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Invasive Plant Species and the Joint Fire Science Program

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Cover photo

Kerry Metlen, University of Montana.

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ABSTRACT

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Invasive nonnative plants may be responsible for serious, long-term ecological impacts, including altering fire behavior and fire regimes. Therefore, knowing how to successfully manage invasive plants and their impacts on natural resources is crucial. We present a summary of research on invasive plants and fire that has been generated through the Joint Fire Science Program—focusing specifically on ecology of species invasions, the interactions between fire and invasives, and the responses of invasives to different management practices. Selected findings include (1) prescribed fire may increase invasive species in some ecosystems; (2) fuel treatments that leave some overstory canopy, minimize exposure of bare ground, and target sites that already host species capable of resprouting may be less likely to promote invasives; and (3) postfire seeding should be approached with caution, as it can increase invasives.

Keywords: Invasive plants, fire management, cheatgrass, fuel treatments, postfire seeding, fire regimes, exotic species.

INTRODUCTION

Invasive nonnative plants are plants introduced into areas outside of their natural ranges, usually as a result of human activities. Plants that are successful invaders often have high growth rates and typically reproduce prolifically. Thus, they have the potential to spread relatively quickly over large areas. Invasive plants may be responsible for serious, long-term ecological impacts; they can cause the decline of native plant species, disrupt nutrient cycling and hydrology, and alter fire regimes.

Orange hawkweed (*Hieracium aurantiacum*), particularly problematic in the Northwestern United States, is an example of an aggressive invader that thrives in disturbed areas.

Disturbances, such as wildfire and prescribed fire, may promote plant invasions via a number of mechanisms. On the other hand, fire can be used to control some invasives. Determining how to successfully manage invasives is crucial, but to do so, much more information is needed on the ecology of species invasions, the interactions between fire and invasives, and the responses of invasives to different management practices.

Several government-funded research programs and initiatives are addressing ways to better understand the biology, ecology, and management of invasive species. Since 1999, the Joint Fire Science Program (JFSP) has funded over 25 projects related to invasive plant species and fire. In this paper we summarize completed and ongoing JFSP research related to fire and invasives.

INTERACTIONS BETWEEN FIRE AND INVASIVES

Fire, like many disturbances, may promote the invasion of nonnative plant species by providing canopy openings, reducing cover of competing vegetation, and creating favorable soil conditions such as newly exposed soil surfaces and increased nutrient availability. Prescribed fire, now used in many ecosystems to remove vegetation that has accumulated as a result of decades of fire suppression, may have the unintended effect of spreading invasive species. Similarly, fire management activities such as fuel reductions can often promote plant invasions, potentially replacing one type of fire hazard represented by existing fuels with another type of hazard from new types of nonnative fuels. Moreover, fire exclusion may promote the invasion of woody species into grasslands.

Invasive plants also may affect fire behavior and fire regimes, often by increasing fuel bed flammability, which increases fire frequency. A classic example of a widespread invader that has greatly altered fire in the Western United States and Canada is cheatgrass (*Bromus tectorum* L.). Cheatgrass is a winter annual, growing rapidly during late winter and early spring and dying in early summer when most other plants are still green. Dead cheatgrass provides a continuous bed of highly flammable fuel that can readily carry a fast-moving fire. When the native flora is poorly adapted to a more frequent fire regime, the cheatgrass is able to gain a competitive advantage, resulting in a grass/fire cycle (D'Antonio and Vitousek 1992). However, not all invasive plants enhance an aspect of a fire regime; a few may actually make sites less flammable (D'Antonio 2000). Documenting and explaining the causes behind the sometimes complex interactions between fire and invasive species is a major goal of JFSP research.

Photo by Tom Iraci, USFS

Prescribed fire may have the unintended effect of increasing invasive species in some ecosystems.

MAJOR QUESTIONS AND FINDINGS

Joint Fire Science Program research projects are addressing many important questions regarding invasives and fire. We grouped projects according to these four broad questions:

1. What Factors Influence Community Susceptibility to Invasion by Nonnative Species After Fire?
2. How Do Fuel Reduction Treatments Affect Invasives?
3. How Do Plant Invasions Affect Fire Regimes?
4. What Are Effective Mitigation Strategies Against Invasive Plants?

Following each question are the related research project titles (in italics), brief descriptions of the projects, and some of the findings to date.

Question 1: What Factors Influence Community Susceptibility to Invasion by Nonnative Species After Fire?

Community structure and disturbances have long been studied as factors contributing to how easily a community (**community susceptibility, community invasibility**) may be invaded by non-native plants. Recently, invasibility after fire has been examined more closely.

"Spatial Interactions Among Fuels, Wildfire, and Nonnative Plants."

In this project, Philip Omi, Molly Hunter, and their team determined factors that contribute to postfire invasion by nonnative plants at three mixed-conifer forests in the Rocky Mountains. Using a survey approach, they selected plots across several strata defined by spatial layers of elevation, aspect, vegetation, fuel treatments, and fire severity and progression. Their main finding was that fire severity was a consistent predictor of nonnative species cover and was a more important predictor of nonnative species establishment than other abiotic variables. These results suggest that high-severity wildfires may be one of the more important mechanisms for continued spread of nonnative species in the Western United States (Final report to the JFSP,[1] Hunter et al. 2006).

Photo by Jamie Barbour, USFS, Focused Science Delivery Program

JFSP research has shown several factors that can contribute to whether an ecosystem is vulnerable to the spread of invasive plants after a fire.

"Weed Invasions Following Fire in Southwestern Colorado: Long-Term Effectiveness of Mitigation Treatments and Future Predictions."

Lisa Floyd-Hanna and colleagues also used a survey approach in the Mesa Verde National Park on the Colorado Plateau to identify plant communities susceptible to postfire weed invasion. Extensive fires occurred in the park in the 1990s resulting in major plant invasions. The team found that invasive species were prevalent in the seed banks in pinyon-juniper woodlands, the community type most vulnerable to invasions after fire. Also, the pinyon-juniper woodlands had a relatively sparse cover of native species capable

[1] The final reports and more information about each project are available on the Joint Fire Science Program's Web site, www.firescience.gov. Search under project title or name of scientist.

Postfire treatments that encourage high vegetative cover, without introducing new nonnative species in contaminated seed mixes, can help prevent further spread of nonnative species.

of rapid postfire sprouting, potentially giving the invasives a competitive advantage. The least vulnerable type of vegetation, mountain shrubland, had a native vegetation that resprouted and quickly grew back, outcompeting the invasives. Soil properties differed substantially in burned versus unburned areas, supporting the idea that nutrient conditions are more favorable for plant growth (especially weeds) in burned areas. In particular, nonnative plant density after fire was weakly correlated with soil nitrate and percentage of silt, suggesting these variables may be important indicators of site susceptibility to invasion (Floyd et al. 2006, JFSP 2006).

"Sagebrush Steppe and Pinyon Juniper Ecosystems: Effects of Changing Fire Regimes, Increased Fuel Loads, and Invasive Species."

Using observational and experimental approaches to examine specific mechanisms behind invasion of cheatgrass in sagebrush ecosystems, Jeanne Chambers and colleagues surveyed and then burned and removed vegetation on sites at different elevations in Utah and Nevada and compared responses of vegetation and soil to untreated plots. Naturally, cheatgrass had different patterns of establishment and growth across elevations. Cheatgrass had low establishment, biomass, and seed production on high-elevation sites, probably owing to ecophysiological limitations resulting from cold temperatures. Cheatgrass had variable establishment, biomass, and seed production at low elevations, probably due to soil characteristics and spatial and temporal variations in soil water. Annual variation in soil water was greater at lower than at upper elevation sites. Soil water and nitrate availability increased with increasing elevation (Wyoming sagebrush to Vasey sagebrush to mountain brush communities), however, unlike soil moisture, nitrate availability was not more variable at lower elevations. In the experiment, the researchers found that removal of herbaceous perennials increased soil water and nitrate availability. Cheatgrass biomass and seed production increased 2 to 3 times following vegetation removal, 2 to 6 times after burning, and 10 to 30 times following removal and burning. This research showed that invasibility by cheatgrass varies across elevation gradients and appears closely related to temperature at higher elevations and soil water availability at lower elevations. High variability in soil water and lower average perennial herbaceous cover may increase invasion potential in lower elevation Wyoming sagebrush sites. Soil water and nitrate availability increase following either fire or removal of vegetation, but on intact sites native perennials typically increase following fire—limiting cheatgrass growth and reproduction. Thus, following these types of resource fluctuations, invasibility is lowest on sites with relatively high cover of perennial herbaceous species, i.e., sites in high ecological condition (Chambers et al. 2007, JFSP 2006).

"Fire and Invasive Grasses in Western Ecosystems."

In this project Matt Brooks, Jayne Belnap, Jon Keeley, and Robert Sanford are investigating the complex relationships among fire, soil nutrient availability, and plant invasions. Annual grass invasions are commonly attributed to fire, yet there are areas of minimal disturbance where alien annual grasses occur and areas of high disturbance that remain invasion-free. Using a combination of extensive field surveys, and field and laboratory experiments, this group is examining some of the mechanisms behind the wide-ranging patterns. The field surveys (across 432 sites) showed that soil characteristics differed between invaded and uninvaded patches and depended on climate. Invaded patches in regions with low winter precipitation had higher available phosphorus than uninvaded patches, but in regions with higher winter precipitation, other nutrients (e.g., manganese and potassium) became important as well. Intensive field experiments are ongoing in three ecosystems in the Western United States: sagebrush steppe, ponderosa pine, and ponderosa-sagebrush ecotone. At the ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) site in Kings Canyon National Park, a plot-scale experiment was initiated to examine the effects of burn season and nine other treatments simulating fire and fire-free conditions on soils and invasives. Early findings show that soil nitrogen was positively related to cheatgrass biomass, and that this occurred independently of fire season. The scientists conclude that where cheatgrass is established in the forest, management using short-return-interval fires is likely to maintain cheatgrass indefinitely. Laboratory studies showed that cheatgrass grew better in soils that were burned compared to unheated soils, and that soil manganese may also play a role in cheatgrass performance, supporting the field surveys. More information on the project is available at http://www. werc.usgs. gov/fire/lv/fireandinvasives (JFSP 2006).

"Fire Effects on Seed Banks and Vegetation in the Eastern Mojave Desert: Implications for Postfire Management."

Matt Brooks and colleagues recently began a project to evaluate the immediate effects of fire on seed banks and vegetation in the Mojave Desert. This project is in response to a specific need expressed by land managers to understand how fire affects seed banks in hot desert regions, especially contrasting native versus nonnative species. This information is needed to help determine if postfire seeding treatments are warranted, especially if they are focused on reducing dominance of invasive nonnative plants (Matt Brooks 2006, pers. comm.).

"Rapid Response to the 2003 Fires in Southern California: Impact of Fuel Age on Fire Behavior and Recovery."

Jon Keeley, Tess Brennan, and Anne Pfaff found that fire severity in chaparral shrublands is not a major determinant of alien plant invasion. But past fire history, in particular fire frequency, is a critical factor because it reduces the capacity for the native shrublands to recover, a necessity for inhibiting alien plant invasion (Keeley et al. 2005).

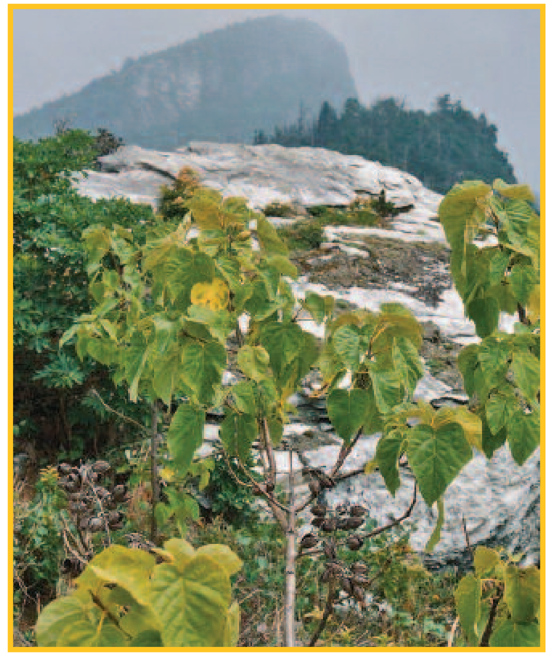

Photo by Dane Kuppinger, University of North Carolina

Paulownia (*Paulownia tomentosa* (Thunb.) Sieb. & Zucc. ex Steud.) a new invader after fire in the Great Smoky Mountains, is like many invaders in that it is strongly associated with bare exposed soil.

"Predicting the Invasion and Survival of the Exotic Species* Paulownia tomentosa *Following Burning in Pine and Oak-Pine Forests."

Dane Kuppinger, Peter White, and Michael Jenkins are examining landscape, watershed, and stand-scale conditions that influence the establishment of *Paulownia* after fire. *Paulownia* has recently invaded extensive areas following fire in the Great Smoky Mountain National Park. Initial analyses show that *Paulownia* occurs in landscape positions associated with high fire intensity and that a useful predictor for *Paulownia* at the stand scale is the amount of bare soil. Additional studies are examining the survivorship of *Paulownia* with time since burning (JFSP 2006).

Photo by Tom Iraci, USFS

Fuel break construction methods that leave some overstory canopy and minimize the amount of exposed mineral soil may be less likely to promote invasion by alien plants than more disruptive methods such as those using bulldozers.

Question 2: How Do Fuel Reduction Treatments Affect Invasives?

Fuels can be reduced by manual or mechanical methods or by prescribed fire, each of which has consequences for invasives.

"Pre-Fire Fuel Manipulation Impacts on Alien Plant Invasion of Wildlands."

In this project, Jon Keeley and colleagues examined 24 fuel breaks across California in a range of vegetation types including chapparal, oak woodland, coniferous forest, and coastal scrub. They found that fuel breaks provide establishment sites for nonnative plants, especially when combined with livestock grazing and in areas with repeated burning. They also found that fuel break construction methods that leave some overstory canopy and minimize the amount of exposed mineral soil may be less likely to promote invasion by alien plants than more disruptive methods such as those using bulldozers (Merriam et al. 2006).

"Fuels Management and Nonnative Plant Species: An Evaluation of Fire and Fire Surrogate Treatments in Chaparral Plant Community."

Similarly, Jennifer Gibson and colleagues found that fuel treatments in shrub (primarily whiteleaf manzanita [*Arctostaphylos viscida* Parry]) communities that retain greater levels of overstory shading and litter or surface cover greatly mitigate risk of increasing exotic plant cover. They took advantage of manipulative treatments implemented in the Whiskeytown National Recreation Area in northern California where native brush was masticated to various degrees and examined the responses of invasive and native plant cover. Invasive plants increased most in masticated plots that were also burned, suggesting that this treatment should be used discriminantly (JFSP 2006).

"Fuel Reduction in Oak Woodlands, Shrublands, and Grasslands of SW Oregon: Consequences for Native Plants and Invasion by Nonnative Species."

Using a retrospective analysis in thinned chaparral and oak communities in southwestern Oregon, Keith Perchemlides and Patricia Muir found that although the relative dominance of exotic and native species did not change between areas thinned 4 to 7 years previously and areas never thinned, among the exotic species, annual grass cover increased strongly in response to thinning (nearly doubling to almost 20 percent cover), whereas exotic annual forb cover decreased.

Photo by Kerry Metlen; Lubrecht Experimental Forest, College of Forestry and Conservation, University of Montana

Canada thistle (*Cirsium arvense*), an invasive forb widely distributed across North America, increased after burning and thinning at the Lubrecht Experimental Forest. Canada thistle is widespread in part because it survives fire and colonizes exposed bare soil in recently burned areas.

These changes occurred across treatments (hand-piled and burned and mechanical mastication), suggesting that fuel reduction in these systems may have the unintended effect of changing fuel dynamics and increasing exotic annual grasses (Pat Muir 2006, pers. comm.).

Photo by Tom Iraci, USFS

JFSP scientists have found that light or moderate-severity burns that keep exposure of bare soil to a minimum are least likely to promote plant invasions.

"Fire Effects and Fuels Management in Blackbrush (*Coleogyne ramosissima *[Torr.]) Shrublands of the Mojave Desert."

Matt Brooks and colleagues examined the effect of using fire to control blackbrush. Blackbrush is considered a hazardous fuel and is often burned, especially at urban-wildland interfaces. Using a field sampling approach, they examined vegetation at three paired (burned and unburned) sites and found that as fire removed the blackbrush, the cover of nonnatives increased. They caution that because blackbrush is slow to recover after fire, invasive annual grasses may replace blackbrush and change the fire cycle. Past land use also may play a role in invasive establishment in that if lands were previously grazed, native herbaceous perennial grasses and forbs may be depleted and invasive grasses may already be present. Rangelands were historically burned across much of the West to replace poor forage species with annual grasses that often provided superior forage (Brooks and Matchett 2003, JFSP 2006).

"Fire and Fire Surrogate Program."

As part of the national **Fire and Fire Surrogate Program** (http://www.fs.fed.us/ffs), Andrew Youngblood and colleagues at the **Hungry Bob Site** in the Blue Mountains of Oregon and Kerry Metlen and Carl Fiedler at the **Lubrecht Site** in western Montana examined how understory vegetation, including nonnatives, responded to thinning, burning, and thinning with burning in mixed ponderosa pine/Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) forests. In Oregon, three invasive grasses were found in areas that were thinned and burned, although two of these were present before the treatments were implemented and all had very low levels of abundances (< 4 percent). Continued monitoring will determine whether these invasives will increase in the future. In Montana, exotic forbs increased 2 and 3 years after treatment with the greatest response in the thin-and-burn treatment. According to the authors, this increase may be an unavoidable short-term consequence of making forests more resilient to exotic invasion should wildfire occur (Metlen and Fiedler 2006, Youngblood et al. 2006).

"Fire and Fire Surrogate Program."

In another analysis from the **Lubrecht Site** in Montana, Erich Dodson and Carl Fieldler examined how invasive plants, in particular those thought to alter ecosystem properties, (i.e., "transformers") responded to the thin, burn, and thin-and-burn restoration treatments. The thin-and-burn treatment yielded the greatest number and abundance (percentage of cover) of exotic plants and transformer species, whereas the control yielded the least. Multiple regression analysis showed that the transformer species were related to the reduction of overstory tree cover and scorch height, suggesting that treatment intensity was important in facilitating invasion. A companion study (Gundale et al. 2006) showed that soil inorganic nitrogen increased most in the thin-and-burn treatment, suggesting increased resource availability may also have enhanced invasion. Specific strategies, such as seeding of native species, limiting grazing, and harvesting in a manner to minimize soil disturbances, may be necessary to limit invasions in these systems (Dodson and Fiedler 2006).

"Effects of Fuel Management Treatments in Pinyon-Juniper Vegetation at a Site on the Colorado Plateau, Evaluating the Effects of Pinyon-Juniper Thinning Treatments at a Wildland/Urban Interface."

In two ongoing projects on the Colorado Plateau and the southern Great Basin, Matt Brooks and colleagues are evaluating the effects of various types of mechanical and chemical thinning treatments for pinyon and juniper woodlands. Response variables are focused on fuel bed and potential fire behavior in addition to general plant community characteristics, especially the subsequent dominance of cheatgrass and other invasive nonnative plants. Preliminary results indicate that some of the treatments are clearly most effective at shifting the woodland landscape towards the desired native shrub-steppe condition. More information is available at http://www.werc.usgs.gov/fire/lv/pj/lakemead (2004 and 2005 annual reports to the JFSP, unpublished).

"Reducing Wildfire Risk by Integration of Prescribed Burning and Biological Control of Invasive Saltcedar (**Tamarix** ***spp.)."***

Another ongoing fuel reduction project seeks to reduce hazardous fuels created by the invasive

Photo by Jon Keeley, USGS

Cheatgrass (*Bromus tectorum*), a noxious invasive annual grass, is found across North America and has exceptional ecosystem altering potential. JFSP research has shown that cheatgrass dominance often increases with fuel reduction treatments. Here, cheatgrass is in both the foreground and across the slope in the distance in the Great Basin desert, north of Reno, Nevada.

nonnative tree, saltcedar (*Tamarix* spp.), in riparian zones in the southern Great Basin. The specific treatment combinations are biocontrol to defoliate and weaken saltcedar trees followed by prescribed fire. There are no results to report yet on this project (Matt Brooks 2006, pers. comm.).

"Fire and Invasive Grasses in Western Ecosystems."

Jon Keeley and Thomas McGinnis further explored how fire affected the persistence of cheatgrass in low-elevation ponderosa pine forests at Kings Canyon National Park. Their findings suggest that increasing time between prescribed fires may inhibit cheatgrass establishment. This is somewhat counter to the goal of restoring historical fire regimes, but may be an appropriate compromise between reducing serious fire hazards and exacerbating alien plant invasions (Keeley and McGinnis 2007).

Question 3: How Do Plant Invasions Affect Fire Regimes?

"Fire and Invasive Plant Ecology and Management: The Need for Integration to Effectively Restore Ecosystems."

Matt Brooks and colleagues organized a special session at an international scientific meeting to present summaries describing the interrelationships between invasive plants and fire. This symposium reviewed the history of fire and invasive plant research and management, summarized the interrelationships between fire and invasive species, highlighted the many complex interrelationships that remain unstudied, provided examples of promising new lines of research, and identified gaps in existing research programs. A significant product from this symposium was a description of the various ways that plant invasions can alter fuel bed characteristics, fire behavior, and fire regimes—which the authors called the invasive plant/fire regime cycle (Brooks et al. 2004).

"Fire Management Options to Control Woody Invasive Plants in the Northeastern and the Mid-Atlantic U.S."

As mentioned previously, not all invasive plants increase fire frequency or intensity. Occasionally, invasive shrubs and trees can reduce fire frequencies below their natural range. Alison Dibble and her team have shown that black locust (*Robinia pseudoacacia* L.), a prominent invasive in eastern pitch pine (*Pinus rigida* P. Mill.) forests, is not as flammable as native vegetation and may actually lengthen fire-return intervals (Dibble and Rees 2005).

Question 4: What Are Effective Mitigation Strategies Against Invasive Plants?

Invasives can be removed by several means including fire, biological control, herbicide use, and mechanical cutting. These and followup seeding practices hold promise for mitigation, but few studies have documented their effectiveness.

"The Use of Fire as a Tool for Controlling Invasive Plants."

Fire is often used as part of integrated pest management programs to control invasive plants. Matt Brooks, additional collaborators, and the California Invasive Plant Council convened a panel of experts to develop state-of-the-science summaries and recommendations for using fire to manage invasive plants. This panel concluded that annual species that produce seeds well after the fire season begins, that have flowering structures embedded within the fuel bed, and that have short-lived seed banks are most amenable to control using fire. In contrast, perennial species with perennating tissue that is either belowground or well above the fuel bed (and thus protected from heating), and that resprout readily because they are adapted to fire or some other form of recurrent disturbance, are not generally amenable to control by fire. Invasive plants that alter the fuel bed structure making it less flammable may also be difficult to control with fire because they produce fuel beds that are relatively inflammable. In all cases, followup monitoring and plans for retreatment are required, and in most cases, fire should be integrated with other control methods. The net effects of any treatment plan on the entire plant community, higher tropic levels, and ecosystem properties, need to be considered before treatments are implemented (DiTomaso and Johnson 2006, DiTomaso et al. 2006, JFSP 2006).

Photo by Tom Iraci, USFS

Researchers have found that certain mitigation treatments can be effective at shifting the woodland landscape towards the desired native shrub-steppe condition.

"Fire Management Options to Control Woody Invasive Plants in the Northeastern and the Mid-Atlantic U.S."

Although burning is often used to control invasive shrubs in the Northeast and Mid-Atlantic States, it may be counterproductive if burns are conducted during dormancy. Using an experimental approach, Alison Dibble and colleagues examined the effect of dormant-season burn, growing-season cut with same-season burn, and growing-season cut followed by a second cut across three sites in the Northeast. For the seven species that were studied, a single treatment, whether applied during the dormant or early growing season, decreased root reserves (essential for resprouting) for less than one growing season. With 2 years of treatment, resprouting still occurred, but growth tended to be less vigorous than for those treated only once. Across species, the authors concluded that carefully applied cutting and prescribed fire treatments, in tandem or alone, can reduce the fire hazard in invaded fuel beds (JFSP 2006).

"Evaluate Treatments to Reduce Hazardous Fine Fuels Created by Nonnative Plants in Zion Canyon."

A project led by Denise Louie and colleagues is evaluating different combinations of three phases of control treatments for invasive annual grasses in riparian zones at Zion National Park (ZNP): (1) biomass reduction (mowing vs. fire); (2) herbicide to target the grasses (different types, rates, and timings); and (3) followup seeding of early-successional native species to compete with invasive grasses that escaped the first two treatments. Preliminary results indicate strong differences among treatments, suggesting that definitive recommendations for future management of invasive annual grasses at ZNP will emerge from this project. These early results were used by the National Park Service to design Burned Area Emergency Response treatments to manage invasive annual grasses after the Kolob Fire of 2006, the largest fire in the history of ZNP (Matt Brooks 2006, pers. comm.).

"Management of Fuel Loading in the Shrub-Steppe."

In field trials, Steven Link and his team tested two herbicides for use against invasives (mostly cheatgrass) in a shrub-steppe community in eastern Washington. Imazapic[2] reduced cheatgrass cover by about 40 percent and increased native vegetation cover by about 10 percent 2 years after application, whereas glyphosphate reduced the cover of both cheatgrass and native species. Imazapic is recommended to reduce cheatgrass but should be used with caution where rare native mustards are present (the mustards were reduced with treatment). The team found that prescribed fire can be used in the fall to prepare surfaces for preemergent herbicide application where cheatgrass cover is less than 50 percent. Link and colleagues also conducted a restoration study and found that fire risk of two communities 8 years after establishment of large bunchgrasses

[2] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

was approximately 77 percent, and decreased further to 66 percent 18 years after restoration. The savings associated with reducing fire risk from 100 percent to 66 percent may be enough to cover the costs of restoring shrub-steppe ecosystems. More information can be found on the project Web site at http://www.tricity.wsu.edu/shrub_ steppe/fire_publications (JFSP 2006).

"Effectiveness of Postfire Seeding to Reduce Cheatgrass (*Bromus tectorum*) Growth and Reproduction in Recently Burned Sagebrush Steppe."

Postfire seeding is often used to suppress the growth and reproduction of cheatgrass in low-elevation sagebrush steppe. Nonnative perennial grasses are traditionally seeded to compete with invasive annuals because of their presumed greater growth rates compared with native perennials, yet few controlled studies have tested this assumption. With a field experiment, Matt Brooks and associates examined the response of cheatgrass and other invasive grasses to postfire seeding of native vs. nonnative perennial grass species. Because of low rainfall, the growth of seeded plants was low the first 2 years. Also, across seeded plots, an invasive perennial grass (bulbous bluegrass [*Poa bulbosa* L.]) increased in dominance, presumably because of soil disturbance that occurred with the seeding technique (a mechanized drill). Researchers will continue to evaluate the responses after seeded plants reach maturity. A Web site with further information is available at http://www.werc.usgs.gov/fire/lv/postfireseeding/greatbasin (JFSP 2006).

"Evaluating Postfire Seeding Treatments Designed to Suppress Cheatgrass (*Bromus tectorum*) in Ponderosa Pine Forests on the Colorado Plateau."

A similar project evaluated the effects of seeding native perennial grasses after fire with and without seedbed preparation on cheatgrass dominance in a basin big sagebrush community on the Colorado Plateau. Preliminary results 3 years posttreatment indicate that seedbed preparation improved establishment of the seeded native species, but also led to increased dominance of a nonnative forb. Responses of cheatgrass among treatments have been nonsignificant so far. This delayed response is likely due to the timing of the fire prior to seeding, which occurred when many cheatgrass plants had emerged as seedlings and were likely killed, thus reducing the onsite population levels (Matt Brooks 2006, pers. comm.).

"Weed Invasions Following Fire in Southwestern Colorado: Long-Term Effectiveness of Mitigation Treatments and Future Predictions."

Lisa Floyd and colleagues reexamined an aerial native plant seeding experiment 7 years after treatments were applied following a fire at Mesa Verde National Park. Density of a persistent postfire invasive (muskthistle [*Carduus nutans* L.]) was reduced by 66 percent, and density of a native grass was doubled in areas that received seeding treatments compared to areas that were not seeded. Although aerial application of native grass seeds did not completely prevent weed invasion, it greatly reduced postfire weed density and rapidly increased the native component of the plant community. Mechanical treatment of muskthistle (removing seed heads and digging plants out with a shovel) was effective only in areas where native grasses were present: musk-thistle was completely absent from these areas 7 years later. Chemical treatment of Canada thistle (*Cirsium arvense (L.) Scop.*) (by using Curtail) for 2 years following fire resulted in almost complete mortality of Canada thistle, which was nearly absent from treated areas 7 years later. Although chemical treatment of Canada thistle was very effective, it is labor-intensive and probably feasible only in localized areas (Floyd et al. 2006, JFSP 2006).

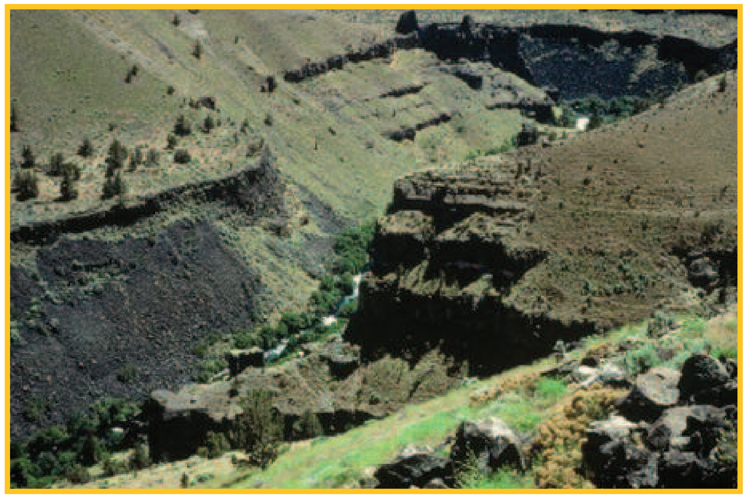

Photo by Tom Iraci, USFS

Application of contaminated seed mixes on landscape scales may introduce a large number of nonnative weed seeds.

"Spatial Interactions Among Fuels, Wildlife, and Nonnative Plants"

Seed mixes are often contaminated with non-native species, and their application on landscape scales may introduce a large number of nonnative weed seeds. Using research from study sites in the Rocky Mountains of Colorado and New Mexico, Philip Omi and colleagues showed that where seed mixes were applied aerially, there was a positive association between the cover of non-native species and seeded grasses. However, where seed mixes were applied by hand or a seed drill on a more limited scale, postfire seeding successfully deterred nonnative species establishment, similar to the effect of abundant native cover. Postfire treatments that encourage high vegetative cover, without introducing new nonnative species in contaminated seed mixes, would best prevent further spread of non-native species. These researchers suggest that hand application of native grass seed mixes may be preferable to broad application of nonnative grass seed (Hunter et al. 2006, JFSP 2006).

"Pre-fire Fuel Manipulation Impacts on Alien Plant Invasion of Wildland."

In another look at the benefits of postfire seeding on invasives, Jon Keeley and colleagues recommend against postfire seeding, particularly in the shrublands and ponderosa pine forests of California and the southwest owing to lack of strong scientific support (Keeley et al. 2006).

ADDITIONAL PROJECTS:

"Invasive Plant and Fire Interactions: Use of the Fire Effects Information System to Provide Information for Managers."

Kevin Ryan and Jane Kapler Smith headed a team that has completed detailed literature reviews on 60 nonnative invasive plant species in the Fire Effects Information System (FEIS, at www.fs.fed.us/database/feis). These reviews synthesize the scientific literature on each species' basic biology, ecology, and relationship to fire. Reviews emphasize how fire affects each species, how the species may alter fire regimes, and potential management actions for specific ecosystems. A comprehensive search of the scientific literature forms the basis for each review. An additional 10 to 20 nonnative invasives will be covered in FEIS under another JFSP task entitled **"Bringing the Fire Effects Information System Up-to-Date and Improving Service to Land Managers"** (JFSP 2006, Jane Kapler Smith 2006, pers. comm.).

"Publication of Literature Synthesis Entitled, 'Effects of Fire on Nonnative Invasive Plants' as 6th Volume in the General Technical Report, 'Wildland Fire in Ecosystems' ('Rainbow' Series)."

Jane Kapler Smith and colleagues are nearing completion of an edited volume summarizing and synthesizing current knowledge about the ecology and management of invasive plants and fire in the United States. This document includes three sections: (1) overview chapters highlighting the potential for nonnative species to increase after fire, the effect of these species on fire regimes, and the use of prescribed fire to control them; (2) analysis of the relationship of fire to invasions and invasible plant communities in seven regions of the United States: the Northeast, Southeast, Central, Interior West, Pacific Northwest and Alaska, Southwest coast, and Hawaiian Islands; and (3) issues of nationwide concern, including knowledge gaps in relation to fire and invasives, postfire rehabilitation, prescribed fire monitoring, and effects of fire surrogate treatments on invasive species (Jane Kapler Smith 2006, pers. comm.).

SUMMARY OF FINDINGS

Have we answered our questions? Partly, yes! We've learned (see detailed bullets below) about several factors that can contribute to whether an ecosystem is vulnerable to invasion, we've learned how prescribed fire and fuel treatments might actually increase invasive species, and we've learned about some successful mitigation strategies against invasives. Many of the projects are ongoing or just beginning. More questions will be answered and tools for managers developed and refined as the word continues to get out. So stay tuned!

- **Invasibility is complex:** Soil seed bank composition, competing native vegetation, soil disturbance and fertility, fire severity, and climatic regime and weather all affect a community's susceptibility to invasion after fire.
- **Prescribed fire can be a problem:** Prescribed fire may have the unintended effect of increasing invasive species in some ecosystems, especially if the ecosystems are in poor ecological condition and the native species capable of establishing or resprouting following fire have been depleted.
- **Fuel treatments matter:** Fuel treatments that leave some overstory canopy, minimize exposure of bare ground, and target sites with species capable of establishing or resprouting may be less likely to promote invasion by alien plant species.
- **Fuel reduction treatments:** Fuel treatments that encourage high vegetative

cover of native species, without introducing new nonnative species (e.g., in contaminated seed mixes or by soil disturbance) may prevent further spread of nonnative species.

- **Mitigation strategies may be effective:** On sites that exhibit species invasions following wildfire, active intervention with herbicides or other treatments designed to control or eliminate the invasive can be highly effective.
- **Postfire seeding:** Seeding treatments should be used with caution, as studies are showing these can increase invasives.

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