collecting grass seed for local farmers to grow; this seed is often used by UNF personnel in disturbed areas to lessen erosion, limit establishment and spread of invasive plant species, and to accelerate vegetation regrowth following fire, logging, or other disturbance. After the School Fire, native grasses, including Idaho fescue (*Festuca idahoensis),* Sandberg's bluegrass (*Poa secunda),* mountain brome (*Bromus carinatus),* and basin wildrye (*Elymus glaucus*), were seeded on approximately 1700 ha burned with high and moderate severity.

The majority of the study sites that had salvage harvesting were treated the winter of 2006-2007 (71% of all salvaged plots). Of the remaining salvaged plots, 14% occurred between 2005-2006, 9% in 2007-2008, and 5% occurred between 2008 and 2009 growing seasons. Litigation and weather conditions influenced whether plots were salvaged or not and the timing of the salvage. Extending salvage logging over a four-year timeframe created difficulty in inferring definitive changes in vegetation response as a result of salvage.

Five additional high burn severity sites were selected with similar slope and pre-fire tree density characteristics to provide replicate conditions to analyze five post-fire BAER treatments (seeding, hydromulch, wheat straw, wood straw, and a control; 105 plots total). Seeding occurred on each of the treated sites with the exception of the control sites prior to the mulch or straw application. Each BAER treatment was applied aerially via helicopter sling loads. Due to critical factors such as the surface area and moisture content of the treatment and velocity of the helicopter during dispersal, even and consistent wheat straw mulch, wood straw mulch and hydromulch applications were nearly impossible. Thus wheat straw and wood straw mulches were often clumped with some areas having complete cover with deep mulch, while other areas had limited or no coverage.

Seven silt fences were systematically positioned within each of the five sites to collect sediment and debris runoff as part of an ongoing analysis of BAER treatment effectiveness. Silt fences ranged in size from 155 – 285 m^2, with slopes ranging from 51 – 70 %. Each silt fence contained three fixed 1x1-m subplots placed in the upper, middle and lower third of the drainage area. General vegetation and ground cover assessments were made on these subplots twice during the growing season. Plant species were also identified and ocular estimates of percent canopy cover by species were recorded (following the protocol established on all of our monitoring sites as described in detail below).

On all plots, site-specific information was collected including slope, aspect, slope position (top, mid, or bottom), distance from nearest road, and plant association. The size and condition of snags and trees (>12.7 cm dbh), tree seedlings (<2.5 cm dbh), and saplings (2.5-12.7 cm dbh) within an 8-m radius of each site center was collected annually. Each plot consisted of five subplots located perpendicular to each other and arranged so that subplot B is located directly upslope. A 1x1 meter plot frame was positioned to identify subplot boundaries. All plant species present in the 1x1-m subplots were identified and a percent canopy cover was ocularly estimated and recorded for each species (grass, forb, shrub, seedling, and moss/lichen). Any vegetation hanging into the plot less than 1-m high was considered part of the plot vegetation. Percent tree canopy cover was estimated by densiometer readings made in each of the four cardinal directions at each subplot. A photo was taken to characterize ground cover and vegetation conditions. Litter and duff depth measurements were recorded in three random positions within the subplot and averaged. All plant species identifications were verified in the Stillinger Herbarium at the University of Idaho; when plants could not be identified they were designated and numbered as unknowns for identification at a later time.

Project objectives

1) Assess immediate post-fire effects on soil and vegetation across the range of pre-fire conditions (including untreated areas and those areas treated mechanically) and the observed range of burn severities.

2) Evaluate the effects of post-fire treatments (wheat straw, native seed, hydromulch with mycorrhizal inoculant, and wood straw mulch; all mulching treatments were also seeded) on belowground soil physical, chemical, and biological properties, vegetation recovery and invasive weed suppression as compared with the no-action treatment in severely burned areas.

3) Monitor soil and vegetation recovery, with particular emphasis on the interaction of non-native invasive species and burn severity, in treated and untreated areas. When possible incorporate post-fire salvage operations in the stratification of post-fire treatment effects.

4) Identify quantitative indicators of burn severity, including both overstory and soil surface effects, from field and remote (Landsat) post-fire measurements.

IV. Key Findings

1) Objective: Assess immediate and monitor longer term (2006-2009) effects of fire, seeding native grasses, and post-fire tree salvage harvest on soil and vegetation.

- Total plant cover was lowest immediately after the fire but increased over time on all plots, but response varied with burn severity. During the first growing season, the increase in plant cover from the start of sampling in early June to the end of July was significant enough to warrant resampling many of the plots. This was largely due to the high amount of precipitation in spring and summer 2006. Total plant cover was highest on low burn severity sites, but the difference between plant cover on low and high burn severity sites decreased over time. Our study concurs with others that three to five years are needed for plants, which may employ a variety of regeneration and establishment strategies, to regrow or establish following large wildfires, and that vegetation often regrows in abundance with species composition affected by burn severity.
- Plant species diversity was significantly higher on low and moderate burn severity sites. Forbs had the highest cover on all plots (except those seeded with native grasses) over all years. Shrub cover increased with time, especially on high severity sites. On all unseeded sites, grass and tree seedling cover remained negligible over time.
- High severity burn areas contained more non-native plant species than areas burned less severely. However non-native plant species occurred in less than 20% of high burn severity plots with a maximum percent canopy cover of 2%. Non-native plant species were absent in unburned plots. Post-fire seeding and salvage logging affected plant species response to fire in all burn severity categories. The most noticeable effects occurred on sites burned at high severity, which are also the sites most likely to be seeded and salvaged.
- Vegetation responded more rapidly in plots that did not receive post-fire salvage tree harvest. Over time, vegetation on salvaged sites is approaching that of the unsalvaged sites in terms of total cover and species diversity. Grass cover did not appear to be negatively affected by salvage tree harvest.
- Native grass seeding as a restoration treatment almost exclusively occurred on severely burned sites. It was only on these seeded sites where grass cover was high. We found up to 80% grass cover on seeded sites in the first two years post-fire. Seeding was very successful, likely due to rains of 2006, and seeding with locally adapted species. Dominance by grasses began to decrease after two years. Other plant forms (forbs, shrubs, and tree seedlings) were able to establish and persist on these sites with high species richness, but they were generally less abundant on sites that had been seeded. Furthermore, grasses appear to be resilient to the impacts of multiple disturbances, as they were found to be abundant on salvaged sites.

2) **Objective: Evaluate each of the four BAER treatments (seeding, hydromulch, wheat straw mulch, wood straw mulch, and control; all high severity sites; all mulching treatments were also seeded) over a four year sampling period 2006-2009 to identify and understand how each treatment affected 1) species richness and Shannon-Wiener diversity measures, and 2) plant response by growth form and regeneration strategy.**

- BAER treatments affected both species richness and diversity, but not uniformly across all treated sites.
- Hydromulch had higher species richness and diversity, with high coverage of grasses, forbs, and shrubs. Hydromulch decomposed rapidly with no residual treatment found two years post-fire, similar to seeded sites.
- Seeding-only treatments had very high cover of grasses and low forbs and shrubs compared to the other treatments and to the control. Species richness was low, presumably due to the high grass cover. Although seeding was done with a locally adapted seed source, seeding decreased the rate of vegetation response post-fire and this will likely have long-term consequences because grass species are very competitive on these sites. Species diversity values were higher on seeded-only sites than other treatments in all years, especially in 2009, when species diversity was higher on seeded-only sites than on all other treatments, except hydromulch.
- Species richness for wheat straw was consistently higher than most treatments throughout all years. Canopy cover of forbs and shrubs were also highest in wheat straw treatments, largely due to survival of these plant types via rhizomes and as residual colonizers. Surprisingly, offsite colonizers generally had low representation in wheat straw treatments, although non-native species and off-site seeds are often transported to rehabilitation sites unintentionally from wheat straw treatments (Beyers 2004).
- The uneven distribution of wood straw treatments resulted in clumps, which likely contributed to the low canopy cover of grass and forbs. Species richness was generally low, especially in the first two years post-fire, for all treatments, but species diversity was the lowest in wood straw treatments, indicating that all types of plants had difficulty establishing and increasing in cover here. Seeds that survived in the seedbank were better able to establish and persist post-fire in the wood straw treatments than plants resprouting from rhizomes, bulbs or other belowground surviving structures.
- Very few, if any, non-native species were introduced via BAER treatments. Only nine non-native species occurred on our plots and all of them with low relative abundance, indicating that the high species richness on seeded sites was not a result of introduced non-native plant species.
- The only two non-native plant species that were common throughout the burned area and produced any discernable percent canopy cover were prickly lettuce (*Lactuca serriola*) and white clover (*Trifolium repens*).
- Offsite colonizers were more common in all treatments than on the control sites, indicating that seeds may have been in the treatment mixes, but not necessarily non-native seeds.
- Vegetation recovered rapidly on all treatments and control following the first growing season post-fire. Plant cover on BAER treatments sites, particularly on seeded and hydromulch sites, often exceeded that of control sites. Grass species will likely continue

to dominate those sites for many years into the future, especially because all seeded grasses were perennial species that will establish extensive below-ground root and rhizome systems. All of these sites were seeded with native grasses prior to BAER treatments, and the seeding was very successful.

- By two years post-fire, total live vegetation cover was well over the 30-50% threshold necessary for protecting the soil surface (Robichaud et al. 2000). There was almost no sediment movement on any of these treatments or control, but there were also no intense rainstorms recorded onsite. Given a large precipitation event, understanding the response of vegetation regeneration in terms of each treatment would likely have been very different, as many treatments may have been washed away or blown off-site, affecting the ways and in what locations vegetation could respond. Large, intense precipitation events that further disturb burned areas could likely negatively impact the susceptibility of a site to invasion by non-native plant species.
- Long-term trajectories are likely to be different by treatment. After four years post-fire, both wood straw and wheat straw mulches were still visible on-site, whereas the hydromulch and seeded treatments were not visible one growing season post-fire. Average total vegetation canopy cover ranged from 7-23% during the first year post-fire, while treatment cover ranged from 0 to approximately 60% of total ground cover (wood 54%; wheat straw 57%; hydromulch 56%). Four years post-fire, both the wood and straw mulch was still present (wood 10% ground cover; wheat straw 3% ground cover).

3) Objective: Evaluate the effects of post-fire treatments (wheat straw mulch, native seed, hydromulch with mycorrhizal inoculant, and wood straw) on belowground soil physical, chemical, and biological properties on severely burned sites.

- We installed 75 plots (15 transects per treatment, including control) to monitor local microclimatic changes in decomposition rates and changes in soil organic matter, C, N, and pH across the range of post-fire mulching treatments. Wood stakes were placed in each mulch treatment to determine changes in biological activity and belowground response.
- These data so far show no evidence of reduced nitrogen availability or restricted microbial activity in the mulch plots compared to the control plot. Both the wood straw and wheat straw mulch treatments appeared to increase soil moisture compared to the control plots, as reflected by the stake moisture data. However, differences between the two types of mulch are more difficult to discern.
- Stake respiration rates were related to stake moisture content, but there were higher stake respiration rates in the wood straw than in the wheat straw plots for the same levels of stake moisture.
- A plausible effect of the mulch is to maintain wetter soil conditions, promoting growth of microorganisms in the stakes which would in turn decrease the C:N ratio and increase stake respiration rates as decomposition proceeds. Based on our limited analysis of six wood stakes, there was no clear trend in stake C:N by plot.
- Our results hint that competition for soil nitrate between microorganisms and plants was reduced in the wood straw plots compared to the wheat straw and untreated plots. We

wish to investigate this more thoroughly with replicated, controlled experiments in post-fire environments.

4) **Objective: Identify quantitative indicators of burn severity and explore other types of remote sensing applications**

- The USFS Remote Sensing Applications Center (RSAC) provides satellite imagery analysis for managing and monitoring wildfires. RSAC produced a BARC map for the School Fire using the delta Normalized Burn Ratio (dNBR), based upon comparison of Multitemporal Landsat images aquired24 July 2005 and 25 Aug 2005. We used this dNBR image to guide the location of monitoring sites.
- We confirmed that 1) the dNBR derived BARC map is more likely to capture fire effects on tree crowns than on the ground, and 2) that the burn severity map correctly classified ~80% of our field plots.
- We also analyzed the utility of high spatial resolution (2.4 m (~8 ft) pixels) Quickbird imagery (one post-fire: 20 and 25 June 2007) to map and detect the spread of invasive species in 40 vegetation patches.
- Quickbird imagery seemed to be a promising solution for mapping invasive species because of the high spatial resolution and the ability to image a large area (both the low elevation Tucannon River (~500 m) and the higher elevation forested area (~1200 m) at the same time.
- A few of the largest and most spectrally distinct patches of soil and straw mulch were detectable in the imagery, but most of the vegetation patches (invasives) were not truly homogenous or large enough (patch sizes were ~10m^2, whereas they should have been ~40m^2) for remote detection. Differences in plant phenology across the elevation range in our study site also challenged imagery interpretation.
- The few invasive weed patches we found were much too small to possibly map using 30m Landsat. Therefore, we tested the utility of Quickbird imagery (obtained through Umatilla National Forest funding) for mapping these patches. However, we were unsuccessful given that the invasive weed patches were so small and diffuse. This doesn't mean that there isn't potential to map invasive weeds using Quickbird or Landsat where large patches of invasive weeds exist, but the invasive weeds problem simply didn't materialize as expected when we wrote the proposal.

V. Management Implications

Weeds pose a serious ecological and economic threat to many western lands and results from this study will assist managers in strategizing where and how this threat can be mitigated. Many federal managers across the West need more information about the effects of multiple disturbances and particular post-fire rehabilitation treatments to reduce the impact of weeds, thus our findings on the vegetation response to burn severity and to post-fire seeding, rehabilitation, and salvage will be of interest to many.

We worked with BAER teams and UNF resource managers to design this study around their questions and data needs and results have been shared with local managers and BAER teams via annual reports and more than eight workshop/field trips. We expect three peer-reviewed publications to be available in the near future.

These products and results combined with other ongoing monitoring efforts provide the needed information about the effectiveness of pre-fire fuels and post-fire rehabilitation treatments to mitigate fire effects and weed response and are helping managers make science-based decisions.

We observed rapid vegetation response post-fire. Burn severity, year and their interaction were statistically significant influences on percent canopy cover of plants in the four years following the 2005 School Fire. Seeding with locally adapted native grasses was so successful (in part because of rainfall in 2006) post-fire that other plants were reduced in abundance though not in species richness. In general, plant cover was less on high severity than on sites burned with low or moderate burn severity. On some very steep slopes burned with high severity, managers implemented seeding and mulching treatments as part of BAER treatments. Wood straw and wheat straw mulch was still present four years post-fire, and this affected vegetation response. Few non-native species were present in any plots, and they were seldom abundant.

VI. Relationship to other findings and ongoing work on this topic

This JFSP project has very strong support and interest from local managers on the Umatilla National Forest, and from BAER teams and other fire and natural resource professionals west-wide. The Umatilla National Forest has provided extensive financial and logistical support for this project. They realized that this project provides a unique opportunity since it was the largest native plant seeding project to date within the Forest Service and that invasive species are a major issue on their Forest and in the West. When the Forest recently received money from litigation related to the fire, they provided funding to us for two years of field work (summer 2010 and summer 2011) and additional QuickBird images, data analysis and write up. They provided $120,000 for this additional work. With this additional funding and year of field sampling we will continue to provide needed information about the effects of multiple disturbances and post-fire rehabilitation treatments on soil and vegetation response:

- **Salvage logging was not a primary focus in our original School Fire proposal; however, we did hope to evaluate the effects of salvage logging relative to other post-fire treatments (see objective 1 above).** The School Fire is an ideal site for such a study, in part because we have many plots on which we measured vegetation abundance and soil infiltration rates post-fire and pre-salvage and we are now monitoring post-salvage. Thus we are able to contrast these with vegetation abundance and soil infiltration rates on sites burned but not salvaged. As we stated above, the salvage logging was delayed at least 12 months due to environmental concerns and legal issues. This 12-month (or greater) delay means that most of our observations and analyses regarding the effects of salvage logging on invasive species and vegetation response are based on only one or two years of data. One more year of field sampling will help to provide more conclusive results; we have funding from the Umatilla National Forest to monitor our plots in 2011.

- **The QuickBird imagery that was acquired one and four years post-fire will be used to help assess the effects of salvage logging on soil disturbance and vegetation recovery.** Preliminary results suggest that increased soil exposure is detectable with

QuickBird imagery. These methods will be applied in another post-fire salvage area (JFSP 06-3-4-21).

- **The post-fire effects data we collected were based on findings from a previous rapid response research project (JFSP 03-2-1-02).** The main goals of that project were to identify quantitative indicators of burn severity that could be rapidly assessed on the ground and mapped remotely, and to explore alternative remote sensing tools (Quickbird) to Landsat-derived NBR and dNBR indices. Our data from the School Fire will be added to the existing database of nine wildfires and will be used to build upon previous conclusions.

- **The spectral data we collected will be added to an online spectral library that was started by research project (JFSP 03-2-1-02).** These data are available on FRAMES (www.frames.nbii.gov) (JFSP 03-4-1-02).

- **The BAER treatments that were applied for erosion mitigation are being tested for effectiveness by our colleagues (JFSP 03-2-3-22).** Thus far, little erosion has been measured on these sites, greatly due to the absence of high-intensity rain events. Five years after the fire, these plots have high vegetation cover, and resemble their less-severely burned counterparts. However, based on other BAER treatment monitoring sites, five years is too soon to assume a site is "recovered". These plots will remain in place and monitoring will continue in the event that a large precipitation event occurs. We will also continue to monitor the vegetation response to the BAER treatments on these plots.

- **Wood stakes were placed in each mulch treatment to determine changes in biological activity and belowground response.** Local microclimatic changes in decomposition rates and changes in soil organic matter, C, N, and pH are being measured across the range of post-fire mulching treatments for the next several years. These data will help to define any chemical and biological changes in the soil due to the mulch treatments that may affect vegetation response.

- **Our efforts in assessing burn severity on the ground and from satellite imagery have informed new research** to develop a fire severity mapping system (JFSP 09-1-07), an analysis of burn severity relative to climate and topography funded by the Rocky Mountain Research Station (Heyerdahl, Luce, and others are lead PIs), and assessment of fuel treatment effectiveness (Hudak et al. *in review*).

VII. Future Work Needed

As we originally proposed, we have completed four years (three years funded by JFSP and one year extension) of monitoring the effects of burn severity and post-fire rehabilitation (native seeding and mulching) on native vegetation and invasive plants. We have drawn significant conclusions, but the inferences we have made about vegetation response to burn severity, prior fuels management, and post-fire treatments have the potential to be much stronger and more scientifically defensible if we are able to devise a long-term monitoring plan for these sites. The ability to draw meaningful conclusions regarding native and invasive vegetation response to salvage logging and post-fire rehabilitation treatments is important because the effects of these treatments on soil and native vegetation response and the spread of invasive species are not well documented or understood. Additional data would also help to clarify the influence of pre- and post-fire management on this vegetation response. We are grateful that the Umatilla National Forest has provided significant funding and logistical support for this project and for ongoing monitoring.

- **In our interactions with BAER teams and Umatilla National Forest managers, students and the public since this study plan was initiated, we have received more questions regarding vegetation response to the mulch treatments than any other aspect of this project.** The different mulch and seeding treatments were applied with the intent of reducing erosion on steep, severely burned hillslopes; however, the apparent effect of these treatments on the vegetation recovery was not anticipated. Post-fire seeding and mulching treatments cost the Umatilla NF ~$370,000. Managers need data to help them compare the ecological and economic impacts of pre- and post-fire management and no-management options on fire effects and soil and vegetation recovery.

  The apparent effects of the BAER treatments on the vegetation recovery provided us with an opportunistic research question. Each treatment was only applied to a single hillslope; therefore all samples within the treatment are pseudoreplicated. This limits our ability to make sound statistical inferences. Based on the interest received from the forest management and BAER community, and the importance of understanding the effect of mulch treatments on vegetation response, we feel this is an ideal research question for a future fire. We are looking for opportunities to implement replicated experiment(s) that will be designed to help us understand the carbon and nitrogen dynamics in plants and soils as affected by addition of wood straw, wheat straw and other mulch treatments, and to use this to help explain the differences in plant responses observed.

- **The Umatilla NF purchased two QuickBird remote sensing images to supplement our JFSP project to support our evaluation of this potential tool for mapping the spread of invasive species.** The invasive species we were tasked with monitoring after the School Fire were those that were present in the disturbed (heavily grazed and recreated) areas of Tucannon River canyon. Umatilla National Forest managers were concerned about the proximity of the known weed populations to adjacent forested areas that were newly disturbed by the fire, and that would be disturbed again by the salvage logging operation. Areas of high burn severity and newly salvaged areas with little remaining vegetation and extensive exposed mineral soils were potentially at risk of weed invasion. We were tasked with identifying new infestations within the forest boundary and mapping and monitoring the extent of weed spread.

  Remote sensing seemed to be a promising solution for mapping and monitoring the weeds because of the ability to image a large area (both the low elevation Tucannon River (500 m or 1800 ft) and the higher elevation forested area (1200 m or 4100 ft) at the same time. Over the course of the 4 summers of field sampling however, we found non-native species on less than 20% of our high severity plots with a maximum of 2% plot cover. This was good news for forest managers concerned with weed infestation after the fire, but ‘bad’ news for a remote sensing analysis. Ultimately, we were unable to identify any specific vegetation species within the remotely sensed imagery because patches were too small or intermixed with other vegetation. The ability to identify specific, in this case, invasive plant phenological signatures was critical to this part of the project. In retrospect, our objectives for the remote detection/monitoring portion of our project were too broad. A single image was unable to capture ideal conditions for the multiple weed species we were interested in, and the dichotomy of elevation within the area of the School Fire only made this issue worse. In the future, multiple species detection may require different imagery such as hyperspectral imagery in order to have a realistic chance of invasive species detection.

- **Comparison of results between this project and related rapid response projects funded by JFSP remains preliminary, but we are beginning to yield useful insights into the interactions between pre-fire conditions and post-fire effects.** We recommend further strengthening cooperative relationships between research and forest management personnel, similar to the relationship we have developed with the Umatilla National Forest. Management-supported research will in turn improve our understanding of the effect of pre-and post-fire treatments on vegetation and soil recovery after fires.

VIII. Deliverables

All proposed products are complete, unless stated otherwise as ***in review*** or ***in prep*** at the end of the citation.

Proposed	**Delivered/status**
Annual progress reports	• Progress reports were completed each year from 2006 through 2009
RJVA	• Annual reports for RJVA between USDA Forest Service and University of Idaho.
Final JFSP project report	• Final report Invasive Species Response to Fire and Post-fire Rehabilitation Following the 2005 School Fire, Umatilla National Forest:A Rapid Response Proposal 06-1-2-03
Data Collection	
We proposed to collect fire effects and plant species inventory data across the range of pre-fire conditions and post-fire rehabilitation treatments for three years post-fire. With a one-year extension, we were able to collect post-fire data for four years.	• We installed 12 study sites immediately after the fire in 2005 and collected preliminary data to characterize the immediate effects of the fire on tree canopies, forest floor and soil across the range of burn severities. These sites were eventually incorporated into the full sampling plan. • We installed 84 study sites across the range of pre- and post-fire conditions to monitor soil and vegetation recovery on the School Fire during April-August 2006. Along with post-fire effects data, we collected Composite Burn Index (CBI) measurements to validate our field site burn severity classifications.

	• We re-sampled 84 study sites in June, July, and August 2007. 1/3 were salvage harvest, 1/3 natural recovery, and 1/3 treated for erosion mitigation. • We re-sampled 84 study sites in June and July 2008. 1/3 were salvage harvest, 1/3 natural recovery, and 1/3 treated for erosion mitigation. • We re-sampled 84 study sites in June 2009. 1/3 were salvage harvest, 1/3 natural recovery, and 1/3 treated for erosion mitigation.
We proposed to collect Landsat and QuickBird remotely sensed imagery to compare these products for mapping burn severity and to investigate the utility of detecting and monitoring the spread of invasive species.	• We obtained two Landsat images: pre-fire (24 July 2005) and post-fire (25 August 2005). • We obtained one-year (2006) and four-year (2009) post-fire QuickBird images. • We collected spatial and spectral data for ~40 patches of native and non-native vegetation species.
Manager's Workshops We proposed to conduct two two-part (office and field) forest-wide meetings with coordinating field trips to our monitoring sites on the Umatilla National Forest. We planned these field trips after our first and third years of field work to present preliminary results to forest managers, interested public, and college students.	**2006:** • We participated in a fieldtrip on May 18th with managers from the Umatilla National Forest (Pomeroy Ranger District and Supervisor's Office, OR), to discuss project objectives and to identify research questions, protocols, and research sites. • We coordinated with Umatilla NF managers to conduct a field trip on September 30th to the School Fire for the FOR 426 Fire Ecology and Management course taught to juniors and seniors in the Department of Forest Resources, University of Idaho. • **Presentation and Field Trip:** School Fire Case Study, FOR 426 Fire Ecology and Management, University of Idaho, October. 34 undergraduate students. **2007:** • **Presentation:** We met with managers (including the District

During three field seasons, we gave three in-office presentations and led eight field trips. Sites visited included our field plots, sites treated for erosion mitigation, native seeding sites, and salvage logging sites. Attendees included local, state, and federal land managers; public groups; and college and high school students.	Ranger, Soil Scientist, Silviculturist, Vegetation and Weed Specialists) and presented project findings and preliminary results at the Pomeroy Ranger District, Pomeroy, WA on January 28th. • **Presentation:** We met with managers (including the Forest Supervisor, Soil Scientist, Silviculturist, Vegetation and Weed Specialists) and presented project findings and preliminary results at the Umatilla National Forest, Supervisor's Office in Pendleton, WA on January 29th. • We led a **field trip** to the School Fire field sites on June 26th. Participants included Umatilla National Forest managers, the Pomeroy District Ranger, and members of the Washington State Resource Advisory Committee. We presented a poster with preliminary results. • We led a **field trip and presented** results to the ID Native Plant (White Pine Chapter) and WA Native Plant Societies (Columbia Basin Chapter) on July 7th. We presented a poster with preliminary results. • "Monitoring Protocols and Results from School Fire Project" **presented** in Fire Ecology and Management course taught at the University of the South, Sewanee, TN (March 22-25; 25 undergraduate students). • **Field trip and presentation: S**chool Fire Case Study to FOR 426 Fire Ecology and Management, University of Idaho, October. 36 undergraduate students). • **Poster:** Robichaud PR, Lewis SA, Morgan P, Lentile LB, Hudak AT. (2007) 2005 School Fire, Umatilla National Forest, Soil and Vegetation Recovery Assessment. **2008:** • **Presentation:** We presented project findings and preliminary results at the Pomeroy District. Participants included Umatilla National Forest managers, the Pomeroy District Ranger, a member of the JFSP governing board, and two University of Idaho students on July 7th. • We led a **field trip** (including the same previously mentioned participants on July 7th) to field sites treated with native seed, sites that had been salvage logged, and silt fences measuring

	the effectiveness of mulch treatments to reduce erosion. • **Presentation and Field Trip:** School Fire Case Study, FOR 426 Fire Ecology and Management, University of Idaho, October. 39 students. **2009:** • We led a **field trip** for Umatilla NF personnel, Regional and WO staffers on July 9th. We presented a poster with our latest results. • We led a **field trip** for a Washington State Department of Ecology team interested in watershed recovery on the School Fire on July 23rd. We presented a poster with our latest results. • We led a **field trip** with Youth Conservation Corps (YCC) students interested in careers in forestry on August 23rd. We presented a poster with our latest results. • **Poster:** Lewis SA, Lentile LB, Morgan P, Robichaud PR, Hudak AT, Moy MM. (2009) Assessing soil and vegetation recovery following the 2005 School Fire - 4 years post-fire. Presented at three field trips. • **Presentation and Field Trip:** School Fire Case Study, FOR 426 Fire Ecology and Management (28 students) and FOR 526 Fire Ecology (10 students), University of Idaho, October 2009.
Technical Transfer Notes to the Umatilla National Forest Detailed methodologies, results, and conclusions will be e-mailed to Umatilla National Forest managers and were available on request. Approximately 100 people received these annual updates.	• We produced a two-page synopsis of project findings after the 2006 field season. We distributed hard copies at 2 regional meetings and 3 fieldtrips. An electronic version was made available for distribution. • We contributed to an online JFSP First Look article in January 2007: Where are the Weeds? Monitoring Weed Response Following the 2005 School Fire, Umatilla National Forest, WA. • We updated a two-page synopsis of project findings after the 2007 field season. We distributed hard copies at our annual

	field trip, and the update was also linked on the Idaho Native Plant Society White Pine Chapter's website: www.whitepineinps.org • We updated a two-page synopsis of project findings after the 2008 field season. Electronic copies were distributed to the Pomeroy Ranger District and the Umatilla National Forest Supervisor's Office. • Our annual updates are posted on the FRAMES (www.frames.nbii.gov) (**JFSP 03-4-1-02**) and "Causes, Consequences and Spatial Variability of Burn Severity" (**JFSP 03-2-1-02**), (www.cnrhome.uidaho.edu/burnseverity) websites.
Technology transfer at Meetings and Trainings We were invited to present our research and results at four native plant and invasive species meetings. We provided recommendations and insights based on our latest results. There was tremendous interest in our project from many people who recreate in the area. We presented results, solicited feedback, and provided recommendations at ten national and regional BAER and Technical	• Morgan PM, Lentile LB, Lewis SA, Robichaud PR, Hudak AT. (2007) Post-fire Expectations for Vegetation Regrowth and Possible Invasive Plants on the School Fire near Pomeroy, WA. Idaho Native Plant Society, White Pine Chapter monthly meeting, 25 January 2007, Moscow, ID. • Robichaud, PR. (2007) Review of postfire rehabilitation and seeding practices for the BLM. BLM National Advisory Committee Meeting, 29 January 2007, Boise, ID. • Robichaud, PR. (2007) Postfire erosion mitigation: tools, treatments and effectiveness. Region 6 Invasive Species and Management workshop, 29 October to 1 November 2007, Bonneville, OR. • Lewis SA, Hudak AT, Lentile LB, Morgan P, Robichaud PR, Moy M. (2010) Using Quickbird satellite imagery for post-wildfire management and research. RMRS Air, Water, and Aquatic Environments Science group videoconference, 19 January 2010, Moscow, ID. • Robichaud, PR. (2009) The latest on postfire treatment effectiveness. National BAER Coordinator's Meeting, 29 January to 1 February 2007, Spokane, WA. • Robichaud, PR. (2007) Latest findings on effectiveness of various post-fire rehabilitation treatments. Technical Fire

Fire Management meetings and trainings.	Management Meeting, 7-18 May 2007, Bothell, WA. • Robichaud, PR. (2007) Postfire Treatment Effectiveness. Region 1 and 6 Introduction to BAER Refresher Course, 13-15 June 2007, Missoula, MT. • Robichaud, PR. (2008) The right tool for the job: BAER research. Region 1, 4, and 6 BAER team leader training, 15 April 2008, Spokane, WA. • Wagenbrenner, JW, Robichaud, PR. (2008) BAER research: progress and plans. Region 2 BAER regional coordinators annual meeting, 12 February 2008, Golden, CO. • Robichaud, PR. (2009) BAER research: progress and plans. Regional and National BAER Coordinators Annual Meeting, 27-30 January 2009, Orlando, FL. • Robichaud, PR. (2009) Latest findings on effectiveness of various post-fire rehabilitation treatments. Department of Interior National Interagency BAER team pre-season meeting, 27 April to 1 May 2009, Boise, ID. • Robichaud, PR. (2009) Latest findings on effectiveness of various postfire rehabilitation treatments. Technical Fire Management Meeting, 14 May 2009, Bothell, WA. • Robichaud, PR. (2009) Postfire burn severity mapping. Technical Fire Management Meeting, 14 May 2009, Bothell, WA. • Robichaud, PR. (2009) Latest findings on effectiveness of various postfire rehabilitation treatments. FS Region 5 Soils Meeting: fire and effects on soils, 22 October 2009, Redding, CA. • Robichaud, PR. (2009) Field guide for mapping post-fire soil burn severity. FS Region 5 Soils Meeting: fire and effects on soils, 22 October 2009, Redding, CA. • Robichaud, PR. (2010) Treatment effectiveness monitoring. Annual Regional BAER Coordinator's Meeting, 1-5 February 2010, Albuquerque, NM. • We participated with (**JFSP 05-4-1-07**) in a panel discussion with six invited managers “Recommendations and Research

	Needs for the Mapping of Active Fire and Post-fire Effects". 11th Biennial USDA Forest Service RSAC, Salt Lake City, Utah, 24-28 April 2006.
We collaborated with RSAC and other working groups to synthesize and recommend methods for quantitative field measurement and remote sensing of burn severity and to widely share our results.	• Lentile LB, Smith AMS, Morgan P, Holden ZA, Falkowski MJ, Gessler PE, Lewis SA, Hudak AT, Robichaud PR. (2006) Panel discussion: challenges and recommendations for the mapping of fire and post-fire effects. RS2006, 24-28 April 2006, Salt Lake City, UT. • Our annual updates are posted on the FRAMES (www.frames.nbii.gov) (**JFSP 03-4-1-02**) and "Causes, Consequences and Spatial Variability of Burn Severity" (**JFSP 03-2-1-02**), (www.cnrhome.uidaho.edu/burnseverity) websites. • Full-text refereed publications are available on the Moscow RMRS website (http://forest.moscowfsl.wsu.edu/library/). All publications will become available as they are completed and accepted for journal publication. • Relevant publications are listed (and more will be added as they are completed) on the Monitoring Trends in Burn Severity website (http://mtbs.gov/scientificreferences.html).
National and Regional Meetings We proposed to present our research and results at two presentations at national conferences. Ultimately we presented seven oral paper presentations and two poster presentations at four national and two regional meetings.	• Miller I, Elliot W, Glaza B, Robichaud P. (2006) Using WEPP Technology to Assess the Distribution of Erosion Risk, Mitigation Benefit, and Peak Flow Following Wildfire. American Geophysical Union (AGU) fall meeting, 11-15 December 2006, San Francisco, CA. • Robichaud PR, Brown RE, Wagenbrenner J. (2007) Effectiveness of Post-fire Rehabilitation Treatments after the 2005 School Fire. Joint Conference of the Society for Ecological Restoration (Northwest Chapter) and Yakima Society of Wetland Scientists (Pacific Northwest Chapter), 25-28 September 2007, Yakima, WA. • Lewis SA, Lentile LB, Morgan P, Robichaud PR, Hudak AT (2007) Monitoring and Mapping Invasive Species Spread Using Remotely Sensed Imagery. Joint Conference of the Society for Ecological Restoration (Northwest Chapter) and Yakima Society of Wetland Scientists (Pacific Northwest

Chapter), 25-28 September 2007, Yakima, WA.

- Lewis SA, Lentile LB, Morgan P, Robichaud PR. (2008) Vegetation response to post-fire treatments. Association for Fire Ecology's Southwest Meeting, Fire in the Southwest: Integrating fire into management of changing ecosystems, 28-31 January 2008, Tucson, AZ.

- Robichaud, PR, Brown, B, Wagenbrenner, JW, Lewis SA. (2008) Effectiveness of post-fire erosion control treatments. Association for Fire Ecology's Fire in the Southwest regional meeting, 30 January 2008, Tucson, AZ.

- Lewis, SA, Lentile LB, Hudak AT, Robichaud PR, Morgan P. (2008) Using Quickbird and Landsat imagery to assess burn severity and monitor vegetation recovery. Remote Sensing Applications Center biennial meeting RS2008, 15-17 April 2008, Salt Lake City, UT.

- Robichaud PR, Lewis SA, Hudak AT, Parsons A, Clark J, Shovic H. (2008) Assessing post-fire burn severity: from lookouts to satellites, a review of technological advances. International Association of Wildland Fire meeting: The ’88 Fires: Yellowstone and Beyond program, 22-26 September 2008, Jackson Hole, WY.

- Lewis SA, Hudak AT, Lentile LB, Morgan P, Robichaud PR, Moy M. (2009) Using Quickbird satellite imagery for post-wildfire management and research. Association for Fire Ecology Fire Congress Meeting, 30 November to 4 December 2010, Savannah, GA.

- Moy M, Holthuijzen M, Morgan P, Lentile L, Lewis S, Robichaud P, Hudak A. (2009) Impacts of pre-fire site conditions, burn severity, and post-fire treatments on plant regeneration following the 2005 School Fire. 4th International Fire Ecology Congress, , 30 November to 4 December 2010, Savannah, GA.

Refereed Publications – two were promised in the original proposal and a third was added after a one-year extension was granted	
1. Pre-fire condition, fire effects, and post-fire response of invasive species	• Moy M, Morgan P, Lentile L, Hudak A, Lewis S, Robichaud P. (2010) Vegetation response influenced by pre-fire site conditions, burn severity, and post-fire seeding and salvage on the 2005 School Fire, Washington, USA. ***In preparation*** *for submission to Forest Ecology and Management, May 2010.* • Holthuijzen M, Morgan M, Moy M, Robichaud P, Hudak A, Lewis S. (2009) Native and non-native invasive plant response to burn severity two years after the 2005 School Fire in Pomeroy, WA. Ecology and conservation biology senior thesis, University of Idaho: Moscow, ID, 35 p. • Lentile L, Holthuijzen M, Morgan M, Moy M, Robichaud P, Hudak A, Lewis S. (2010) Native and non-native invasive plant response to burn severity four years after the 2005 School Fire in Pomeroy, WA. ***In preparation*** *for submission to refereed journal in summer/fall 2010.*
2. Post-fire treatments and invasive species spread	• Robichaud PR, Lewis SA, Brown RE, Ashmun LE. (2009) Emergency post-fire rehabilitation treatment effectiveness on burned area ecology and long term restoration. *Journal of Fire Ecology,* 5(1): 115-128. • Moy M, Morgan P, Lentile L, Hudak A, Lewis S, Robichaud P. (2010) Plant response to burned area emergency response (BAER) treatments following the School Fire, Washington, USA. ***In preparation*** *for submission to refereed journal in summer 2010.*
3. Using remotely sensed imagery for detecting invasive species spread	• Based on poor results, we were unable to write a full manuscript on using remotely sensed imagery to detect invasive species. However, we presented our results and recommendations at one national meeting and one technology transfer meeting. The few invasive weed patches we found were much too small to possibly map using 30m Landsat.

	Therefore, we tested the utility of QuickBird imagery (obtained through Umatilla National Forest funding) for mapping these patches. However, we were unsuccessful given that the invasive weed patches were so small and diffuse. This doesn't mean that there isn't potential to map invasive weeds using QuickBird or Landsat where large patches of invasive weeds exist, but the invasive weeds problem simply didn't materialize as expected when we wrote the proposal. • Robichaud, PR, Parsons A, Lewis SA, Hudak AT, Clark JT. (2009) Assessing post-fire burn severity on the ground and from satellites: a review of technological advances [abstract]. Page 113 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The ’88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

IX. References

Bassett J, Busskohl C, Clifton C, Erickson V, Gobar C Justice D, Powell D, Riley S, Sanchez S, Vickery C. 2002. Tucannon Ecosystem Analysis. Accessed: March 30, 2010. https://scholarsbank.uoregon.edu/xmlui/bitstream/handle/1794/6671/Tucannon_Ecosystem_Analysis.pdf?sequence=1

Beyers JL. 2004. Postfire seeding for erosion control: effectiveness and impacts on native plant communities. Conserv. Biol. 18(4): 947–956.

Cerda A, Robichaud PR. 2009. Fire effects and restoration strategies.Enfield, NH. Science Publishers (USA). Vol. 5 of *Land reconstruction and management*. 605 p.

Crawford JA, Wahren CHA, Kyle S, Moir WH. 2001. Responses of exotic plant species to fires in *Pinus ponderosa* forests in northern Arizona. J. Veg. Sci. 12: 261-268.

D'Antonio C, Vitousek P. 1992. Biological invasions by exotic grasses, the grass/fire cycle. *Annual Rev. Ecol. System.* 23:63-87.

Grigal DF, Vance ED. 2000. Influence of soil organic matter on forest productivity. New Zealand J. For. Sci. 30:169–205.

Harvey AE, Geist JM, McDonald GI, Jurgensen MF, Cochran PH, Zabowski D, Meurisse RT. 1994. Biotic and abiotic processes in eastside ecosystems: the effects of management on soil properties, processes, and productivity. USDA Forest Service, Pacific Northwest Research Station, Gen. Tech. Rep. PNW-GTR-23. Portland, OR, 21 p.

Hudak, AT, Rickert I, Morgan P, Strand E, Lewis SA, Hoffman C, Holden ZA, Clark JT, and Robichaud PR. An Assessment of Fuel Treatment Effectiveness in the Interior Western US. USDA Forest Service, Rocky Mountain Research Station, Gen. Tech. Rep., in review.

Johnson DW, Curtis PS. 2001. Effects of forest management on soil C and N storage. Forest Ecology Management 140: 227–238.

Jurgensen M, Reed D, Page-Dumroese D, Laks P, Collins A, Mroz G, Degorski M. 2006. Wood strength loss as a measure of decomposition in northern forest mineral soil. Eur. J. Soil Biol. 42:23-31.

Key CH, Benson NC. 2006. Landscape assessment: ground measure of severity, the Composite Burn Index, and remote sensing of severity, the Normalized Burn Index. In 'FIREMON: Fire Effects Monitoring and Inventory System'. (Eds DC Lutes, RE Keane, JF Caratti, CH Key, NC Benson, S Sutherland, LJ Gangi) USDA Forest Service, Rocky Mountain Research Station, Gen. Tech. Rep. RMRS-GTR-164-CD: LA1-51. (Ogden, UT).

Kruse R, Bend E, Bierzychudek P. 2004. Native plant regeneration and introduction of non-natives following post-fire rehabilitation with straw mulch and barley seeding. For. Ecol. Manage. 196(2-3):299–310.

Lentile LB, Morgan P, Hudak AT, Bobbitt MJ, Lewis SA, Smith AMS, Robichaud PR. 2007. Post-fire burn severity and vegetation response following eight large wildfires across the western US. *Journal of Fire Ecology* 3(1): 91-108.

Marshall VG. 2000. Impacts of forest harvesting on biological processes in forest soils. For. Ecol. Manage. 133:43–60.

Neary DG, Klopatek CC, DeBano LF, Ffolliott PF. 1999. Fire effects on belowground sustainability: a review and synthesis. For. Ecol. and Manage. 122:51–71.

Powers RF, Tiarks AE, Boyle JR. 1998. Assessing soil quality: practical standards for sustainable forest productivity. *In* the contribution of soil science to the development and implementation of criteria and indicators of sustainable forest management. Ed. by EA Davidson, MB Adams, K Ramakrishna. SSSA Pub. No. 53, SSSA, Madison, WI. pp. 53–80.

Robichaud PR. 2005. Measurement of post-fire hilllslope erosion to evaluate and model rehabilitation treatment effectiveness and recovery. Int. J. Wildland Fire 14 (4):475–485.

Robichaud, PR. 2009. Post-fire Stabilization and Rehabilitation. In: Fire Effects on Soils and Restoration Strategies. Science Publishers, Enfield, NH, USA.

Robichaud PR, Beyers JL, Neary DG. 2000. Evaluating the effectiveness of post-fire rehabilitation treatments. USDA Forest Service, Rocky Mountain Research Station, Gen. Tech. Rep. RMRS-GTR-63. 85 p.

Robichaud PR, Lewis SA, Brown RE, Ashmun LE. 2009. Emergency post-fire rehabilitation treatment effectiveness on burned area ecology and long term restoration. Journal of Fire Ecology, 5(1): 115-128.

Wienk CL, Hull-Sieg, C, McPherson GR 2004. Evaluating the role of cutting treatments, fire and soil seed banks in an experimental framework in ponderosa pine forests of the Black Hills, SD. For. Ecol. Manage. 192(2-3):375–393.

USDA, 2006. The School Fire Salvage Recovery Project, Final Environmental Impacts Statement. Accessed May 2, 2010. Available at: http://www.fs.fed.us/r6/uma/projects/readroom/pomeroy/school/index.shtml.