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Chapter 12:

Gaps in Scientific Knowledge About Fire and Nonnative Invasive Plants

"The issue I am attempting to deal with… is not knowledge but ignorance. In ignorance I believe I may pronounce myself a fair expert."

Wendell Berry (2000), *Life is a Miracle*

Abstract—*The potential for nonnative, invasive plants to alter an ecosystem depends on species traits, ecosystem characteristics, and the effects of disturbances, including fire. This study identifies gaps in science-based knowledge about the relationships between fire and nonnative invasive plants in the United States. The literature was searched for information on 60 nonnative invasives. Information was synthesized and placed online in the Fire Effects Information System (FEIS, www.fs.fed.us/database/feis), and sources were tallied for topics considered crucial for understanding each species' relationship to fire. These tallies were analyzed to assess knowledge gaps. Fewer than half of the species examined had high-quality information on heat tolerance, postfire establishment, effects of varying fire regimes (severities, seasons, and intervals between burns), or long-term effects of fire. Information was generally available on biological and ecological characteristics relating to fire, although it was sometimes incomplete. Most information about species distribution used too coarse a scale or unsystematic observations, rendering it of little help in assessing invasiveness and invasibility of ecosystems, especially in regard to fire. Quantitative information on the impact of nonnative plants on native plant communities and long-term effects on ecosystems was sparse. Researchers can improve the knowledge available on nonnative invasive plants for managers by applying rigorous scientific methods and reporting the scope of the research, in both scientific papers and literature reviews. Managers can use this knowledge most effectively by applying scientific findings with caution appropriate to the scope of the research, monitoring treatment results over longer periods of time, and adapting management techniques as new information becomes available.*

Introduction

Wildland managers face challenges in obtaining and using information about nonnative invasive plant species (as defined in chapter 1) and fire. What they require is detailed knowledge about complex issues, including:

- The likelihood of establishment, persistence, and spread of nonnative invasives under various disturbance regimes;
- The probable interactions of invasive species with native plant species, and how these interactions influence community and ecosystem properties; and
- Quantitative descriptions of results of management actions, particularly fire exclusion, use of prescribed fire, and postfire rehabilitation.

What is usually available to managers is a smattering of knowledge about the biology of the nonnative plant itself (sometimes available only from the region of origin or not available in English); information from agricultural science that focuses on interactions of the nonnative species with crop plants and tillage systems; and some knowledge about North American ecosystems and fire, framed almost entirely in terms of native species. Relatively little information specifically addresses nonnative invasive species' interactions with fire in native North American plant communities. The scope of this problem is greater than a lack of knowledge about invasives themselves, because the nature and condition of a plant community strongly influence its susceptibility to invasion (chapter 2). Even where scientists have reported interactions between nonnative invasives and wildland fire in specific ecosystems, the knowledge may be anecdotal or incomplete (D'Antonio 2000; Grace and others 2001; McPherson 2001), applicable only to a specific ecosystem under a narrow range of conditions (Klinger and others 2006a), or limited to laboratory conditions (so applicability to field conditions is unknown).

To assess the quality of information on fire and invasive species that is available to managers, we identified information gaps on the basic biology, ecology, and relationship to fire for 60 nonnative invasive plant species. Our goal was to address two main questions:

1. How can research contribute most meaningfully to increasing and sharing knowledge about nonnative invasives and fire?
2. How can managers best apply current scientific knowledge about nonnative invasives and fire?

Methods

In spring 2001, we began a 4-year project to synthesize knowledge on fire and nonnative invasive plants for the Fire Effects Information System (FEIS, online at www.fs.fed.us/database/feis). Our task was to produce literature reviews covering 60 nonnative invasives. We selected the species to be covered by asking land managers from federal agencies throughout the continental United States (excluding Alaska) for nominations, resulting in a list of 162 species. We excluded species recently covered in FEIS (medusahead (*Taeniatherum caput-medusae*), leafy spurge (*Euphorbia esula*), smooth brome (*Bromus inermis*), and red brome (*B. rubens*)) and then excluded the species with the least scientific literature available on basic biology, ecology, and fire. Table 12-1 lists the species selected, their grouping into knowledge syntheses (called "species reviews" in FEIS), and the date that each was completed. Our list is neither a random nor a systematic sample of nonnative plant species in North America, but it represents many nonnative invasives about which managers are concerned and about which at least some scientific research has been published.

For each species or group of species on our list, we obtained, reviewed, and synthesized information from the scientific literature. We searched for information by scientific and common names using two main sources: (1) the Citation Retrieval System, which is the citation database for the Fire Effects Library at the USDA Forest Service Fire Sciences Laboratory, Missoula, Montana (available at http://feis-crs.org); and (2) WEBSPIRS from Silver Platter, provided by the USDA Forest Service, Rocky Mountain Research Station Library, Fort Collins, Colorado. These searches yielded peer-reviewed journal articles, literature reviews, proceedings from scientific meetings, theses and dissertations, book chapters, and technical papers from research groups in state and federal agencies. Our sources were not restricted to single-species studies; any literature that included the species of interest was reviewed and pertinent information was included in the review. We also conducted Internet searches for each species, which generally yielded information from non-peer-reviewed sources such as University Extension Services and natural history organizations. In the process of reviewing the literature, we frequently discovered and obtained additional pertinent articles. Finally, where knowledge gaps remained after the literature search, we occasionally obtained information in the form of personal communications from researchers and managers familiar with the species.

We used the FEIS species review template (table 12-2) to ensure completeness and consistency of information. While planning and writing species reviews, we kept

Table 12-1—Nonnative invasive plant species used for this analysis. Common names are from the Fire Effects Information System (FEIS, www.fs.fed.us/database/feis) or PLANTS database (plants.usda.gov).

Scientific name(s)	Common name(s)	Number species[a]	Date completed[b]
Acer platanoides	Norway maple	1	May-03
Acroptilon repens	Russian knapweed	1	Feb-02
Ailanthus altissima	Tree-of-heaven	1	Feb-04
Alliaria petiolata	Garlic mustard	1	Oct-01
Arundo donax	Giant reed	1	April-04
Bromus tectorum	Cheatgrass	1	Apr-03
Cardaria draba, C. pubescens, C. chalapensis	Hoary cress species	3	Feb-04
Carduus nutans	Musk thistle	1	Jun-02
Celastrus orbiculatus	Oriental bittersweet	1	March-05
Centaurea diffusa	Diffuse knapweed	1	Oct-01
Centaurea maculosa	Spotted knapweed	1	Sep-01
Centaurea solstitialis	Yellow starthistle	1	Jun-03
Chondrilla juncea	Rush skeletonweed	1	Mar-04
Cirsium arvense	Canada thistle	1	Nov-01
Cirsium vulgare	Bull thistle	1	Aug-02
Convolvulus arvensis	Field bindweed	1	Jul-04
Cynoglossum officinale	Houndstongue	1	Aug-02
Cytisus scoparius, C. striatus	Scotch and Portuguese broom	2	Dec-05
Elaeagnus angustifolia	Russian-olive	1	Aug-05
Elaeagnus umbellata	Autumn-olive	1	Oct-03
Genista monspessulana	French broom	1	Dec-05
Hypericum perforatum	Common St. Johnswort	1	Jan-05
Imperata cylindrica, I. brasiliensis	Cogongrass, Brazilian satintail	2	July-05
Lepidium latifolium	Perennial pepperweed	1	Oct-04
Lespedeza cuneata	Sericea lespedeza	1	Feb-04
Ligustrum vulgare, L. sinense, L. japonicum, L. amurense	Privet species	4	Jun-03
Linaria dalmatica, L. vulgaris	Dalmatian and yellow toadflax	2	Aug-03
Lonicera japonica	Japanese honeysuckle	1	Dec-02
Lonicera fragrantissima, L. maackii, L. morrowii, L. tatarica, L. xylosteum, L. x *bella*	Bush honeysuckles	6	Nov-04
Lygodium microphyllum, L. japonicum	Climbing fern species	2	Dec-05
Lythrum salicaria	Purple loosestrife	1	Jun-02
Melaleuca quinquenervia	Melaleuca	1	Sept-05
Microstegium vimineum	Japanese stiltgrass	1	Jan-05
Potentilla recta	Sulfur cinquefoil	1	Dec-03
Pueraria montana var. *lobata*	Kudzu	1	Jul-02
Rosa multiflora	Multiflora rose	1	Sept-02
Schinus terebinthifolius	Brazilian pepper	1	Jan-06
Sonchus arvensis	Perennial sowthistle	1	Aug-04
Sorghum halepense	Johnson grass	1	May-04
Spartium junceum	Spanish broom	1	Dec-05
Tamarix ramosissima, T. chinensis, T. parviflora, T. gallica	Saltcedar, small-flowered tamarisk, French tamarisk	4	Aug-03
Triadica sebifera	Chinese tallow	1	Sept-05
Ulex europaeus	Gorse	1	March-06

[a] Number of species included in the review
[b] Date the species review went online; literature that became available after that date is not included in the review or this analysis.

Table 12-2—Structure of FEIS plant species reviews and topics covered in each section of a review. Sections and topics highlighted in bold print were considered crucial for understanding relationship between plant species and fire. Sources providing information on these topics were tallied for this analysis.

Review section	Topics covered
Introductory information	Scientific and common names, abbreviations, synonyms, code names Taxonomy description **Life form** (tree, shrub, herb, etc.) Legal status (threatened, endangered, etc.) Authorship and citation
Distribution and occurrence[a]	
Botanical and ecological characteristics	General characteristics **Raunkiaer life form**[b] Reproduction (includes breeding system, pollination, **seed production, seed dispersal, seed banking, germination/establishment/seedbed requirements, growth, and asexual reproduction and regeneration**[c] **Site characteristics**[a] (includes topography, elevation, climate, and soils) **Successional information** (includes **longevity,**[a] **response to disturbance**[c], and **competitive interactions**[a]) Seasonal patterns (**aboveground phenology, belowground phenology**)
Fire ecology	Fire adaptations (including **heat tolerance of tissues** and **seed**), fire regimes **Postfire regeneration strategies**
Fire effects	**Immediate fire effect on plant** Species response to fire (includes **postfire establishment** and postfire **vegetative response**) Fire management considerations (includes fire as a control agent)
Fire Research Project (fire experiment)[d]	
Management considerations	Importance to livestock and wildlife Other uses Impacts and control
Literature cited	

[a] Information on distribution, site characteristics, succession, longevity, and competitive interactions was combined for this paper to examine available information on where a nonnative species occurs and where it may become invasive.

[b] Raunkiaer (1934)

[c] Information on asexual regeneration and response to disturbance was combined for this paper to examine available information on post-injury regeneration potential.

[d] "Fire Research Project" is an optional category in a FEIS species review that describes research providing quantitative information on the prefire and postfire plant community, burning conditions, and fire behavior. It is included only if such research is available.

track of knowledge gaps as follows: We identified sections and topics crucial for understanding the plant's relationship to fire (shown in bold print, table 12-2). To this list of topics, we added questions related to fuels and fire regimes: Does any available research provide information about nonnative invasive plants' fuel characteristics or compare the fuel characteristics of invaded versus uninvaded sites? Does research provide evidence that nonnative plant invasions alter presettlement or reference fire regimes? We then added questions related to fire experiments: Does any research describe effects of fires of different severities, fires in different seasons, or fire treatments repeated at different intervals? Does research describe fire effects after the first postfire year?

As we wrote each species review, we used key phrases, such as "research is needed" and "incompletely understood" to identify knowledge gaps. A subsequent search of completed reviews for these key phrases highlighted topics with knowledge gaps.

Knowledge gaps were often attributable to lack of information, but some occurred because the available information covered only a narrow range of conditions or a small geographic area. Knowledge gaps also occurred when information was of uncertain quality, such as anecdotal evidence and assertions unsubstantiated by data. Such knowledge can be useful to managers, but it is important that readers recognize its limited scope of inference. To help readers apply published knowledge appropriately, Krueger and Kelley (2000) suggest identifying the nature of cited publications and classifying them as either professional resource knowledge, experimental research, case history, or scientific synthesis. In a similar vein, we developed a numerical scale to rank publications on fire and invasive species. This scale represents a continuum of information "quality," based on the study's evident rigor and clear scope of inference—from "high" (rank of 4) to "no information" (rank of 0):

- 4 Evidence from primary research published in a peer-reviewed journal
- 3 Evidence from primary research published in a technical paper from a research group in a state or federal agency, thesis or dissertation, book chapter, proceedings, or flora
- 2 Other substantial, published or unpublished experimental or observational data
- 1 Assertion with no experimental or observational data (that is, source of evidence for the assertion is unknown)
- 0 No information or assertions at all

The highest value in the information-quality scale (4) represented primary research published in peer-reviewed journals; for these articles, the population, variables, and scope of inference were usually well described, and blind peer review indicated the knowledge was probably reliable. An information quality value of 3 represented similar information published in an outlet that was reviewed by peers, but not anonymously. We classified publications ranked 3 and 4 as "high-quality" information. A value of 2 represented reports that had not been reviewed, such as reports of management or control activities, as well as information reported without a description of rigorous scientific procedure (that is, not containing hypotheses, controls, replication, or statistical analyses) and thus having unknown certainty and scope of inference. A value of 1 represented knowledge considered poor in quality or reliability, such as anecdotal knowledge and casual observations, for which the scope of inference was poorly defined or not described at all. Anecdotal information of this type was often found in literature or knowledge reviews.

Because the information-quality scale was subjective it had the potential to misrepresent the quality of information. We recognized, for example, that blind peer review does not guarantee accuracy even though we ranked its information quality as high (4), and a single peer-reviewed study may not have provided sufficient information to support widespread application. In contrast, a manager may possess bountiful, accurate, unpublished data (ranked 2) or accurate anecdotal information (ranked 1) that applies directly to management. Therefore we consider the information-quality scale a rough but useful indicator of information quality.

We examined the knowledge gaps in each species review using the information-quality scale. For botanical and ecological information, we recorded the highest quality of information available on identified topics. For fire-related information, we identified the highest quality of information available on each topic and also tallied the total number of citations, of any quality, available on each topic.

Results

No knowledge gaps were identified in any of the 43 species reviews for three of the highlighted topics in table 12-2: life form, seed production, and aboveground phenology. High-quality information was also available for every review on species distribution. However, much of this information comes from documents such as floras and reviews, whose main objective is not necessarily to gather and report distribution information, and thus has limited usefulness for estimating a species' potential to invade a particular plant community. Other distribution information comes from sources reporting coarse scale information. For example, low-resolution state and county distribution maps, such as those in the Plants (http://plants.usda.gov/) and Invaders (http://invader.dbs.umt.edu/) databases, are widely available but have insufficient detail for determining a species' ecological amplitude and potential to invade other sites and plant communities. Comprehensive inventory information was not available for any of the species that we reviewed.

High-quality information on site requirements was available for most species reviewed, but this information was usually not systematic or detailed enough to help managers assess invasiveness. For most species, the literature provided site information primarily for areas where the species is most problematic[1], where research has been conducted[2], or where it occurs in its native range[3]. For some species[4], this information was provided in reports from agricultural settings, suggesting that the species will spread into natural areas but not describing the sites or plant communities most likely to be invaded. Ironically, we sometimes inferred distribution of nonnative invasives from publications describing the geographic range where planting of those species has been recommended[5].

Knowledge gaps were identified for several species on the remaining topics highlighted in table 12-2. Table 12-3 shows the highest quality of information found for biological and ecological topics in each species review. For example, seed dispersal for Norway maple (*Acer platanoides*) is described by at least one article ranked 4, that is, containing primary research and published in a peer-reviewed journal. Only anecdotal information (ranked 1) is available regarding seed dispersal for sericea lespedeza (*Lespedeza cuneata*). The prevalence of high-quality citations (ranked 3 or 4) regarding biological and ecological topics is shown in figure 12-1.

Information on phenology of flowering and seed production was generally available for all species examined, although seed production information is typically limited to a particular set of conditions and rarely related to or available for postfire conditions. While high-quality information on post-injury regeneration was available for 88 percent of the species examined knowledge about belowground phenology and regeneration from underground tissue was often lacking (table 12-3, fig. 12-1). Information on seasonal changes in carbohydrate reserves of roots and other underground tissues was found for only about half (48 percent) of species reviews on biennial and perennial plants (fig. 12-1). Knowledge about depth of belowground perennating tissue was rarely available for the species reviewed.

High-quality information on seedbed requirements was available for 81 percent (table 12-3; fig. 12-1) of species reviews, but little of this information was specific to postfire situations. Most species reviews had high-quality information for seed dispersal (88 percent) and seed banking (77 percent) (table 12-3; fig. 12-1). However, seed banking information for several of these species reviews comes either from outside North America or from laboratory experiments, so they still lack information that is directly applicable to North American ecosystems. For example, the literature on rush skeletonweed (*Chondrilla juncea*) comes primarily from Australia, so its applicability to field conditions in North American wildlands is difficult to assess. Evidence of seed longevity has implications for seed banking, and for sulfur cinquefoil (*Potentilla recta*) and perennial pepperweed (*Lepidium latifolium*) is provided by only one laboratory study for each species (table 12-3), while only anecdotal observations from the field provide information on seed banking for these species. Information on the relationship between seed banking, field conditions, and disturbance is rarely available for nonnative invasive species.

We found high-quality information on longevity and/or succession for 77 percent of our species reviews (table 12-3; fig. 12-1); however, this information was often limited in scope. As with species distributions, information may be available where the species is most problematic and where studies have been conducted, but is lacking in other areas. Thus it was typically insufficient to provide a clear understanding of the potential for a particular invasive species to alter successional trajectories in newly invaded communities.

Table 12-4 describes both the quantity and quality of information found on fire-related topics for each species review. Quantity is expressed as the total number of sources cited in the species review, of any quality. Quality is expressed as in table 12-3, that is, the highest rank given any citation for that topic. For example, two sources provided information on postfire seedling establishment of bull thistle (*Cirsium vulgare*); the highest information-quality rank among these citations was 3, indicating that either one or both sources described primary research and was published in a technical paper, thesis, dissertation, book chapter, proceedings, or flora.

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[1] Examples: *Bromus tectorum*, *Chondrilla juncea*, *Centaurea solstitialis*, *C. diffusa*, *C. maculosa*, *Elaeagnus angustifolia*, *E. umbellata*, *Hypericum perforatum*, *Lepidium latifolium*, *Lespedeza cuneata*, *Ligustrum* spp., *Lonicera japonica*, *Lythrum salicaria*, *Potentilla recta*, *Pueraria montana* var. lobata, and *Rosa multiflora*

[2] Examples: *Acer platanoides*, *Alliaria petiolata*, *Cardaria* spp. *Celastrus orbiculatus*, *Centaurea repens*, *Cytisus* spp., *Elaeagnus umbellata*, *Genista monspessulana*, *Lespedeza cuneata*, *Ligustrum* spp., *Linaria* spp., *Lonicera japonica*, *Lythrum salicaria*, *Pueraria montana* var. lobata, *Rosa multiflora*, and *Spartium junceum*

[3] Examples: *Acer platanoides*, *Centaurea repens*, *Cynoglossum officinale*, and *Lythrum salicaria*

[4] Examples: *Cardaria* spp., *Centaurea repens*, *Chondrilla juncea*, *Convolvulus arvensis*, *Imperata cylindrica*, and *Lespedeza cuneata*

[5] Examples: *Acer platanoides*, *Elaeagnus angustifolia*, *E. umbellata*, *Lespedeza cuneata*

Table 12-3—Highest quality ranking of information available on aspects of biology and ecology for nonnative invasive plant species reviews. See “Methods” for explanation of ranks 0 to 4 used in table.

Species review	Seed dispersal	Seed banking	Optimum seed bed	Post-injury regeneration	Succession /longevity	Below-ground phenology
Norway maple	4	0	4	4	4	0
Russian knapweed	4	0	4	4	4	4
Tree-of-heaven	4	3	4	3	4	1
Garlic mustard	4	4	4	4	0	0
Giant reed	3	0	0	4	3	2
Cheatgrass	4	4	4	4	4	n/a[a]
Hoary cress[b]	4	3	4	4	0	4
Musk thistle	4	4	4	4	4	4
Oriental bittersweet	4	4	4	4	4	0
Diffuse knapweed	4	0	4	3	3	0
Spotted knapweed	4	4	4	4	4	0
Yellow starthistle	4	4	4	4	4	n/a[a]
Rush skeletonweed	4	4	4	4	0	0
Canada thistle	4	4	4	3	3	4
Bull thistle	4	4	4	4	4	4
Field bindweed	4	4	4	4	4	4
Houndstongue	4	4	4	4	4	4
Brooms[b]	4	4	4	4	4	2
Russian-olive	4	4	4	3	4	0
Autumn-olive	4	0	0	1	0	0
French broom	4	4	3	3	2	2
Common St. Johnswort	4	4	4	4	4	0
Cogongrass[b]	4	4	4	4	4	0
Perennial pepperweed	4	4	0	4	4	4
Sericea lespedeza	1	1	1	1	1	0
Privet[b]	4	4	0	4	4	0
Toadflax[b]	4	4	4	4	3	0
Japanese honeysuckle	4	4	3	3	4	4
Bush honeysuckles[b]	4	4	4	4	4	0
Climbing ferns[b]	2	1	0	1	1	0
Purple loosestrife	4	4	4	4	4	0
Melaleuca	4	4	4	3	2	2
Japanese stiltgrass	4	4	4	3	4	n/a[a]
Sulfur cinquefoil	0	4	4	4	4	0
Kudzu	0	2	0	3	0	3
Multiflora rose	4	1	0	2	0	0
Brazilian pepper	3	4	4	3	3	0
Perennial sowthistle	4	4	4	4	4	4
Johnson grass	4	4	4	4	4	4
Spanish broom	2	2	4	2	4	0
Tamarisk[b]	4	4	4	4	4	4
Chinese tallow	4	4	4	4	4	4
Gorse	3	4	4	4	4	0

[a] Topic not applicable to annual species.

[b] Two or more species included in review; see table 12-1 for complete list of species included. Ranked information may not apply to all species in that review.

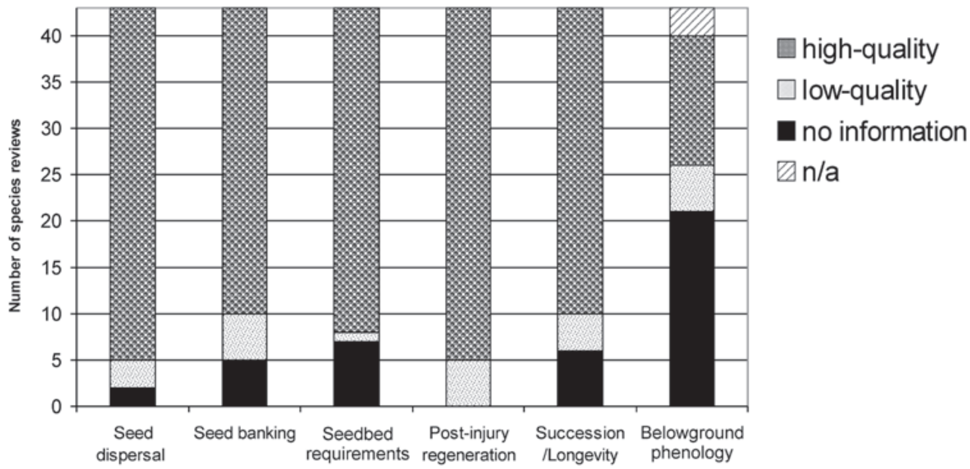

Figure 12-1—Highest quality of information available on botanical and ecological topics for 43 species reviews in FEIS. "Low quality" = rank of 1 or 2. "High quality" = rank 3 or 4. See "Methods" for explanation of information-quality ranking.

When quality of information is displayed for all species reviews, it is clear that less information is available on fire-related topics than on biological and ecological topics (figs. 12-1 and 12-2). For all fire-related topics except immediate fire effects and postfire vegetative response, more than half of reviews have no information at all (fig. 12-2).

For species that do have information on fire related topics, research results are still sparse and incomplete. While figure 12-2 breaks this information down according to quality, figure 12-3 breaks it down by the number of citations (of any quality) on each topic. As in figure 12-2, the dark portion of each bar indicates the number of reviews with no information (zero citations). If one considers the remaining reviews, those that have at least some information on a given fire-related topic, about half have only one or two citations on that topic (fig. 12-3).

Managers and members of the public often express concern about establishment and spread of nonnative invasives after fire, but even this topic shows a paucity of information. We found some information on postfire seedling establishment for 44 percent of species reviews (figs. 12-2 and 12-3). Examples include musk thistle (*Carduus nutans*) (Goodrich 1999; Grace and others 2001; Heidel 1987; Hulbert 1986), Canada thistle (*Cirsium arvense*) (Ahlgren 1979; Doyle and others 1998; Floyd-Hanna and others 1997; Goodrich and Rooks 1999; Hutchison 1992a; Rowe 1983; Smith, K. 1985; Thompson and Shay 1989; Turner and others 1997; Willard and others 1995), bull thistle (Messinger 1974; Shearer and Stickney 1991), and houndstongue (*Cynoglossium officinale*) (Johnson 1998). Ten of the 17 articles cited for these species rank high on the information-quality scale; however of the ten, only seven provide information on characteristics of prefire or unburned vegetation, six provide descriptions of fuels, fire behavior, burn conditions, or fire severity, and one gives detailed information on proximity and productivity of seed sources. For most species that we examined, the available information is not sufficient to conclude that, if the species occurs in a particular area and a fire occurs, it is likely to become invasive in the burned area.

We found high-quality information on vegetative response to fire for only 37 percent of species reviews (table 12-4; fig. 12-2), making predictions of postfire persistence and vegetative spread difficult for most species. While high-quality information was available for most species reviews on regeneration after mechanical disturbance (table 12-3; fig. 12-1), and this information can alert managers to the possibility of postfire regeneration, fires and mechanical disturbances cannot be assumed to evoke equivalent responses.

Fewer than half the species reviews (40 percent) had information on fuel characteristics of that species, or information on how fuel characteristics in invaded communities may be altered from uninvaded conditions. Where information is available, it is mostly anecdotal or speculative, as reflected by the number of reviews for which only low-quality information was available—8 of the 17 reviews provide only low-quality information on fuels. Similarly, only 30 percent of the species reviewed had information available on fire regime changes in invaded communities, and more than half of this information was anecdotal (table 12-4; fig. 12-2).

Table 12-4—Information available on relationships of nonnative invasive plants to fire. Total number of sources available on each topic for each species review is given in parentheses, followed by highest-ranked quality of information. See "Methods" section for explanation of ranks 0 to 4 used in table.

Species review	Heat tolerance, tissue	Heat tolerance, seed	Immediate fire effects on plant	Postfire seedling establishment	Postfire vegetative response	Postfire increase (source unknown)	Fuels	Fire regimes
Norway maple	0	0	0	0	(1)2	0	0	0
Russian knapweed	0	0	(1)2	0	0	0	0	0
Tree-of-heaven	0	0	0	0	(2)2	0	0	0
Garlic mustard	0	0	(4)4	0	(2)4	(2)4	(1)2	0
Giant reed	0	0	(2)2	0	(4)2	0	(1)1	(1)1
Cheatgrass[a]	0	(10)4	(17)4	(29)4	0	0	(32)4	(37)4
Hoary cress[b]	0	(1)1	(1)2	(1)1	(1)2	(1)1	0	0
Musk thistle	0	0	(3)1	(4)2	(3)2	(3)2	0	0
Oriental bittersweet	0	0	0	0	0	0	0	0
Diffuse knapweed	0	(1)1	(2)2	(2)2	(1)1	(4)2	0	0
Spotted knapweed	0	(1)4	0	0	0	(5)3	(3)3	0
Yellow starthistle	0	(1)2	(6)4	(4)4	(2)3	0	(2)2	0
Rush skeletonweed	0	0	0	0	0	(1)1	0	0
Canada thistle	0	0	(2)3	(10)4	(4)4	(8)4	0	(1)2
Bull thistle	0	(1)4	0	(2)3	0	(4)3	0	0
Field bindweed	0	(3)4	0	0	0	0	0	0
Houndstongue	0	0	0	(1)3	0	0	0	0
Brooms[b]	0	(4)4	(1)4	(4)4	(3)4	0	(3)3	(3)2
Russian-olive	0	0	(2)2	0	(4)2	(1)2	0	0
Autumn-olive	0	0	0	0	(3)1	0	0	0
French broom	0	0	(7)4	(8)4	(1)3	0	(4)3	0
Common St. Johnswort	0	(1)3	(1)3	(3)4	(1)4	(6)2	(1)1	0
Cogongrass[b]	0	0	(1)2	(2)4	(9)3	(2)4	(9)4	(15)4
Perennial pepperweed	0	0	(2)3	0	(1)3	0	0	0
Sericea lespedeza	0	(3)4	(3)2	(4)1	(1)1	(1)3	0	0
Privet[b]	0	0	(2)4	0	(2)4	0	0	0
Toadflax[b]	0	0	0	0	0	(6)4	0	0
Japanese honeysuckle	0	0	(5)4	0	(6)4	(1)4	0	(2)3
Bush honeysuckles[b]	0	(2)1	(3)1	0	(6)3	0	0	0
Climbing ferns[b]	0	0	0	0	0	0	(2)1	(2)1
Purple loosestrife	0	0	(4)3	0	0	0	(2)3	0
Melaleuca	0	0	(13)3	(6)4	(7)2	0	(10)4	(8)2
Japanese stiltgrass	0	0	(1)4	(4)4	(1)1	0	(2)2	0
Sulfur cinquefoil	0	0	(1)4	(1)2	0	0	0	(1)2
Kudzu	0	(3)4	(4)3	0	(2)3	0	0	0
Multiflora rose	0	0	0	0	0	0	0	0
Brazilian pepper	0	(1)4	(5)4	(1)1	(4)4	0	(2)2	(5)4
Perennial sowthistle	0	0	0	(2)4	(1)4	(1)4	0	0
Johnson grass	0	(1)4	(2)2	0	0	(4)4	0	0
Spanish broom	0	(1)1	(1)1	0	(1)1	0	0	0
Tamarisk[b]	0	(1)3	(6)4	0	(5)4	(3)4	(8)3	(7)4
Chinese tallow	0	0	(5)3	0	(2)2	0	(4)2	(3)2
Gorse	0	(4)4	(10)4	(9)4	(9)4	(5)4	(12)4	(6)4

[a] For all species except cheatgrass, we cited every source found on fire-related topics. A few cheatgrass studies were not cited because information was ample and they added no new information to the species review, so the total number of citations for topics under cheatgrass may be conservative. Similarly, cheatgrass studies reporting on a topic in a preliminary document and continued in a subsequent document were counted as one study.

[b] Two or more species included in review; see table 12-1 for complete list of species included. Ranked information may not apply to all species in that review.

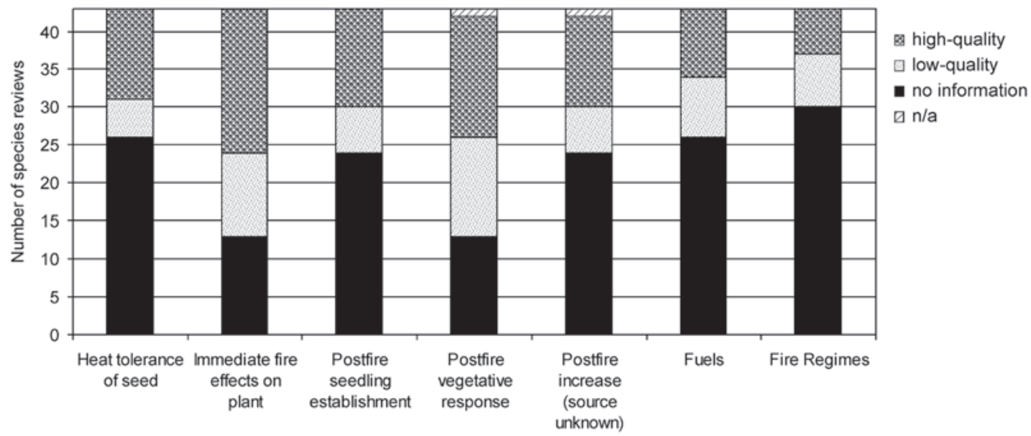

Figure 12-2—Highest quality of information available on fire and fuels topics for 43 species reviews in FEIS. "Low quality" = rank of 1 or 2. "High quality" = rank 3 or 4. See "Methods" for explanation of information-quality ranking.

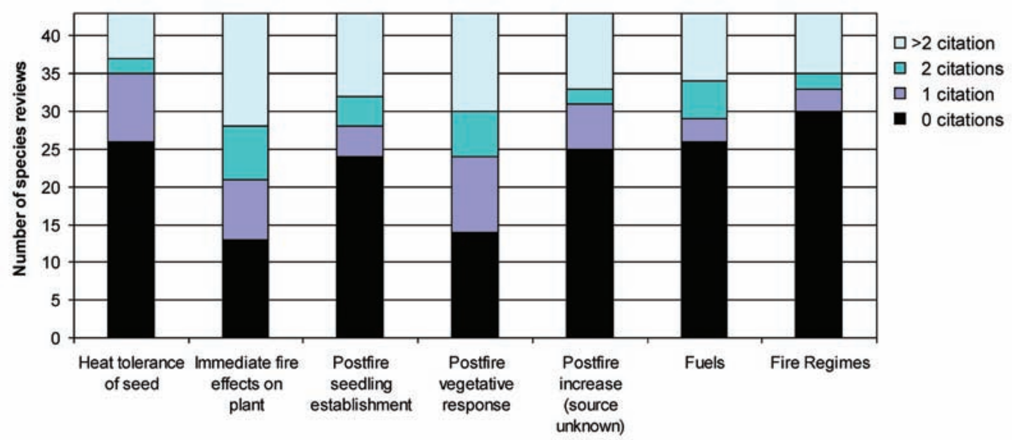

Figure 12-3—Frequency of zero, one, two, and more than two citations of any quality covering fire and fuels topics for 43 species reviews in FEIS. "0" in this graph corresponds to "no information" in figure 12-2.

Many species reviews refer to experiments on fire effects, and most of these references are of high quality. However, very few fire experiments report the effects of variation in fire severity, season, or burn interval; furthermore, most of these studies report results from only 1 postfire year so they are not useful for understanding postfire succession (table 12-5; fig. 12-4). Of our 43 species reviews, 37 percent cite no direct experimental evidence of the effects of fire. Where experimental evidence of fire effects is reported, it often lacks important information regardless of quality rating. In the case of Russian knapweed (*Acroptilon repens*), for example, an article published in a peer-reviewed journal (Bottoms and Whitson 1998) concludes that the species cannot be effectively controlled by burning. However, the article fails to provide any information on prefire plant community, fuels, fire behavior, or burn conditions.

Of the experiments cited, very few address the effects of varied fire regime characteristics and postfire succession. Less than a third of our species reviews contain any information on the differential effects of fire severity, season of burn, or interval between fires on nonnative invasives (table 12-5; fig. 12-4). Among the remaining reviews that contain some information on variation in a fire regime characteristic or succession, only a handful—one to three for each topic—have more than two citations (fig. 12-5). For most species, it is unclear how responses to fire might change over time. Among our species reviews, 30 percent had studies reporting plant responses over multiple years (fig. 12-4), and few offered insight about the potential effects of long-term maintenance of native fire regimes on nonnative invasive plants.

Table 12-5—Information available on fire experiments and addressing relationships between nonnative invasive species and aspects of the fire regime. Total number of sources available on each topic for each species review is given in parentheses, followed by highest-ranked quality of information. See "Methods" section for explanation of ranks 0 to 4 used in table.

Species review	Fire experiment	Varying fire severities	Varying burn seasons	Varying burn intervals	Multiple postfire years
Norway maple	0	0	0	0	0
Russian knapweed	(2)2	0	0	0	0
Tree-of-heaven	0	0	0	0	0
Garlic mustard	(5)4	(1)4	(3)4	0	(2)4
Giant reed	0	0	0	0	0
Cheatgrass	(19)4	(3)4	(2)4	0	(15)4
Hoary cress[a]	0	0	0	0	0
Musk thistle	(1)2	0	0	0	0
Oriental bittersweet	0	0	0	0	0
Diffuse knapweed	0	0	0	0	0
Spotted knapweed	(2)3	0	0	0	(1)3
Yellow starthistle	(3)4	0	0	0	0
Rush skeletonweed	0	0	0	0	0
Canada thistle	(13)4	(1)4	(2)4	(2)3	(2)4
Bull thistle	(1)3	0	0	0	0
Field bindweed	0	0	0	0	0
Houndstongue	0	0	0	0	0
Brooms[a]	(2)4	0	(2)4	0	0
Russian-olive	0	0	0	0	0
Autumn-olive	0	0	0	0	0
French broom	(4)4	0	0	(1)4	(1)3
Common St. Johnswort	(6)4	(1)4	(1)4	0	(2)4
Cogongrass[a]	(2)4	0	0	0	(1)3
Perennial pepperweed	(1)3	0	0	0	0
Sericea lespedeza	(1)3	0	(1)3	0	0
Privet[a]	0	0	0	0	0
Toadflax[a]	(6)4	0	(1)3	0	0
Japanese honeysuckle	(8)4	0	(2)4	0	(3)4
Bush honeysuckles[a]	(2)3	0	0	0	(2)3
Climbing ferns[a]	0	0	0	0	0
Purple loosestrife	0	0	0	0	0
Melaleuca	(3)4	0	(1)3	(1)3	(2)3
Japanese stiltgrass	(1)4	0	0	0	0
Sulfur cinquefoil	(1)4	0	(1)4	0	0
Kudzu	0	0	0	0	0
Multiflora rose	(1)4	(1)4	0	0	0
Brazilian pepper	(3)4	0	0	0	(2)4
Perennial sowthistle	(3)4	0	(1)4	0	0
Johnson grass	(2)4	0	(1)4	0	(1)4
Spanish broom	0	0	0	0	0
Tamarisk[a]	(8)4	(2)4	(1)3	(2)2	0
Chinese tallow	(2)3	0	(2)2	0	0
Gorse	(8)4	(3)4	(2)4	0	(7)4

[a] Two or more species included in review; see table 12-1 for complete list of species included. Ranked and tallied information may not apply to all species in that review.

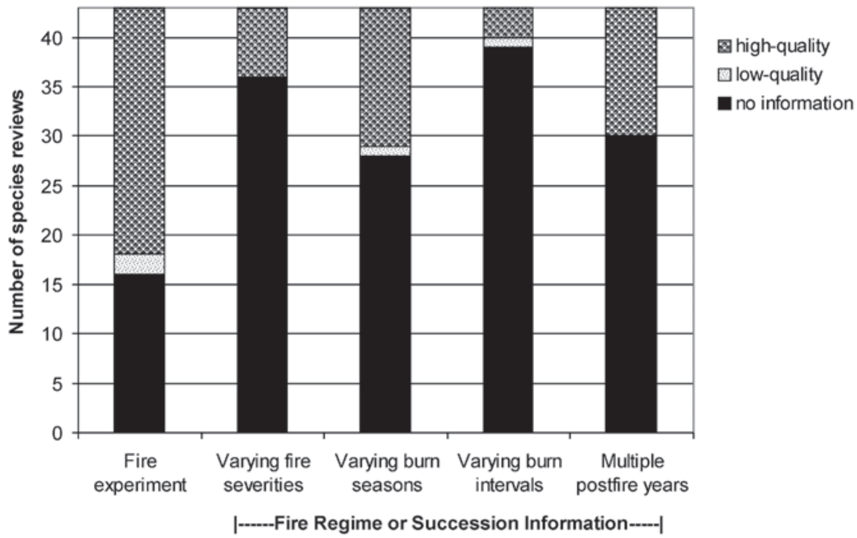

Figure 12-4—Highest quality of information available from fire experiments for 43 species reviews in FEIS. “Low quality” = rank of 1 or 2. “High quality” = rank 3 or 4. See “Methods” for explanation of information-quality ranking.

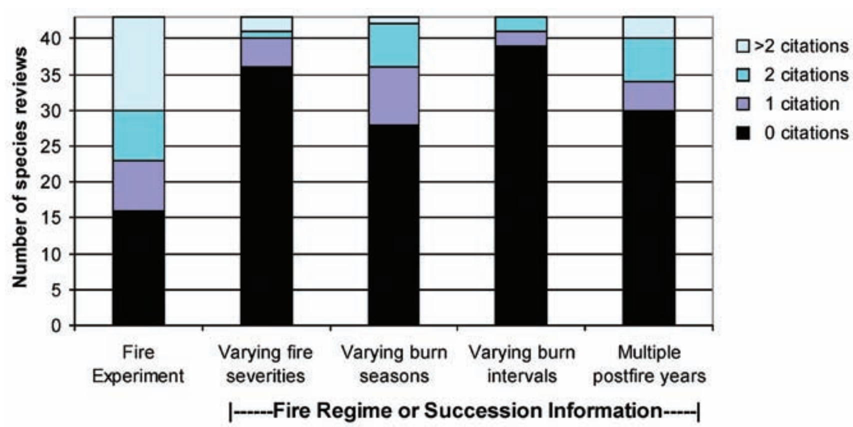

Figure 12-5—Frequency of zero, one, two, and more than two citations of any quality covering fire experiments for 43 species reviews in FEIS. “0” in this graph corresponds to “no information” in figure 12-4.

Discussion

Many articles describe fire’s relationship with nonnative invasive species, but the quality and quantity of information are often inadequate for managers to use with confidence. A manager planning a prescribed burn, for example, needs to know which nonnative invasives are of concern and assess the potential for establishment, persistence, and/or spread of those species after fire in a particular area. At the very least, the manager needs information on basic biological traits of each species, such as vegetative reproduction and requirements for seedling establishment. Better would be information on how those traits are expressed in response to fire. Additional information on the ecology and invasiveness of each species under various environmental conditions would further improve the manager’s basis for decisions. If no information is available for the particular ecosystem under consideration, a literature review synthesizing research from other ecosystems or a model predicting species response based on basic biological traits and ecological relationships could be helpful. The best information that a manager could hope for would describe long-term outcomes from fire research that has a scope of inference covering that ecosystem under various burning conditions, at varying times of year, with varying fire severities and intervals between burns. Publications with such a comprehensive scope and content are few when considered in light of the number of nonnative, invasive plants in the United States and the probability that invasiveness varies from one plant community to another. Here we discuss the ways in which information on basic biology, invasiveness and invasibility, distribution, ecology, and responses to fire, heat, and fire regimes pertains to managing invasives and fire. We compare the knowledge available for FEIS species reviews with the knowledge needed to manage with confidence, and we offer suggestions on how to deal with the fact that managers frequently need more knowledge than is available.

Basic Biology

The ability of a plant to establish, persist, and/or spread in a postfire community depends partly on its resistance to heat injury (chapter 2), and may be inferred from experimental evidence or, with less certainty, from information on reproductive strategies. Responses to fire vary with plant phenology relative to timing of the fire, the location of perennating buds and seeds relative to lethal heat loads, seed production, seed dispersal, seed longevity, and requirements for successful seedling establishment (chapter 2). Information on seasonal changes in carbohydrate reserves of roots and other underground tissues may help managers understand when fire will have the greatest impact on perennial species. Our results indicate that while information on phenology of flowering and seed production is generally available for the species reviewed, information on seasonal changes in carbohydrate reserves of roots and other underground parts is less abundant (fig. 12-1). Descriptions of depth of underground perennating tissues, crucial for understanding the varying effects of different fire severities, are rarely available.

In the absence of information on postfire regeneration, knowledge of a plant's ability to regenerate after mechanical injury or removal of top growth may help managers assess the likelihood that a plant will sprout after fire. High-quality information on post-injury regeneration was available for the majority of the species examined in this study; however, fires and mechanical disturbances alter a site in different ways, so biological responses cannot be assumed to be equivalent. Where high-quality information is lacking on this topic, it does not always indicate scant or poor information. For species such as melaleuca, for example, post-injury regeneration is so prolific and so obvious that there is no need for peer-reviewed literature to demonstrate this response.

The ability of a plant to establish from seed in a postfire environment depends on seed production and dispersal, requirements for germination and seedling establishment, and seed bank dynamics. We found high-quality information on seed production, dispersal, and seedbed requirements for germination for most species reviews, although this was rarely available for postfire conditions. Similarly, most species reviews had high-quality information on seed banking (fig. 12-1); however, the scope of applicability of this information was usually limited to laboratory experiments or field studies on other continents. A description of seed bank dynamics, including seed longevity, temporal and spatial variation in the number of viable seeds stored in the soil, and the seed bank's relationship to disturbances, can help managers assess the potential role of invasive species in a postfire environment (Pyke 1994). In many communities, nonnative species are common in soil seed banks, and there are differences between the species growing on the site and those present in the soil seed bank (for example, Halpern and others 1999; Kramer and Johnson 1987; Laughlin 2003; Leckie and others 2000; Livingston and Allessio 1968; Pratt and others 1984; Rice 1989). These differences may lead to substantial changes in community composition following fire, including establishment of nonnatives. Seed longevity also influences fire's effectiveness in controlling annual plants (Brooks and Pyke 2001). More research is needed on the relationship between seed banking, germination requirements, field conditions, and fire.

Impacts, Invasiveness, and Invasibility

To make informed decisions about nonnative invasive species and fire, managers need to know when a nonnative species threatens a native ecosystem. For example, species that alter fuel characteristics of invaded communities may alter fire regimes such that an invasive plant/fire cycle is established (chapter 3). Assertions regarding impacts of particular nonnative species on native ecosystems are abundant in the literature; however, quantitative evaluations of these impacts are not common. In fact, little formal attention has been given to defining what is meant by "impact" or to connecting ecological theory with particular measures of impact (Parker and others 1999). For example, reviews by Hager and McCoy (1998) and Anderson (1995) describe purported negative impacts caused by purple loosestrife (*Lythrum salicaria*) in North America. Both papers express concern that claims of ecological harm caused by purple loosestrife (for example, Thompson and others 1987) are not supported by quantitative assessments, so some management activities aimed at controlling the species could be inappropriate. Parker and others (1999) point out that disagreements on the impact of historical invasions reflect the fact that ecologists have no common framework for quantifying or comparing the impacts of invaders. Managers are therefore cautioned to read generalizations regarding the impacts of nonnative, invasive species with care.

Distribution and Site Information

The likelihood that a nonnative, invasive species will establish, persist and spread in an area is determined not only by properties of the species, but also by the structure, composition, and successional status of the native plant community, site factors and conditions, landscape structure (Rejmánek and others 2005a; Sakai and others 2001; Simberloff 2003), and the species' current distribution. In this study, the information available on distribution of nonnative invasive species had limited usefulness for estimating the potential for a particular species to invade after fire. Comprehensive information on distribution and site requirements was not available for any of the species reviewed. The information currently available is often based on county records rather than systematic surveys. Because of this, it may reflect the density of botanists in a particular area more than the density of invasive plants (Moerman and Estabrook 2006; Schwartz 1997).

The most consistent predictor of invasiveness may be a species' success in previous invasions (for example, Kolar and Lodge 2001; Williamson 1999). Based on this idea, Williamson (1999) emphasizes the need for more studies on the population dynamics of invaders and better definitions of their demographic parameters. Similarly, in a review of literature on sulfur cinquefoil, Powell (1996) suggests that surveys including geographic location, plant community type, seral stage, site characteristics (including disturbance and management history), and size, density, and canopy cover of infestations can help establish ecological limits of nonnative plants, define potential North American distributions, and identify other areas where a nonnative species is likely to be invasive. Such surveys could also provide a baseline for monitoring populations, direction for management activities, and a means for evaluating management effectiveness (Powell 1996). Mack and others (2000) agree, adding that such information would be useful for calculating an invasive's rate of spread. While surveys such as these may seem unrealistic given the resources needed to survey large areas, it may be possible to detect occurrence and spread of invasives using satellite remote sensing, aerial photography, hyperspectral imagery, or other spatial information technologies (review by Byers and others 2002).

Ecological Information

A nonnative species' invasiveness in a postfire environment depends not only on the species' location and response to fire, but also on the response of other plants in the community (chapter 2). Like Grace and others (2001), we found that information is very incomplete with regard to fire effects on competitive interactions between nonnative invasives and the native plant community. It is routinely asserted that a nonnative, invasive species "outcompetes" native species, but rarely are these assertions supported by quantitative data. A review by Vilà and Weiner (2004) of published pair-wise experiments between invading and native plant species[6] suggests that the effect of nonnative invasives on native species is usually stronger than vice versa. However, because the selection of invaders and natives for study is not random (that is, the plants most frequently chosen for study are those that cause the most trouble), the data could be biased towards highly competitive invaders and natives that may be weaker than average competitors. Furthermore, the reviewers point out, methods that have been used to investigate competition between invasive and native species are often limited in scope and applicability (Vilà and Weiner 2004).

Information on persistence of a nonnative, invasive plant species on a particular type of site, and how persistence of this species may change successional trajectories, is important for assessing potential impacts of invasion, but is available only for a limited number of species and locations. Long-term research in a variety of locations or plant communities with contrasting characteristics might help managers assess potential persistence, spread, and successional trajectories after a species has become established in an area, and understand what changes may occur after fire. Additionally, control plots maintained without intervention or attempts at reducing invasives are essential for long-term research. Results from a study on Illinois prairie vegetation illustrate this point. Anderson and Schwegman (1991) studied 20 years of change in a prairie plant community, which included substantial cover of Japanese honeysuckle (*Lonicera japonica*), in response to four prescribed burns. The study compared different burn treatments, but it did not compare burned with unburned plots. Control plots were established and measured in the first 2 years of the study, and no changes were observed during these

[6] Nonnative, invasive plant species included in the Vilà and Weiner (2004) review and also addressed in our project include *Ailanthus altissima*, *Bromus tectorum*, *Centaurea diffusa*, *C. maculosa*, *C. solstitialis*, *Hypericum perforatum*, and *Lonicera japonica*.

2 years (Anderson and Schwegman 1971). No data or results from control plots were reported for subsequent years (Anderson 1972; Anderson and Schwegman 1991; Schwegman and Anderson 1986). Without long-term data from controls, however, the researchers could not compare long-term variation within burns to variation over the same time in unburned areas. They could have attributed long-term changes to fire alone when variation may have been caused by other factors, such as weather. Where information on competition and long-term successional patterns is unavailable—and this would be in most ecosystems—sustained monitoring, analysis of local patterns of change, and flexible, adaptive approaches to management can provide guidance.

Responses to Fire, Heat, and Postfire Conditions

While information on heat tolerance of perennating tissue and seed would be helpful to managers, measuring heat transfer into plant tissues is complex. Observations and models describing heat tolerance currently focus mainly on damage to trees during fires with relatively low fireline intensities (Dickinson and Johnson 2001, 2004; Jones and others 2004). We found no sources describing heat tolerance of perennating tissues for the nonnative invasives examined in this study, and only 28 percent of reviews include high-quality information on heat tolerance of seed (table 12-4; fig. 12-2)[7]. Most of this research is based on laboratory observations, which may not replicate field conditions. Exposure to smoke or chemicals leached from charred material contributes to breaking seed dormancy for some species (Keeley and Fotheringham 1998a). Information on smoke and char effects was not found for our species reviews, although one study is available on how exposure of cheatgrass (*Bromus tectorum*) seeds to smoke affects its seedling development (Blank and Young 1998).

Field Experiments Addressing Fire Effects

Information on basic biology, ecological interactions, and responses to heat may not apply directly to fire responses under field conditions (Harrod and Reichard 2001). Information concerning the effects of specific fire behavior on nonnative invasives in a specific plant community under specific fuel and weather conditions may be essential for unraveling the effects of fire from those of other variables. Reports from comprehensive fire research studies and well-documented prescribed fires are sparse in the literature, as are reports of experiments describing the use of fire to control nonnative invasive plants (but see chapter 4). Where such information is available, it is sometimes too limited in scope (one or two sites) to support application on other sites, in different ecosystems, under different burning conditions.

We found relatively few papers on fire effects that distinguished between postfire seedling establishment and postfire vegetative recovery. If research does not differentiate between seedlings and stems of vegetative origin, managers will have limited ability to predict postfire population dynamics. In the first year after fire, it is often relatively simple for field observers to determine whether a plant originated from seed or from underground parts; researchers should record and report this information as a routine part of fire effects studies.

Even when the relationship between a nonnative invasive species and fire is described by high-quality research, the information may not be widely applicable to management. Causes of limited scope of inference and suggestions for addressing these limitations are presented in table 12-6.

Responses to varying fire regime characteristics—When using fire as a tool to change or maintain floristic composition in a plant community, one must consider not only the effects of individual fires, but also the effects of the imposed fire regime (chapter 1) over a long time. In some cases, fire managers aim to promote native species by introducing fire at seasons and intervals that approximate presettlement or reference fire regimes, but little information is available regarding the effects of these fire regimes on nonnative invasive species. In other cases, the presettlement fire regime of the invaded ecosystems is unknown; examples include ecosystems where yellow starthistle (*Centaurea solstitialis*) and tamarisk (*Tamarix* spp.) are most problematic (chapters 8 and 9). Likewise, little is known about the differential effects of fire severity, season of burn, or interval between fires on nonnative invasives. In some cases, comparative studies on the effects of burning in different seasons may be lacking because management constraints require that burning be conducted during a particular season; wherever possible, research should measure and report variation in fire severity and fire season relative to plant phenology.

[7] Reviews for *Bromus tectorum* and *Genista monspessulana* do include experimental evidence describing fire effects on seed (Alexander and D'Antonio 2003; Keeley and others 1981; Odion and Haubensak 2002; Young and Evans 1978; Young and others 1976), though the research does not directly address heat tolerance. Several references describe germination of *Hypericum perforatum* seed after fire (for example, Briese 1996; Sampson and Parker 1930; Walker 2000), and one study examines heat tolerance of *H. perforatum* seed in the laboratory (Sampson and Parker 1930).

Table 12-6—Reasons for limited scope of inference from high quality research on fire effects.

Cause of limited scope	Example, explanation	Ways to address
Research not specifically designed to assess interactions between fire and nonnative invasive plants	Fire effects on *Lonicera japonica* are described by 11 studies, 9 of high quality, but fire effects are incidental to the study and not thoroughly covered for 7 of these.	Incidental data on fire might improve the usefulness of such research for fire managers; better would be research designed for understanding nonnatives and fire.
Fire effects described by only one study. A single study rarely covers multiple ecosystems, seasons, and burning conditions, so the information is usually not sufficient for generalizing.	Occurred for 7 of the 27 FEIS species reviews with experimental information, while another 7 reviews cite only 2 studies (fig. 12-5).	Monitor results of management actions based on results from a single study, and use adaptive management as new information becomes available.
Fire effects described by several studies but only one vegetation type	Several studies have been conducted on prescribed burning to control *Centaurea solstitialis* (DiTomaso and others 1999; Hastings and DiTomaso 1996; Martin and Martin 1999), but all were within a single ecosystem type, so the information is insufficient to generalize to other ecosystems.	Monitor results of management actions based on results from studies in other vegetation types, and use adaptive management as new information becomes available.
Fire effects described primarily outside North America	Some fire effects experiments on *Hypericum perforatum* (for example, Briese 1996) and *Ulex europaeus* (for example, Johnson 2001; Soto and others 1997) were conducted in Australia, New Zealand, or Europe. It is difficult to have confidence that this experimental evidence applies to North American plant communities.	Monitor results of management actions based on results from studies on other continents, and use adaptive management as new information becomes available.
Complex patterns of fire severity that cannot be correlated with postfire vegetation	Faulkner and others (1989) conducted research on invasives including *Ligustrum sinense*. Fire behavior varied from plot to plot, apparently confounding detection of immediate effects on aboveground plant parts.	Design burn studies to account for as much variation as possible; avoid burning when conditions for fire spread are marginal.
Incomplete or ineffective burn treatments	Rawinski (1982) attempted to compare the effects of burning after cutting with cutting alone on *Lythrum salicaria*. Attempts to burn *Lythrum salicaria* stems that had been cut were generally ineffective, so treatments could not be compared.	Avoid burning when conditions for fire spread are marginal.

The lack of information on plant responses over multiple years and the potential effects of long-term maintenance of native fire regimes on nonnative invasive plants impedes long-term planning and restoration of ecosystem processes. Anderson and Schwegman's (1991) study illustrates both the value of long-term research and the need to use control plots for the duration of a study. They examined effects of burning on southern Illinois prairie vegetation, including invasive Japanese honeysuckle, over the course of 20 years. Japanese honeysuckle decreased with frequent fire and increased after burning treatments ceased. However, this study lacked long-term control plots and so failed to compare changes in burned plots with changes in the surrounding unburned plant community.

Representing Information Quality in Literature Reviews: Potential for Illusions of Knowledge

While managers need the knowledge produced by science to make decisions, they generally rely on scientists to search the scientific literature and synthesize information. When scientists write literature reviews (including reviews within articles presenting primary research), book chapters, and agricultural extension literature, they need to frame and qualify information so managers will understand the kind of knowledge being reported (for example, Krueger and Kelley's (2000) categorization of natural resources literature). In our study, unsubstantiated assertions (quality ranking of 1) were found in one or more species reviews for every fire-related topic (table 12-4). Without context and hedging, such assertions create an illusion of certainty about a subject for which no empirical evidence is available, and the reader cannot determine how well the results apply to a particular management question. Readers should note when information is provided on a study's scope of inference and apply unsubstantiated assertions with caution. The 2003 Data Quality Act (Public Law 106-554, Section 515) requires that Federal land managers base decisions on high-quality information; literature reviews that fail to identify what kind of information is cited or misquote original research do a disservice to their readers.

Monitoring, Data Sharing, and Adaptive Management

Managers need not depend completely on published reports to form a useful body of knowledge. Records of management treatments, especially those preceded by measurement and followed by monitoring and data analysis, can inform and contribute to local management (Christian 2003) when a flexible, adaptive approach is used. When supplemented by complete site descriptions and shared across sites, landscapes, and regions, monitoring data could provide substantial guidance for management of invasives and fire. Well-designed, long-term monitoring programs can provide valuable ecological information about the invasion process and how individual ecosystems are affected (Blossey 1999); the ways in which data will be analyzed and presented must be addressed in the design phase for monitoring to be useful in assessing treatment success (Christian 2003). Suggestions for monitoring interactions between fire and nonnative species are discussed more thoroughly in chapter 15.

Conclusions

Current scientific knowledge about the relationship between invasive plants, ecosystem characteristics, and fire regimes is limited in quantity and quality. Scientists have the responsibility and require the necessary resources to study interactions between invasives, native communities, and fire, and variation in all of these factors. In addition, timely reporting of research is critical, including careful descriptions of the population studied and variables controlled, in both primary research and reviews of the literature. It is very difficult for managers to access information in unpublished reports; even if they can obtain such data, it may not be provided with contextual information that enables managers to assess its applicability to the ecosystems they are managing. Furthermore, the Data Quality Act (Public Law 106-554, Section 515) obligates managers to rely mainly on results published in peer-reviewed literature.

McPherson (2001) suggests that the enormity, complexity, and importance of management make the creative application of existing knowledge as important, and as difficult, as the development of new knowledge. High-quality information on the relationships between nonnative, invasive plants and fire is sparse when compared with the need for knowledge. More information is continually becoming available, but research cannot possibly investigate every possible combination of nonnative species and plant community in the United States, especially since nonnative plants continue to be introduced. Where research specific to a species and community is lacking, managers often rely on the synthesis provided by literature reviews, so it is important that reviews describe not only general ecological patterns but also the scope and limitations of the knowledge presented. When managers apply science to management in a specific plant community, they have the responsibility to recognize the limitations of current knowledge, apply generalizations cautiously, identify needs for site-specific knowledge, monitor results over many years, and use results adaptively, improving the management of nonnative invasive species in impacted plant communities over time.

Notes