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Chapter 4:

Use of Fire to Manage Populations of Nonnative Invasive Plants

Introduction

It may be impossible to overstate the complexity of relationships among wildland ecosystems, fires, and nonnative invasives. Strategies for managing these relationships are similarly complex; they require information on local plant phenology, ability to produce various levels of fire severity within burns, willingness to combine fire with other management techniques, and systematic monitoring to improve effectiveness. Oversimplification and short-sightedness in planning can lead to unintended degradation of the ecosystem; lack of monitoring may leave such consequences unnoticed and unaddressed. An inventory of the knowledge needed for planning an effective burning program could begin with the topics listed in table 4-1; managers need to understand the regeneration strategies and phenology of both target and desired species and their respective sensitivity to fire regime characteristics. Extensive information like this is currently available for only a few invasive species. If the information is not

Table 4-1—Inventory of species-specific knowledge needed to assess potential for using prescribed fire to control nonnative invasive plants. This information is needed not only for the invasive species but also for desired native species.

Topic	
Postfire regeneration from seed (production, dispersal, mobility, use of seed bank)	
Postfire vegetative regeneration strategies & location of perennating tissues	
Season	Most vulnerable to fire Least vulnerable to fire
Fire interval	Most favorable to regeneration Least favorable to regeneration
Probable fire effect	Low-severity High-severity

available to managers, they must monitor treatment sites carefully and learn from experience.

To assess the potential for managing nonnative invasive species with prescribed fire, managers must integrate knowledge about individual species. This includes understanding the condition of the plant community to be treated and altering conditions on the site that favor nonnatives (Brooks 2006; Keeley 2006b). If disturbance favors the invasive more than desired natives, fire alone is probably inappropriate (Keeley 2006b). If desired species are unable to establish dominance soon after a treatment, the target species or another undesired species is likely to take over (Goodwin and others 2002). Finally, ecological considerations must be integrated with practical aspects of fire management:

- What fire season(s), severities, and intervals seem most desirable for meeting treatment objectives?
- What fuels, weather conditions, and firing techniques are needed to produce the needed fire behavior?
- During what seasons, and how long after previous fire, are these conditions present?
- What other treatments might enhance the benefits of fire? Can fire be used to enhance the benefits or reduce the negative impacts of other treatments?

Treatments that prove successful in one place may not succeed in another (McPherson 2001). Garlic mustard (*Alliaria petiolata*), a nonnative biennial herb, provides an example of a species with fire responses that vary with fire regime characteristics and with the plant community being treated. In an Illinois oak (*Quercus* spp.) forest, spring fires with flame lengths up to 6 inches (15 cm) and fairly uniform burning reduced the density of both seedlings and mature garlic mustard plants (Nuzzo 1991); lower-intensity, less uniform fires had no appreciable effect. In another study of an oak forest in Illinois, a series of three annual dormant-season fires (flame heights up to 4 feet (1.2 m)) maintained garlic mustard at low percent cover, whereas it increased substantially without fire. Increased native species cover and richness accompanied decreases in garlic mustard (Nuzzo and others 1996). Conversely, in hardwood forests of Kentucky dominated by sugar maple (*Acer saccharum*) and white ash (*Fraxinus americana*), repeated prescribed fires had no appreciable effect on garlic mustard abundance or richness of native species (Luken and Shea 2000). Perhaps the only generalization that can be applied to management of invasive species with fire is that results of any treatment should be monitored and evaluated so management programs can be improved with time and experience (chapter 15).

Scientific literature on control of nonnative invasives with prescribed fire is limited. A recent comprehensive literature search and case history review found only 235 references on this topic (Rice 2005, review). Many of these were proceedings, abstracts, or managers' reports without supporting data. Relatively few publications report studies with replicated treatments and controls that meet the standards of peer reviewed journals. Details on fuel loads and fire behavior are generally lacking. But the biggest challenge to applying research on burning to control invasives is the variability of plant invasions themselves—the apparently limitless potential interactions of target invasives, desirable competitors, fuel properties, fire behavior, climate, and other ecosystem properties.

Despite the limitations of the knowledge available, a survey of studies conducted in North America provides insights about the use of fire for controlling nonnative invasive species. There are many ways to examine this subject. In the first section below, we discuss the effects of fire alone for managing invasives. Second, we look at fire combined with other management tools. In the third section, we examine the potential for manipulating three aspects of the fire regime—fire severity, uniformity, and frequency—to control undesired species and move the ecosystem toward a desired condition. Finally, in the last section we take a brief look at political and logistical aspects of managing nonnative species with prescribed fire. While this chapter looks at several facets of use of prescribed fire for controlling nonnative invasive species, it does not attempt to describe management of individual species in depth; for that information, see discussions of individual species in the bioregional chapters (chapters 5 through 11) and other sources, especially the Fire Effects Information System (FEIS, www.fs.fed.us/database/feis) and The Nature Conservancy's Element Stewardship Abstracts (tncweeds.ucdavis.edu/esadocs.html).

Use of Fire Alone to Control Nonnative Invasive Plants

To achieve long-term control of a nonnative invasive population with fire, managers must consider the species' regeneration strategies (by seed and vegetative means), phenology, and site requirements (reviews by Brooks 2006; DiTomaso 2006a; Rice 2005). To favor native or other desired species, the same considerations apply (table 4-1).

Prevention of Reproduction by Seed

Preventing Flowering or Seed Set—Prescribed fire can be used to prevent seed production in nonnative invasive species by killing aboveground tissues prior to flowering or seed maturation. The fire must be severe enough to damage target plants, so success may depend on quantity and quality of fuel on the site (see "Prescribed Fire Severity and Uniformity in Relation to Fuel Beds" page 57). Two examples highlight the importance of evaluating effectiveness over the long term and the difficulty of using fire to both reduce the target species and enhance native species.

Multiyear burning in California grasslands provided only temporary control of yellow starthistle (*Centaurea solstitialis*), a nonnative invasive annual forb. Yellow starthistle was associated with a variety of nonnative annual grasses and also native species, including purple needlegrass (*Nassella pulchra*), blue wildrye (*Elymus glaucus*), and beardless wildrye (*Leymus triticoides*). Conducting prescribed burns during late floral bud stage or early flowering stage of yellow starthistle prevented seed production while allowing for seed dispersal by associated vegetation (Hastings and DiTomaso 1996). Reduction in yellow starthistle vegetative cover following 3 consecutive years of burning corresponded to a 99 percent depletion of yellow starthistle seeds in the soil seed bank. During the same period, species richness and native forb cover increased on burned sites compared to unburned controls (Hastings and DiTomaso 1996; Kyser and DiTomaso 2002). Four years after cessation of annual burning on these sites, however, yellow starthistle cover and seed bank density had increased to near pretreatment levels, and native forbs, total plant cover, and diversity had declined (Kyser and DiTomaso 2002).

Use of prescribed fire to control biennial species is complex, but some success was achieved at a 45-year-old restored tallgrass prairie site in Minnesota. Prescribed burning of second-year biennial sweetclover (*Melilotus* spp.) prevented seed formation and reduced sweetclover frequency. However, the optimal burning schedule for reducing sweetclover (a sequence of early spring burning one year, followed by a May burn the next year) reduced native forb frequencies. Dormant season burns were least successful at controlling sweetclover but increased native forb frequencies (Kline 1983).

Destroying Seeds in Inflorescences—Burning the seeds of nonnative invasive annual grasses before they disperse is a goal of many restoration programs (for example see Allen 1995; Kan and Pollack 2000; Menke 1992). Important considerations for success include burning when seeds are most vulnerable to heat and before they are dispersed to the soil surface, and producing fires severe enough to kill the seed.

Seeds of many species are most vulnerable to heat damage before they are fully cured (DiTomaso and others 2001; Furbush 1953; McKell and others 1962). Backfiring has been recommended (McKell and others 1962; Murphy and Turner 1959) to maximize fuel consumption and thus heat produced, and to increase the duration of heating. McKell and others (1962) burned California grasslands dominated by medusahead (*Taeniatherum caput-medusae*), a nonnative annual grass, at different times as the seed developed and dispersed. Stands burned with a slow-moving backfire while medusahead seed was in the soft dough stage (highest moisture content) had the lowest density of mature medusahead the next growing season. Similarly, early June burning of medusahead infestations in northern California rangelands when desirable annual grasses had cured but medusahead seed was still in the milk to early dough stage "effectively removed" medusahead and increased desirable forage for at least 3 years (Furbush 1953). DiTomaso and others (2001) completely burned a barbed goatgrass (*Aegilops triuncialis*) infestation in California in 2 consecutive years when goatgrass seed was still in the soft dough stage. The barbed goatgrass seedling density in this pasture was reduced to 16 percent of the control in the year after the first burn and to zero the year after a second burn. Density reduction was less in a second pasture, which did not have enough fuel for a complete burn in the second year.

In fires carried by fine grasses and forbs, fire temperatures may be higher in the fine fuel canopy than at the soil surface (Brooks 2002; DiTomaso and others 1999). Under these conditions, seeds retained in inflorescences are likely to be more susceptible to fire than seeds on or in the soil. Brooks (2002) reports this phenomenon for red brome (*Bromus rubens*), a nonnative annual grass invading many sites in the Mojave Desert; Kan and Pollak (2000) report the same phenomenon for medusahead. However, a grassland fire may consume most of the standing dead biomass and still not produce enough heat to kill seeds in intact seedheads. For example, Sharp and others (1957) measured 87 percent germination of medusahead seeds collected after a prescribed fire that burned the culms nearly to the head but did not scorch the heads. Kan and Pollak (2000) comment that August burns (after seed dispersal) may actually increase medusahead abundance.

Laboratory studies confirm that extending the magnitude and duration of heating can greatly increase seed mortality for some nonnative species—for example, jointed goatgrass (*Aegilops cylindrica*) (Willis and others 1988; Young and others 1990) and spotted knapweed (*Centaurea biebersteinii*) (Abella and MacDonald 2000). Duration of heating in prescribed burns can be manipulated by planning the burn for a time when fuels are abundant, scheduling for the time of day with the highest temperatures, and manipulating ignition patterns. Deferring grazing increases fine fuels and can thus increase heat release (George

1992). Deferring grazing also avoids livestock-caused seed dispersal, which deposits seed on the ground and may make it less vulnerable to fire (Kan and Pollak 2000; Major and others 1960).

Destroying Seeds in the Litter and Soil—Grassland and surface fires may kill seed in the litter layer (Daubenmire 1968a; DeBano and others 2005, review), but it is often difficult to produce high enough fire severity at the soil surface to cause mortality. Species that release seed rapidly after maturation are especially difficult to eradicate with fire. For example, cheatgrass (*Bromus tectorum*) seeds begin to disperse shortly after culms cure enough to carry a fire. Consequently, for most of the year, almost all cheatgrass seeds are in the litter or on the soil. Fire may consume most of this seed, but some is likely to survive and establish highly fecund plants the following year. Thus fire is unlikely to cause long-term reduction of cheatgrass (Zouhar 2003a, FEIS review).

Mortality of invasive grass seed may be higher under the canopy of burned shrubs, where woody fuels increase heat release, than in open areas. Fires often destroy cheatgrass seed located directly under the sagebrush (*Artemisia* spp.) canopy (Young and Evans 1978). These areas must be planted with desirable species the year of the fire, however, or they will be reinvaded by seed from cheatgrass growing in the shrub interspaces, where sagebrush and woody fuels are lacking and hence burning is less severe (Evans and Young 1987).

Seeds in the soil are unlikely to be damaged by grassland fires (Daubenmire 1968a,b; Vogl 1974), and fires in shrublands and woodlands do not generally produce enough heat to kill seed buried deeper than about 2 inches (5 cm), since soil temperatures at this depth may not change at all during fire (Whelan 1995). However, the soil may experience temperatures lethal to seeds when heavy fuels, such as large woody fuels or deep duff, burn for long periods (chapter 2). Peak temperatures from spring and summer prescribed fires in the Mojave Desert varied with aboveground fuels and vertical location (fig. 4-1). Temperatures in areas with sparse grass/forb cover and along the edge of native creosote bush (*Larrea tridentata*) plants were not lethal to seeds, but temperatures under the shrubs, as deep as <1 inch (2 cm) below the soil surface, were lethal to red brome and native annual seeds. The spatial variability in fire severity led to complex fire effects on the plant community. While burning reduced red brome and native annuals under the burned shrub canopy for the 4 years of the study, two nonnative perennials—Mediterranean grass (*Schismus* spp.) and cutleaf filaree (*Erodium cicutarium*), which occur more commonly near the dripline than under the shrub canopy—recovered to preburn levels by the second postfire year. Also under the drip line, native annuals increased during the first 3 postfire years (Brooks 2002).

Ground fires in habitats with heavy litter and duff could produce lethal temperature regimes below the soil surface, but there are no reported cases where this type of burn has been employed to control invasive plants. Ground fires severe enough to destroy buried seed would probably kill perennating tissues of desired native plants, a negative consequence likely to outweigh the benefits of reducing the nonnative seed bank.

Depleting the Seed Bank by Fire-stimulated Germination—Synchronous germination of significant portions of the seed bank can increase target populations' vulnerability to follow-up treatments, including repeat burning. French broom (*Genista monspessulana*) and Scotch broom (*Cytisus scoparius*) are nonnative woody plants that invade grasslands, woodlands, and open forests; these species are currently most problematic in Washington, Oregon, and

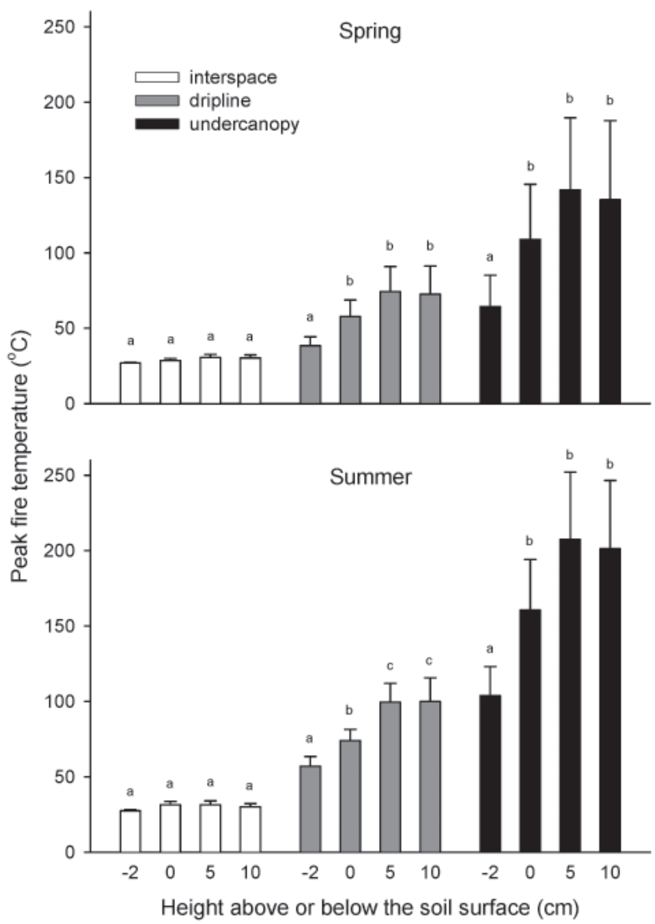

Figure 4-1—Peak fire temperature for three microhabitats and four heights from the soil surface in two seasons. Significant differences are indicated by different lower case letters. (Adapted from Brooks 2002, with permission from the Ecological Society of America.)

California (Zouhar 2005a,c, FEIS reviews). Standing, herbicide-treated, or cut broom stands in California are burned to kill aboveground tissues and to kill seed or encourage germination from the persistent seed bank (Bossard 2000a,b; Boyd 1995). Follow-up treatments with prescribed fire, propane torch, hand pulling, brush cutter, or herbicide within 2 to 3 years can kill sprouts and seedlings before new seeds are produced. With appropriate timing, seedlings may also die during seasonal drought periods following germination. Repeated prescribed burning is most effective if grasses are present to carry the fire (see "Prescribed Fire Severity and Uniformity in Relation to Fuel Beds" page 57). Removal sites should be monitored annually for 5 to 10 years to locate and kill new seedlings (Bossard 2000a,b).

Fire has also been used to deplete the seed bank of white and yellow sweetclover (*Melilotus alba*, *M. officinalis*) in Minnesota prairies (Cole 1991; Kline 1983,1986), but the benefit of seed reduction may be offset by reduction in native species cover (see "Preventing Flowering or Seed Set" page 48).

Induced Mortality and Prevention or Delay of Resprouting

Control of invasive biennial and perennial species requires either direct mortality of perennating tissues or depletion of carbohydrate reserves in these tissues (Whelan 1995).

Direct Mortality—It is generally not feasible to kill belowground perennating tissues with prescribed fire. Daubenmire (1968a) and Whelan (1995) reviewed studies of surface fires and found that soil temperatures below 1 inch (2.5 cm) are unlikely to reach 212 °F (100 °C) during a fire, even with high surface fuel loads in shrublands and forests. Temperatures decline rapidly with small increases in soil depth, reaching temperatures no higher than 120 °F (50 °C) 2 inches (5 cm) below the surface (Whelan 1995). Plant cell death begins when temperatures reach 120 to 130 °F (50 to 55 °C) (Hare 1961).

Direct mortality from fire has been achieved for some woody species by use of cutting or herbicides to increase fuel loads (see "Treatments that Increase Effectiveness of Prescribed Fire" page 53 and "Prescribed Fire Severity and Uniformity in Relation to Fuel Beds" page 57). In addition, prescribed fire may be effective for controlling species with shallow perennating buds. Steuter (1988) burned a mixedgrass prairie in South Dakota to suppress absinth wormwood (*Artemisia absinthium*), a nonnative invasive subshrub that has perennating buds at or near the soil surface. A series of four early May fires within a 5-year period reduced density of absinth wormwood by 96 percent.

Prescribed Burning to Deplete Carbohydrate Reserves—Repeated fires have been used to reduce postfire sprouting in some woody species, probably by reducing the plants' carbohydrate reserves. Managers of fire-adapted midwestern and eastern plant communities often suggest annual or biennial burning to control sprouting of nonnative shrubs if the burn treatment can be repeated for periods as long as 5 or 6 years (Heidorn 1991, review). In Alabama, annual burning during very dry periods eliminated European and Chinese privet (*Ligustrum vulgare* and *L. sinense*) (Batcher 2000a, TNC review), whereas a single burn treatment in northwestern Georgia (Faulkner and others 1989) caused no significant change in Chinese privet.

Use of repeated fire has produced equivocal results for several woody species. Glossy buckthorn (*Frangula alnus*) and common buckthorn (*Rhamnus cathartica*) are nonnative shrubs that form dense thickets in native grasslands. They have been reported both to decrease (Grese 1992, review) and increase (Post and others 1990) after repeated prescribed fire. In wet prairies of the Willamette Valley, Oregon, neither a single fall burn nor two consecutive fall burns significantly altered the density of nonnative invasive shrubs (sweetbriar rose (*Rosa eglanteria*), Himalayan blackberry (*Rubus discolor*), and cutleaf blackberry (*R. laciniatus*)) or trees (oneseed hawthorn (*Crataegus monogyna*) and cultivated pear (*Pyrus communis*)) (Pendergrass and others 1998). Nevertheless, the authors comment that repeated burning may gradually reduce the density and retard the expansion of woody species.

Prescribed burns are often conducted during the dormant season to protect vulnerable wildlife species (for example, Mitchell and Malecki 2003; Schramm 1978), but some researchers suggest that growing season burns would offer better control of woody nonnatives. Dormant season burns in the Northeast are followed by profuse sprouting from the roots and rhizomes of many nonnative woody species. Total nonstructural carbohydrate reserves are lowest during the growing season, so burning late in the growing season may deplete root carbohydrates of nonnatives more effectively than dormant-season burns (Richburg and others 2001; Richburg and Patterson 2003b). The same principle may apply in coastal prairies and forests in the southern United States being invaded by Chinese tallow (*Triadica sebifera*), a nonnative tree. The species is difficult to control with fire, but prescribed fires have reduced sprouting of small trees and prevented tallow from gaining dominance (Grace 1998; Grace and others 2001). Growing-season burns were more effective than dormant-season burns. Intense fires can damage large tallow trees, but stands of Chinese tallow suppress herbaceous species needed to carry fire, so frequent burning is not usually feasible (Grace and others 2001, 2005).

Burning to Favor Native Species

Taking Advantage of Varying Plant Phenology—Burning while an invasive species is actively growing and desired native species are dormant can reduce the invasive and simultaneously enhance the productivity of native species. This technique has been studied mainly in grassland ecosystems. In an Iowa prairie remnant burned 1 to 3 times in 3 years, native vegetation began growing earlier, matured earlier, and produced more flower stalks on burned than unburned sites. Repeated fires reduced the density of the nonnative invasive Kentucky bluegrass (*Poa pratensis*), which was beginning growth at the time of burning while native grasses were still dormant (Ehrenreich 1959). Willson (1992) found that burning in mid-May reduced smooth brome (*Bromus inermis*) and increased big bluestem (*Andropogon gerardii*), the desired native dominant, in a Nebraska tallgrass prairie. Smooth brome tillers were elongating at the time of burning. Earlier burning, when tillers were emerging, did not reduce smooth brome, as demonstrated by this study and also research by Anderson (1994).

Since plant communities are usually complex mixtures of species, it is not surprising that burn treatments that reduce nonnative invasive species often have mixed effects on the native plant community. It may be very difficult to use fire to reduce a nonnative species if a desired species has similar phenology. Two Wisconsin studies on prairie restoration and maintenance demonstrate this point. In one study native tallgrass prairie species were planted in abandoned fields dominated by nonnatives Kentucky bluegrass and Canada bluegrass (*Poa compressa*), and the sites were burned the following spring and 1 year later. Burns occurred while nonnative bluegrasses and natives Canada wildrye (*Elymus canadensis*) and Virginia wildrye (*Elymus virginicus*) were actively growing, but before other natives (indiangrass (*Sorghastrum nutans*), switchgrass (*Panicum virgatum*), big bluestem, and little bluestem (*Schizachyrium scoparium*)) commenced growth. One year after the second burn, the bluegrasses and wildryes had declined; most other native grasses had increased (Robocker and Miller 1955). A second study examined the effects of 8 burns in 10 years on a prairie remnant (Henderson 1992). Repeated late-spring fires reduced Kentucky bluegrass but also reduced native sedges (*Carex* spp.), bunchgrasses, and some forbs. Native porcupinegrass (*Hesperostipa spartea*) increased. In the same area, late fall and early spring burns reduced Kentucky bluegrass and had less effect on native species.

Where a site is infested with multiple nonnative invasive species, differences in their phenologies limit the benefits of burning. The manager may need to determine which species is most detrimental to the ecosystem and focus resources on controlling it (Randall 1996). Reports of fire effects in tallgrass prairie demonstrate the complexity of scheduling prescribed burns to maximize benefits. Late April burns on an Illinois prairie eliminated Kentucky bluegrass, which began growth in early April and reached peak production in mid-May. But the burns did not eliminate smooth brome, which began growth in mid-April and reached peak production about 3 months after the burns, although its productivity was reduced (Old 1969). Becker's (1989) research on repeat spring burning of prairie in southwestern Minnesota also had complex results. Five consecutive spring burns reduced cover of Kentucky bluegrass, smooth brome, and Canada thistle (*Cirsium arvense*), and native prairie species were favored in locations near prairie remnants. However, large patches of quackgrass (*Elymus repens*) persisted and expanded slightly into areas where invading woody species were killed, probably because quackgrass was not actively growing at the time of the fires.

Use of fire in California grasslands demonstrates the need for flexibility in scheduling burns to take advantage of susceptible phenological stages. Prescribed fire reduced nonnative invasive grasses (red brome, mouse barley (*Hordeum murinum*), slender oat (*Avena barbata*), and wild oat (*Avena fatua*)) and increased native plant cover in California grasslands if it was applied just before the invasive grasses set seed. However, the time of seed set in these grasslands can vary by as much as 2 months from year to year, depending on precipitation (Meyer and Schiffman 1999). More detail on this experiment is provided in "Burning Litter to Manipulate Species Composition" below. Thus monitoring of grass phenology and flexibility in management are both needed to use fire effectively. Flexibility and detailed scheduling may also be needed for use of fire in treatment areas that are large or cover complex terrain, where plant phenology and burning conditions may vary across the area.

If native species are sparse or low in vigor, burning will probably not shift dominance from nonnative invasives to native species, as demonstrated by pasture restoration efforts in Iowa (Rosburg and Glenn-Lewin 1992) and studies of "abused" rangeland in southern Nebraska (Schacht and Stubbendieck 1985).

Burning Litter to Manipulate Species Composition—Burning may stimulate fire-adapted native species by removing dead stems and litter, and may reduce nonnatives that grow well in litter. However, this technique is ineffective where litter removal leaves many surviving invasives or favors establishment of new invasives.

Season-dependent success with burning to remove litter is illustrated by research in the California grasslands described above (Meyer and Schiffman

1999). Initially, cover by nonnative annual grasses was greater than 97 percent. Litter was removed by burning and clipping/raking. Late spring burns and fall burns significantly increased cover and diversity of native vegetation and reduced cover and seed viability of nonnative grasses. Neither winter burns, which were less severe, nor partial mulch removal enhanced native cover or reduced nonnative cover significantly. Litter removal by fire can reduce other nonnative species, including soft chess (*Bromus hordeaceus*) (Heady 1956), cheatgrass (Evans and Young 1970, 1972; Young and others 1972a), and medusahead (Evans and Young 1970).

The usefulness of litter removal to reduce nonnative annual grass abundance is compromised if individual nonnatives respond with increased vigor and fecundity in the postfire environment. Examples from Sierra Nevada foothills and Midwestern prairie sites illustrate this point. At a Sierra Nevada foothills ponderosa pine site infested with nonnative annual grasses, a fall wildfire consumed the 1- to 2-inch (3- to 5-cm) litter layer. Cheatgrass and soft chess were reduced but not eliminated on burned plots; seedling density was 16 percent of that on adjacent unburned plots in the growing season after the fire. The reduction in annual grass density was not significant in the second postburn growing season, however, and by the third year the burned and unburned plots had near equal abundance of nonnative annual grasses. Effects on native species were not reported (Smith 1970). Whisenant and Uresk (1990) burned plots in Badlands National Park, South Dakota, that were dominated by Japanese brome (*Bromus japonicus*) and western wheatgrass (*Agropyron smithii*). Burning reduced Japanese brome density and standing crop in the first postfire growing season and favored native grasses, but Japanese brome density returned to preburn levels by the second growing season as litter began to accumulate (Whisenant 1990b; Whisenant and Uresk 1990).

While litter removal may reduce some nonnative annual grasses, nonnative forbs with regeneration facilitated by seed-to-soil contact often increase after litter removal. Cutleaf filaree seeds have a twisted, awn-like structure that forces the seed deep into the soil as it wets and dries, thus favoring establishment of this nonnative forb on bare soil (Bentley and Fenner 1958); germination is inhibited by a litter layer (Howard 1992a, FEIS review). Pickford (1932) noted a high abundance of cutleaf filaree in the Great Salt Lake Valley, Utah, in sagebrush and cheatgrass areas subject to frequent burning. Meyer and Schiffman (1999) measured a tenfold increase in cutleaf filaree on late spring burn plots in contrast to unburned control plots in a California grassland. In creosote bush and blackbrush (*Coleogyne ramosissima*) communities, cutleaf filaree cover was greater on burned than control plots 2 to 14 years after burns (Brooks 2002; Brooks and Matchett 2003).

Fire Combined with Other Treatments

If invasive species are generally promoted by fire, it does not make sense to attempt to use fire alone to reduce them (Keeley 2006b); however, fire is sometimes effective when used in combination with other treatments. Use of fire to deplete the seed bank, when mature plants will be controlled by other means, is discussed above (see "Depleting the Seed Bank by Fire-stimulated Germination" page 50), as is use of fire to suppress target species by litter removal. Mechanical and herbicide treatments can be useful to prepare for prescribed burning, especially on sites with sparse fuels. In addition, fire can be used to increase herbicide efficacy, prepare for other disturbance treatments, prepare a site for introduction of desired native species, and promote expansion of biocontrol organisms.

Treatments that Increase Effectiveness of Prescribed Fire

Mechanical, cultural, and chemical treatments can be used to increase the effectiveness of prescribed fire. Melaleuca (*Melaleuca quinquenervia*) is a nonnative tree that rapidly establishes, spreads, and eventually dominates southeastern wetland coastal communities and is well adapted to fire (Molnar and others 1991). A control program in southern Florida integrates cutting mature melaleuca, treating stumps with herbicide, and prescribed burning 6 to 12 months later to kill seedlings (Myers and others 2001). Complex programs of cutting, herbicide treatment, prescribed fire, and hand pulling have been combined to reduce French broom and Scotch broom in California (see "Depleting the Seed Bank by Fire-stimulated Germination" page 50). Research in the Northeastern states showed that cutting in early summer followed by burning in late summer prevented full recovery of nonstructural carbohydrates for at least 2 years in common buckthorn and another nonnative woody species, Japanese barberry (*Berberis thunbergii*). Growing season treatments were more effective than dormant season treatments (Richburg and Patterson 2003a).

Fire has been combined with grazing to restore tallgrass prairie in Oklahoma (Fuhlendorf and Engle 2004), based on the assumption that the native plant community evolved under a grazing-fire regime. This study compared plant community composition on unburned sites with sites managed in a patchy burn pattern, where one-third of the area was burned each year. Cattle were "moderately stocked" in both treatments.

In patch-treated areas, livestock devoted 75 percent of their grazing time to the most recently burned area. Treatment had little effect on native tallgrasses during the 4 years of the study. Abundance, diversity, and structural complexity of native forbs increased in patch-burned areas but did not change in untreated areas. Cover of sericea lespedeza (*Lespedeza cuneata*), a nonnative invasive forb, showed no net change on patch-burned areas but increased steadily on unburned areas.

Prescribed Fire to Enhance Efficacy of Other Treatments

Burning to Increase Herbicide Efficacy—Fire can be used to prepare a site for herbicide treatment, and combining herbicides with prescribed fire may reduce the amount of herbicide needed or the number of applications required. Herbicides may be more effective after fire in part because postfire herbaceous growth tends to be more succulent and have a less-developed cuticle than unburned herbage, resulting in more efficient absorption of herbicide (DiTomaso and others 2006a). It is important to note, however, that some herbicides cannot be applied immediately after burning, lest charcoal bind the active ingredient and make it unavailable for plant uptake (DiTomaso, personal communication 2004). Burning cheatgrass stands before emergence in preparation for applying herbicide may increase efficacy and reduce the herbicide required for control (Vollmer and Vollmer, personal communication 2005). DiTomaso's (2006b) review reports that yellow starthistle control usually requires 3 years of prescribed burning or clopyralid treatment when either method is used alone, but a similar level of control can be accomplished in only 2 years when a prescribed burn is conducted in the summer of the first year and clopyralid is applied the following winter or early spring. Fire has been used prior to herbicide application to enhance control of many other invasive species, including:

- Grasses (Lehmann lovegrass (*Eragrostis lehmanniana*), ripgut brome (*Bromus diandrus*), medusahead, and tall fescue (*Lolium arundinaceum*)) (Rice 2005; Washburn and others 2002)
- Forbs (fennel (*Foeniculum vulgare*), Sahara mustard (*Brassica tournefortii*), and perennial pepperweed (*Lepidium latifolium*)) (Rice 2005)
- Shrubs and trees (Macartney rose (*Rosa bracteata*), French broom, Scotch broom, gorse (*Ulex europaeus*), and tamarisk) (Gordon and Scifres 1977; Gordon and others 1982; Rice 2005)
- Vines (Japanese honeysuckle (*Lonicera japonica*) and kudzu (*Pueraria montana* var. *lobata*)) (Rice 2005)

Some success with this approach has also been reported for controlling medusahead (Carpinelli 2005) and squarrose knapweed (*Centaurea triumfettii*) (Dewey and others 2000). However, fire did not enhance herbicide effectiveness for controlling spotted knapweed (Carpenter 1986; Rice and Harrington 2005a), St. Johnswort (*Hypericum perforatum*), leafy spurge (*Euphorbia esula*), or Dalmatian toadflax (*Linaria dalmatica*) in western Montana (Rice and Harrington 2005a) (fig. 4-2).

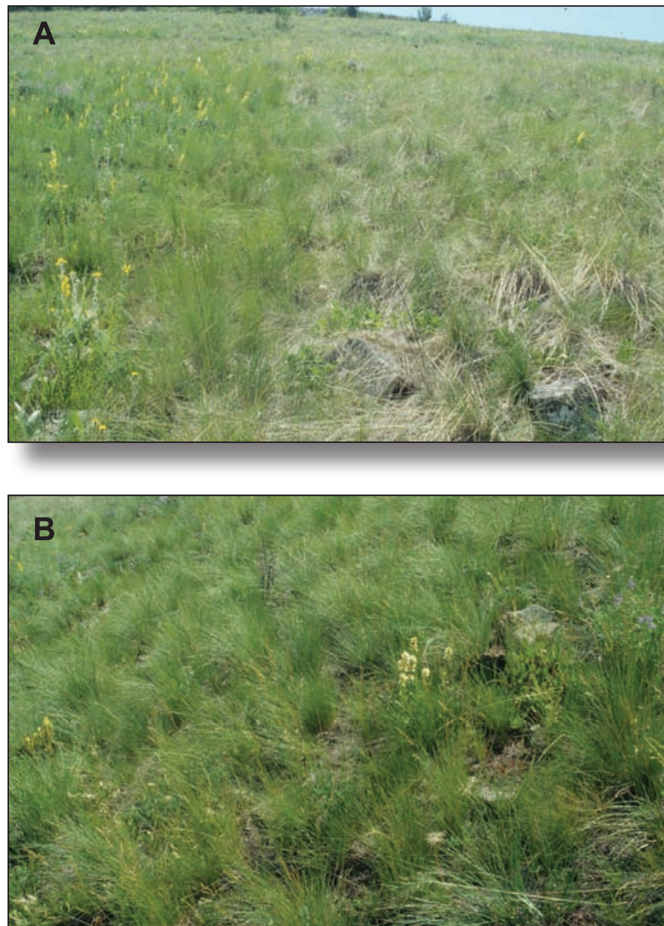

Figure 4-2—Mountain grassland at National Bison Range, Montana, 3 months after April burning to assess fire effects on Dalmatian toadflax. (A) Left side: Burn-only treatment produced no changes in Dalmatian toadflax cover or cover of native grasses relative to control plots. (A) Right side: Spray-only treatments reduced Dalmatian toadflax and enhanced native grass cover. (B) Spray-burn combination reduced Dalmatian toadflax, but native grass cover did not increase until the second growing season after burning. (Photos by Mick Harrington.)

Burning has been used in the southern states to prepare sites dominated by kudzu for efficient herbicide application, and fire is also used after herbicides to promote germination of native plants from the seed bank and encourage kudzu seed germination; seedlings can then be eliminated with herbicides (Munger 2002b, FEIS review).

The National Park Service has been using prescribed burning for over a decade to prepare tamarisk-invaded sites in the Lake Mead area for herbicide treatment (Curt Deuser, personal communication 2004). Prescribed crown fires are used to consume as much aboveground tamarisk biomass as possible; extreme fire weather conditions are usually necessary to initiate these fires, and yet they reduce tamarisk by 10 percent or less. Within 6 to 12 months of the burn, tamarisk sprouts are treated with low volume basal spray, which increases mortality to over 95 percent.

Even if combinations of fire or herbicide treatments control the target species, they may not enhance the native plant community. Research on Santa Cruz Island, California, found that although fire increased the effectiveness of herbicide for reducing fennel, the native plant community did not recover. The most substantial change that followed herbicide treatment, with and without fire, was an increase in other nonnative forbs and nonnative annual grasses (R. Klinger, personal communication 2006; Ogden and Rejmánek 2005).

Burning Before Flood Treatment—In wetland management, top-killing nonnative invasives with fire before flooding may allow water to cover sprouts, which may in turn reduce regrowth. Bahia grass (*Paspalum notatum*) was top-killed with fire in Florida wetlands, then flooded; percent cover declined from 25 percent before treatment to 11 percent after flooding. The time elapsed between treatments and observations was not reported, so success of the program is difficult to gauge (Van Horn and others 1995).

Fire is used with flooding to restore native woody species and animal habitat in the Bosque del Apache National Wildlife Refuge, New Mexico. Friederici (1995) reports that late summer burning followed by flooding reduced tamarisk. Taylor and McDaniel (1998a) describe combinations of herbicide treatment, mechanical removal, and burning that killed or top-killed tamarisk and disposed of residual biomass. Planting of native tree and shrub species on treated sites met with limited success, but natural recruitment of natives was very successful in areas flood-irrigated after tamarisk removal. These changes in habitat composition and structure were accompanied by increases in animal diversity: During the 5 years following treatment, the number of bird, small mammal, and reptile/amphibian species increased in the restored area.

Burning Before Seeding or Planting—Burning may be used to prepare a site dominated by nonnative invasive species for planting desired species. This approach has met with success in grasslands, especially those with deep litter. In the central Great Plains, herbicides were applied in the fall to a mixedgrass prairie infested with leafy spurge, Kentucky bluegrass, and smooth brome. Residual litter was burned the following spring, and native tallgrasses (big bluestem, indiangrass, and switchgrass) were then drill seeded. Nonnative grasses declined and native tallgrass production increased following these treatments. Where native tallgrass productivity was high, leafy spurge productivity was reduced. Litter removal by burning was considered an important part of the treatment, although results were not compared to an unburned control (Masters and Nissen 1998; Masters and others 1996).

Burning cheatgrass in sagebrush steppe has proven useful in preparation for seeding of desired grass species (Rasmussen 1994). Seeded perennial grasses established successfully after summer burning of cheatgrass-infested rangeland in the Palouse of eastern Washington. Burning reduced the cheatgrass seed crop and facilitated soil contact by planted native seeds. Cheatgrass seedlings emerged (90 stems/m^2) along with the desired perennial grasses, but cheatgrass density was less than on untreated sites or sites treated with herbicide or disking (all more than 170 stems/m^2). Fall herbicide application on burned sites reduced cheatgrass seedling density to less than 40 stems/m^2 (Haferkamp and others 1987).

The success of burning/seeding programs is limited if seed from target species is abundant adjacent to treated areas (Maret and Wilson 2000).

Burning to Enhance Biocontrol Efficacy—A recurring theme in this volume is the importance of managing **for** desired conditions or species as well as managing **against** invasives that have negative impacts on the ecosystem. Desired species may include introduced biological control agents already present on a site.

Prescribed fire may seem incompatible with use of biocontrol agents, especially insects; however, integration of knowledge about the invasive species, the biocontrol agent, and the fire regime may lead to a successful management program (Briese 1996) (fig. 4-3). Many factors listed in figure 4-3 have already been considered in this chapter, but some merit specific discussion here: The scale and uniformity of burns are important because they influence the availability of refugia for biocontrol agents and the ability of the biocontrol agent to recolonize the burned area. Fire season and frequency may need adjustment to accommodate the life cycle and reproductive capacity of the control agent. If the biocontrol agent passes some

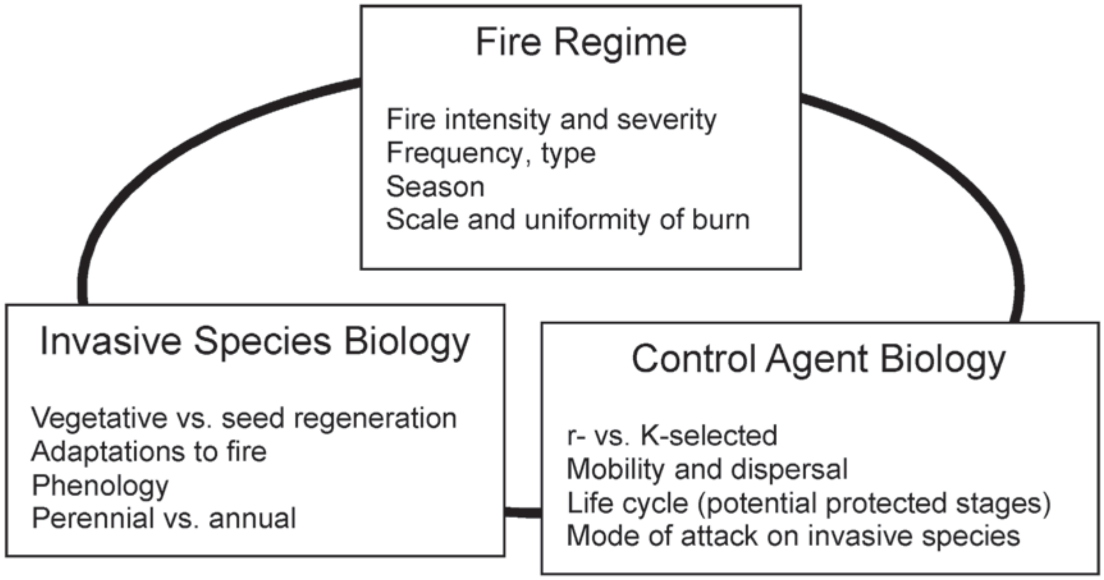

Figure 4-3—Interactions that need to be considered for management combining fire and biocontrol. (Adapted from Briese 1996.)

of its life cycle in a protected location (for example, root-boring larvae), the protected phase may provide a good season for burning. High-intensity wildfires in western Montana did not eliminate populations of *Agapeta zoegana,* a biocontrol agent that feeds on roots of spotted knapweed and has been introduced in many locations in western Montana (Sturdevant and Dewey 2002). Briese (1996) suggests that '*r*-selected' biocontrol agents could be preferable to '*K*-selected' agents if burning is planned, since the former could rapidly establish and increase after fire and would be more likely to have an impact on target plant density before another burn.

Research on grasslands in North Dakota demonstrates successful use of prescribed fire during seasons when a biocontrol agent is below ground. Areas invaded by leafy spurge were burned in mid-October and mid-May before the introduction of leafy spurge flea beetles (*Aphthona nigriscutis*). The beetles established successfully on 83 percent of burned plots, more than twice the establishment rate on unburned plots—possibly because litter removal favored establishment. Plots where flea beetle colonies established were then burned again in mid-October or mid-May. The adults were not active and juveniles were below ground at the time of both burns, and beetle populations were not affected. No reduction in leafy spurge density was attributed to the flea beetles in this short-term, small-plot study, but a large release of the beetles in a different area led to reduction of leafy spurge. The authors caution that spring burns of established colonies must be timed to allow leafy spurge regrowth before adult beetles emerge and need a food source (Fellows and Newton 1999).

Altering Fire Severity, Uniformity, Extent, and Frequency to Control Nonnative Invasive Plants

Thus far, this chapter has mentioned several aspects of the fire regime, but only seasonality of burning is discussed in detail (see "Prescribed Burning to Deplete Carbohydrate Reserves" page 51 and "Taking Advantage of Varying Plant Phenology" page 52). This section addresses several other aspects of fire regimes in relation to use of fire to control populations of nonnative invasive plants.

Prescribed Fire Severity and Uniformity in Relation to Season

Severity of prescribed fire varies with fuel moisture, which varies with season. For example, spring fires were too patchy to reduce density or cover of Scotch broom thickets in western Washington because grass cover was sparse and fuel moisture was high, whereas fall fires burned more continuously, produced higher maximum temperatures, and reduced Scotch broom significantly (Tveten and Fonda 1999). As mentioned in "Depleting the Seed Bank by Fire-stimulated Germination" (pg. 50), summer may be the optimal time to burn Scotch broom because seedlings germinating after fire will be exposed to harsh, dry conditions, increasing mortality.

The severity of fire prescribed for tamarisk control may also vary with season. One year after July burns on the Ouray National Wildlife Refuge, northeastern

Utah, 64 percent of tamarisk plants failed to sprout. Significantly fewer tamarisk plants were killed by September and October treatments, ranging from 4 to 9 percent. Fuels were drier and wind speeds were lower during the July burns than during fall burns (Howard and others 1983), possibly contributing to greater fire residence time and thus greater severity in July burns.

Prescribed Fire Severity and Uniformity in Relation to Fuel Beds

Some invasive forbs and trees reduce the amount and continuity of fine surface fuels and thus may reduce the ability of fires to spread, limit the time available for prescribed burning, or reduce fire severity. In a management review, Glass (1991) comments that two nonnative invasive forbs, cutleaf and common teasel (*Dipsacus laciniatus* and *D. sylvestris*), can be controlled in sparse, open grasslands by late spring burns. After teasel cover becomes dense, however, fire does not carry well so other treatments are needed—though they can perhaps be combined with fire. In western Montana, a discontinuous, nonuniform fuel bed forms as spotted knapweed density increases and displaces fine grasses. The coarse knapweed stems do not carry fire well under mild weather conditions, so the range of conditions that will produce effective but safe burns is narrow in knapweed-infested sites (Xanthopoulos 1986) (fig. 4-4). Some invasive woody species also reduce fine fuels. For example, beneath the canopy of Brazilian pepper (*Schinus terebinthifolius*), a nonnative invasive shrub-tree in Florida, grasses—and hence fine fuels—decrease as the plants increase in size. Doren and Whiteaker (1990) found that small Brazilian pepper plants with heavy grass fuel accumulations could be killed or severely retarded in growth by repeated biennial spring burning, but larger plants on sites with less grassy fuel either recovered rapidly from less severe burning or did not burn at all.

Numerous techniques have been used for increasing fine fuels to make prescribed burning feasible or increase its effectiveness. These include adding dead fine fuels to a site, cutting or mowing, planting noninvasive annual grasses, deferring grazing, and using herbicides to increase dead fuels. In Illinois prairies being converted from dominance by invasive cool-season grasses and forbs to native prairie species, Schramm (1978) recommends adding dry straw to facilitate spread of spring fires the first year after seeding. A common practice for reducing Scotch broom and French broom in the West is to cut the mature stems and let them cure prior to burning, thus increasing fire severity to discourage postfire sprouting and encourage germination from the soil seed bank (see

Figure 4-4—Fall prescribed burn in a mountain grassland in western Montana following herbicide treatment to reduce spotted knapweed. Due to low wind speeds, fire did not spread readily, as indicated by short flame lengths and patchy burn pattern. (Photo by Mick Harrington.)

"Depleting the Seed Bank by Fire-stimulated Germination" page 50). Boyd (1995) found that cut fuels in a site dominated by French broom in California were sufficient for one burn, but fine fuels were insufficient to fuel a second burn severe enough to kill broom resprouts and seedlings. Introduction of two annual grasses (soft chess and rattail sixweeks grass (*Vulpia myuros*)) increased fuels and effectiveness of fire. A previous seeding of grain barley (*Hordeum vulgare*) to increase fine fuel had failed to establish.

Litter and standing dead biomass must be present in a burned area before it can be reburned successfully. In rangelands, deferral of grazing can increase the fuel load and thus the heat produced by burning (George 1992; Rice 2005). In ecosystems where productivity is low, either due to site conditions or fluctuating weather patterns, several years' growth may be needed for accumulation of enough litter and dead fuel to carry an effective fire. Young and others (1972b) initially burned medusahead stands near Alturas, California, using a backing fire. Less litter and increased poverty weed (*Iva axillaris*), a native subshrub with succulent leaves, prevented second- and third-year fires from carrying with backfires and necessitated use of head fires. The three annual burns did not reduce medusahead.

Extent and Uniformity of Burns

Treatments to reduce nonnative invasive plants generally must cover a large enough area to prevent immediate re-establishment of the invasive. Many invasive species annually produce copious amounts of easily-dispersed seed (Bryson and Carter 2004). Such species cannot be eradicated from a small area if a propagule source is nearby. Thus fire size, uniform severity, and the condition of adjacent areas are important considerations. Research in sagebrush grasslands (Young and Evans 1978) and creosote bush scrub communities (Brooks 2002) demonstrates how spatial variation in fuels and fire severity can limit the effectiveness of fire for controlling nonnative invasive annual grasses (see details under "Destroying Seeds in the Litter and Soil" page 50). In Sierra Nevada forests, management strategies to reduce postfire invasion by nonnative species into fire-created gaps include elimination of nonnative seed sources from roadsides and other disturbed areas adjacent to burn sites and increasing the size of prescribed burns to increase the distance from seed sources (Keeley 2001).

Another issue related to the size and uniformity of burns is the regenerative capacity of desired native species: Can they establish in a treated area rapidly enough to attain dominance before the target invasive species re-establishes or is replaced by other invasives? Ogden and Rejmánek (2005) compared small- and large-scale treatments to restore grasslands on Santa Cruz Island, California. Fire-herbicide treatments at both scales reduced fennel but also led to substantial increases in nonnative invasive grasses (oats (*Avena* spp.), soft chess, Italian ryegrass (*Lolium multiflorum*), mouse barley, and ripgut brome). In the small-scale treatments, native species increased in cover and diversity, but this effect did not occur in the large-scale study site—probably because the small-scale plots were embedded in a more diverse plant community and, because of a higher ratio of edge to treated area, natives could spread readily into the treated area.

Fire Frequency

Where invasive species are susceptible to fire, a single burn usually only provides short-term control followed by recovery of the invasive in subsequent growing seasons or invasion by other undesired species (Rice 2005). Repeated burning is usually needed to sustain dominance of native species and suppression of invasives—a pattern that is not surprising in native communities that evolved with frequent fire. For example, one-time burning provided only short-term control of nonnative cool-season grasses in mixedgrass prairie in South Dakota (Whisenant and Bulsiewicz 1986), and of spotted knapweed in prairie remnants in Michigan (Emery and Gross 2005). In contrast, frequent burning of tallgrass prairie reduced abundance of nonnative cool-season grasses while stimulating native warm-season grasses (Smith and Knapp 1999, 2001; Svedarsky and others 1986). Parsons and Stohlgren (1989) found that repeated spring and fall fires reduced the diversity and dominance of nonnative invasive grasses in Sierra Nevada foothills grasslands, but this effect lasted less than 2 years. "Prescribed Burning to Deplete Carbohydrate Reserves" (pg. 51) presents some examples of the use of repeated burns to control nonnative invasive woody species.

Even where a plant community seems adapted to frequent fire, fuels may not accumulate rapidly enough to support fires frequent enough, severe enough, or uniform enough to accomplish management objectives. An example comes from California grasslands dominated by nonnative annual grasses, where DiTomaso and others (2001) conducted late spring burns for two consecutive years to reduce barbed goatgrass. The first burn was complete on all study sites, but fuels were too sparse to support a complete second burn on two of the three sites. Control of barbed goatgrass after the second burn was proportional to the completeness of the burns; a burn that covered about half of one study site did not reduce barbed goatgrass cover at all (fig. 4-5).

High-frequency burning, even in ecosystems with short presettlement fire-return intervals, may increase the likelihood of new invasions, cause unwanted erosion, or reduce desired native species. DiTomaso's

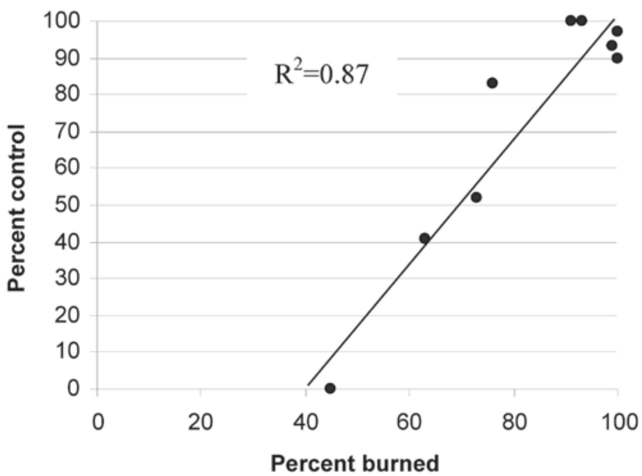

Figure 4-5—Relationship between completeness of burn and control (percent reduction in cover) of barbed goatgrass in a California grassland. (Adapted with permission from DiTomaso and others 2001, California Agriculture 55(6):47-53; copyright UC Regents 2001.)

(2006b) review notes that repeated burning may accelerate establishment and spread of invasive species not targeted by the original treatment, especially producers of abundant windblown seed. Repeated burning also exposes the soil to repeated heating and postfire raindrop impact, increasing the risk of erosion (Brooks and others 2004). In western Washington, 50 years of annual broadcast burning converted a community dominated by native perennial bunchgrasses, especially Idaho fescue (*Festuca idahoensis*), to one dominated by nonnative invasive grasses and forbs. On the other hand, fire exclusion allowed woody species, including the nonnative Scotch broom, to establish and persist (Tveten and Fonda 1999). A northern prairie grassland in the aspen parkland of east-central Alberta was burned each spring for at least 24 years. Annual burning significantly reduced smooth brome cover, but native rough fescue (*Festuca altaica*) cover was also 50 percent lower, and several other native cool-season grasses declined under this regime (Anderson and Bailey 1980). These results suggest that burning with variable frequency should be considered for controlling nonnatives and promoting native species. Variable fire-return intervals no doubt characterized many historic fire regimes and may be important for maintaining desired plant community composition and structure (Wills 2000).

In ecosystems that have not evolved with frequent fire, fire-return intervals short enough to suppress one nonnative invasive species may favor another or may cause other negative impacts. For example, multiple burn treatments are likely to select against native animals that have young at the time of burning (DiTomaso 1997). Keeley (2001) observes that frequent understory burns could reduce nonnative bull thistle (*Cirsium vulgare*) in ponderosa pine forests of the Sierra Nevada, but they would also severely reduce ponderosa pine seedlings. For prescribed fire to control Scotch broom effectively in Oregon white oak (*Quercus garryana*) woodlands, it must be applied frequently enough to prevent fuel buildup but not so frequently that nonnative herbaceous species are favored over native species (Zouhar 2005a).

Management of a Human Process: Constraints on Use of Prescribed Fire

Prescribed fire can be used to control some invasions by nonnative plant species, especially when integrated with other control methods in a long-term program. Fire is often seen as a means of treating a large area in a cost effective manner (Minnich 2006). However, use of fire is accompanied by concerns about safety and effects on other resources. The political and logistical obstacles to use of fire are not necessarily related to the objective. Responsibilities for safety and protection of property apply to use of fire for any purpose, and these challenges have been discussed by many authors. Minnich (2006) presents a thorough discussion of issues in regard to using prescribed fire for invasive species control, summarized here.

Any group or agency using prescribed fire is responsible for safety and protection of property. Operational challenges include staffing with a qualified program coordinator and fire manager, completing agreements with partners, and obtaining necessary training and equipment. Other obstacles include

- Restrictions on allowable burn area or season due to smoke impacts
- Lack of a suitable time window for completing the burn
- Opposition from neighbors and the community
- Unwillingness of employees to assume additional work or responsibility
- Lack of commitment at higher levels of an organization
- Lack of support from regulatory agencies

Use of prescribed fire may also conflict with other management needs or resource objectives, another issue not unique to use of fire to control invasive species. While the optimum time for a prescribed burn may be summer or fall, resources may be unavailable during these seasons due to wildfire activity, competing projects, or limited funds (Minnich 2006).

A common ecosystem-related problem is that timing of burns interferes with wildlife needs. DiTomaso (1997) notes that fire's potential impact on small animals and insects may be the most overlooked risk of burning. Spring burning is prohibited on many wildlife refuges because of impacts on nesting birds (Rice 2005). Illinois grasslands, for example, can be burned from mid-March to mid-April, but after that, burning may disrupt nesting birds and cause mortality to reptiles (Schramm 1978). The author's description of the difficulty of accomplishing a successful burn within a limited time is apt. One must be "poised and ready to burn at the proper moment" since usually there is only one chance for a "good" burn. In some areas, such as bush honeysuckle and buckthorn stands, nonnative species have formed dense monospecific communities that native songbirds now depend upon. In such cases, the nonnative species may need to be removed incrementally, in coordination with restoration of native shrubs, to provide continuous nesting habitat (Whelan and Dilger 1992). These few examples demonstrate the importance of developing clear objectives regarding nonnative invasive species and integrating all management programs to meet management goals.

Conclusions

To determine if fire can be used to reduce invasions by nonnative species, precise knowledge of invasive plant morphology, phenology, and life history must be combined with knowledge of the invaded site, its community composition, condition, and fire regime. Nonnative species that survive and/or reproduce successfully in burned areas are not likely to be suppressed by fire alone unless some aspect of the fire regime (usually season, frequency, or severity) can be manipulated to stress the nonnative without stressing the native species. This kind of treatment is most likely to succeed in ecosystems where the native plant community responds well to fire. Burning has been used with some success in grasslands and to prepare a site dominated by nonnative invasive species for planting of desired species.

It is possible to combine fire with other treatments to reduce plant invasions. In wetlands of Florida and riparian areas of the Southwest, fire has been used to top-kill nonnative species before flooding, a treatment combination that may reduce bahia grass in Florida and tamarisk in New Mexico. Fire has been used to prepare invaded sites for herbicide treatment, and herbicides have been used before fire to increase dead fuels, thus increasing fire intensity and severity. While success has been reported with these techniques in a variety of plant communities, there have also been failures, and long-term studies are few. The order, number, and timing of treatments influence success, so monitoring, follow-up over the long term, and an adaptive approach are essential components of a treatment program.

Treatments to reduce invasions by nonnative plants must cover a large enough area to prevent immediate re-establishment of the invasive. Even then, success will likely be limited if seed from target species is abundant adjacent to treated areas or if other conditions (soil disturbance or climate change, for instance) prevent desired native species from increasing and dominating on treated sites.