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Chapter 14:

Effects of Fire Suppression and Postfire Management Activities on Plant Invasions

This chapter explains how various fire suppression and postfire management activities can increase or decrease the potential for plant invasions following fire. A conceptual model is used to summarize the basic processes associated with plant invasions and show how specific fire management activities can be designed to minimize the potential for invasion. The recommendations provided are focused specifically on invasive plant management, although other considerations can take precedence under certain situations. Every fire presents a unique combination of site history and management goals, and the approaches adopted for management always involve tradeoffs between alternative combinations of management actions. The information in this chapter is designed to help land managers make more informed decisions on integrating invasive plant management into fire suppression and postfire management operations.

Challenges of Identifying Postfire Plant Invasions

Invasion means the establishment, persistence, and spread of a species outside of its native range into a region that it did not historically occupy, with the demonstrated or potential ability to cause significant ecological consequences (chapter 1). However, it is often difficult to know whether or not a species was present prior to a discrete event (for example, before a fire or fire management action), because comprehensive plant surveys do not exist for most areas. Even where prior plant surveys do exist, they are not typically designed to detect nonnative invasive plants. In addition, these surveys may not include species that were present but not detected or species that dispersed into the region subsequent to the most recent sampling date (Brooks and Klinger, in press). Although regional invasive databases are becoming more available (for example, for

Hawai`i, www.hear.org), they typically do not possess the spatial resolution necessary for planning postfire management actions at local scales.

Most cases of postfire invasions reported in the literature involve plant species that were present prior to fire and then expanded their distribution and dominance following fire (D'Antonio 2000, review). Although fire may not be necessary for a species to establish within a region, it may trigger an increase in dominance to the point that it begins to cause ecological harm—for example, by altering fire regimes (chapter 3).

From an ecological standpoint and from the perspective of land managers, the potential for plant invasions to cause ecological harm is the reason why fire operation guidelines are needed to help minimize the chances of plant invasions and mitigate their negative effects. Thus, the details of whether a species was not previously present or was only present in low numbers prior to a fire may not be critical to the development of management actions designed to prevent the species from becoming a management problem. In this chapter, the term invasion and all derivatives thereof (including invasibility and invasion potential) are used in the context of both the (1) establishment of new species in an area they did not previously occupy, and (2) increase in abundance or dominance of species previously present but relatively less common.

The Invasion Process

Plant invasions have been associated with many factors including disturbances, proximity to previously invaded sites, pathways and vectors of spread, characteristics of potential invaders, altered resource availability, and disruption of ecological processes (Brooks and Klinger, in press; D'Antonio 1993; Davis and others 2000; Hobbs and Huenneke 1992; Lonsdale 1999; Maron and Connors 1996). In the current chapter, these factors are combined into two primary groups: (1) resource availability, and (2) propagule pressure (modified from Brooks 2007a). The concept of "propagule pressure" as used in this chapter includes both the rates of dispersal (numbers per dispersal event and frequency of dispersal events (Williamson and Fitter 1996)) and the characteristics of those species, including their ability to survive and reproduce. This two-part model predicts that landscapes are more invasible if the availability of limiting resources is high than if resource availability is low, but only if propagule pressure is sufficiently high and comprised of species with characteristics that allow them to establish new populations under prevailing environmental conditions (fig. 14-1). This approach to characterizing plant invasions differs from that of chapter 2 and other publications (for example, Davis and others 2000; Lonsdale 1999) only in the sense that it distills the major causative factors affecting invasions down into two primary factors for the purposes of developing and explaining management recommendations.

Plant resource availability is a function of the supply of light, water, and mineral nutrients and the proportions of these resources that are unused by vegetation or other organisms, such as soil microbes. Using mineral nutrients as an example, resource availability can increase due to direct additions to the landscape (fertilization), increased rates of production within

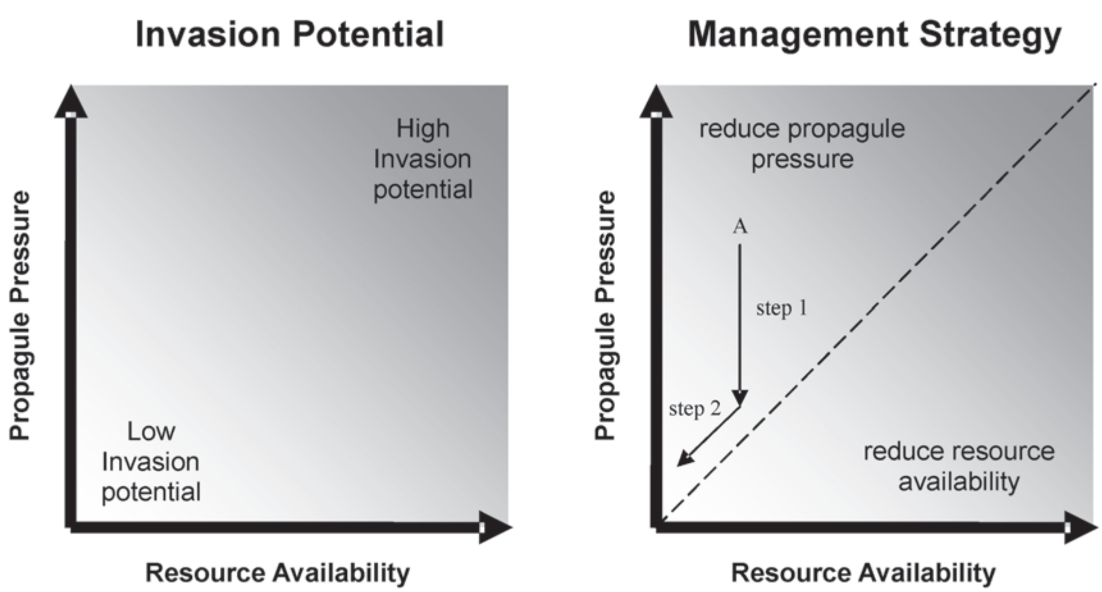

Figure 14-1—Main factors influencing invasion potential and a recommended management strategy to most efficiently minimize invasion potential. (Adapted from Brooks 2007a.)

the landscape (increased nutrient cycling following fire), or reduced rates of uptake following declines in resource use from extant plants after they are thinned or removed (biomass consumed by fire). Alternatively, mineral nutrient availability can decrease by volatilization during fire, rapid recovery of vegetation following fire, or success of revegetation efforts (for example, seeding).

Propagule pressure is typically used to mean the number of viable propagules available to establish and increase populations, and traditional definitions have focused on long-distance dispersal of individuals into regions to which they are not native (for example, Blackburn and Duncan 2001). This term has also been applied to the spread of nonnative species within regions where they have already established (for example, see Colautti and MacIsaac 2004). Percent cover of invading species has been found to decrease with increasing distance from initial points of invasion (Rouget and Richardson 2003), suggesting that dispersal rates are highest near established populations. These findings suggest that the concept of propagule pressure can be applied to different parts of the invasion process (Colautti and MacIsaac 2004; Lockwood and others 2005) and, in particular, to the stages of initial introduction and subsequent spread. By this more inclusive definition, propagule pressure can increase as a result of long distance dispersal from offsite populations (for species not previously present), local dispersal from onsite populations (for species previously present), or a combination of both. Propagule pressure can also be negatively affected by predators or diseases that reduce the reproductive rates of invading populations. This broad definition of propagule pressure is adopted here because it coincides with the definition presented earlier in this chapter that postfire invasions include both the establishment of new species in an area they did not previously occupy and the increase in dominance of species previously present.

Propagule pressure as used in the current chapter is also affected by the suitability of the component species to reproduce under prevailing environmental conditions. This approach places resource availability and propagule pressure on even par related to their theoretical scope. Just as the importance of resource availability varies among potentially limiting resource—such as light, water, and mineral nutrients—so too does the importance of propagule pressure vary among species, which can range from those likely to establish and cause undesirable effects to those not likely to establish. Phrased another way, it is not the increase in resource availability that necessarily matters, but rather the increase in resources that would otherwise be limiting to plant growth. Similarly, it is not the increase in propagule dispersal rates that matters, but rather the increase in propagules that can establish and reproduce under prevailing environmental conditions and ultimately cause undesirable ecological effects.

Since resource availability and propagule pressure of nonnative species are positively related to landscape invasibility, minimizing these two factors should be a significant consideration in land management activities (Brooks 2007a). Prioritizing which of the two factors to focus management actions on will depend on their relative importance on the landscape (fig. 14-1). For example, if propagule pressure is high but resource availability is moderately low (point A in fig. 14-1), then management actions should focus on reducing propagule pressure as a first step, which alone can significantly reduce invasion potential. If a further reduction of invasion potential is needed, then a management strategy focused on reducing both propagule pressure and resource supply is a potentially efficient and effective second step. In the sections that follow, these concepts are used to explain ways in which fire suppression and postfire management activities can influence plant invasions, both positively and negatively.

Effects of Fire Suppression Activities on Plant Invasions

Resource Availability

Fire suppression activities rarely lead to increased resource availability, although there are a few possible exceptions (table 14-1). For example, the use of fire retardants composed of ammonium phosphate adds a source of nitrogen and phosphorus that can lead to increased productivity of invasive plants in landscapes where these nutrients limit plant growth. Ripgut brome (*Bromus diandrus*), a highly flammable nonnative annual grass of significant management concern in western North America, increased by a factor of five in response to fire retardant added to burned areas, and by a factor of eight in response to the same retardant added to unburned areas during the first post-treatment year (Larson and Duncan 1982). Responses may depend on the effects of other factors limiting plant growth, such as soil moisture. This variable response seems to be exhibited by the nonnative Kentucky bluegrass (*Poa pratensis*), which increased significantly in growth following fire retardant application in a mesic northern prairie ecosystem (Larson and Newton 1996) but not in a more arid Great Basin ecosystem where soil moisture was assumed to be more limiting to plant growth than mineral nutrients (Larson and others 1999). Even if fire retardant increases growth rates of nonnative plants for a few postfire years, these increases may be less over the long term than those caused by fireline construction

Table 14-1—Recommendations for minimizing the potential of plant invasions during fire suppression activities. (Adapted from Asher and others 2001; Goodwin and Sheley 2001; and the U.S. Department of Agriculture, Forest Service 2001.)

Resource Availability

Minimizing Resource Input

Minimize the use of fire retardants containing nitrogen and/or phosphorus, except potentially where their use reduces the need for vegetation removal.

Maximizing Resource Uptake

Minimize vegetation removal in the construction of control lines.

- Use wet lines and foam lines as much as possible.
- Use narrow handlines in preference to broad dozer lines or blacklines.

Tie control lines into pre-existing fuel breaks (for example, bare rock and managed fuel zones) to minimize the amount of new vegetation removal.

Cover exposed soil with an organic mulch (for example, chipped fuels) where control lines were established to promote microbial activity that will use nitrogen and phosphorus, thus reducing their availability to invading plants.

Propagule Pressure

Preventing Deliberate Dispersal

There are no fire suppression activities with the potential to deliberately introduce nonnative propagules.

Minimizing Accidental Dispersal

Implement a postfire monitoring and control plan for invasive plants, focusing on populations of high priority invasive plants known to exist before the fire and on areas of significant fire management activity during the fire (for example, fire camps and dozer lines).

Ensure that vehicles, equipment, and personnel do not disperse propagules into burned areas.

- Coordinate with local personnel who know the locations of high priority invasive plants or who can quickly survey sites for their presence.
- Include warnings to avoid known areas infested with invasive plants during briefings at the beginning of each shift.
- Avoid establishing staging areas (for example, fire camps and helibases) in areas dominated by high priority invasive plants.
- If populations of high priority invasive plants occur within or near staging areas, flag their perimeters so that vehicle and foot traffic can avoid them.
- Inspect vehicles and equipment and wash them if they have propagules or materials that may contain propagules (such as mud) on them. Inspections should be done when vehicles first arrive at the fire and periodically during the fire as they return from the field.
- Avoid using water from impoundments infested with invasive plants.

If fire management options include prescribed fire or wildland fire use for resource benefits, address invasive plants in the environmental assessment. The assessment should document the distribution of high priority invasive plants and evaluate the potential for the burn to increase their dominance. If this potential is high, either remove those areas from the burn unit or develop and implement a postfire mitigation plan.

Identify populations of high priority invasive plants within areas burned by wildfire and focus postfire control efforts in those areas.

or the increased acreage burned if retardant is not used. Research on this topic is currently lacking, but enough evidence exists to consider fire retardants a potential contributor to plant invasions (table 14-1).

The construction of fuelbreaks and some firelines, both by hand crews and by heavy equipment, could lead to increased nutrient availability due to reduced consumption because plants have been removed (fig. 14-2; table 14-1). Merriam and others (2006) found that nonnative plants were often more abundant within fuelbreaks than in the surrounding landscape in California shrublands. In another example, a 16-fold increase in spotted knapweed (*Centaurea biebersteinii*) density was found on dozer lines between postfire years 1 and 3 in ponderosa pine forests in western Montana (Sutherland, unpublished data, 2008). Adjacent burned plots were free of spotted knapweed the first year after fire but had been invaded by knapweed by the third year after fire; propagules within the dozer lines were the apparent source. Over many decades, nonnative species may increase in dominance both within fuelbreaks and in adjacent areas, up to about 10 to 20 m (Giessow 1997; Merriam and others 2006).

Pre-existing fuelbreaks that are planted with less flammable noninvasive vegetation (that is, greenstripping) may reduce the need for complete vegetation removal during a fire (Pellant 1990) and thus reduce the likelihood of invasion. In addition, less destructive control lines, such as wet lines or foam lines, may be less likely to increase plant invasions because extant vegetation is left in place. Mop-up activities that include raking organic material back over control lines may reduce subsequent increases in nutrient availability; organic mulch added in this process can increase microbial metabolism of available soil nutrients and reduce incident light, thereby suppressing germination of invasive plants. These recommendations follow from the plant invasion theory discussed earlier in this chapter and in chapter 2, but they have not been rigorously studied and should be evaluated in future studies.

Figure 14-2—Fuelbreak construction in a sagebrush (*Artemisia* spp.) steppe/pinyon-juniper (*Pinus-Juniperus*) woodland ecotone on the Colorado Plateau in northwestern Arizona. (Photo by Tim Duck, BLM, Arizona Strip Field Office.)

Fire suppression activities may promote plant invasions, but their influence on the amount of area that is ultimately burned needs to be considered as a potential counter-balancing factor. For example, if 100 acres of control line reduce a wildfire's area by 1,000 acres, then there may be a net reduction in the invasion potential of the landscape compared to the situation if no control lines were established. This is a simplistic example, and in reality many factors need to be considered, including the potential effects of the fire on native vegetation and the fire's proximity to populations of invasive nonnative plants. In addition, invasion potential is only one of many considerations in fire planning, and the benefits of fire as an ecosystem process (for example, in a frequent surface fire regime) may be more ecologically valuable than the potential negative effects of fire as a promoter of plant invasions.

Propagule Pressure

Fire suppression activities seem more likely to influence propagule pressure than resource availability (table 14-1). Firefighting crews and their equipment may disperse invasive plant propagules as they travel from other regions. They may also be vectors for local dispersal within the area of the fire. For example, fire camps are typically set up where the terrain is hospitable and where their ecological impacts will be minimal. These areas are typically large, flat clearings that have been disturbed in the past (for example, campgrounds, pastures, clearcuts, old fields). In many respects, it makes sense to localize the impacts caused by fire camps in areas that are already significantly altered. However, these areas often support populations of invasive plants. Propagules of these plants may adhere to fire personnel and their equipment as they move about camp and thereby may be dispersed elsewhere into the management unit as crews leave camp for the fireline.

Fire crew equipment largely consists of personal belongings (boots, clothes, sleeping bag, tent), personal protective equipment (gloves, helmet, goggles, fire pack, fire shelter), and hand tools (shovels, pulaskis, axes, fire rakes, hoes). This equipment can serve as vectors for the dispersal of invasive plants unless it is cleaned prior to reuse at other locations. At the least, firefighters should be given instructions to clean these items prior to leaving and arriving at a fire site. This practice has become standard operating procedure for fire crews following recent increased awareness of invasive plant management issues (Roberts, personal communication, 2005). It should also be adopted by contractors who provide support services such as food, restrooms, and showers.

Bulldozers and other heavy equipment can potentially spread invasives since they often accumulate significant amounts of soil and vegetation debris in their undercarriages (Matt Brooks, personal observation, St. George Utah, summer 2005). When heavy equipment is used, it should be washed prior to transport, at a commercial washing station enroute, or on-site when it arrives. It is becoming increasingly common for heavy equipment to be inspected prior to entering a fire zone, and in some cases equipment has been turned away if it shows signs of mud and other debris of unknown origin (Anderson, personal communication, 2004).

Aircraft are often used to transport and disperse water, foam, or other fire retardant materials. There is concern that aircraft such as helicopters with buckets or airplanes with holding tanks could become vectors for the introduction and local dispersal of invasive aquatic or riparian species, especially into local waterways from other regions, but also into upland areas. Nonnative species could establish in or along springs and creeks occurring within upland areas, but the risk for establishment in the fire area is probably low because the water is typically deposited onto non-aquatic upland sites.

The probability of dispersing aquatic or riparian plant propagules into burned areas from long distances is also probably low because water is typically obtained from local sources near fires. However, propagules can remain on equipment after water is released, and they may be dispersed into new geographic regions if aircraft are not decontaminated before being assigned to a new fire. There is also probably more potential for aircraft to disperse propagules between water sources in the vicinity of a fire than for them to disperse propagules into burned areas. Propagules may adhere to water holding tanks or buckets after water drops and then fall off during the next filling event. Repeated use of the same water source can help reduce the chances of such cross contamination. In addition, to help reduce the chance for local dispersal of invasive nonnative propagules, resource advisors assigned to a fire should identify preferable sources of water based on where existing populations of invasives occur. This requires pre-existing information that typically comes from the personal knowledge of local land managers but could also be based on comprehensive surveys and mapping efforts. Inspection and decontamination of water holding equipment before or immediately after fire should also reduce the dispersal risk.

Effects of Postfire Management Activities on Plant Invasions

There are three primary stages of postfire management planning and treatment implementation in the United States: (1) emergency stabilization, (2) rehabilitation, and (3) restoration. These terms reflect the policies and funding sources associated with all federal, and some state, land management agencies. The first two stages are generally under the purview of emergency fire management funding authorities, whereas the third stage is typically associated with nonfire programs and funding authorities (for example, natural resource management).

Emergency stabilization is focused on mitigating the immediate effects of fire and fire suppression activities during the first postfire year. The specific objectives are "to determine the need for and to prescribe and implement emergency treatments to minimize threats to life or property or to stabilize and prevent further unacceptable degradation to natural and cultural resources resulting from the effects of a fire" (USDA and USDI 2006a). The time period for emergency stabilization begins with containment of a fire and continues for 1 year. Emergency stabilization plans can be developed by local land management units (for example, BLM field offices, NPS park units, FWS refuges, Forest Service districts) or by overhead crews that specialize in this task (for example, Burned Area Emergency Response teams). In either case, a Burned Area Emergency Response (BAER) plan needs to be developed outlining the specific treatments and other activities that are proposed.

The most common objective of emergency stabilization plans is the prevention of soil erosion, but treatments for this purpose may have unintended impacts on invasive species. For example, contour felling of ponderosa pines in western Montana trapped not only overland sediment but also spotted knapweed seeds. Spotted knapweed densities were four- to five-fold higher above felled logs than 3 meters below the logs. Application of straw mulch had the opposite impact in perennial bunchgrass communities in western Montana (Sutherland, unpublished data, 2008). Burned, unmulched grasslands had spotted knapweed densities 50 times higher than burned, mulched grasslands 1 year after wildfire and 5 times higher 3 years after wildfire. Although burned, mulched grasslands had lower forb and total vegetation cover 1 year after fire; by 3 years following fire there was little difference.

During recent years, the prevention of plant invasions has increasingly been identified as a goal of emergency stabilization. Recent interagency guidelines from the United States Departments of Agriculture and Interior provide an excellent summary of how invasive plant management can be integrated into BAER plans (table 14-2) (USDA and USDI 2006a). Activities may focus on managing resource availability (for example, revegetation with noninvasive vegetation to minimize the availability of soil nutrients or light) or managing propagule pressure of invasive nonnatives (for example, postfire detection and monitoring, chemical, biological, mechanical, cultural and/or physical control treatment methods). Under emergency stabilization, this work can be done only if the management unit has a pre-existing program and/or approved plan to treat invasive plants. Emergency stabilization for invasive plant management is hampered by the policy of setting targets for reducing invasive plant numbers at prefire levels and not at some more ecologically relevant level. Also, the effective management of invasive plants often requires an integrated pest management approach, which is extremely difficult to implement within the 1-year emergency stabilization timeframe. For example, a single BAER application of the herbicide picloram eliminated spotted knapweed 1 year following wildfire in Montana perennial bunch grasslands (Sutherland, unpublished data, 2008). However, 3 years after herbicide application, spotted knapweed had re-established on 90 percent of these sprayed plots and knapweed cover was approaching pretreatment levels.

Rehabilitation plans focus on mitigating the effects of fire and fire suppression activities during the first 3 postfire years (USDA and USDI 2006b). They often involve reconstruction of minor infrastructure damaged as the result of fire (for example, fences and outbuildings), but they are increasingly addressing invasive plant issues as well. The management of propagule pressure, via monitoring for and direct control of plants known to be invasive in the area, is the most common approach during the rehabilitation phase. Species that are known to be the greatest management problems are typically the focus of these monitoring and control efforts. If target species are not previously known, then prioritization systems may be applied

Table 14-2—Federal interagency guidelines for the management of invasive plants within Emergency Stabilization (ES) and Rehabilitation plans (R) (USDA and USDI 2006a,b).

Emergency Stabilization and Rehabilitation funds can be used to control nonnative invasive plants in burned areas only if an approved plan for their management is in place prior to the wildfire. Integrated pest management methods are preferred, and they can include chemical, biological, mechanical, cultural, and physical treatments for minimizing the establishment of invasive species used in conjunction with vegetative treatments, or for site preparation for other treatments. Pesticides must be previously approved for use on public lands, and all applicable label and environmental restrictions must be adhered to.

Allowable Actions

- Assessments to determine the need for treatment associated with:
    - Known infestations
    - Possibility of new infestation due to management actions
    - Suspected contaminated equipment use areas (ES, R)
- Treatments to prevent detrimental invasion (not present on the site) by nonnative invasive species (ES, R)
- Treatment of invasive plants introduced or increased by the wildfire. The treatment objective when the population is increased is to maintain the invasion at no more than pre-wildfire conditions. (ES, R)
- Treatments to prevent the permanent impairment of designated critical habitat for federal and state listed, proposed, or candidate threatened and endangered species (ES)

Prohibited Actions

- Systematic inventories of burned areas (ES, R)
- Treatments designed to achieve historic conditions or conditions described in an approved land management plan, but that did not exist before the fire (ES)
- Treatments beyond 1 year post wildfire containment (ES)

to help identify them. Herbicide treatments may be proposed as follow-ups to initial treatments applied during emergency stabilization actions, which together can be designed as two phases of an integrated pest management plan. Seeding treatments are not frequently included in rehabilitation plans because land managers generally believe that the window of opportunity for pre-empting resources for invasive plants is mostly confined to the first postfire year (Matt Brooks, personal observation during the Hackberry Fire Complex BAER team planning session, Primm Nevada, Summer 2005). Revegetation is frequently proposed in rehabilitation plans, though it is not necessarily to suppress the establishment and spread of invasives. It is typically proposed to help native vegetation recover following fire, especially if the fire was thought to be excessively severe or otherwise undesirable.

Restoration is focused on the management of vegetation beyond the first 3 postfire years. It has been defined as "the continuation of rehabilitation beyond the initial 3 years, or the repair or replacement of major facilities damaged by fire" (USDA and USDI 2006a,b). The restoration phase has a much more comprehensive and long-term perspective than either emergency response or rehabilitation. Because restoration is separated in time from the emergency responses elicited by fire, it is almost universally managed by nonfire programs and funding authorities such as natural resources. The one exception may be fuels management (chapter 13), which is funded through fire programs and often has objectives that align with long-term restoration plans. Such objectives include the manipulation of vegetation (fuels) to restore more natural conditions and desired fire regimes. An example of this would be the thinning of understory vegetation in ponderosa pine forests with the objectives of reducing the potential for severe crown fire and restoring a more historically natural fire regime of frequent, low- to moderate-intensity surface fires. This long-term perspective of restoration projects is often very helpful in developing comprehensive plans for managing nonnative invasive plants, because short-term dominance by these species may be acceptable if over time their dominance wanes as native species recover.

Resource Availability

The use of fertilizers that may be pelletized with seed prior to application is not generally recommended because it can increase levels of available nutrients (table 14-3). Pelletized seed is also very expensive, adding significantly to the cost of seeding treatments (Roberts, personal communication, 2005). Invasive plants often utilize these extra mineral resources to the detriment of native species (for example, Brooks 2003). Nonnative and potentially invasive nitrogen fixing plants such as dryland alfalfa (*Medicago* spp.) and sweetclover (*Melilotus* spp.) have historically been included in seed mixes because they can provide a relatively inexpensive way to increase available soil nitrogen. More recently, native nitrogen fixing plants such as lupines (*Lupinus* spp.) have been included in seeding mixes. Although these nitrogen fixers could increase levels of available soil nitrogen and thereby increase dominance of invasive plants, such causative links have not been established by research and are not readily observed in the field (Pellant, personal communication, 2005). Alternatively, the addition of recalcitrant carbon sources, such as hydromulch, hay, or chipped fuels, can reduce available soil nutrients and shade the soil, thus suppressing the germination of invasive plant seeds.

Seeding of plant species that can rapidly establish and grow has the potential to usurp soil resources and intercept light, thus potentially reducing postfire dominance of invasive nonnative species (Pellant and Monsen 1993). In large-scale applications, seed is typically applied aerially (fig. 14-3). In smaller-scale applications, seed can be applied using a rangeland drill or broadcast and integrated into the soil by discing, harrowing, chaining, or raking. Although the establishment rate of seeded species is generally improved by integrating the seed into the soil, the associated tilling may damage existing vegetation and increase invasibility (Lynch 2003). Research is needed to compare the net effects that seeding versus seeding plus tilling has on the short- and long-term dominance of invasive plants.

Figure 14-3—Aerial seeding operation as part of the Emergency Stabilization Plan following the 2004 Chrome fire in southern Nevada. (BLM, Ely Field Office file photo.)

In the past, mostly nonnative species such as the perennial crested wheatgrass (*Agropyron* spp.) and Russian wildrye (*Psathrostachys juncea*) have been used in postfire seeding mixes (Pellant, personal communication, 2005). Nonnatives have been used because they are relatively inexpensive and readily available for seeding compared to most native species, and observations over the years suggest that they can compete with and suppress undesirable invasive nonnative plants (Roberts, personal communication, 2005). The logic of establishing one nonnative plant to prevent increased dominance by another is based on the idea that some nonnative species can dominate without producing severe negative ecological effects. For example, many nonnative annual grasses (such as *Bromus* spp. *Avena* spp.) produce more continuous fuels with lower fuel moisture during the heat of summer than nonnative perennial grasses, which grow more discontinuously and remain green throughout the year (Brooks and others 2004). It is believed that replacement of the nonnative annuals with nonnative perennials may increase the fire-return interval to the point were native vegetation adapted to longer fire-return intervals can recover in the Intermountain West of North America. Observations of decades-old crested wheatgrass seedings suggest that this may be occurring naturally in the Great Basin desert (Pellant and Lysne 2005).

Although seedings of nonnative perennial grasses have often been used in postfire landscapes to compete with other less desirable nonnative plants, relatively little has been known about the effectiveness of these treatments until recently (Pellant 1990; Pellant and Lysne 2005; Pellant and Monsen 1993). Some older publications provide evidence that nonnative perennial grass seeding can suppress cheatgrass (*Bromus tectorum*) (Hull 1974; Hull and Holmgren 1964; Hull and Pechanec 1947; Hull and Stewart 1948; Robertson and Pearse 1945), which alters fire regimes in some ecosystems of western North America (Brooks and Pyke 2001; chapter 3). However, these studies were very limited and relied largely on observational data.

A recent publication (Chambers and others 2007) reports that establishment, growth, and reproduction of cheatgrass is much higher following fire where herbaceous perennial plants (mostly native and nonnative bunchgrasses) were removed than where they were left intact in Intermountain West shrublands. Herbaceous perennials typically have high survival rates after fires in semiarid shrublands (Wright and Bailey 1982), and their quick recovery results in high utilization rates of soil nutrients such as nitrate, reducing nutrient availability and the subsequent productivity of cheatgrass in postfire landscapes (Chambers and others 2007). In contrast, where herbaceous species are removed, postfire levels of soil nitrate are relatively higher, resulting in increased production of cheatgrass. These results suggest that the maintenance of herbaceous perennials as a major prefire vegetation component may reduce the need for postfire management actions to control fine fuels created by cheatgrass. This study also suggests that postfire seedings of herbaceous perennials may suppress the dominance of invasive plants such as cheatgrass. However, the suppressive effects of seedings on invasive plants may not be evident during the first few postfire years, while they are only established as seedlings. It may take a number of years until mature stands develop and reach levels that effectively suppress invasives.

There is often strong pressure to quickly re-establish prevailing land use activities following fires. If these activities affect resource availability, they may inadvertently increase the invasibility of the landscape. For example, livestock grazing is a common use of public lands, and one of its primary effects is the removal of plant biomass, mostly herbaceous perennials that are typical forage species (Vallentine 2001). Biomass removal generally reduces competition and increases the availability of soil nutrients, which in theory increases landscape invasibility. If it is possible to target grazing on undesirable invasive plants, then it may help counteract the effects of increased soil nutrients. Reduced biomass of invasives that alter fire regimes may also help mitigate the ecosystem impacts of those species. However, it is difficult to control what livestock eat. In addition, repeated grazing in focused areas over long periods can lead to other problems such as soil erosion, soil compaction, and loss of native species diversity; and even short periods of grazing may allow nonnatives to rise to dominance. Further research is clearly needed in this area.

Propagule Pressure—Management of propagule pressure of invasive nonnative plants often focuses on direct control of nascent populations in postfire landscapes (table 14-3). For maximum effectiveness, this approach should include the following steps: (1) initial monitoring to locate nascent populations that may spread across the postfire landscape, (2) prioritization to decide which species need to be actively managed and where they need to be managed, (3) implementation of control treatments, (4) evaluation of treatment effectiveness, and (5) determination of the need for retreatment.

The first three steps need to be implemented during the first postfire year if they are supported by emergency stabilization funds. This timeframe makes the most sense ecologically as well, because during this time there is minimal competition from the extant vegetation and invasive plants have the greatest potential for establishment and spread.

Monitoring for new invaders should focus on likely pathways of invasion. These include linear corridors

Table 14-3—Recommendations for minimizing the potential of plant invasions during emergency stabilization, rehabilitation, and restoration activities. (Adapted from Asher and others 2001; Goodwin and Sheley 2001; and U.S. Department of Agriculture Forest Service 2001.)

Resource Availability
Minimizing Resource Input
Do not use fertilizers to promote plant growth.
Consider not using nitrogen-fixing plants in landscapes where increased nitrogen may increase invasibility.
Maximizing Resource Uptake
Consider covering exposed soil with an organic mulch (hydromulch or chipped fuels) to promote microbial activity that will take up N and P and reduce its availability to invading plants.
Minimize land uses that may reduce vigor of resprouting or establishing native plants (for example, livestock grazing).
Consider revegetating with fast-growing but noninvasive species to increase the uptake of resources that would otherwise be utilized by invasive species.
Propagule Pressure
Preventing Deliberate Dispersal
Revegetate with native species or nonnatives that are not likely to become invasive.
Minimizing Accidental Dispersal
Consider temporary closure of public access to burned areas to minimize propagule pressure.
Survey burned areas to locate nascent populations of invasive nonnative plants and eradicate or contain them so they don't spread across the postfire landscape.
Ensure that vehicles, equipment, and personnel do not disperse propagules into the project site.
Test seed mixes or other types of revegetation materials to ensure that they do not contain invasive species as contaminants.
Implement a monitoring and retreatment plan for invasive plants after the initial treatments are applied.

along which invaders can spread, such as roadsides, railroads, and utility rights-of-way (Brooks and Berry 2006; Brooks and Pyke 2001). They also include focused areas of disturbance to which invaders may disperse over long distances, such as livestock corrals or watering sites, mines, camping areas, OHV and military staging areas, old townsites, firelines, and backcountry landing zones (Brooks and Pyke 2001; Brooks and others 2006). Because these areas are extensive, monitoring should also be extensive, necessitating rapid assessment techniques, such as visual surveys of a given area (for example, between mile markers along a roadside) for a given amount of time. Ideally, this process can be complemented by pre-existing invasive plant maps to get the most comprehensive distributional assessment upon which prioritization and control plans can be based.

Prioritization of species and site may not be completed in time to implement control efforts within 1 postfire year. It requires a pre-existing prioritization of species within or adjacent to the burned area (for example, Brooks and Klinger, in press). Prioritization systems typically consider (1) the relative ecological and/or economic threats that the species pose, (2) their potential to spread and establish populations quickly, (3) their potential geographic and/or ecological ranges, and (4) the feasibility of control (Fox, A. and others 2001; Hiebert and Stubbendieck 1993; Morse and others 2004; Timmins and Williams 1987; Warner and others 2003; Weiss and McLaren 1999). Effectiveness monitoring should continue for an additional 2 years beyond control treatments with emergency stabilization funds, but follow-up treatments typically require additional funding before they can be implemented as part of rehabilitation or restoration plans.

Any land-use activity increases the chance for accidental introduction of invasive plant propagules, so minimizing these activities in postfire landscapes can reduce the potential for plant invasions. Any person or thing traveling into a recently burned area should be considered a potential vector, and the temporary closure of postfire landscapes to people and livestock can help reduce the potential for dispersal of nonnative invasive plants. In addition, postfire treatments that include the addition of organic materials (for example, straw mulch) or seed mixes have the potential to inadvertently introduce propagules of invasive nonnative species. It is imperative that these materials be certified weed-free and tested before they are applied. This practice would have been very beneficial after the 2000 Cerro Grande fire in New Mexico, where over 1 billion cheatgrass seeds were estimated to have contaminated an aerial seed mix that was applied as part of postfire management treatments (Keeley and others 2006a).

The intentional introduction of nonnative species is another source of invasive plant propagules that is not often scrutinized. Any species included in a seed mix should be evaluated for its potential to become a management problem in the future. Native species appropriate for the local vegetation (that is, local genotypes) are generally not a concern. In contrast, species that are not native to the area have the potential to introduce new functional types to the local vegetation that may change plant community relationships and ecosystem dynamics in the future. Many species of nonnative plants have been used for years in revegetation applications and appear to have some positive effects on plant community diversity as a result of their ability to compete with other, less desirable nonnative plants (Pellant, personal communication 2005; Roberts, personal communication, 2005). However, the research supporting these assumptions is limited, and decisions to include nonnative species in seed mixes should only be made after careful consideration of potential positive and negative outcomes.

Summary

The adage that an ounce of prevention is worth a pound of cure surely applies to the management of invasive plants. Fire managers share the responsibility of managing pubic lands with other resource management professionals, and they can play a key role in the prevention of plant invasions associated with wildland fires that may otherwise become significant and often intractable problems in the future. Postfire invasions that are prevented by some relatively simple actions by fire management personnel can reap great future rewards in terms of managing invasive plants.

The recommendations presented in this chapter are not meant to be comprehensive lists of actions that land managers should take to reduce the potential for plant invasions following fires. Rather, they are designed to provide some examples of procedures that can be integrated into land management plans. References to resource availability and propagule pressure as the primary causative factors of plant invasions were made to demonstrate how any land management action can be evaluated for its potential to affect landscape invasibility.

Many steps can be taken to minimize postfire plant invasions. Some are relatively simple and should not significantly impede fire management activities, whereas others may impose significant new layers of procedures. As always, firefighter safety is paramount in fire operations, and protection of natural resources and property is secondary. However, a fair amount of discretion is involved in determining how fire and postfire operations are carried out. Within this discretionary range, actions to reduce the potential for plant invasions need to be weighed against other considerations to arrive at a successful strategy for managing nonnative invasive species associated with fire.

Notes