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Principal Short-Term Findings of the National Fire and Fire Surrogate Study

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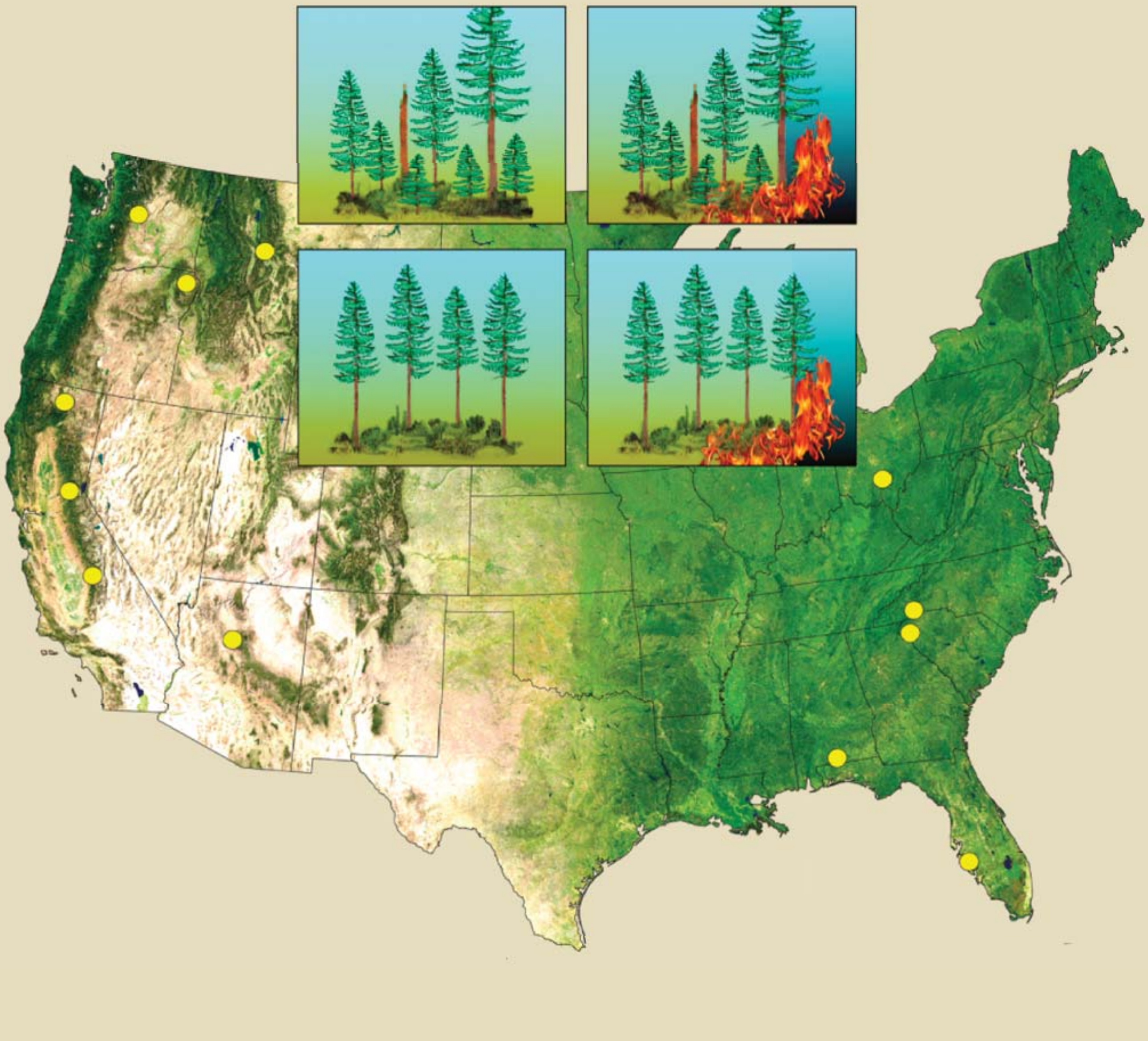

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Disclaimer

Abstract

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Principal findings of the National Fire and Fire Surrogate (FFS) study are presented in an annotated bibliography and summarized in tabular form by site, discipline (ecosystem component), treatment type, and major theme. Composed of 12 sites, the FFS is a comprehensive multidisciplinary experiment designed to evaluate the costs and ecological consequences of alternative fuel reduction treatments in seasonally dry forests of the United States. The FFS has a common experimental design across the 12-site network, with each site a fully replicated experiment that compares four treatments: prescribed fire, mechanical treatments, mechanical + prescribed fire, and an unmanipulated control. We measured treatment cost and variables within several components of the ecosystem, including vegetation, the fuel bed, soils, bark beetles, tree diseases, and wildlife in the same 10-ha experimental units. This design allowed us to assemble a fairly comprehensive picture of ecosystem response to treatment at the site scale, and to compare treatment response across a wide variety of conditions. Results of 206 technical articles on short-term findings are summarized here, with the following general conclusions: (1) For most sites, treatments modified stand structures and fuels to the point where posttreatment stands would be expected to be much more resistant to moderate wildfire. (2) For the great majority of ecosystem components, including the vegetation, soils, and animal species, short-term responses to treatments were subtle and transient. (3) Comparison of fire risk reduction and ecological effects between 1-year and several years posttreatment suggests that while effects tend to dampen with time, fire risk increases, owing to treatment-induced collapse of burned portions of stands. (4) Each multivariate analysis conducted has demonstrated that critical components of these ecosystems are strongly linked, suggesting that managers would be prudent to conduct fuel reduction work with the entire ecosystem in mind. (5) Multisite analyses generally show strong site-specific effects for many ecosystem components, which reduces the broad applicability of findings, and suggests that practitioners might do well to employ adaptive management at the local or regional scale. (6) Mechanical treatments do not serve as surrogates for fire for the great majority of ecosystem components, suggesting that fire could be introduced and maintained as a process in these systems whenever possible. (7) For research to best inform management on fuel reduction strategies through time, longer measurement times posttreatment are needed, as well as repeated applications of treatments; short-term results of the FFS are insufficient to comment on long-term ecosystem trajectories.

Keywords: Fuel reduction, prescribed fire, forest thinning, dry forests.

Contents

Introduction

Prescribed fire and thinning have been the most commonly used fuel reduction practices in seasonally dry forests of the United States since the 1970s (Agee and Skinner 2005). These practices are popular because forest managers realize that frequent disturbance is necessary to maintain stand structure in pine-dominated forests of southeastern and western North America (Arno et al. 1997, Biswell et al. 1973, Van Lear and Waldrop 1989, Weaver 1943). Historically, low-intensity surface fires burned frequently in these forests and tended to reduce the quantity of fuels, break up their spatial continuity, and discourage the establishment of shrubs and fire-intolerant tree species, leading eventually to stands dominated by larger diameter trees (Brockway et al. 2005, Youngblood et al. 2004). Fire suppression, preferential harvest of large-diameter trees, stand conversion, and livestock grazing over the past 100 to 150 years, among other factors, have shifted fuel bed conditions over millions of hectares in the Southeast and the West (Agee 1993, Brockway et al. 2005, Parsons and DeBenedetti 1979, Stephens and Ruth 2005). As a result, recent wildfires in seasonally dry forests have tended to be larger and more severe, even in areas that have no history of stand-replacement fires (Hessburg and Agee 2003, Knapp et al. 2005, Parsons and DeBenedetti 1979). This scenario explains why prescribed fire and thinning are increasingly used by managers in seasonally dry forests to change the only factor in the fire formula they can: the quantity and spatial continuity of fuels (Agee and Skinner 2005).

Prescribed fire has been the most attractive fuel reduction practice for ecologically minded forest managers, for the obvious reason that it is most likely to emulate the natural process that it is designed to replace (McRae et al. 2001). Unfortunately, when forest managers attempt to apply prescribed fire, they are often constrained by social, economic, and administrative issues, such that the window of opportunity for its application is often narrowed or eliminated (Brunson and Shindler 2004, Winter et al. 2002). As a result, fuel reduction surrogates such as forest thinning or mastication have become more attractive (Crow and Perera 2004). The assumption is that if managers can use mechanical treatments to reduce fuels and accomplish the same stand structure goals as those obtained by prescribed fire, the constraints and risks posed by the application of fire can be avoided. The only problem with this idea is that we know very little about how mechanical treatments compare with prescribed fire, particularly in terms of ecological effects and their interactions (Weatherspoon 2000). Furthermore, because few multisite studies have been conducted, we have little confidence in how the comparison between alternative fuel reduction methods might play out when repeated in different forests having different conditions (Waldrop and McIver 2006). These considerations provided the incentive behind the genesis and development of the National Fire and Fire Surrogate (FFS) study (McIver and Weatherspoon 2010).

The FFS was designed primarily to evaluate how alternative fuel reduction treatments influence a multitude of ecological effects at 12 sites nationwide (fig. 1). The study also included analysis of the cost of fuel reduction treatments and their social acceptability. As of 31 December 2010, short-term results of this study had been published in 206 technical articles, including several multisite syntheses, and organized collections in four journals. The primary purpose of this report is to summarize the principal findings published in these technical articles in a way that allows the reader to understand the consequences of alternative fuel reduction treatments across many dry forest types for a wide array of key ecological

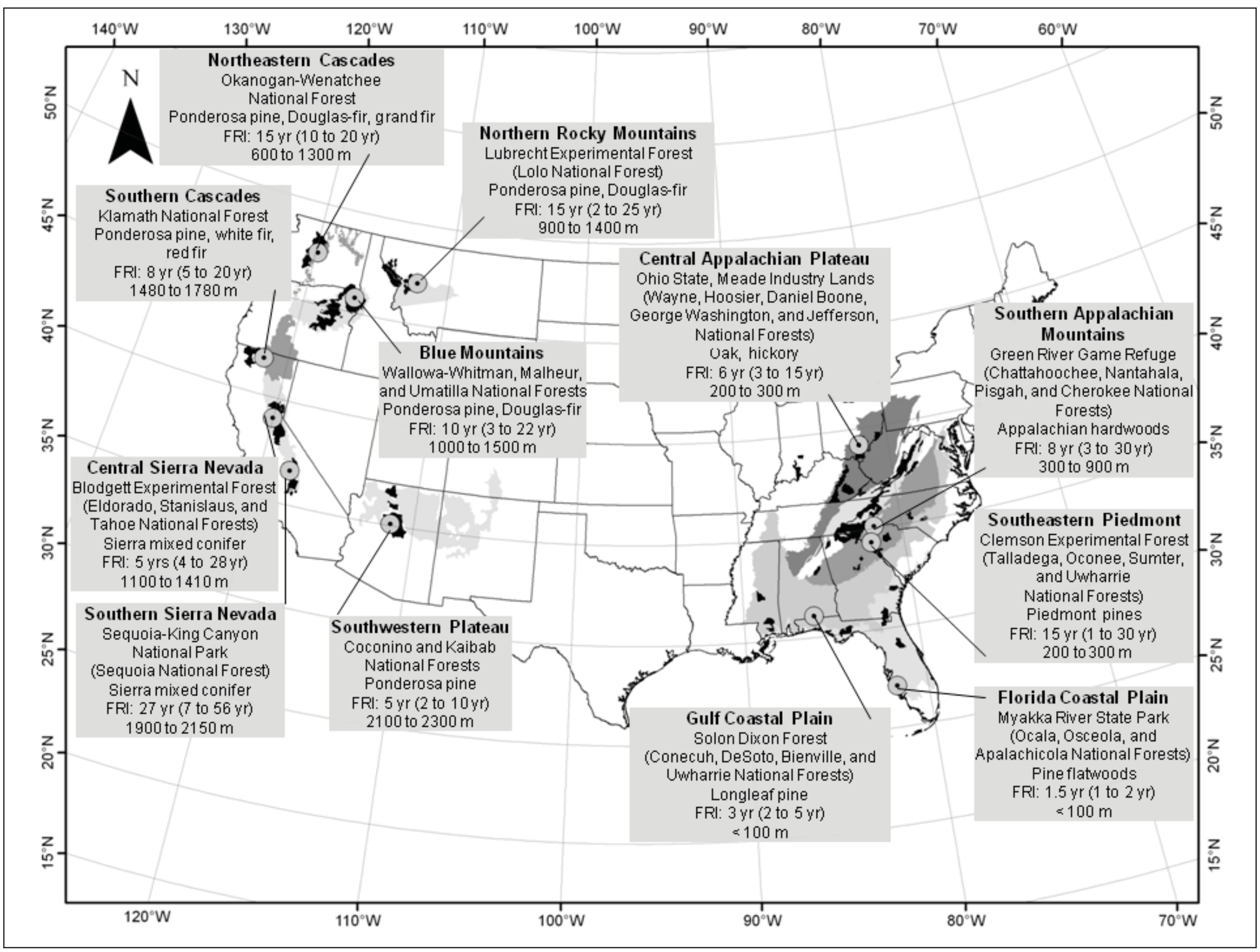

Figure 1—Location of the 12 national Fire and Fire Surrogate (FFS) study sites, showing relevant national forests (black shaded areas), forest type, fire-return interval (FRI, mean and range in years), and elevation range (m). For sites located on state or private lands, relevant national forests are given in parentheses. Lighter shading indicates "representative land base," or the area to which FFS results can be most directly applied for each site. Representative land bases are derived from Level III ecoregions (U.S. Environmental Protection Agency 2007). (From McIver and Weatherspoon 2010, used with permission of the authors and publisher.)

variables. We first describe the design of the FFS study as a multisite, multivariate, comparative experiment. We present a chronology of the project, from its inception in 1996 to the conclusion of its short-term phase in 2010. We summarize the considerable outreach effort, including activities such as tours, local presentations, and workshops, in addition to more formal products such as national conferences and scientific publications. We then present the principal short-term findings, starting with a summary of treatment effectiveness at the site level (first-order effects), then continuing with highlights of ecological effects summarized by treatment, management theme, discipline, and site. These highlights are linked to the core of this report, an annotated bibliography provided in table 14 of all findings, arranged first by site and then by discipline.

FFS Study Design

The FFS study was conducted in seasonally dry forests administered by the U.S. Department of Agriculture (USDA) Forest Service, National Park Service, state parks, universities, and private industry at 12 sites across the United States, five in the East, and seven in the Western interior (fig. 1). An additional site in New Mexico was dropped from the network because of the loss of several experiment units to wildfires in 2002 and 2003. Of the five sites in the Eastern United States, two in the Appalachian region are hardwood-dominated (Central Appalachian Plateau and Southern Appalachian Mountains), featuring forests composed of a variety of oaks, maples, and hickories (Waldrop et al. 2008). The Gulf Coastal Plain site is dominated by longleaf pine (*Pinus palustris* Mill.), a conifer species with a fire-dependent ecology (Outcalt 2005). The Southeastern Piedmont site is situated in a forest that has grown back in cotton fields abandoned in the 19th century, and is dominated by loblolly (*P. taeda* L.) and shortleaf (*P. echinata* Mill.) pines, with hardwoods in the understory and in the swales (Phillips and Waldrop 2008). Finally, the Florida Coastal Plain site has a sparse overstory of slash pine (*P. elliottii* Engelm.) and longleaf pine, and an understory dominated by saw palmetto (*Serenoa repens* (Bartram) Small) (Outcalt and Foltz 2004). While the details of management history of the eastern sites differ considerably, stand structures generally reflect considerable burning and clearing over the past 250 years (McCarthy 1995). Each of the seven western sites is dominated by conifer species, principally ponderosa pine (*P. ponderosa* P. & C. Lawson) and Douglas-fir (*Pseudotsuga menziesii* (Mirbel) Franco). Sites differ considerably in productivity, reflected by a range in annual precipitation from at least 160 cm at the Southern and Central Sierra Nevada sites in California (Stephens and Moghaddas 2005b) to less than 50 cm at the Southwestern Plateau in northern Arizona (Hurteau et al. 2010). Located on national park lands, the Southern Sierra Nevada site had never been logged (Knapp et al. 2005), but the other six western sites have stand structures that reflect a history of logging, from the early part of the 20th century through the 1980s (table 1). In all of these forests, the largest trees were logged earlier in the 20th century, with more recent prescriptions focused on thinning from below (Dodson et al. 2008, Metlen and Fiedler 2006, Ritchie 2005, Youngblood et al. 2006).

Fuel reduction treatments were applied between 1998 and 2004 at all 12 sites. Eleven sites received four treatments: prescribed fire only (burn), some form of thinning applied as a mechanical treatment only (mechanical), a combination of mechanical treatment applied first followed by prescribed (mechanical + burn), and an untreated or unmanipulated treatment (control). At the Southern Sierra Nevada site (National Park Service), no mechanical treatments were allowed, thus the two active treatments were early and late-season burns (table 1). Treatment was replicated at all 12 sites three or four times at the stand level. These replicates are referred to as "experimental units" and most statistical analyses were conducted at this scale. Each unit was at least 10 ha, with the perimeter surrounded by a buffer of at least 50 m that received a similar treatment. All pre- and posttreatment measurements were taken in reference to a set of points established on a 40- to 60-m grid in the interior of each unit.

The 80/80 rule served as a minimum treatment target and provided a common basis for designing treatments across the network of sites.

The detailed prescriptions for mechanical fuel reductions and underburning were unique to each site, but the common objective for all treatments was to achieve stand and fuel conditions such that, if subjected to a head fire under the 80th percentile weather conditions, at least 80 percent of the basal area of the dominant and co-dominant trees would survive (80/80 rule). Clearly, because the alternative fuel reduction treatments would be expected to influence stands and fuel beds in fundamentally different ways, we did not expect posttreatment stands to look the same for all treatments. Rather, the 80/80 rule was designed as a guide that fire management officers and silviculturists could use to envision the kinds of treatments we wanted (Stephens et al. 2009). In addition, we anticipated that sites differed in the extent to which local managers would "push the envelope" with respect to the burn treatment in particular, and so the 80/80 rule also tended to dampen potential among-site variation of this kind. For mechanical treatments, managers at each site used a biomass or saw-log removal system that was locally applicable to that site, but always with the 80/80 rule in mind. Burning was conducted in the fall or spring based on common local practices, or both seasons at the Southern Sierra Nevada site. At western sites, the combination mechanical + burning treatment was implemented with at least a full season between cutting and burning for fuels added during mechanical harvesting to dry before burning. While the method of application of prescribed fire was fairly uniform throughout the 12 sites, the mechanical treatments were more variable. At most sites, mechanical harvesters were used to thin trees. At the Central Sierra Nevada site, trees less than 25 cm in diameter were mechanically masticated to further break down the fuel bed. At the Florida Coastal Plain site, the saw palmetto understory was masticated, leaving the sparse overstory untouched. At the Southern Appalachian Mountains site, all tree stems greater than 1.8 m height and less than 10.2 cm diameter were felled, as well as all shrubs, regardless of size.

The core experimental design for the FFS study included common treatments and response variables, and minimum replication standards and plot sizes. Ecological variables are interpreted within six ecosystem components or disciplines (table 2): (1) vegetation, including trees, shrubs, forbs, and grasses; (2) the relevant fuel bed, comprising the forest floor, woody fuels, and live fuels (particularly for the Eastern sites); (3) soils and the forest floor, with a focus on carbon, nitrogen, exchangeable ions, and bulk density; (4) fauna, including small mammals, birds, and macroinvertebrates; (5) bark beetles on pine-dominated sites; and (6) root diseases and dwarf mistletoe. Most variables were measured the year before sites were treated, and for as many years as possible after treatment (1 to 4 years). Several statistical methods were used for analysis, including general linear models for univariate analyses, structural equation modeling for multivariate questions, and meta-analyses for multisite comparisons. The FFS study was also designed to measure costs of alternative fuel reduction treatments, and estimates of these were made for each of the 12 sites. Some sites also measured productivity of the principal machines used (e.g., Blue Mountains), and one site (Central Sierra Nevada) assessed the social acceptance of the various fuel reduction methods.

Chronology

Although the national FFS study was carried out in large part within the period during which the project received funding from the Joint Fire Science Program (2000–2006), research activity associated with the project occurred between 1996 and 2010 (table 3). In this section, we summarize the chronology of the FFS from its inception in 1996 to publication of the final short-term results in late 2010.

The idea for an experiment that would directly compare the ecological effects of alternative fuel reduction methods was proposed almost simultaneously by two different teams of scientists. At the Pacific Southwest Research Station's Silviculture Lab in Redding, California, Phil Weatherspoon and Carl Skinner began to envision a comparative experiment in early 1996 after having evaluated separately the effects of both prescribed fire and its mechanical surrogates (Weatherspoon and Skinner 1995) and having proposed, in cooperation with a number of other scientists and land managers, California-based FFS-type studies. In February 1996, James McIver

Table 1—Management history and treatment information for 12 study sites of the national Fire and Fire Surrogate study

Site name and location	Past management history	Year and type of treatment
Northeastern Cascades, Okanogan-Wenatchee National Forest, central Washington (Dodsen et al. 2008)	Logged in the 1930s and precommercial thinned in the 1970s; fires excluded since the early 1900s; heavily grazed in the early 20^{th} century.	Mechanical (2001): felled, limbed, and bucked with chain saws, yarded with helicopters, residue left on site. Burn (2004): underburned in the spring with backing and strip head fires.
Blue Mountains, Wallowa-Whitman National Forest, northeastern Oregon (Youngblood et al. 2006)	Harvested in the early 20^{th} century and as recently as 1986; fires excluded since the early 1900s; grazed; most trees 60 to 90 years old.	Mechanical (1998): felled, limbed, and bucked with single-grip harvesters, yarded with forwarders, residue left on site. Burn (2000): underburned in the fall with strip head fires.
Northern Rocky Mountains, Lubrecht Experimental Forest, University of Montana, western Montana (Metlen and Fiedler 2006)	Logged in the early 20^{th} century; fires suppressed since the early 1900s; grazed since the early 1900s.	Mechanical (2002): felled, limbed, and bucked with single-grip harvesters, yarded with forwarders, residue left on site. Burn (2002): underburned in the spring with strip head fires.
Southern Cascades, Klamath National Forest, northeastern California (Ritchie 2005)	Railroad logged in the 1920s; sanitation and salvage logged since the 1920s.	Mechanical (2001): felled with feller-bunchers, whole tree yarded with skidders. Burn (2001): underburned in the fall with strip head fires.
Central Sierra Nevada, Blodgett Experimental Forest, University of California-Berkeley, central California (Stephens and Moghaddas 2005a)	Railroad logged in early 20^{th} century; sanitation and salvage logged in the mid-1970s; commercial harvested recently with various methods.	Mechanical (2002): felled, limbed, and bucked trees greater than 25 cm in diameter with chain saws, lopped and scattered tops and limbs, yarded with skidders, masticated 70 percent of trees less than 25 cm in diameter. Burn (2002): underburned in the fall with backing and strip head fires.
Southern Sierra Nevada, Sequoia National Park, south-central California (Knapp et al. 2005)	Fires suppressed since the early 20^{th} century.	Burn (2002, 2003): fall and spring underburns with strip head fires.

Table 1—Management history and treatment information for 12 study sites of the national Fire and Fire Surrogate study (continued)

Site name and location	Past management history	Year and type of treatment
Southwestern Plateau, Kaibab and Coconino National Forests, northern Arizona (Converse et al. 2006b)	Harvested; grazed; limited low thinned in the early 1990s.	Mechanical (2003): felled, limbed, and bucked trees greater than 13 cm in diameter with chain saws, felled and lopped smaller trees. Burn (2003): underburned in the fall with backing and strip head fires.
Central Appalachian Plateau, Vinton Furnace Experimental Forest, Mead/Westvaco Corporation and Ohio State Forest lands, southern Ohio (Waldrop et al. 2008)	Forests largely cut over during the 1800s; human-ignited fires common prior to early 1880s; fires suppressed since the early 1900s.	Mechanical (2001): felled, limbed, and bucked with chain saws. Burn (2001): underburned in the spring with strip head fires.
Southern Appalachian Mountains, Green River Game Lands, state of North Carolina, western North Carolina, western North Carolina (Waldrop et al. 2008)	Forests largely cut over during the 1800s; human-ignited fires common prior to early 1880s; fires suppressed since the early 1900s.	Mechanical (2001–2002): felled trees and all shrubs with chain-saws. Burn (2003, 2006): underburned in the winter with ignitions by hand and by helicopter with strip head fires and spot fires.
Southeastern Piedmont, Clemson Experimental Forest, Clemson University, western South Carolina (Phillips and Waldrop 2008)	Land cleared and farmed for cotton and other row crops from 1800 to 1930; forests reestablished in 1930 to 1950.	Mechanical (2000–2001): felled with feller-bunchers, whole tree yarded with skidders, residue left on site. Burn (burn only 2001 and 2004, mechanical + burn 2002 and 2005): underburned in the winter with ignitions by hand with strip head fires.
Gulf Coastal Plain, Auburn University, Solon Dixon Experimental Forest, southern Alabama (Outcalt 2005)	Naturally regenerated mixed pine managed for timber and naval stores by private families from 1880s to 1981; burned infrequently.	Mechanical (2002): felled with feller-bunchers, limbed with chain saws, whole tree yarded with skidders. Burn (2002): underburned with strip head fires.
Florida Coastal Plain, Myakka River State Park, west-central Florida (Outcalt and Foltz 2004)	Underburned frequently during the past 15 years.	Mechanical (2002): chopped with aerator pulled by rubber tired tractor. Burn (2000, 2001): underburned in the spring with strip head fires.

Table 2—Discipline or component studied in the national Fire and Fire Surrogate study, including variable group, measurement scale, measurement intervals, and sites where measured

Component	Variable group	Measurement scale	Measurement interval	Sites
Site characterization	Slope, aspect, global position, topographic position, elevation	Unit	Pretreatment	All
Weather	Precipitation, temperature	Control core plots	Throughout study	All
Vegetation	Trees, shrubs, grasses, forbs, density, cover, richness, patchiness, and spatial pattern	Plot within unit	Pretreatment, several posttreatment	All
Fuels	Litter, duff, shrub biomass, woody fuel	Transects on grid within unit	Pretreatment, several posttreatment	All
Soil characterization	Depth, texture, classification	Unit	Pretreatment	All
Soil properties	Carbon and nitrogen dynamics, major cations and ions, pH, soil bulk density and soil strength	Plots within unit	Pretreatment, several posttreatment	All
Avian fauna	Songbird density, richness, nest density, diversity/behavior of bark-gleaning taxa	Unit	Pretreatment, several posttreatment	All
Mammalian fauna	Small mammal density, richness	Unit	Pretreatment, several posttreatment	Western sites; Southern Appalachian Mountains
Bark beetles	Activity in pine trees	Unit	Pretreatment, several posttreatment	Western sites
Diseases	Root disease, dwarf mistletoe	Unit	Pretreatment, several posttreatment	All
Economics	Treatment cost, machine productivity	Site	Posttreatment	All
Sociopolitical	Social acceptance of treatments	Region	Posttreatment	Central Sierra Nevada

Table 3—Chronology of key events in the development of the national Fire and Fire Surrogate (FFS) study, 1996 though 2010

Date	Event
February 1996	Weatherspoon and Skinner called for FFS study in Sierra Nevada
February 1996	McIver and Youngblood proposed FFS study to U.S. Department of Agriculture-National Research Initiative (Blue Mountains site)
October 1997	Weatherspoon discussed the potential for national FFS with Conard
November 1997	Joint Fire Science Program (JFSP) established
June 1998	JFSP funded preproposal to design FFS
June 1998	Pretreatment data collection initiated and mechanical treatments applied at Blue Mountains site
September 1998	Steering committee began developing national FFS experiment proposal
December 1999	First proceedings paper published
January 2000	Steering committee submitted FFS proposal to JFSP
February 2000	JFSP funded FFS
April 2000	Pretreatment data collection began at most sites
Spring 2000	Treatment implementation phase began for most sites
May 2000	Financial agreements signed between JFSP and FFS research institutions
October 2000	Database manager hired and database development began
Spring 2001	First round of posttreatment data collection began at most sites
June 2002	First master's thesis published
Spring 2004	First round of treatments completed at 12 sites
October 2004	First journal paper published
June 2005	First Ph.D. dissertation published
May 2006	Initial funding completed and final reports submitted to JFSP
November 2006	First national FFS symposium held in San Diego, California
May 2008	First collection of 12 papers published in *Forest Ecology and Management*
March 2009	Second collection of five papers published in *Ecological Applications*
December 2009	Second national symposium held in Savannah, Georgia
February 2010	Third collection of 12 papers published in *Forest Science*
December 2010	Fourth collection of seven papers published in *Open Environmental Sciences*

and Andrew Youngblood, of the Pacific Northwest Research Station's La Grande, Oregon, Forestry Sciences Lab, submitted a proposal to the USDA National Research Initiative entitled, "Alternative fuel reduction methods in Blue Mountain dry forests," which was subsequently funded in September 1996. That proposal described methods that were similar to those eventually adopted by the FFS steering committee, allowing the Blue Mountains to be included as one of 11 initial FFS sites. The idea for a national FFS study germinated at a national "Fuels research proposal workshop" held in November 1997. The fire scientists and fire managers attending this workshop were asked to identify high-priority fire research needs that would provide input to the interagency committee drafting the Congressionally mandated Fire Sciences Plan. This plan would guide the initial decisionmaking of the new Joint Fire Science Program (JFSP; U.S. Department of the Interior and the USDA Forest Service; established in early 1998) in allocating new federal funding to address the most pressing fire science and management issues of the day. At this workshop, Weatherspoon proposed a multiple-site FFS-type project to be implemented in California or, if interest and support warranted, in several locations across the Western United States. A number of attendees considered this proposed project to have substantial merit, and several suggested that it be expanded to a national scale. At the conclusion of the workshop, a group of attendees interested in the FFS-type proposal met to discuss next steps. Significantly, the group included Susan Conard, chairperson of the interagency drafting committee and soon thereafter chairperson of the JFSP Governing Board, who strongly supported the vision of a national FFS-type study. Based in part on this group's discussion, Weatherspoon and Skinner organized an initial FFS meeting in January 1998 to begin the process of defining and designing this national study.

It is certainly fortuitous that the JFSP emerged at the same time that several scientists were envisioning an FFS-type project, because it is unlikely that other granting agencies could have supported such an ambitious national project. In September 1998, Weatherspoon and the FFS steering committee received a planning grant from the JFSP to design a national multisite, multidisciplinary FFS study that would evaluate the economics and ecological consequences of prescribed fire and its mechanical surrogates in seasonally dry forests of the United States. Shortly thereafter, McIver and Youngblood presented the design of their previously funded experiment at the Blue Mountains site in northeastern Oregon, and sufficient portions of the design were adopted by the national FFS steering committee, resulting in the Blue Mountains site becoming the initial FFS site. The FFS design was completed in December 1999, and in February 2000, the JFSP decided to fund the national experiment.

Pretreatment data collection began in May 1998 for the Blue Mountains site. Data collection began in April 2000 for eight additional sites, three in the East, and five in the West. The two remaining eastern sites (Southern Appalachian Mountains and Gulf Coastal Plain) were funded by the National Fire Plan, and pretreatment data collection began in 2001 using the same protocols as sites funded by the JFSP. In the West, the Central Sierra Nevada site also began data collection in 2001. Treatment implementation began in 1998 (Blue Mountains site), and the first round was completed with the prescribed burns at the Northeastern Cascades site in 2004. By the end of the JFSP-funded period (April 30, 2006), most of the eastern sites had applied a second or third prescribed fire. The first round of posttreatment data collection (after all treatments were implemented) began in 2001 and continued through 2004. Additional years of posttreatment data were also collected at most sites, continuing through the summer of 2006. Site-level analysis began within a few months after the first round of treatments had been implemented (by early 2002), and the earliest articles with short-term results were published beginning in late 2002. By the end of the JFSP-funded period, 100 data papers were published, including 24 theses and dissertations, 32 proceedings or general technical reports, and 44 peer-reviewed journal articles. By the end of 2010, this number had increased to 206 total publications, including 113 journal articles. Although the analysis phase of the initial study is largely finished, outreach continues as scientists conduct field tours and present papers on short-term results at conferences and workshops.

FFS Outreach

Early in 2001, within 8 months of funding, principal investigators of the FFS study developed a "Communications Plan," which served as an outreach guide for each site and the network as a whole. This plan identified all potential audiences and prescribed content and medium for products and activities aimed at those audiences throughout the study period. The primary audience throughout the network and the study period was the natural resource land manager, primarily federal, but also state, local, and private. An important secondary audience was the "active" public, those individuals in the private sector who take a keen interest in natural resource issues. Finally, the tertiary audience was other scientists/educators, because in reality, much of the information that natural resource managers use is acquired through the traditional educational process, delivered to them through universities or through continuing education programs.

From October 2000 through the end of 2010, a total of at least 644 products were delivered, including 206 technical articles, 111 invited oral presentations, 68 tours, 174 posters/presentations at conferences, and 20 major workshops (table 4).

Table 4—Summary of principal outreach products and activities of the national Fire and Fire Surrogate study, by media and site

	National Fire and Fire Surrogate study sites														
	Northeastern Cascades	Blue Mountains	Northern Rocky Mountains	Southern Cascades	Central Sierra Nevada	Southern Sierra Nevada	Southwestern Plateau	Central Appalachian Plateau	Southern Appalachian Mountains	Southeastern Piedmont	Gulf Coastal Plain	Florida Coastal Plain	Regional	Network	Total
Products:															
Brochure	1	1	1	1	1	1	1	2	1	3	1			1	15
Data request		5													5
Database														1	1
National conference papers														23	23
Poster														2	2
Publications	20	12	14	4	15	8	4	30	18	22	9	4	10	36	206
Slide show/PowerPoint														2	2
Study plan														1	1
Web site	1		1		1	1			1		1	1		1	8
Activities:															
Contributed talk/paper										2				1	3
Invited speaker presentation	3	6	9	5	42	9	1	7	2	4	2	7		14	111
Newspaper/magazine article			1		1				1						3
Poster			4	2	4			23	3	5	5	3		1	50
Presentation		3		4	21	13	1	3		1	1	1		11	59
Slide show/PowerPoint			9					23	15	16				2	65
Tours/site visits	3	2	16		15	3		5	5	2	15	2			68
TV/radio broadcast	1								1						2
Workshop/training		1	1	8	4	2		1				1		2	20
Total	29	30	56	24	104	37	7	94	47	55	34	19	10	98	644

Note that the actual number of delivered products is considerably higher, because with the exception of technical articles, table 4 does not contain any outreach delivered after the funding period ended (May 2006). Nonetheless, although it is very difficult to measure the actual impact of any given research project, FFS principal investigators invested a significant amount of time and energy in outreach to deliver the vast amount of information collected to the intended audiences.

Toward the end of the study period, FFS principal investigators held a series of four regional workshops across the country (Youngblood et al. 2007). To each workshop we invited key individuals representing our primary audience (natural resource land managers), and we used participatory evaluation as a means of assessing the efficacy of our outreach effort. We asked four overarching questions at each workshop: (1) Who needs fuel reduction information? (2) What information do they need? (3) Why do they need it? and (4) How can it best be delivered to them? Participants helped to determine key users of fuel reduction information, identified the most important pieces of information needed by them, and made recommendations on how best to deliver the information to the key users. While each regional workshop was to some extent idiosyncratic in terms of output, a common theme identified by most participants was that the most effective means of outreach would be to open and maintain direct communication lines between scientists and managers working in the fuel reduction arena. Certainly, information tended to be delivered most effectively and most efficiently to those land managers who had the opportunity to work directly with scientists at the study sites themselves, throughout the treatment implementation, posttreatment measurement, and science delivery processes.

Much of the expense of experimental research is personnel. A substantial amount of work is needed to accomplish project objectives, such as planning, surveying, measuring, managing data, analysis, writing, and outreach. An implicit yet critically important aspect of such research is the training of future professionals, especially to the extent that the work is performed by students and junior staff at various stages of career development. Thus the USDA Forest Service and the Department of the Interior, through funding distributed by the JFSP, are in effect training professionals for future work in their agencies, the private sector, universities, and other professional fields. Across the FFS network, dozens of students were engaged in the process of research, including undergraduate, graduate, and postdoctoral. We have no way of tracking the dozens of undergraduate students who were involved in FFS. Successful graduate students, however, left behind a record of their work in their master's theses, doctoral dissertations, and journal articles; all of these were assigned FFS publication numbers and are summarized in the bibliography. A total of 41 postgraduate students completed research associated with FFS sites, including 4 postdoctoral scientists, 8 doctoral students, and 27 master's students (table 5). Two students published papers while in degree programs but did not finish degrees. Of the 32 individuals about whom we have information, 8 have found permanent work with state or federal agencies, 4 are university faculty members, and 6 are professionals within the private sector. Clearly, the FFS study has been a fertile training ground for natural resource professionals, especially those working in forestry, silviculture, and fire-related fields.

FFS study results were featured in four special issues of refereed journals.

Any outreach program that supports a scientific research project must have a core of information to draw upon, preferably published in peer-reviewed outlets. Although the journal article is generally considered the gold standard for technical communication and peer validation, in recent years, articles placed in collections of proceedings, general technical reports, and graduate student theses typically receive some form of peer review, and therefore can also be included in the core of the knowledge base for a research project. For the FFS study, a total of 206 technical articles were published between 1999 and 2010, including 111 in scientific journals, 27 master's theses, 8 Ph.D. dissertations, and 46 in collections of proceedings or in technical reports (table 6). Of the peer-reviewed journal papers, 33 were published as collections in four journals: *Forest Ecology and Management* vol. 255 (2008), *Ecological Applications* vol. 19 (2009), *Forest Science* vol. 56 (2010), and *Open Environmental Sciences* vol. 4 (2010).

Because the FFS study included common research protocols across sites for the same ecological component or scientific discipline (table 2), we grouped technical articles into these ecological components or disciplines by site to provide easy access to those wanting to compare responses within a discipline among sites or ecoregions (table 7). Similarly, we grouped the collection of technical articles into second-order or more applied themes of common interest, such as treatment effect size, heterogeneity of treatment effects with treatment units, and implications for nonnative or exotic plants (table 8). Many of these technical papers reflect the multisite, multivariate design of the FFS study, which builds a more confident knowledge base when it comes to when, where, and how to plan a fuel reduction program. Key multisite articles include those focusing on soils and carbon, vegetation, fuels, wildlife, economics, outreach, and multiple variables. Key multivariate articles consider such related topics as prescribed fire, fuels, and spatial heterogeneity; fuels, fire behavior, and bark beetles; soil, microbes, and vegetation; fire, patchiness, invertebrates; and fuels, fire, carbon, and risk reduction.

Finally, three contributions can be considered syntheses, having drawn upon information from several FFS sites in addition to other literature in an effort to

Table 5—Number of graduate students and postdoctoral scientists completing studies between 2002 and 2008 using the national Fire and Fire Surrogate study platform as a training venue for furthering their professional experience

Fire and Fire Surrogate study site	Continued in school	Post-doctorate	State or federal agencies	University faculty	Professional or private	Unknown	Total
Northeastern Cascades	1		1		1	3	6
Blue Mountains	1			1	2	1	5
Northern Rocky Mountains	3			1			4
Central Sierra Nevada	2	1	1				4
Southern Sierra Nevada			1	1			2
Southwestern Plateau			1				1
Central Appalachian Plateau	1	1	1				3
Southern Appalachian Mountains			1				1
Southeastern Piedmont	2	2	1	1	3	3	12
Gulf Coastal Plain			1			1	2
Florida Coastal Plain						1	1
Total	10	4	8	4	6	9	41

Table 6—Number of technical papers based on the national Fire and Fire Surrogate study, published between 2004 and 2010, by ecosystem component or scientific discipline and publication type

Ecosystem component or discipline	Journal	Proceedings/ book chapters	General technical report	Masters thesis	Ph.D. dissertation	Synthesis or literature review	Popular	Total
Overstory vegetation	17	8					1	26
Understory vegetation	12	2		2	1	1	1	19
Fuels and fire behavior	13	11	2	2			1	29
Soils	17	7		4	1			29
Vertebrates	26	2		10	3	1	1	43
Invertebrates	8	1		2	1			12
Bark beetles	3	1		1				5
Pathology and fungi	4		1	5				10
Economics	1	1		1	1		1	5
Sociology	1		1				1	3
Multivariate	5	7			1	1		14
General study description 1	4	6	1					
Total	111	46	5	27	8	3	6	206

Table 7—Reference number of papers from the national Fire and Fire Surrogate (FFS) study, published between 2004 and 2010, by site, ecoregion, and ecosystem component or scientific discipline (see table 14 for reference listing)

FFS site	U.S. Environmental Protection Agency Level III Ecoregion	Overstory vegetation	Understory vegetation	Fuels and fire behavior	Soils	Vertebrates	Inverts	Bark beetles	Pathology and fungi	Economics	Sociology	Multivariate	Study description
Northeastern Cascades	East Cascades Slopes	1–3	4, 5	6–8	9, 10	11, 12			13–19				20
Blue Mountains	Blue Mountains	21	23, 24	25, 26		27			28	29–31		33	32
Northern Rocky Mountains	Middle Rockies	34	35–39	40	41–43	44, 45		46				47	
Southern Cascades	East Cascades Slopes	48		49	50			51					
Central Sierra Nevada	Sierra Nevada	52–54	55	56–58	59–61	62, 63	64, 65				66		
Southern Sierra Nevada	Sierra Nevada		67	68–70	71	72	73	74					
Southwestern Plateau	Arizona Plateau					75–78							
Central Appalachian Plateau	Western Allegheny Plateau	79–88	89, 90, 92, 93	94–98	99–103	104	105–107					108	
Southern Appalachian Mountains	Blue Ridge		144	114, 145–148	149	150–157	158–160						
Southeastern Piedmont	Piedmont	109	110	111–113	115–118	119–127	128, 129	130, 131					
Gulf Coastal Plain	Southeast Plains	135–137				138–143						206	
Florida Coastal Plain	Southern Coastal Plain				132	133	134						
Regional (2 to 4 sites)	NA	161	91	162	163, 164	165			166, 167			168–170	
Network (multisite)	NA	22, 171	172	173, 174	175–180	181–185				186, 187	188, 189	199–205	190–198

NA = not applicable.

Table 8—Reference number of papers from the national Fire and Fire Surrogate (FFS) study, published between 2004 and 2010, by site, forest type, and theme (see table 14 for reference listing)

FFS site	Forest type	Fire vs. surrogate	Effect size	Effect of duration	Heterogeneity	Restoration	Species adaptation	Exotic plants	Tradeoffs	Regional	Application
Northeastern Cascades	Pine, mixed conifer	2–4,10–12, 19, 20	1–5, 6–8, 10, 12, 19, 20	19	5		11–18	4	8, 11–12		5
Blue Mountains	Pine, mixed conifer	21, 23–24, 26–28, 31–33	21, 24–26, 28, 32–33	26, 33		23–24, 28, 29, 31	24, 27 24, 28	21, 23,	31		25
Northern Rocky Mountains	Pine, mixed conifer	34–47	34, 36–39, 41, 43, 44, 46, 47	36–39, 41	36, 41	34, 36, 38, 39	44	35, 37, 39	37		36, 41
Southern Cascades	Mixed conifer	50, 51	48–51						48		
Central Sierra Nevada	Mixed conifer	52–56, 58, 59, 61–65	52–61, 63–65	53, 61, 64	59, 64, 65	57, 58	63–65	55	54, 56, 63		66
Southern Sierra Nevada	Mixed conifer		67, 68, 70–74	67	69, 70, 73		72, 73	67	67, 68		67
Southwestern Plateau	Pine	78	75–78	75–77							
Central Appalachian Plateau	Hardwood	79–82, 86, 88, 90, 92–97, 99, 101–104, 106, 108	79, 81, 82, 84–86, 89, 90, 92, 93, 95, 96, 98–103, 105, 106, 108	79–81, 85, 89, 90, 98, 101,107	84, 99	92	102				83, 87

Table 8—Reference number of papers from the national Fire and Fire Surrogate (FFS) study, published between 2004 and 2010, by site, forest type, and theme (see table 14 for reference listing) (continued)

FFS site	Forest type	Fire vs. surrogate	Effect size	Effect of duration	Heterogeneity	Restoration	Species adaptation	Exotic plants	Tradeoffs	Regional	Application
Southern Appalachian Mountains	Hardwood	146, 147, 149, 152, 155–159	114, 144, 148, 150–152, 154–160	144, 147, 149, 151		144, 147	146, 151–153				145
Southeast Piedmont	Piedmont pine	109–112, 115–119, 122, 123, 125–131	109–113, 115, 117–118, 121, 128–131	110, 111, 115, 118, 128		126	119, 123, 126, 130, 131		118, 120, 124		130, 131
Gulf Coastal Plain	Longleaf pine	137, 142, 206	135–137, 139–143	135, 139		137	138, 140		206		
Florida Coastal Plain	Slash pine	132	132				133, 134				
Regional (2 to 4 sites)	Variable	91, 162–169	91, 162–168, 170	161, 162, 164, 167, 170		170				162	167
Network (12)	Variable	171, 172, 174, 176–178, 180–182, 184, 186–200, 202, 203, 205	22, 171, 172, 174, 176–183, 188, 190–199, 201, 203, 205	172, 175, 179, 180, 182, 183, 187, 194, 197, 199, 201, 203	201, 202	22, 171, 172, 175, 177, 202	181, 184	172, 202, 203	187–189, 203	22, 175, 176, 187, 194	171–173, 181, 182, 185, 186, 189, 204

focus on major subject areas of nontarget botanicals, vertebrates, and prescribed fire season of burn. These syntheses were all designed with land manager input, which was used not only to determine content, but also to insure that the products were built in a form readily useable by natural resource managers.

Findings

The principal short-term findings of the FFS study reported here are all extracted from research published in theses, dissertations, proceedings, general technical reports, or in peer-reviewed journals (table 6). We start by describing the effectiveness of the prescribed treatments in terms of the stated short-term goal of fuel reduction. This provides not only a glimpse of first-order effects that are important for natural resource managers, but also sets the stage for interpretation of the second-order effects that are the primary focus of FFS research. Obviously, if treatments are poorly implemented, any second-order effect would have little practical value. Next we present a summary of key findings, organized by treatment, management theme, discipline, and site. While some textual interpretation is provided, key findings are organized into a set of annotated tables, such that the reader can more easily link statements to the published literature. We hope that the organization of findings in several ways (by treatment theme, discipline, and site) will cover a wider range of needs of our intended audience. Finally, we provide an annotated list of all 401 findings that we extracted from the 206 published articles, organized first by site (ecoregion), then by discipline (ecological component, sociology, or economics). Each publication is classified based on site, principal discipline, and publication type. The full citation is provided for each article, and each finding is also linked to supporting literature outside the FFS. A searchable database of all findings, their supporting literature, and PDFs of all 206 articles is posted on the Fire Research and Management Exchange System (FRAMES) Web site (www.frames.gov/ffs).

We provide an annotated list of 401 findings extracted from 206 published articles.

Treatment Effectiveness

The first mark of a successful manipulative experiment is that all treatments must be implemented such that target variables are changed in predictable ways, as close to prescription as possible. In the case of the FFS study, target variables were components of stand structure and the fuel bed associated with fuel reduction. In general, to meet the 80/80 requirement, we aimed for reductions in the density and basal area of living trees and total woody fuel mass. Most sites had good success in meeting short-term fuel reduction objectives for the various treatments.

When applied as distinct treatments, both prescribed fire and mechanical treatments had reasonably consistent short-term effects on stand structure and fuels

Table 9—Immediate effect of treatment implementation on live tree density, basal area, snag density, and total fuel mass for the 12 sites in the national Fire and Fire Surrogate (FFS) study, for burn (B), mechanical (M), and mechanical + burn (M+B) treatments (↑ = increase; ↓ = decrease; 0 = no trend change for indicated variable, with trend indicated by nonoverlapping standard errors)

	Live tree density			Basal area			Snag density			Total fuel mass		
FFS site	**B**	**M**	**M+B**	**B**	**M**	**M+B**	**B**	**M**	**M+B**	**B**	**M**	**M+B**
Northeast Cascades	0	↓	↓	0	↓	↓	0	0	0	↓	↑	0
Blue Mountains	0	↓	↓	0	↓	↓	↑	0	0	↓	0	↓
Northern Rocky Mountains	0	↓	↓	0	↓	↓	↑	0	↑	↓	↑	↓
Southern Cascades[a]	0	↓	↓	0	↓	↓	↑	↓	↓	↓	0	↓
Central Sierra Nevada	0	↓	↓	0	↓	↓	↑	↓	↓	↓	0	↓
Southern Sierra Nevada[b]	↓	NA	NA	↓	NA	NA	↑	NA	NA	↓	NA	NA
Southwestern Plateau	0	↓	↓	0	↓	↓	↑	↓	0	↓	0	↓
Central Appalachian Plateau	0	↓	↓	0	↓	↓	0	↓	↓	0	↑	0
Southern Appalachian Mountains	0	0	↓	0	0	0	↑	0	↑	↓	0	0
Southeastern Piedmont	0	↓	↓	0	0	↓	↑	0	↑	↓	0	0
Gulf Coastal Plain	0	↓	↓	0	↓	↓	↑	↓	↑	0	0	↓
Florida Coastal Plain	0	0	0	0	0	↑	↑	0	0	0	0	0

NA = not applicable.

[a] Pretreatment data not available for Southern Cascades site; effect trends are estimated with the use of control units.

[b] Mechanical treatments not implemented at Southern Sierra Nevada site in Sequoia National Park; trajectories combine spring + fall burns.

across the FFS network (Schwilk et al. 2009). As expected, fire alone had little influence on live stand structure (tree density, basal area), but tended to increase the density of small snags, and for the western sites in particular, decrease the mass of woody fuels (table 9). Mechanical treatment, on the other hand, had nearly opposite effects on stand structure and fuels, resulting in lower live tree density, basal area, and snag density (at some sites), but either did not influence or increased woody fuel mass. The only exception to these general patterns was at the Florida Coastal Plain site, where fuel treatments were designed only to target the understory.

A somewhat less consistent picture emerges when we examine short-term effects of treatments when applied in combination (first mechanical, then prescribed fire). While the combined treatment affected live tree parameters in almost the same way as for the mechanical treatment, there were distinct differences between western and most eastern FFS sites in effects on snags and total fuel mass. Among western sites, snag density tended to either remain unchanged or **decreased** after the mechanical + burn treatment, while among the four eastern sites at which overstory treatment was emphasized, three sites experienced **increased** snag density. Furthermore, while the combined mechanical + burn treatment decreased woody fuel mass at nearly every western site, only at the Gulf Coastal Plain site did the combination of mechanical and fire treatments have this effect. Interestingly, in terms of treatment effectiveness, the Gulf Coastal Plain site was similar to the western sites, while the other eastern sites were more variable.

Fire performance analysis conducted at six western sites indicated that the mechanical + burn treatment was the most effective treatment.

In terms of predicted posttreatment fire behavior, fire performance analyses conducted at six western sites (excluding Northeastern Cascades) strongly indicated that the mechanical + burn treatment was the most effective treatment in these dry forest systems (Stephens et al. 2009). This is not surprising; only the combination treatment resulted in short-term stand structure and fuel bed conditions—reduced live tree density, live basal area, and fuel mass—that would be expected to substantially influence future fire behavior. In contrast, at the Central Appalachian Plateau and Southeast Piedmont sites, both eastern sites at which potential fire behavior analyses were conducted, burning was the most effective treatment, possibly because slash created by the mechanical treatment had not sufficiently dried by the time fires were applied (Iverson et al. 2003, Mohr and Waldrop 2006). In terms of fuel treatment effectiveness therefore, the combination mechanical + burn most closely resembled the mechanical treatment for these two eastern sites.

Table 10—Principal distinctions among three fuel reduction treatments compared in the national Fire and Fire Surrogate study

Treatment	Summary of effects
Burn	Burn treatments had little effect on live stand structure, but increased small snag density and decreased woody fuel mass. Fuel reduction was greater with fall burns than spring burns at western sites. Burning alone was more effective in fuel reduction than the combined mechanical + burn treatment in the east, especially when slash was not dry when fire was applied. Costs in the West were higher than the Southeast owing to drier conditions resulting in higher risk of fire escapes and greater smoke production. More people in California favored fire as a fuel reduction practice, but many worried about the risk of escape. For ecological effects, burns: • Were most similar to the combined mechanical + burn treatments • Retained more carbon in the soil than mechanical or no treatments • Can enhance short-term productivity, but at the expense of nutrient standing stocks • Decreased soil moisture, which favored more xeric plant species • Favored shorter lived, herbaceous plant species • Caused short-term decreases in shrub cover, but stands recovered to initial levels 2 to 4 years after burning • Altered surface-dwelling beetle species compositions, increasing the abundance of rare species • Altered feeding guild structure of arthropod communities • Increased bark beetle activity, which in turn attracted bark-foraging birds including passerines and woodpeckers • Increased patchiness, leading to heterogeneity in nutrients and increased stand-level plant species richness • Created forest heterogeneity similar to wildfires owing to spatial variation in topographic and biotic factors
Mechanical	Mechanical treatments decreased basal area and stand density, but had little effect on surface fuels. Mechanical treatments were similar to the untreated control in fuel and fire risk reduction, resulting in more severe modeled fire behavior and tree mortality than treatments that included burns. At several sites, mechanical treatments returned revenue that helped to offset the cost of other treatment activities, including fire. In a broad survey in California, the majority of people believed mechanical treatments to be an acceptable method to reduce fuels, and also trusted the land managers to implement them properly. For ecological effects, mechanical treatments: • Were not a surrogate for fire for the great majority of ecological variables • Produced results similar to the untreated control for most variables • Altered carbon and nitrogen dynamics in different ways than did burning • Created or maintained more mesic conditions for plant responses • Had little effect on arthropod species

Table 10—Principal distinctions among three fuel reduction treatments compared in the national Fire and Fire Surrogate study (continued)

Treatment	Summary of effects
Mechanical (cont.)	• Had no effect on bark beetles or bark-foraging bird species at western sites • Attracted foliage-gleaning and canopy-nesting bird species at some eastern sites • Did not alter within-stand patchiness
Mechanical + burn	Mechanical + burn treatments decreased basal area and stand density similarly to the mechanical treatments, but there were distinct differences between western and most eastern FFS sites in effects on snags and total fuel mass. Snag density was unchanged or decreased after treatment at western sites, while snag density increased at three eastern sites. Mechanical + burn treatments were less effective than burn treatments at eastern sites because fuels were not consumed by fires after mechanical treatments. For ecological effects, the mechanical + burn treatments: • Were more similar to burn treatments for most ecological variables, with generally greater magnitude of change for soils, plants, invertebrates (particularly bark beetle activity), and vertebrates • Likely were the most effective treatments in increasing resiliency of the overstory structure and composition • Diverged more from the other treatments in soil chemistry response with increased time after treatments • Favored herbaceous species, including exotic and transformer species • Created potential tradeoffs such as changes in down woody debris or large snags, and changes in natives plant species or exotic plant species

Highlights of Findings

Alternative treatments—

As expected, alternative fuel reduction treatments had markedly different effects on most ecological variables, across the spectrum of ecosystem components that were studied (table 10). This is largely because fire has unique effects on ecosystems, and these effects cannot be simulated by changing forest structure in any other way. Consumption by fire stores more carbon in the soil, increases mineral soil exposure, decreases soil moisture, enhances short-term productivity, and favors more xeric plant species. Changes in vegetation structure, and the patchiness of these effects within stands, can have measurable effects on invertebrates and small vertebrates, in terms of abundance, species composition, and species richness at the stand level. First-order fire effects attract bark beetles and reduce a tree's ability to repel bark beetle attacks, which cause further modification of resources, in turn attracting bark-foraging birds. In the short term, ground and foliage-nesting birds are discouraged by changes in vegetation structure, and together with changes in bird foraging guilds, bird species composition can diverge between fire and mechanically treated stands. The dominance of fire effects causes the mechanical + burn treatment to sort with the burn-only treatment, while the mechanical-only treatment tends to sort with the unmanipulated control for the great majority of ecological variables.

Social acceptance of fuel reduction treatments was quite high in the one survey performed in California, although prescribed fire is preferred as a restoration treatment, and mechanical treatments are rated as less risky in terms of fire escape and smoke production. In some forest stands, harvest of merchantable trees before burning clearly mitigated the costs of fuel reduction, and so market conditions permitting, the combination mechanical + burn treatment offers the fastest avenue to restoration of large structure in seasonally dry forests.

Themes—

In terms of "second-order" ecological effects, the most conspicuous patterns observed throughout the FFS network were that FFS treatments generally caused subtle and transient short-term effects, and that these effects were markedly different depending on whether fire was applied (table 11). Because of its capricious nature, fire also tended to enhance within-stand heterogeneity, which in turn influenced other variables such as herbaceous plant and invertebrate species richness. The distinctiveness of fire as a mechanism for change also led to habitat changes for both plants and animals, and generally favored species that were adapted to more xeric conditions. The combination mechanical + burn treatment had generally additive effects, and therefore caused the most significant short-term effects for most ecological variables. The attractiveness of the mechanical + burn treatment as

Table 11—Principal short-term findings of the national Fire and Fire Surrogate study by theme and major ecosystem component (see table 14 for reference listing)

Theme	Finding	Relevant treatments	Trees	Understory	Fuels	Soils	Bark beetles	Vertebrate biodiversity	Invertebrates fungal biodiversity
Fire vs. surrogate	For the great majority of variables, mechanical treatments did not serve as surrogates for fire, with mechanical treatments resulting in effects similar to untreated controls for most ecological variables, while the burn and mechanical + burn treatments resulted in similar effects	Fire vs. no fire	2, 3, 21, 34, 52–54, 79–82, 86, 88, 109, 137, 171, 206	4, 23, 24, 35–39, 55, 90–93, 109, 110, 172	26, 40, 56, 58, 94–97, 111, 112, 146, 147, 162, 174	10, 41–43, 50, 59, 61, 99, 101–103, 115–118, 132, 149, 163, 164, 176–178, 180	46, 51, 130, 131, 206	11, 12, 27, 44, 45, 63, 78, 104, 119, 122, 123, 125–127, 142, 152, 155–157, 165, 181, 182, 184	19, 28, 64, 65, 106, 128, 129, 158, 159, 166, 167, 206
Effect size	Ecological effects of fire and fire surrogate treatments were generally subtle and transient, suggesting that these kinds of treatments resemble the magnitude of historical disturbances in seasonally dry forest ecosystems	All	1–3, 21, 22, 34, 48, 52–54, 79, 81, 82, 84–86, 109, 135–137, 171	4, 5, 24, 36–39, 55, 67, 89–93, 109, 110, 144, 172	6–8, 25, 26, 49, 56–58, 68, 70, 95–98, 111–114, 148, 162, 174	10, 41, 43, 50, 59–61, 71, 99–103, 115, 117, 118, 132, 163, 164, 176–180	46, 51, 74, 130, 131	12, 44, 63, 72, 75–78, 121, 139–143, 150–152, 154–157, 165, 181, 183	19, 28, 64, 65, 73, 105, 106, 128, 129, 158–160, 166, 167
Effect duration	In most cases, ecological variables tended to return to pretreatment conditions after several years, including key components of the fuel bed	All	53, 79–81, 85, 135, 161	36, 37, 39, 67, 89, 90, 110, 144, 172	26, 28, 147, 162	41, 61, 101, 115, 118, 149, 164, 175, 179, 180		75–77, 139, 151, 182, 183	19, 64, 107, 107, 128, 167
East vs. West	Eastern sites differed from western sites in several important ways, suggesting the need to consider issues such as carbon sequestration and the frequency of repeated burns and mechanical entries	All	22		162	175, 176			
Species adaptation	Species generally responded to treatments in a manner consistent with their life history characteristics; most native species demonstrated positive responses consistent with adaptation to frequent, low-intensity fire	All		24			130, 131	11, 12, 27, 44, 63, 72, 119, 123, 126, 133, 138, 140, 151, 153, 181, 184	13–18, 64, 65, 73, 134

Table 12—Principal short-term findings of the national Fire and Fire Surrogate (FFS) study by discipline and ecosystem components (see table 14 for reference listing)

Discipline and ecosystem component	Finding	Key papers
Overstory vegetation	At all 12 FFS sites, all active fuel reduction treatments changed forest structure, with burning treatments leading to greater reduction in surface fuels, and thinning treatments leading to greater reductions in tree density. Complementary effects of thinning and burning made the combination mechanical + burn treatment the most effective at meeting short-term fuel reduction objectives. But although each of the active treatments was effective in shifting diameter distributions toward larger trees, no single entry is sufficient to restore historical structure.	22, 81, 86, 138, 169, 171, 204
Understory vegetation	Although all FFS treatments tended to increase cover and richness of herbaceous plants, treatments that included fire favored more xeric species, through decreases in litter and increases in exposure of mineral soil. Most threatened endangered and sensitive plant species were favored by fire, probably because fire suppression over the years has been the primary mechanism for their decline. Mechanical + burn treatments had the greatest short-term effects at multiple scales, increasing the dominance of both herbaceous natives and exotic “transformer” species; there will often be tradeoffs between the desire for rapid restoration of historical native conditions and the need to limit establishment and rapid growth of weedy species. Landscape context, or the proximity of proposed treatments to nearby roads, wildland-urban interface, or previous plant invasions, will influence exotic plant invasion and thus the effectiveness of treatments.	37, 55, 110, 172
Fuels and fire behavior	Most sites met short-term fuel reduction objectives, as measured by posttreatment stand structure and fuel bed variables. Burns had little influence on live stand structure, but increased small snag density and decreased fuel mass. Mechanical treatments had nearly the opposite effect, decreasing live tree density, basal area, and snag density with little change or an increase in woody fuel mass. The combination mechanical + burn treatments were the most effective at meeting stand structure and fuel objectives, having generally additive effects. Fire performance analyses conducted at six western sites strongly indicated that mechanical + burn treatments was most effective in reducing short-term fire risk. For two eastern sites at which potential fire behavior analyses were conducted (Central Appalachian Plateau and Southeastern Piedmont), the most effective treatment was burn alone, because slash created by the mechanical treatment was not consumed or had not sufficiently dried by the time burns were applied. Repeat entries of both mechanical and burn treatments will be necessary to meet long-term restoration objectives.	8, 26, 52, 68, 98, 174
Soils	Soils varied considerably among the 12 FFS sites, representing six soil orders and over 50 named soil series. Eastern and western sites responded differently to fuel reduction treatments in terms of nitrogen (N) and carbon (C) storage, suggesting different management approaches; strategies that maximize C gain by minimizing N loss may be more applicable in western forests where C and N are tightly linked but not in those eastern forests where atmospheric N deposition has decoupled C and N cycles. While burning tended to decrease total ecosystem C, these losses were offset by increasing C uptake in the years following fire. Mechanical + burn treatments tended to generate the highest fire severity, and produced the greatest magnitude of effects, although overall treatment effects were generally modest and transient for most variables, including soil microbes, microarthropods, soil enzyme activity, soil N, soil C, cations, and soil compaction. Mechanical treatments did not serve as surrogates for fire in terms of soils, owing to distinctly different primary effects, and also the tendency for fire to produce more spatial heterogeneity in fuels, which leads to patchiness in soil variables. Few long-term experimental studies exist to help understand links among fire, the soil, microbes, plants, and ecosystem function.	176, 177, 178, 179, 180, 200

Table 12—Principal short-term findings of the national Fire and Fire Surrogate (FFS) study by discipline and ecosystem components (see table 14 for reference listing) (continued)

Discipline and ecosystem component	Finding	Key papers
Vertebrates	Effects of fuel reduction treatments on vertebrate species varied among species, but were generally subtle, transient, and different for fire versus mechanical treatments. Fire-adapted birds including many cavity-nesters and bark-foragers tended to respond most favorably to treatments including fire, and tended to forage on larger than average trees. Mechanical + burn treatments had the greatest effect on smaller and more sedentary vertebrates such as reptiles and amphibians through decreases in litter and increases in mineral soil exposure and herbaceous vegetation. Because effects tended to be site-specific, adaptive management at the local level may be most useful in understanding vertebrate responses to treatments.	165, 181, 182, 183, 184
Invertebrates	Short-term impacts of treatments on litter arthropods were subtle, but treatments that included burning altered feeding guild composition and increased richness in the two western sites at which they were studied. Burning increased within-stand heterogeneity in arthropod habitat through decreased litter depth and increased mineral soil exposure and herbaceous vegetation cover, all of which were patchy at small scales. Compared to burning, mechanical treatments had lower impacts and favored species similar to controls.	64, 73, 159, 160
Bark beetles	Four western sites exhibited bark beetle effects after treatment. In each case, incidence of bark beetles was directly related to the application of fire, and to fire severity, with tree mortality generally restricted to smaller trees. Mortality of larger trees occurred after mechanical + burn treatments where cured logging slash was concentrated and resulted in increased fire intensity. There was no evidence at any site of bark beetle attacks spreading to adjacent green trees, which was probably owing to a combination of high tree vigor in residual stands and low background populations of bark beetles.	33, 46, 51, 74
Fungi and pathology	Each site at which fungi were studied, researchers reported high fungal species richness, including many previously unreported species, and species of potential importance for biological control. At the Blue Mountains site, ectomycorrhizal fungi associated with plant roots responded negatively to fire in the short term, with greater effects in stands where logging slash left in the woods increased fire severity. At the Southeastern Piedmont site, incidence of the forest pathogen *Leptographium* was reduced by treatments, but rebounded within 5 years. At the Northeastern Cascades site, the mechanical + burn treatment caused the greatest reduction in incidence of dwarf mistletoe, and modeling suggested that the effect may last 20 years.	15, 19, 28, 167
Operational economics	In general, the lower the value of harvested product in a fuel reduction project, the more advantage there was to use “purpose-built” machines designed specifically for a particular operation. On federal lands, giving contract officers more flexibility to decide on the details of a fuel reduction operation (e.g., whether to remove small trees, or whether to treat slash on site) makes senses given market volatility. Financial analyses of costs and revenues of fuel reduction treatments provided only a partial picture; a complete cost-benefit analysis involves both short- and long-term ecological effects and monetary values assigned to nonmarket issues.	29, 31, 187
Sociology and outreach	Surveys conducted at the Central Sierra Nevada site indicated that while most respondents understood the need for fuel reduction, fewer individuals found mechanical treatments to be as acceptable as fire for fuels management. Forest managers tend to favor the use of existing electronic platforms within which to place information, favored the synthesis of technical papers by topic, and emphasized the value of one-on-one contact with researchers. Multisite, multivariate studies like the FFS are challenging to execute, and success depends on several key features: adequate funding, design, partnerships, collegiality among researchers, standardization, data management, and outreach.	189, 190, 199

a rapid means of achieving forest restoration goals, however, is tempered somewhat by tradeoffs in effects, as the combination treatment tended to increase cover of exotics and decrease cover of coarse woody debris, which offers key habitat for both invertebrates and vertebrates. Finally, because of differences in overall site productivity, most eastern sites were distinctly different from western sites, especially in soil, fuel, and vegetation effects.

Ecosystem components—

The most substantial short-term effects were observed for those ecosystem components that were the target for fuel reduction treatments in the first place: vegetation (overstory and understory) and the fuel bed (table 12). This is not surprising, because both mechanical and burning treatments are designed to change stand structure (both living and dead trees), and the components of the fuel bed that influence fire behavior (herbaceous vegetation, surface woody fuels). For most other components of the ecosystem, however, observed effects were more subtle, suggesting that fuel reduction treatments are relatively benign, at least as currently implemented. This is partly because these kinds of treatments leave an intact forest behind. But it is also because many flora and fauna are adapted to low-intensity fire, and to the extent that thinning treatments mimic natural disturbances such as wind-throw, are also adapted to low-intensity mechanical treatments. Even for disturbance agents such as bark beetles, which can drastically accelerate changes in forest structure because of their capacity for rapid increase, effects were very modest, suggesting that managers can apply these kinds of treatments without fear of unintended consequences. Individual fires have unique characteristics and effects because of temporal and spatial variation, however, suggesting that mechanical treatments are not surrogates for many ecological variables, and repeated application of mechanical treatments without fire would likely result in conditions divergent from those occurring in fire-adapted systems where fire is a common disturbance event.

Sites—

Overall, treatment implementation was remarkably successful for nearly all sites, with most treatments applied on schedule, and with enough intensity to achieve first-order effects that approached management objectives (table 13). There were some distinct differences in treatment effectiveness, however, mostly related to forest type (eastern hardwood forests compared to western conifer forests), and to the type of machines used for thinning (cut-to-length compared to whole-tree harvest systems; see table 1). As a group, eastern sites were more dissimilar from one another, with the two hardwood sites (Central Appalachian Plateau and

Table 13—Principal short-term findings of the national Fire and Fire Surrogate (FFS) study by site and ecoregion (see table 14 for reference listing)

FFS site	U.S. Environmental Protection Agency Level III ecoregion	Findings	References
Northeastern Cascades	East Cascades Slopes	Hand-felling and helicopter yarding met thinning prescriptions, but a spring burn under cool moist conditions failed to reduce fire risk in treated stands. Although treatment effects were marked in some cases, they were generally overwhelmed by considerable within-site variability in topography, soils, and fire history. Mechanical + burn treatments had by far the greatest influence on the ecosystem, resulting in the highest quality habitat for cavity nesting birds, the greatest increases in both native and exotic plant species richness, and the greatest reduction in the incidence of dwarf mistletoe.	2, 4, 8, 9, 10, 11, 12, 19
Blue Mountains	Blue Mountains	Cut-to-length logging system (harvester + forwarder) met thinning prescriptions with net revenue gain, and fall burns initially reduced fire risk and reduced fuel mass for up to 4 years. Treatment effects on the ecosystem were generally subtle, but differed between mechanical and burn treatments, with thinned stands generally having effects similar to untreated stands. Although treatment effects were sometimes confounded by variation in soils, mechanical + burn treatments had the greatest overall influence on the ecosystem, resulting in the highest quality habitat for nuthatches, the greatest changes in both native and exotic understory plant species, the highest incidence of bark beetle attack and tree death, the greatest reduction in coarse woody debris, and the most reduction in duff mass and fine root biomass.	21, 24, 26, 27, 28, 29, 31, 33
Northern Rocky Mountains	Middle Rockies	Cut-to-length logging system (harvester + forwarder) met thinning prescriptions, and a spring prescribed fire reduced fuel mass and fire risk. Because of patchiness of fire severity, burning increased spatial heterogeneity of surface fuels and total inorganic nitrogen, which in turn led to higher plant species richness at the stand level up to 2 years after treatment. Treatment effects on the ecosystem were generally subtle, but differed between mechanical and burn treatments, with thinned stands generally having effects similar to untreated stands. The mechanical + burn treatment was the most effective in creating stand conditions that could resist moderate wildfire, and resulted in habitat changes for small mammals and birds, the greatest increases in both native and exotic plant species richness, and changes in processes associated with decomposition.	34, 36, 37, 39, 41, 45

Table 13—Principal short-term findings of the national Fire and Fire Surrogate (FFS) study by site and ecoregion (see table 14 for reference listing) (continued)

FFS site	U.S. Environmental Protection Agency Level III ecoregion	Findings	References
Southern Cascades	East Cascades Slopes	Trees cut with a feller-buncher and skidded whole, a system that met thinning prescriptions, and a fall prescribed fire were successful for reducing fuel mass and fire risk. The mechanical + burn treatment was the most effective in creating stand conditions that would reduce the probability of crown fire. Burning increased bark beetle-caused tree mortality (both pine and fir), with mortality concentrated in the smaller diameter trees. For soils, thinning did not serve as a surrogate for fire, with notable changes owing to burning in soil pH, total inorganic nitrogen, soil carbon, and microbial actions and these changes could lead to differences in tree growth in the intermediate term.	48, 49, 50, 51
Central Sierra Nevada	Sierra Nevada	Trees >25 cm in diameter were hand-felled, limbed and bucked, then yarded by skidder. Trees <25 cm were masticated on site, and with these mechanical practices thinning prescriptions were achieved; a relatively intense late fall prescribed fire reduced surface fuel mass and treatments including fire were successful at reducing projected fire risk. The mechanical + burn treatment was the most effective in creating stand conditions that would enhance fire resiliency, but also had the greatest impact on ecological conditions, by reducing coarse woody debris, altering soil carbon and nitrogen conditions, increasing exposed mineral soil, increasing the density of fir and pine seedlings, and increasing the cover and richness of exotic plant species. Logging and burning both increased spatial heterogeneity, which may have played a role in increasing both plant and arthropod species richness in treated stands. In general, observed soil chemical effects of burning would be expected to enhance short-term stand productivity.	52, 53, 54, 55, 56, 60, 61, 63, 64
Southern Sierra Nevada	Sierra Nevada	No mechanical treatments were applied, but both spring and fall burns reduced total fuel loads and projected fire risk. Native plant species richness increased after both spring and fall burns and burning off-season (spring) was not measurably detrimental to native plants. There was no difference in effects between spring and fall burns on tree mortality, pine bark beetle incidence, and ground arthropod or small mammal populations; fall burns however, consumed more total fuel mass and coarse woody debris, and had a more dramatic effect on soil abiotic conditions, mineral soil carbon, total inorganic nitrogen, and microbial activity, whereas spring burns caused higher incidence of fir bark beetles. Both spring and fall burning substantially increased within-stand heterogeneity, indicating that prescribed fires in Sierra Nevada forests can mimic wildfires in the creation of spatial mosaics.	68, 69, 71, 72, 73, 74

Table 13—Principal short-term findings of the national Fire and Fire Surrogate (FFS) study by site and ecoregion (see table 14 for reference listing) (continued)

FFS site	U.S. Environmental Protection Agency Level III ecoregion	Findings	References
Southwest Plateau	Arizona Plateau	Trees >13 cm in diameter were hand-felled, limbed and bucked, then yarded by skidder. Trees <13 cm were felled, limbed and scattered, and with these mechanical practices thinning prescriptions were achieved. A fall prescribed fire reduced surface fuel mass when applied without prior thinning, but mechanical + burn treatments had about the same total fuel mass as controls; overall, the three active treatments only slightly reduced projected fire risk. Most soil properties either were unchanged by treatment or showed subtle effects: vegetation carbon declined in all treatments, dead wood increased in the two treatments including thinning, and the remaining soil properties were unchanged, including soil nitrogen, total ecosystem carbon, soil pH, total inorganic nitrogen, soil carbon:nitrogen ratio, and soil bulk density. Burning increased deer mouse abundance, but reduced pine chipmunk abundance. Bluebird home-range size was 50 percent bigger in thin-only units compared to controls, but 30 percent smaller in the mechanical + burn units.	75, 77, 78
Central Appalachian Plateau	West Allegheny Plateau	Trees were felled by hand and yarded by skidders to landings. Mechanical treatments met all prescription elements. Dormant season prescribed fires followed and burned under prescribed intensity. All active treatments changed forest structure and the surface fuel bed. The mechanical + burn treatment produced the coolest burns, probably because additional slash had not dried sufficiently before fire. Even on more favorable xeric sites, oak regeneration remained at a competitive disadvantage 4 years after treatment, suggesting that repeated hot fires may be necessary to restore hardwood forests to oak dominance. On mesic sites, oak reestablishment is more problematic. In general, treatment effects on the soil, forest floor, understory vegetation, and tree species were modest and transient.	79, 81, 84, 85, 86, 89, 92, 97, 98, 99, 100, 101, 102
Southern Appalachian Mountains	Blue Ridge	All trees and ericaceous shrubs >1.4 m high were cut and left on site, as per prescription; dormant-season burns were then conducted to top-kill suppressed trees and reduce shrub cover. For some ecological variables (e.g., reptiles and amphibians), fuel treatments had subtle effects; for other variables (pollinator species richness, overall bird diversity, understory plant species richness and cover), the combined mechanical + burn treatments had the greatest magnitude effects.	146, 151, 152, 153, 154, 158, 159, 167

Table 13—Principal short-term findings of the national Fire and Fire Surrogate (FFS) study by site and ecoregion (see table 14 for reference listing) (continued)

FFS site	U.S. Environmental Protection Agency Level III ecoregion	Findings	References
Southeastern Piedmont	Piedmont	Trees were thinned from below, and yarded by skidders to landings. Mechanical treatments successfully met all prescription elements. Dormant-season fires followed and burned under prescribed intensity. In general, treatment effects on ecological variables were modest and transient, including components of the fauna (birds, spiders, beetles), the flora (understory and overstory richness), and the soils (carbon, nitrogen, bulk density). Thinning did not serve as a surrogate for fire for most ecological variables, including bats, understory plant species richness, microbial activity and rates, foliage-gleaning and canopy nesting birds, and lizard and reptile abundance.	110, 111, 113, 117, 119, 124, 127, 129, 130, 165, 166, 167
Gulf Coastal Plain	Southeast Plains	Thinning from below and underburning were implemented within prescription to produce predicted changes in tree density, tree basal area, and down woody fuels. Slash removal after thinning but before burning decreased residual tree mortality owing to fire. Thinning was most effective for reducing mid-story hardwoods, while burning was more effective at reducing understory hardwoods; therefore, the combination treatment would most rapidly achieve longleaf pine restoration goals. Small mammals were differentially affected by fuel reduction treatments.	135, 138, 139, 140, 141
Florida Coastal Plain	Southern Coastal Plain	Mastication of saw palmetto understory successfully met fuel reduction prescription. Burns during the growing season met prescribed intensity; flanking fires were the most successful in avoiding crown scorch. Fire treatments lowered soil moisture levels below that favorable to microbial activity.	132, 133, 136, 137

Southern Appalachian Mountains) tending to sort together for many variables, while the three pine sites tended to express more idiosyncratic effects. Despite substantial differences in productivity and forest structure, the seven western sites expressed similar effects for many variables. For some variables, there were consistent effects across both eastern and western sites (e.g., response of native and exotic herbaceous vegetation), and in these cases, managers in most dry forest systems can predict with reasonable confidence what will happen when they apply treatments. But one of the most important findings of this study is that for some ecological variables that were analyzed across the FFS network, "site" often explained the most variation in response to treatment. Examples include multisite analyses on small mammal populations (Converse et al. 2006a) and avian nest survival (Farris et al. 2010a). This means that, in some cases, managers may be unable to predict responses for some variables at the local level unless site-specific data are available, especially for variables that are distant from first-order effects (e.g., small mammals or birds). The best tool available to understand response well enough to construct management plans for the future will therefore be adaptive management conducted at the local level.

Likely the most important part of this report is table 14, a detailed listing of principal science findings summarized in the previously mentioned tables, with each science finding listed by individual reference number and arranged by site, discipline, and treatment. This table is directly linked to tables 7, 8, 11, 12, and 13 by the reference number. Included in table 14 is an indication of supporting literature from other sources, where available.

Table 14—Principal citations of the national Fire and Fire Surrogate (FFS) study with their findings, by site, discipline, treatment, and theme, with supporting literature (treatment codes: B = burn, M = mechanical, M+B = mechanical + burn; theme codes: 1 = fire vs. surrogates, 2 = effect size, 3 = effect duration, 4 = regional, 5 = species adaptation, 6 = heterogeneity, 7 = tradeoffs, 8 = restoration, 9 = exotics, 10 = application)

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
1	Harrod, R.J.; Povak, N.A.; Peterson, D.W. 2007. Comparing the effectiveness of thinning and prescribed fire for modifying structure in dry coniferous forests. In: Butler, B.W.; Cook, W., comps. Proceedings, the fire environment-innovations, management, and policy. Proceedings RMRS-P-46CD. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 329–346.	Northeastern Cascades	Overstory vegetation	B	2	Relatively cool spring burns raised canopy height but increased density of small dead trees.	No other studies have reported similar findings.
1	Harrod et al. 2007.	Northeastern Cascades	Overstory vegetation	B	2	Effectiveness of spring burns can be limited by cool, wet conditions in the northeastern Cascades.	No other studies have reported similar findings.
1	Harrod et al. 2007.	Northeastern Cascades	Overstory vegetation	M	2	Tree stocking and canopy fuels were reduced to less than 50 percent of pretreatment values after mechanical treatments, but activity fuels, which would be expected to increase fire intensity, were left.	No other studies have reported similar findings.
2	Hessburg, P.F.; Povak, N.A.; Salter, R.B. 2010. Thinning and prescribed fire effects on snag abundance and spatial pattern in an eastern Cascade Range dry forest, Washington, USA. Forest Science. 56(1): 74–87.	Northeastern Cascades	Overstory vegetation	B, M, M+B	1, 2	Seventy-five percent of snags had evidence of bark beetle attacks across all units before and after treatments.	Innes et al. (2006) observed that a single prescribed fire had no effect on the spatial distribution of snags.
2	Hessburg et al. 2010.	Northeastern Cascades	Overstory vegetation	B, M+B	1, 2	Red turpentine beetle occurrence increased after burn treatments.	Other studies have reported increases in red turpentine beetle activity after prescribed fires (Fettig et al. 2008, Ganz et al. 2003, Schwilk et al. 2006), but incidence of tree mortality in these studies was low.

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Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
2	Hessburg et al. 2010.	Northeastern Cascades	Overstory vegetation	B, M+B	2	Snag abundance for the smaller size classes increased after burn and mechanical + burn treatments, but snag abundance in the largest size classes declined and clumpiness in snag distribution was retained.	Some studies have reported declines in snag densities after single prescribed fires (Bagne et al. 2008, Machmer 2002). Other studies have reported snag retention rates similar to this study (Stephens and Moghaddas 2005b, Youngblood et al. 2006).
2	Hessburg et al. 2010.	Northeastern Cascades	Overstory vegetation	M	2	Snag numbers declined after mechanical treatments, and snag spatial distributions shifted from clumped to random.	No other studies have reported similar findings.
3	Harrod, R.J.; Peterson, D.W.; Povak, N.A.; Dodson, E.K. 2009. Thinning and prescribed fire effects on overstory tree and snag structure in dry coniferous forests of the interior Pacific Northwest. Forest Ecology and Management. 258(5): 712–721.	Northeastern Cascades	Overstory vegetation	B, M+B	1, 2	Snag density increased after burn treatments, but tree density or canopy fuel loading were unchanged. The burns were less intense than desired, perhaps leading to fewer structural changes.	Stephens and Moghaddas (2005b) found that burn treatments resulted in a greater number of new snags compared to thinning or no treatment.
3	Harrod et al. 2009.	Northeastern Cascades	Overstory vegetation	M, M+B	1, 2	Tree density and canopy bulk density were reduced, and canopy base height was increased the most by mechanical treatments.	This result is consistent with other FFS sites (Schwilk et al. 2009).
3	Harrod et al. 2009.	Northeastern Cascades	Overstory vegetation	M+B	1, 2	Fire hazard was reduced the most by mechanical + burn treatments because of the complementary effects on canopy and surface fuels, although this treatment also increased the density of standing dead trees.	Fulé et al. (2002) found that thinning reduced canopy fuels and modeled fire severity.

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
4	Dodson, E.K.; Peterson, D.W.; Harrod, R.J. 2008. Understory vegetation response to thinning and burning restoration treatments in dry conifer forests of the eastern Cascades, USA. Forest Ecology and Management. 255(8/9): 3130–3140.	Northeastern Cascades	Understory vegetation	B, M, M+B	1, 2	Understory plant cover and species composition were unchanged by any of the treatments.	Stable understory plant cover and species composition after fuel reduction treatments was reported by Abella and Covington (2004), Metlen and Fielder (2006), and Metlen et al. (2004).
4	Dodson et al. 2008.	Northeastern Cascades	Understory vegetation	B, M, M+B	1, 2	Plant life forms differed substantially in their response to treatments, with forbs having much greater richness response than grasses or shrubs.	Other studies have reported differing responses among plant life forms (Collins et al. 2007, Metlen and Fiedler 2006, Metlen et al. 2004, Moore et al. 2006).
4	Dodson et al. 2008.	Northeastern Cascades	Understory vegetation	B, M, M+B	1, 2, 9	Native plant species richness increased after mechanical + burn treatments, with greater response where species richness was initially low.	Pretreatment condition was important for understanding inter-annual changes in understory variables (Fulé et al. 2005, Vose and White 1991). Both increases in understory richness (Metlen and Fiedler 2006, Wienk et al. 2004) and decreases in understory richness (Collins et al. 2007, Fulé et al. 2005, Metlen et al. 2004) were reported after fuel reduction treatments. Wayman and North (2007) reported that thin + burn treatments have the most dramatic effects on the understory.

Table 14—Principal citations of the national Fire and Fire Surrogate (FFS) study with their findings, by site, discipline, treatment, and theme, with supporting literature (treatment codes: B = burn, M = mechanical, M+B = mechanical + burn; theme codes: 1 = fire vs. surrogates, 2 = effect size, 3 = effect duration, 4 = regional, 5 = species adaptation, 6 = heterogeneity, 7 = tradeoffs, 8 = restoration, 9 = exotics, 10 = application) (continued)

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
4	Dodson et al. 2008.	Northeastern Cascades	Understory vegetation	M+B	2, 9	Exotic plant species were relatively uncommon, but cover and richness of these species increased more after the mechanical + burn treatments.	Slight increases in the number of exotic plant species after fuel reduction treatments, especially after thin + burn treatments, were reported by Collins et al. (2007), Dodson and Fiedler (2006), and Griffis et al. (2001). No effect of fuel reduction treatments on exotic species richness was found by Fornwalt et al. (2003) and Wayman and North (2007).
5	Dodson, E.K.; Peterson, D.W. 2010. Dry coniferous forest restoration and understory plant diversity: the importance of community heterogeneity and the scale of observation. Forest Ecology and Management. 260(10): 1702–1707.	Northeastern Cascades	Understory vegetation	B, M, M+B	10	Effects of fuel reduction treatments on understory plant species richness was examined at several spatial scales using "additive diversity partitioning."	No other studies have reported similar findings.
5	Dodson and Peterson 2010.	Northeastern Cascades	Understory vegetation	B, M, M+B	2	Understory plant species richness did not differ among treatments at quadrat and plot scales.	Abella and Covington (2004), Metlen and Fiedler (2006), and Nelson et al. (2008) reported negligible treatment effects on understory vegetation at small scales.
5	Dodson and Peterson 2010.	Northeastern Cascades	Understory vegetation	B, M, M+B	2	Understory plant species richness and risk of local species extirpation remained unchanged after mechanical and burn treatments.	Halpern and Spies (1995) and Battles et al. (2001) reported that disturbances can increase disturbance-adapted species by decreasing or extirpating late-successional species.

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
5	Dodson and Peterson 2010.	Northeastern Cascades	Understory vegetation	B, M, M+B	2, 6	Herbaceous species richness at the stand level increased after fuel reduction treatments because of increased community heterogeneity within stands.	Both thinning and burning treatments produced patchiness in fuels and soil exposure within stands (Agee and Lolley 2006), thus promoting heterogeneity in environmental conditions, which probably led to increases in plant species richness at the stand scale.
5	Dodson and Peterson 2010.	Northeastern Cascades	Understory Vegetation	M+B	6	Understory heterogeneity increased the most after mechanical + burn treatments because of colonization by species that were absent before the treatments.	Dodson et al. (2007) reported a similar pattern and suggested that seasonally dry forests support species that are adapted to frequent low-severity disturbances.
6	Kopper, K.E. 2002. Meta-analysis design and interpretation: a case study of prescribed fire effects on fuel loadings in ponderosa pine ecosystems. Seattle, WA: University of Washington. 36 p. M.S. thesis.	Northeastern Cascades	Fuels and fire behavior	B	2	Preplanned meta-analyses allow more flexibility in choice between mixed- and fixed-effects models, demonstrating that meta-analysis will always be more effective for planned multisite studies like the FFS, compared to quantitative analysis of independent studies.	Gurevitch and Hedges (1999) stated that mixed-effects models incorporate random variation, thus making them more appealing for ecological applications.
6	Kopper 2002.	Northeastern Cascades	Fuels and fire behavior	B	2	Although more than 40 journal articles specifically addressed fuel reduction in ponderosa pine forests, only eight published articles contained adequate statistical summary information for meta-analysis of organic (combined litter and duff) or downed woody fuel reduction after prescribed fire.	Eight studies served as the basis for preliminary meta-analysis of fuel bed effects after prescribed burning in ponderosa pine forests (Busse et al. 2000, Davis et al. 1964, Kalabokidis and Wakimoto 1992,

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Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
							Kauffman and Martin 1989, Kovacic et al. 1986, Landsberg et al. 1984, Sackett and Haase 1998, and Sweeney and Biswell 1961).
7	Lolley, M.R. 2005. Wildland fuel conditions and effects of modeled fuel treatments on wildland fire behavior and severity in dry forests of the Wenatchee Mountains. Seattle, WA: University of Washington. 145 p. M.S. thesis.	Northeastern Cascades	Fuels and fire behavior	B, M+B	2	Mass of tree tops and branches and the depth and mass of forest floor declined after burning but likely resulted in little change to potential fire behavior.	No other studies have reported similar findings.
8	Agee, J.K.; Lolley, M.R. 2006. Thinning and prescribed fire effects on fuels and potential fire behavior in an eastern Cascades forest, Washington. Fire Ecology. 2(2): 142–158.	Northeastern Cascades	Fuels and fire behavior	B, M+B	2	Spring burning decreased slash fuels and the depth and mass of forest floor, but early greenup of herbaceous fuels had a dampening effect on fire spread and likely resulted in little change to potential fire behavior.	Knapp et al. (2005) and Stephens and Moghaddas (2005a) reported that spring burns reduced woody fuels but overall had mixed effects because of moisture levels of herbaceous fuels.
8	Agee and Lolley 2006.	Northeastern Cascades	Fuels and fire behavior	M	2, 7	Canopy closure and canopy bulk density declined and canopy base height increased after mechanical treatments, yet these treatments increased slash fuels, which led to increased projected surface fire potential under extreme weather conditions.	No other studies have reported similar findings.
9	Dolan, E. 2002. Soil and site variability in the northeast Wenatchee Mountains. Seattle, WA: University of Washington. 83 p. M.S. thesis.	Northeastern Cascades	Soils	B, M, M+B		Although site conditions included steep, highly variable topography, and eight soil types, including young, thin soils lacking an A horizon and mature, deep soils with multiple Bt horizons, most variation in soil type was explained by current vegetation rather than by topography.	Phillips et al. (1996) discussed factors behind the development and persistence of soil variability.

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
10	Hatten, J.; Zabowski, D.; Scherer, G.; Dolan, E. 2005. A comparison of soil properties after contemporary wildfire and fire suppression. Forest Ecology and Management. 220(1–3): 227–241.	Northeastern Cascades	Soils	B	1, 2	Chemical or physical soil properties did not differ between unburned stands and burned stands. Site factors, such as slope, aspect, erosion, and differential deposition appear to have far greater influence on soil properties than fire.	Choromanska and DeLuca (2001) and Covington and Sackett (1984) found about 50–percent reduction in O-horizon depth. Typically, fire raises pH of forest soils (DeBano et al. 1998). Kraemer and Hermann (1979) and Wagle and Kitchen (1972) found no differences in extractable phosphorus between burned and unburned plots. Grier (1975) reported that base cations decreased after a wildfire. Monleon et al. (1997) found that burning caused changes in nitrogen availability.
10	Hatten et al. 2005.	Northeastern Cascades	Soils	B	2	Hydrophobicity did not differ between unburned and burned stands.	DeBano (2000) and Huffman et al. (2001) reported little increased hydrophobicity after low-intensity fires.
11	Lyons, A.L.; Gaines, W.L.; Lehmkuhl, J.F.; Harrod, R.J. 2008. Short-term effects of fire and fire surrogate treatments on foraging tree selection by cavity-nesting birds in dry forests of central Washington. Forest Ecology and Management. 255(8/9): 3203–3211.	Northeastern Cascades	Vertebrates	B, M, M+B	1, 5, 7	Cavity-nesting birds were more likely to be observed foraging in treated stands, especially those after mechanical + burn treatments, and these birds foraged in larger trees in treated stands. Fuel reduction treatments that remove smaller trees and retain larger trees and snags will improve foraging habitat for cavity-nesting birds, particularly nuthatches and woodpeckers.	Large trees are known to be favored by cavity-nesting birds (Lundquist and Manuwal 1990). Treatments that accelerate the development of large trees, such as the FFS treatments, would likely create better foraging habitat for

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Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
							cavity-nesting birds (Dickson et al. 2004). Work by Kotliar et al. (2002) focused on the effects of severe fires on cavity nesters, while Gaines et al. (2007, 2010) and Zebehazy et al. (2004) studied the entire avian community response to FFS treatments. No experimental studies have focused on the response of cavity nesters to low-intensity FFS treatments.
12	Gaines, W.; Haggard, M.; Begley, J.; Lehmkuhl, J.; Lyons, A. 2010. Short-term effects of thinning and burning restoration treatments on avian community composition, density, and nest survival in the eastern Cascades dry forests, Washington. Forest Science. 56(1): 88–99.	Northeastern Cascades	Vertebrates	B, M, M+B,	1, 2	Abundance of bird species (except chipping sparrow) increased with fuel reduction treatment, and daily survival rates of nesting guilds were similar for treated vs. untreated stands. Spring burning likely was responsible for any lack of treatment effect for chipping sparrow.	Gaines et al. (2007) found that chipping sparrows increased in treated stands. Mixed results for mountain chickadee response to treatment have been reported (Finch et al. 1997, Gaines et al. 2007). Enhanced habitat conditions and abundance of white-headed woodpecker after fuel reduction treatment were reported by Gaines et al. (2007). Medin and Booth (1989) showed positive influence of treatment on olive-sided flycatcher. Treatments that reduce canopy

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
							cover may enhance western bluebird habitat (Wightman and Germaine 2006).
12	Gaines et al. 2010.	Northeastern Cascades	Vertebrates	B, M, M+B	1, 5, 7	Cavity and foliar nesting bird species used trees that were larger in diameter than the stand average, regardless of treatment, suggesting that management activities that promote larger trees will favor these species.	Large trees are important for nesting and foraging for mountain chickadees (Lyons et al. 2008). Large trees are important as habitat for cavity-nesting species (Bull et al. 1997, Dickson et al. 2004, Lundquist and Manuwal 1990).
13	Hoff, J.A. 2002. Fungal diversity in woody roots of east-slope Cascade ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*). Pullman, WA: Washington State University. 76 p. M.S. thesis.	Northeastern Cascades	Pathology and fungi	B, M, M+B	5	Findings for this thesis can be found in papers Nos. 14 and 15.	
14	Hoff, J.A.; Klopfenstein, N.B.; Tonn, J.R.; McDonald, G.I.; Zambino, P.J.; Rogers, J.D.; Peever, T.L.; Carris, L.M. 2004b. Roles of woody root-associated fungi in forest ecosystem processes: recent advances in fungal identification. Res. Pap. RMRS-RP-47. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 6 p.	Northeastern Cascades	Pathology and fungi	B, M, M+B	5	Most belowground species of endophytic fungi in western dry forest ecosystems are largely unknown, yet likely have important ecological functions.	Smith et al. (2005) report on the response of ectomycorrhizal fungi to fuel reduction treatments in ponderosa pine forests of northeastern Oregon. Most other work with ectomycorrhizal fungi is focused on other forest ecosystems (Cullings et al. 2000, Johannesson and Stenlid 1999).
15	Hoff, J.A.; Klopfenstein, N.B.; McDonald, G.I.; Tonn, J.R.; Kim, M.S.; Zambino, P.J.; Hessburg, P.F.; Rogers, J.D.; Peever, T.L.; Carris, L.M. 2004a. Fungal endophytes in woody roots of Douglas-fir (*Pseudotsuga menziesii*) and ponderosa pine (*Pinus ponderosa*). Forest Pathology. 34(4): 255–271.	Northeastern Cascades	Pathology and fungi	B, M, M+B	5	A total of 27 genera of endophytic fungi were found inhabiting large woody roots of healthy Douglas-fir and ponderosa pine	Park et al. (2001) demonstrated that *Byssochlampys nivea* inhibited growth of important forest.

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Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
						trees in the northeastern Cascades, including the potential biological control agent *Byssochlampys nivea*, found in more than 20 percent of root isolates.	pathogens such as *Phytophthora cinnamomi* and inhibited egg hatching of certain nematodes. Ramsey (2005) reported that *B. nivea* was common in several eastern Cascade sites in central Washington
15	Hoff et al. 2004a.	Northeastern Cascades	Pathology and fungi	B, M, M+B	5	Fungal species composition and diversity were uncorrelated with either tree host or plant association, suggesting that the type of microenvironment that occurs in a particular dry forest may be more important than plant species; therefore, seasonally dry forests that differ in temporal heterogeneity of environmental conditions would be expected to host more fungal species.	No other studies have reported similar findings.
16	Ramsey, A.C. 2005. Ecology of fungal endophytes in Douglas-fir and ponderosa pine roots in eastern Washington. Seattle, WA: University of Washington. 75 p. M.S. thesis.	Northeastern Cascades	Pathology and fungi	B, M, M+B	5	The potential biological control agent *Byssochlampys nivea* was isolated.	Hoff et al. (2004a) found this fungal species at the Northeastern Cascades FFS site.
17	Goetz, J.; Dugan, F.M. 2006. *Alternaria malorum*: a mini-review with new records for hosts and pathogenicity. Pacific Northwest Fungi. 1: 1–8.	Northeastern Cascades	Pathology and fungi	B, M, M+B	5	The pathogenic fungus *Alternaria malorum*, once thought to be rare, is a common fungus associated with ponderosa pine roots.	Dugan et al. (2005) and Schnellhardt and Heald (1936) isolated *Alternaria malorum* and suggested that this species was common.
18	Goetz, J.R., III. 2006. Fungal endophytes isolated from large roots of Douglas-fir (*Pseudotsuga menziesii*) and ponderosa pine (*Pinus ponderosa*). Pullman, WA: Washington State University. 116 p. M.S. thesis.	Northeastern Cascades	Pathology and fungi	B, M, M+B	5	The pathogenic fungus *Alternaria malorum*, once thought to be rare, is a common fungus associated with ponderosa pine roots.	No other studies have reported similar findings.

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
19	Hessburg, P.F.; Povak, N.A.; Salter, R.B. 2008. Thinning and prescribed fire effects on dwarf mistletoe severity in an eastern Cascade Range dry forest, Washington. Forest Ecology and Management. 255(7): 2907–2915.	Northeastern Cascades	Pathology and fungi	B, M, M+B	1, 2, 3	Dwarf mistletoe severity was reduced the most after mechanical + burn treatments, followed by mechanical and then burn treatments. Stand growth projections suggested that reductions would persist for about 20 years.	Conklin and Armstrong (2001) reported that well-implemented, periodic burns could reduce dwarf mistletoe severity in southwestern forests.
20	Agee, J.K.; Lehmkuhl, J.F., comps. 2009. Dry forests of the Northeastern Cascades Fire and Fire Surrogate project site, Mission Creek, Okanogan-Wenatchee National Forest. Res. Pap. PNW-RP-577. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 158 p.	Northeastern Cascades	General and study description	B, M, M+B	1, 2	This paper provides the study plan for the Northeastern Cascades FFS study site.	No other studies have reported similar findings.
21	Youngblood, A.; Metlen, K.L.; Coe, K. 2006. Changes in stand structure and composition after restoration treatments in low elevation dry forests of northeastern Oregon. Forest Ecology and Management. 234(1–3):143–163.	Blue Mountains	Overstory vegetation	B, M, M+B	1, 2	Unique sets of understory plant species (indicator species) that characterized each treatment were identified.	Metlen et al. (2006) also identified indicator species for different fuel reduction treatments.
21	Youngblood et al. 2006.	Blue Mountains	Overstory vegetation	B, M, M+B	1, 2, 9	Short-term ecosystem consequences of fuel reduction treatments were modest. Quadratic mean diameter was higher and stand basal area was lower after mechanical treatments than after burn treatments. Seedling density was lower, coarse woody debris was less, and numbers of invasive species higher after burn treatments compared to mechanical treatments.	Metlen et al. (2004, 2006) reported that understory plant community responses to treatments indicated that most species were adapted to frequent low-intensity fires. Changes were more subtle than changes observed after wildfire (Crawford et al. 2001, Griffis et al. 2001, Passovoy and Fulé 2006).
21	Youngblood et al. 2006.	Blue Mountains	Overstory vegetation	B, M, M+B	1, 2, 9	Fire-tolerant understory plant species increased in cover after burn treatments, especially on fine-textured soils. Understory	No other studies have reported similar findings.

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Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
						plant communities contained fewer shade-tolerant, moist-site species but more rhizomatous species after mechanical treatments than after other treatments. Abundance of species common on shallow, coarse-texture soils increased after mechanical + burn treatments.	
21	Youngblood et al. 2006.	Blue Mountains	Overstory vegetation	M+B	2, 9	The basal area reduction target was met with mechanical + burn treatments, yet the number of invasive plant species increased and volume and number of large woody debris was reduced.	Torgersen (2002) reported similar volumes and numbers of logs after thinning and after burning. Knapp et al. (2005) and Stephens and Moghaddas (2005b) reported similar declines in log resources after burning.
22	Youngblood, A. 2010. Thinning and burning in dry coniferous forests of the western United States: effectiveness in altering diameter distributions. Forest Science. 56(1): 46–59.	Network	Overstory vegetation	B, M, M+B	2	Meta-analysis across all seven western FFS sites involving 57,000 live trees indicated that the fuel reduction treatments increased mean stand diameters.	No other studies have reported similar findings.
22	Youngblood 2010.	Network	Overstory vegetation	M+B	2	Mechanical + burn treatment effects on stand structure were additive, affecting trees on both ends of the diameter distribution.	No other studies have reported similar findings.
22	Youngblood 2010.	Network	Overstory vegetation	B, M	2, 4	Meta-analysis across all seven western FFS sites indicated that the thin treatment affected the diameter distribution by removing more of the larger trees while the burn treatment affected the diameter distribution by removing more of the smaller trees.	No other studies have reported similar findings.

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
22	Youngblood 2010.	Network	Overstory vegetation	B, M, M+B	2, 8	Although burn, mechanical, and mechanical + burn treatments were successful in shifting size distributions to larger trees, no single entry will mitigate nearly a century of fire exclusion in seasonally dry forests of the interior Western United States.	No other studies have reported similar findings.
23	Metlen, K.L. 2002. Undergrowth vegetation response to fuel reduction treatments in the Blue Mountains of eastern Oregon. Missoula, MT: University of Montana. 74 p. M.S. thesis.	Blue Mountains	Understory vegetation	B, M, M+B	1, 8, 9	Findings for this thesis can be found in paper No. 24.	No other studies have reported similar findings.
24	Metlen, K.L.; Fiedler, C.E.; Youngblood, A. 2004. Understory response to fuel reduction treatments in the Blue Mountains of northeastern Oregon. Northwest Science. 78(3): 175–185.	Blue Mountains	Understory vegetation	B, M, M+B	1, 8, 9	A full assessment of understory response (both diversity and cover) to treatment likely would require several more years of posttreatment data.	Scherer et al. (2000) found higher understory plant species diversity several years after a low thinning. Understory plant cover increased for 8 years after treatment in ponderosa pine forests (McConnell and Smith 1970). Lehmkuhl (2002) reported increased plant species richness several years after burning in clearcuts in coastal Washington.
24	Metlen et al. 2004.	Blue Mountains	Understory vegetation	B, M, M+B	1, 2	Mechanical treatments did not serve as a surrogate for fire; forb cover and plant species richness but not diversity declined after mechanical treatments while shrub and total cover declined after burn treatments.	Johnson (1998) reported similar short-term results after wildfires and suggested that most native plant species in these ecosystems are adapted to low-intensity disturbances such as thinning and surface fire. Nieppola (1992) and Scherer et al. (2000) reported that fire treatments reduced plant species richness.

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Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
24	Metlen et al. 2004.	Blue Mountains	Understory vegetation	B, M+B	1, 2	The magnitude of effects was greater for mechanical + burn treatments than for burn treatments, even though both treatments had similar responses.	No other studies have reported similar findings.
24	Metlen et al. 2004.	Blue Mountains	Understory vegetation	B, M+B	2, 5	Short-term response of understory plants was generally modest, with a trend toward increased evenness after burn treatments. Individual species responded to treatments in a manner consistent with their life-history characteristics. Resiliency of the understory plant community to fire and the effect of burning on individual plant species demonstrated their adaptation to frequent low-intensity fire.	Grant and Loneragan (2001) reported that fire treatments tended to increase evenness because of reductions in the cover of common plants. No other studies have reported increased evenness after surface burning in interior West ponderosa pine forests.
25	Matzka, P.; Kellogg, L. 1999. Thinning with prescribed fire and timber harvesting mechanization for forest restoration: a review of past and present research. In: Proceedings, 1999 international mountain logging and 10th Pacific Northwest skyline symposium. Corvallis, OR: Oregon State University: 293–302.	Blue Mountains	Fuels and fire behavior	M	2, 10	Logging operations research expanded on earlier work in mixed-conifer forests and provided new knowledge for the management of these stands.	Brown (1995), working in mixed-conifer forests, reported that the fuel reduction treatments conducted by using a combination of single-grip harvester and a small cable yarder (skyline system) on flat ground was economically feasible. Drews et al. (1998) reported that costs for yarding in mixed-conifer forests were higher with cable yarding than with a cut-to-length harvester/forwarder system.

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
26	Youngblood, A.; Wright, C.S.; Ottmar, R.D.; McIver, J.D. 2008. Changes in fuelbed characteristics and resulting fire potentials after fuel reduction treatments in dry forests of the Blue Mountains, northeastern Oregon. Forest Ecology and Management. 255(8/9): 3151–3169.	Blue Mountains	Fuels and fire behavior	B, M, M+B	1, 2, 3	The number of down logs was less after burn and mechanical + burn treatments than after mechanical treatments.	Burning reduced several measures of coarse woody debris at the Central Sierra FFS site (Stephens and Moghaddas 2005b). Log mass and cover were reduced with burning, especially with fall burns compared to spring burns, while the density of logs was unchanged at the Southern Sierra FFS (Knapp et al. 2005).
26	Youngblood et al. 2008.	Blue Mountains	Fuels and fire behavior	B, M, M+B	1, 2, 3	Surface fuel bed mass was reduced by burn treatments. Three years after applying fire, total fuel loads (mass) was reduced by about 66 percent with the burn treatment and about 50 percent with the mechanical + burn treatment.	Knapp et al. (2005) and Stephens and Moghaddas (2005a) reported greater change in various fuel bed components after fuel reduction treatments. Fulé et al. (2005) reported comparable fuel loadings after burn treatments, with surface fuels reduced to about 33 percent the mass of untreated stands 5 years after treatment. Fulé et al. (2005) also reported that fuel mass 5 years after their combination thin and burn treatment was similar to their untreated fuel mass because of the accumulation of fire-killed trees.

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Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
26	Youngblood et al. 2008.	Blue Mountains	Fuels and fire behavior	B, M+B	2, 3	Burn treatments initially reduced fire risk, yet after 3 years, treatments converged for various measures of fire risk, indicating that a single entry resulted in only transient effectiveness.	Pollet and Omi (2002), working in the Tahoe Basin, and Stephens et al. (2009) working at several western FFS study sites, showed greater overall reduction in fire risk, while Agee and Lolley (2006) achieved more modest fire risk reduction in the northeastern Cascades.
26	Youngblood et al. 2008.	Blue Mountains	Fuels and fire behavior	M	2, 3	Thinning slash increased fuel mass initially, but these fuels declined in mass to pretreatment levels after 6 years.	No other studies have reported similar findings.
27	Rothenbach, C.A. 2007. The response of nuthatches (*Sitta* spp.) to restorative treatments in ponderosa pine ecosystems of northeastern Oregon. Prince George, BC: University of Northern British Columbia. 112 p. M.S. thesis.	Blue Mountains	Vertebrates	M+B	1, 5	Foraging habitat suitability for both white-breasted and pygmy nuthatches improved more after mechanical + burn treatments than other treatments because these birds prefer large partially burned trees; habitat for red-breasted nuthatches remained unchanged.	Balda et al. (1983), Csuti et al. (1997), and Kingery and Ghalambor (2001) reported that pygmy nuthatches prefer open stands. Morrison et al. (1989) reported that nuthatch food was generally more abundant in stands treated by both thinning and burning.
28	Smith, J.E.; McKay, D.; Brenner, G.; McIver, J.; Spatafora, J.W. 2005. Early impacts of forest restoration treatments on the ectomycorrhizal fungal community and fine root biomass in a mixed conifer forest. Journal of Applied Ecology. 42(3): 526–535.	Blue Mountains	Pathology and fungi	B, M, M+B	1, 8, 9	The ectomycorrhizal fungal community was composed of a large number of infrequently detected species. The distribution of *Cenococcum* species, *Piloderma* species, *Rhizopogon salebrosus,* and *Wilcoxina rehmii*) before and after treatments showed that some ectomycorrhizal fungi species survived or rapidly reestablished after fuel reduction treatments.	No other studies have reported similar findings.

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
28	Smith et al. 2005.	Blue Mountains	Pathology and fungi	B, M+B, C	1, 2	Ectomycorrhizal fungi species richness, live root biomass, and duff levels were reduced by burn treatments; these responses tended to be greater after mechanical + burn treatments because thinning slash likely led to higher fire severity.	Korb et al. (2003) found no effect of restoration treatments, including fire, on the proportion of tree roots colonized by ectomycorrhizal fungi. Jonsson et al. (1999) reported little change in ectomycorrhizal fungi richness after low-intensity wildfires that did not consume the litter layer. In contrast, Stendell et al. (1999) reported that abundant ectomycorrhizal fungi were reduced by a high-intensity prescribed fire that consumed the litter layer.
29	Coulter, E.D. 1999. Hungry Bob harvest production study: mechanical thinning for fuel reduction in the Blue Mountains of northeast Oregon. Corvallis, OR: Oregon State University. 96 p. M.S. thesis.	Blue Mountains	Economics	M	8	For operational fuel reduction projects with cut-to-length mechanical logging systems, purpose-built harvesters and forwarders were more efficient than converted machines (e.g., excavator modified to harvester).	Matzka and Kellogg (2000) refined this finding after modeling, and predicted that as long as the saw-log component of an operation exceeded 10 percent, purpose-built harvesters were more efficient.
30	Matzka, P.J.; Kellogg, L.D. 2000. An economic model for evaluating factors affecting biomass reduction and forest restoration. In: Proceedings, Council of Forest Engineering/Canadian Woodlands Forum Conference. Kelowna, B.C.: [Publisher unknown]. 5 p.	Blue Mountains	Economics	M		Purpose-built single-grip harvesters generated more revenue per unit time than retrofitted machines, except when saw-logs fell below 10 percent of total volume.	Dodson-Coulter (1999) showed that purpose-built harvesters and forwarders were more efficient than modified machines.

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Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
31	Matzka, P.J. 2003. Thinning with prescribed fire and timber harvesting mechanization for fuels reduction and forest restoration. Corvallis, OR: Oregon State University. 228 p. Ph.D. dissertation.	Blue Mountains	Economics	B, M, M+B	1, 7, 8	With a cut-to-length harvesting system, single grip harvesters and forwarding machines varied considerably in production rates. The type of harvested material was important for explaining variation in harvester production, whereas the distance and number of stops were important for the forwarder. Results demonstrated that fuel reduction projects that require the processing of more down wood material would yield higher net revenues and cost less per acre with purpose-built machines.	Drews et al. (1998) reported similar results from a cut-to-length system in a high-elevation mixed-conifer forest. McIver et al. (2003) reported costs and revenues for a mixed-conifer fuel reduction project. Holtzscher and Landford (1996) reported tree diameter effects on cost and productivity of cut-to-length systems.
31	Matzka 2003.	Blue Mountains	Economics	B, M, M+B	1, 7, 8	Net revenues from thinning averaged $315 per acre, while costs of prescribed fire averaged $51 per acre, demonstrating that the thinning operation paid the costs of fuel reduction.	No other studies have reported the costs and revenue of an operational-scale fuel reduction project.
31	Matzka 2003.	Blue Mountains	Economics	B, M, M+B	1, 7, 8	Douglas-fir (*Pseudotsuga menziesii*) required about 10 percent more time to process per diameter than ponderosa pine (*Pinus ponderosa*), suggesting that tree species will influence harvest costs in fuel reduction projects.	Raymond and Moore (1989) reported that differences in production based on tree species was related to differences among limb sizes.
32	McIver, J.D.; Youngblood, A.; Niwa, C.; Smith, J.; Ottmar, R.; Matzka, P. 2000b. Alternative fuel reduction methods in Blue Mountain dry forests: an introduction to the Hungry Bob project. In: Neuenschwander, L.F.; Ryan, K.C.; Goldberg, G.E., eds. Proceedings, crossing the millennium: integrating spatial technologies and ecological principles for a new age in fire management, 1999 Joint Fire Science conference. Moscow, ID: University of Idaho Press, online version: 282–286.	Blue Mountains	General and study description	B, M, M+B	1, 2	This paper describes the FFS study design: no findings presented.	No other studies have reported similar findings.

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
33	Youngblood, A.; Grace, J.B.; McIver, J.D. 2009. Delayed conifer mortality after fuel reduction treatments: interactive effects of fuel, fire intensity, and bark beetles. Ecological Applications. 19(2): 321–337.	Blue Mountains	Multivariate	B, M, M+B	1, 2, 3	Red turpentine beetles and wood-boring beetles caused most of the tree mortality attributable to insects.	No studies have implicated red turpentine or wood-boring beetles as mortality agents after prescribed surface fire in natural ponderosa pine stands. Rappaport et al. (2001) attributed ponderosa pine mortality to red turpentine beetles in a 17–year-old plantation, Fettig et al. (2006) implicated red turpentine beetle in stands where logging residues were chipped and retained on site, and Cognato et al. (2005) found red turpentine beetle mortality in a native pine of China.
33	Youngblood et al. 2009.	Blue Mountains	Multivariate	B, M+B	1	Fire was the greatest source of mortality in small-diameter trees, while posttreatment windstorms caused the greatest mortality of large trees.	No other studies have reported similar findings.
33	Youngblood et al. 2009.	Blue Mountains	Multivariate	B, M+B	1	Fire in the mechanical + burn treatment burned hotter than in the burn treatment owing to the higher levels of surface fuels generated by the thinning operation.	No other studies have reported similar findings.
33	Youngblood et al. 2009.	Blue Mountains	Multivariate	M+B	2	Structural equation modeling showed that bark-beetle-caused tree mortality was greatest after the mechanical + burn treatment compared with other treatments. Delayed mortality of large-diameter	No other studies have experimentally linked bark-beetle-caused tree mortality to fuel loads, fire intensity, and fire severity. Levels of

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						ponderosa pine from bark beetles and wood borers was directly related to surface fire severity and bole charring, which in turn depended on fire intensity, which in turn was greater where thinning increased slash fuels.	mortality caused by bark beetles were consistent with work from northern Arizona (Zausen et al. 2005).
34	Fiedler, C.E.; Metlen, K.L.; Dodson, E.K. 2010. Restoration treatment effects on stand structure, tree growth, and fire hazard in a ponderosa pine/Douglas-fir forest in Montana. Forest Science. 56(1): 18–31.	Northern Rockies	Overstory vegetation	M+B	1, 2	The mechanical + burn treatment was the most effective in creating stand conditions that could resist moderate wildfire by increasing quadratic mean diameter, height to live crown, and tree growth rate, and lowering canopy cover and crown fire potential compared to other treatments.	Youngblood et al. (2006) and Stephens and Moghaddas (2005a) reported that the mechanical + burn treatment increased quadratic mean diameter, thus demonstrating that a single thinning entry can increase average residual tree size. Canopy cover levels between 30 and 50 percent were considered adequate to create sustainable, fire-resilient ponderosa pine stands (Hollenstein et al. 2001, van Wangtendonk 1996, Waltz et al. 2003). Growth response to thinning is well known, although burning can cause reductions in growth rate through root and cambial damage (Fajardo et al. 2007).
34	Fiedler et al. 2010.	Northern Rockies	Overstory vegetation	M, M+B	8	Residual tree densities after mechanical and mechanical + burn treatments were within	Fiedler et al. (1988) listed recommendations for tree density to

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
						the recommended density for regenerating ponderosa pine (*Pinus ponderosa*), suggesting that thinning is sufficient to meet long-term restoration goals in western Montana.	achieve regeneration of ponderosa pine (*Pinus ponderosa*).
35	Dodson, E.K. 2004. Monitoring change in exotic plant abundance after fuel reduction/restoration treatments in ponderosa pine forests of western Montana. Missoula, MT: University of Montana. 99 p. M.S. thesis.	Northern Rockies	Understory vegetation	B, M, M+B	1, 9	Findings for this thesis can be found in papers Nos. 37 and 39.	No other studies have reported similar findings.
36	Metlen, K.L.; Fiedler, C.E. 2006. Restoration treatment effects on the understory of ponderosa pine/Douglas-fir forests in western Montana, USA. Forest Ecology and Management. 222(1-3): 355–369.	Northern Rockies	Understory vegetation	B, M	1, 2	Overstory canopy cover was reduced after mechanical treatments leading to increased light levels on the forest floor but not after burn treatments.	No other studies have reported similar findings.
36	Metlen and Fiedler 2006.	Northern Rockies	Understory vegetation	B, M, M+B	1, 2	Forbs were the most responsive life form to fuel reduction treatments, and both species richness and cover increased after treatment, especially after mechanical + burn treatments.	Short-term shrub response to fire has been documented in other dry forest or savannah ecosystems (Antos et al. 1983, MacKenzie et al. 2004, Metlen et al. 2004, Schoennagel et al. 2004).
36	Metlen and Fiedler 2006.	Northern Rockies	Understory vegetation	B, M, M+B	1, 2	Sapling density was reduced by all three treatments.	No other studies have reported similar findings.
36	Metlen and Fiedler 2006.	Northern Rockies	Understory vegetation	B, M, M+B	1, 2, 3	Plant species richness at plot scale (1000 m^2) was greater 3 years after burn, mechanical, and mechanical + burn treatments than before treatments, with the greatest increase after mechanical + burn treatments and the least increase after the burn treatments.	Griffis et al. (2001) reported similar treatment effects. Wienk et al. (2004) reported that species richness declined the first year after thinning and then increased. Increasing species richness of forbs after burning was reported by Busse et al. (2000).

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Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
36	Metlen and Fiedler 2006.	Northern Rockies	Understory vegetation	B, M+B	1, 2, 3	Evenness (Simpson's Index) initially increased after the burning treatment, but treatment differences were not distinguishable 3 years later.	No other studies have reported similar findings.
36	Metlen and Fiedler 2006.	Northern Rockies	Understory vegetation	B, M+B	1, 2, 3	Shrub richness and abundance at the 1-m^2 scale was reduced initially by burning.	No other studies have reported similar findings.
36	Metlen and Fiedler 2006.	Northern Rockies	Understory vegetation	B, M, M+B	1, 6, 10	Responses of plants to the three treatments suggested that maximum heterogeneity and diversity at the landscape scale could be achieved by applying a mix of treatments.	No other studies have reported similar findings.
36	Metlen and Fiedler 2006.	Northern Rockies	Understory vegetation	M+B	2, 8	Conditions most similar to those described for stand under natural disturbance regimes, with reduced conifer regeneration and increased native understory species richness and abundance, were created by mechanical + burn treatments.	No other studies have reported similar findings.
37	Dodson, E.K.; Fiedler, C.E. 2006. Impacts of restoration treatments on alien plant invasion in *Pinus ponderosa* forests, Montana, USA. Journal of Applied Ecology. 43(5): 887–897.	Northern Rockies	Understory vegetation	B, M	1, 2, 9	Greater exotic and transformer plant species (species capable of altering environmental conditions) at 100-m^2 and 1000-m^2 scales were found after burn and after mechanical treatments than in untreated stands.	No other studies have reported similar findings.
37	Dodson and Fiedler 2006.	Northern Rockies	Understory vegetation	B, M, M+B	1, 3	Four transformer plant species (species capable of altering environmental conditions) were identified as indicators after mechanical + burn treatments, while one species was identified after mechanical treatments. No transformer plant species were identified for burn and untreated conditions. Strong links between	The ability of exotic species to persist several years after treatment may complicate restoration efforts and suggests the need to continue monitoring understory species dynamics (Halpern et al. 1999).

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
						treatment and indicator species suggested the need to continue monitoring key transformer species, such as Canada thistle (*Cirsium vulgare*).	
37	Dodson and Fiedler 2006.	Northern Rockies	Understory vegetation	B, M, M+B	1, 7, 9	There may be a tradeoff between the need to accomplish fuel reduction objectives in a timely manner and the risk of establishment of exotic transformer species (plant species capable of altering environmental conditions).	No other studies have reported similar findings.
37	Dodson and Fiedler 2006.	Northern Rockies	Understory vegetation	M+B	2, 9	Species richness and cover of exotic transformer species (plant species capable of altering environmental conditions) were greater after the mechanical + burn treatment than after other treatments at spatial scales of 1 m^2, 100 m^2, and 1000 m^2.	Increased exotic species richness after burning (Fulé et al. 2005, Griffis et al. 2001, Wienk et al. 2004) and after thinning (Haeussler et al. 2002, Thysell and Carey 2001) was previously reported, although the FFS study at the Northern Rocky Mountains site was conducted unusually in operational scale experiment units (Bennett and Adams 2004).
37	Dodson and Fiedler 2006.	Northern Rockies	Understory vegetation	M+B	2, 9	Cover of transformer species (plant species capable of altering environmental conditions) was greatest after the mechanical + burn treatments, likely the result of increased fire intensity and severity because cover of these species was positively correlated with tree crown scorch height and negatively correlated with tree density.	Increased cover of certain exotic species after combined treatments was reported by Griffis et al. (2001) and Wienk et al. (2004).

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Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
38	Metlen, K.L.; Dodson, E.K.; Fiedler, C.E. 2006. Vegetation response to restoration treatments in ponderosa pine-Douglas-fir forests. In: Fire Effects Information System. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. www.fs.fed.us/database/feis/research_project_summaries/Metlen06/all.html (Date accessed Jan. 23, 2012).	Northern Rockies	Understory vegetation	B, M, M+B	1, 2, 9	Findings for this publication can be found in papers Nos. 37 and 39.	
39	Dodson, E.K.; Metlen, K.L.; Fiedler, C.E. 2007. Common and uncommon understory species differentially respond to restoration treatments in ponderosa pine/Douglas-fir forests, Montana. Restoration Ecology. 15(4): 696–708.	Northern Rockies	Understory vegetation	B, M+B	1, 2	Short-lived species (annual and biennial) were favored by treatments that included burning.	Positive responses by short-lived plant species have been reported for thinning (McConnell and Smith 1965), burning (Laughlin et al. 2004, Merrill et al. 1980), and combined treatments (Fulé et al. 2005).
39	Dodson et al. 2007.	Northern Rockies	Understory vegetation	B, M, M+B,	1, 2, 9	Species richness of common native plants was greater after mechanical treatments, while uncommon native species richness increased after burn, mechanical, and especially the mechanical + burn treatments.	Fire exclusion reduced understory plant richness in forests with frequent fire regimes (Covington and Moore 1994, Fulé et al. 1997, Laughlin et al. 2004, Wienk et al. 2004).
39	Dodson et al. 2007.	Northern Rockies	Understory vegetation	B, M, M+B	1, 8, 9	Restoration treatments fostered native plant species richness by minimally affecting common species while benefiting more uncommon disturbance-dependent species.	Uncommon native species may benefit from restoration treatments that reestablish conditions and processes that are critical components of their evolutionary history (Fiedler et al. 1992, White and Jentsch 2001).
39	Dodson et al. 2007.	Northern Rockies	Understory vegetation	M, M+B	2, 3	Graminoids were exclusively indicative of the mechanical treatment.	Griffis et al. 2001 reported that graminoid richness can be promoted by burning.

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
40	Gundale, M.J.; DeLuca, T.H. 2006. Temperature and source material influence ecological attributes of ponderosa pine and Douglas-fir charcoal. Forest Ecology and Management. 231(1–3): 86–93.	Northern Rockies	Fuels and fire behavior	B	1	Charring temperature is a critical variable for production of charcoal that may enhance plant growth, suggesting that fire intensity is important for predicting the extent to which site productivity is enhanced. Spatial heterogeneity in productivity was associated with the creation of charcoal at different temperatures, corresponding to spatial heterogeneity in fuels, fire intensity, and fire severity.	Zackrisson et al. (1996) suggested that charcoal may serve a key ecological function in boreal forests, with spatial variation in burning temperature responsible for creating differing levels of charcoal.
40	Gundale and DeLuca 2006.	Northern Rockies	Fuels and fire behavior	B	1	Charcoal formed at high temperatures is more effective at adsorbing allelochemical compounds such as catechin (found in many weedy plant species), suggesting that the mechanism for enhancing plant growth may be sorption of nitrification-inhibiting compounds.	Catechin has been identified from root exudates of spotted knapweed (*Centaurea maculosa*) (Bais et al. 2003), which in turn have been shown to have strong allelopathic effects on native plant species. Hille and den Ouden (2005) reported that naturally produced charcoal was less effective at adsorbing allelochemicals compared to artificial, “activated charcoal;” however these authors used “low temperature” natural charcoal produced at 450 degrees Celcius, compared to 800 degrees for the current study.

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Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
41	Gundale, M.J.; DeLuca, T.H.; Fiedler, C.E.; Ramsey, P.W.; Harrington, M.G.; Gannon, J.E. 2005. Restoration treatments in a Montana ponderosa pine forest: effects on soil physical, chemical and biological properties. Forest Ecology and Management. 213(1–3): 25–38.	Northern Rockies	Soils	B, M+B	1, 2	Burning caused many soil chemical changes in the upper levels of soil, yet heating on average was not sufficient to alter soil microbe communities, nor to cause shifts in exchangeable ions such as calcium, magnesium, sodium, potassium, or in pH.	Short-term losses of microbial biomass or shifts in microbial community structure have been reported (Choromanska and DeLuca et al. 2002, Korb et al. 2003), as have shifts in exchangeable ions (Klemmedson 1992).
41	Gundale et al. 2005.	Northern Rockies	Soils	M+B	1, 2, 3	Phospholipid fatty acids, owing to increased abundance of actinomycetes, increased 16 to 18 weeks after burning in mechanical + burn treatments. Carbon:nitrogen ratios in the O horizon were lower the first year after burning in mechanical + burn treatments. Greater ammonium and nitrification levels in the O horizon lasted 3 years after burning. Decomposition rates were higher after mechanical + burn treatments.	Ammonium concentrations increased between 2 and 20 times after fire (Covington and Sackett 1992, DeLuca and Zouhar 2000, Kaye and Hart 1998, Monleon et al. 1997).
41	Gundale et al. 2005.	Northern Rockies	Soils	B, M+B	1, 6, 10	There was substantial spatial heterogeneity in burn severity within stands, and this led to patchiness of soil nutrient effects. Information on soil effects at the stand level may be more applicable to actual management operations than information from studies conducted on smaller, more homogeneous burn plots.	No other studies have reported similar findings.
42	Gundale, M.J.; DeLuca, T.H. 2007. Charcoal effects on soil solution chemistry and growth of *Koeleria macrantha* in the ponderosa pine/Douglas-fir ecosystem. Biology and Fertility of Soils. 43(3): 303–311.	Northern Rockies	Soils	B, M+B	1	Charcoal produced in a fire enhanced the growth of the native perennial grass *Koeleria macrantha*, probably through the sorption of	Zackrisson et al. (1996) and DeLuca et al. (2002) reported the capacity of charcoal to adsorb.

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
						nitrification-inhibiting compounds such as phenols.	phenolic compounds. DeLuca et al. (2006) showed that charcoal created during wildfires increased nitrification rates.
42	Gundale and DeLuca 2007.	Northern Rockies	Soils	B, M+B	1	Charcoal produced at low temperature in a laboratory setting had different properties than charcoal created during a wildfire, suggesting that temperature and oxygen concentration may be important in producing charcoal with growth-enhancing effects.	No other studies have reported similar findings.
43	Burgoyne, T.A.; DeLuca, T.H. 2009. Short-term effects of forest restoration management on non-symbiotic nitrogen-fixation in western Montana. Forest Ecology and Management. 258(7): 1369–1375.	Northern Rockies	Soils	B, M, M+B	1	Nitrogen-fixation rates (0.26 kg $N{\cdot}ha^{-1}{\cdot}yr^{-1}$) would likely require 40 to 100 years to replenish soil nitrogen lost through wildfire or through whole-tree harvest.	Soil nitrogen loss was estimated at 230 kg $N{\cdot}ha^{-1}$ after stand-replacing wildfire (Wan et al. 2001) and 100 kg $N{\cdot}ha^{-1}$ after whole-tree harvesting (Wei et al. 1997).
43	Burgoyne and DeLuca 2009.	Northern Rockies	Soils	B, M, M+B	2	Nitrogen-fixation rates were slightly higher overall in control stands compared to treated stands. The overall low nitrogen-fixation rates were likely the result of environmentally dry conditions in these forests.	Wei and Kimmins (1998) reported similar results, while Jurgensen et al. (1992) reported nitrogen-fixation rates in mineral soil were lower in treated stands 6 years after treatment. Chen and Hicks (2003) reported high rates of nitrogen fixation in decaying roots of old-growth stands.

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Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
43	Burgoyne and DeLuca 2009.	Northern Rockies	Soils	B, M+B	2	Nitrogen fixation rates were nearly nonexistent in root systems of stumps or fire-killed trees, but rates were not affected by treatment in mineral soil or decomposing roots.	Wei and Kimmins (1998) reported higher rates of nitrogen fixation in woody roots of fire-killed trees than in mineral soil.
44	Woolf, J.C. 2003. Effects of thinning and prescribed burning on birds and small mammals. Missoula, MT: University of Montana. 126 p. M.S. thesis.	Northern Rockies	Vertebrates	B, M, M+B	1, 2	Golden mantled ground squirrels, deer mice, and yellow-pine chipmunks were more abundant after burn treatments while red-backed voles were more abundant without burning.	Deer mice were reported to favor burned areas (Ream 1981). Red-backed voles were reported to prefer more mesic, closed-canopy conditions (Foresman 2001). Other studies have shown mixed response of chipmunks to burning (Ahlgren 1966).
44	Woolf 2003.	Northern Rockies	Vertebrates	B, M+B	2, 5	Bird communities showed little short-term response to fuel reduction treatments, yet black-backed woodpecker and olive-sided flycatchers, both considered sensitive (U.S. Forest Service classification) were found only after burn treatments.	Black-backed woodpeckers are attracted to burned stands, especially when bark beetles are actively colonizing trees (Hutto 1995, Murphy and Lehnhausen 1998).
44	Woolf 2003.	Northern Rockies	Vertebrates	B, M+B	5	Red-breasted nuthatches and mountain chickadees used untreated sites most often, while black-backed woodpeckers, hairy woodpeckers, and white-breasted nuthatches foraged in burned units more frequently. Most bird species preferred large-diameter trees for foraging.	Altered foraging behavior of bark-foraging birds after mechanical fuel reduction treatments was reported by Szaro and Balda (1979) and Weikel (1997). No other studies have compared bark foraging behavior in burned and unburned units.

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
45	Pierson, J.C.; Mills, L.S.; Christian, D.P. 2010. Foraging patterns of cavity-nesting birds in fire-suppressed and prescribe-burned ponderosa pine forests in Montana. Open Environmental Sciences. 4: 41–52.	Northern Rockies	Vertebrates	B, M, M+B	1	Most cavity-nesting bird species foraged selectively on the largest trees in treated and untreated stands.	Other studies have reported that many cavity-nesting bird species select the largest trees for foraging (Gunn and Hagan 2000, Lundquist and Manuwal 1990, Saab and Dudley 1998, Villard and Beninger 1993).
45	Pierson et al. 2010.	Northern Rockies	Vertebrates	B, M+B	1	Cavity-nesting birds, including black-backed woodpeckers, hairy woodpeckers, and white-breasted nuthatches, responded positively to burn treatments.	Gaines et al. (2007) reported that more red-breasted nuthatches were found in untreated stands than in burned or thinned stands. White-breasted nuthatches and black-backed woodpeckers were found more often in burned forests (Gaines et al. 2007, Smucker et al. 2005).
46	Six, D.L.; Skov, K. 2009. Response of bark beetles and their natural enemies to fire and fire surrogate treatments in mixed-conifer forests in western Montana. Forest Ecology and Management. 258(5): 761–772.	Northern Rockies	Bark beetles	B, M, M+B	1	Tree mortality resulting from bark beetles was greatest after burn treatments and was positively influenced by fire severity.	No other studies have reported similar findings.
46	Six and Skov 2009.	Northern Rockies	Bark beetles	B, M+B	1	Douglas-fir, pine engraver, and western pine beetle populations increased after burn treatments, but adjacent green trees were not attacked. Failure of bark beetles to spread likely resulted from low numbers in the background beetle populations and high tree vigor.	Variability in the tendency of bark beetles to move to adjacent green trees likely results from tree vigor and the number of host trees available to support amplification of bark beetle population (Peterson and Arbaugh 1989). Movement of bark beetles into

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Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
							green trees after the Yellowstone fires in 1988 likely resulted from the large number of fire-weakened trees and prolonged drought after the fires (Amman and Ryan 1991). Fettig and McKelvey (2010) reported that the amount of bark beetle-caused tree mortality increased on unburned split plots compared to adjacent burned split plots 3 to 5 years after burning.
46	Six and Skov 2009.	Northern Rockies	Bark beetles	B, M+B	2	Increased resin flow in burned trees late in the growing season did not affect bark beetle attack success.	Increased resin flow in fire-damaged trees may increase resistance to bark beetle attack (Feeney et al. 1998, Perrakis and Agee 2006).
47	Gundale, M.J. 2005. Nitrogen cycling and spatial heterogeneity following fire and restoration treatments in the ponderosa pine/Douglas-fir ecosystem. Missoula, MT: University of Montana. 166 p. Ph.D. dissertation.	Northern Rockies	Multivariate	B, M, M+B	1, 2	Findings for this dissertation can be found in papers Nos. 40 and 42.	
48	Miesel, J.R.; Boerner, R.E.J.; Skinner, C.N. 2008. Mechanical restoration of California mixed-conifer forests: Does it matter which trees are cut? Restoration Ecology. 17(6): 784–795.	Southern Cascades	Overstory vegetation	M	2	Different thinning treatments may lead to soil differences that may affect growth rates of residual trees and growth and survivorship of newly established seedlings.	No other studies have reported similar findings.

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48	Miesel et al. 2008.	Southern Cascades	Overstory vegetation	M	7	In a size-preference thinning treatment, inorganic nitrogen availability, soil organic carbon content, phenol oxidase activity and forest floor carbon:nitrogen ratio were greater than a pine-preference thinning treatment. Conversely, forest floor nitrogen and soil pH were greater in the pine-preference treatment.	Spatial distribution of the remaining trees may also influence soil pH and inorganic nitrogen. Concentrations of inorganic nitrogen were greater in cut openings where more than five trees were removed in a lodgepole pine stand in Wyoming than in uncut stands. Gap size did not affect ammonium (Parsons et al. 1994).
49	Schmidt, D.A.; Taylor, A.H.; Skinner, C.N. 2008. The influence of fuels treatment and landscape arrangement on simulated fire behavior, southern Cascade Range, California. Forest Ecology and Management. 255(8/9): 3170–3184.	Southern Cascades	Fuels and fire behavior	B, M+B	2	At the landscape level, fuel reduction treatment type, amount, and arrangement of fuels had important effects on both fire spread and fire intensity. In this landscape, there was the potential to reduce high-intensity fire behavior while treating only some areas by relying on strategically placed fuel treatments when these treatments were arranged by using Finney's optimal SPLATs design.	Little research has evaluated whether differences in the effectiveness of stand-scale fuel treatments scale up to forest landscapes, or how the spatial arrangement of treatment units influence the effectiveness of treatments to reduce fire risk across forested landscapes (Finney 2001, Loehle 2004).
49	Schmidt et al. 2008.	Southern Cascades	Fuels and fire behavior	M+B	2	Simulated fire behavior at the stand level demonstrated that the mechanical + burn treatment was the most effective in reducing future surface and crown fire behavior.	No other studies have reported similar findings.
50	Miesel, J.; Skinner, C.; Boerner, R. 2006. Impact of fire on soil resource patterns in mixed-conifer forests in the southern Cascade range of northern California. In: Dickinson, M.B., ed. Proceedings, fire in eastern oak forests: delivering science to land managers. Gen. Tech. Rep. NRS-P-1. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station: 290.	Southern Cascades	Soils	B, M+B	1, 2	Soil pH and total inorganic nitrogen increased after burn treatments, while there was no change in nitrogen mineralization and acid phosphatase activity was reduced.	No other studies have reported similar findings.

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Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
50	Miesel et al. 2006.	Southern Cascades	Soils	B	2	The carbon:nitrogen ratio increased and soil organic carbon declined after burn treatments. The carbon:nitrogen ratio and soil organic carbon remained unchanged after mechanical + burn treatments, while chitinase activity declined.	No other studies have reported similar findings.
51	Fettig, C.; Borys, R.; Dabney, C. 2010. Effects of fire and fire surrogate treatments on bark beetle-caused tree mortality in the southern Cascades, California. Forest Science. 56(1): 60–73.	Southern Cascades	Bark beetles	B, M, M+B	1	Bark beetle-caused tree mortality was concentrated in the smaller diameter classes.	McHugh and Kolb (2003) reported that mortality 3 years after fire was greatest in the smallest diameter trees. In contrast, Kolb et al. (2007) reported a “U-shaped” distribution of ponderosa pine mortality with greater mortality of both small- and large-diameter trees compared to medium-diameter trees.
51	Fettig et al. 2010.	Southern Cascades	Bark beetles	M, M+B	1, 2	Bark beetle attacks resulted in higher rates of fir mortality after mechanical + burn treatments than after mechanical treatments during both sample periods, but not cumulatively during the 4–year period.	Stand susceptibility to bark beetle attack can be reduced by reducing tree density (Fettig et al. 2007). Sartwell (1971) suggested that slow growth preceded mortality of nearly all trees killed by mountain pine beetle in the Pacific Northwest and suggested thinning to reduce tree competition and increase individual tree growth. Others have reported that restoration treatments,

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							including thinning and a combination of thinning and burning, improved tree vigor, growth, and decreased the likelihood of bark beetle attacks on individual trees (Feeney et al. 1998, Kolb et al. 1998, Sala et al. 2005, Skov et al. 2005, Stone et al. 1999, Wallin et al. 2004, 2008, Zausen et al. 2005).
51	Fettig et al. 2010.	Southern Cascades	Bark beetles	B, M, M+B	2	Rates of bark beetle-caused tree mortality, cumulatively over the 4–year study period, were higher and ponderosa pine (*Pinus ponderosa*) mortality was greater 2 years after burn treatments than other treatments. Bark beetle-caused mortality after the mechanical treatments did not differ from the untreated stands.	Oester et al. (2005) compared different thinning strategies and found the highest levels of bark beetle-caused mortality in untreated stands.
52	Stephens, S.L.; Moghaddas, J.J. 2005a. Experimental fuel treatment impacts on forest structure, potential fire behavior, and predicted tree mortality in a California mixed conifer forest. Forest Ecology and Management. 215(1–3): 21–36.	Central Sierra Nevada	Overstory vegetation	M	1	Modeled fire behavior and tree mortality was greater after the mechanical and the control treatments than after treatments that included fire as a surface fuel treatment.	No other studies have reported similar findings.
52	Stephens and Moghaddas 2005a.	Central Sierra Nevada	Overstory vegetation	B, M+B	1, 2	The combined litter and duff fuel load, average fire line intensity, rate of spread, and predicted mortality declined after burn treatments.	Tinker and Knight (2000) reported that more standing dead trees that could become coarse woody debris (logs) remained after burning treatments than after combined thinning and burning treatments.

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Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
52	Stephens and Moghaddas 2005a.	Central Sierra Nevada	Overstory vegetation	M, M+B	1, 2	Crown bulk density was reduced 19 percent after mechanical and mechanical + burn treatments.	Similar reductions in crown fuels after thinning treatments were reported in northeast Oregon (McIver et al. 2003) and Arizona (Fulé et al. 2001).
53	Kobziar, L.; Moghaddas, J.; Stephens, S.L. 2006. Tree mortality patterns following prescribed fires in a mixed conifer forest. Canadian Journal of Forest Research. 36(12): 3222–3238.	Central Sierra Nevada	Overstory vegetation	B, M+B	1	Predictions of tree mortality after fire were developed for use with modeling programs BEHAVE or FOFEM. Low mortality of large-diameter white fir (*Abies concolor*) likely occurred because trees were relatively young and resilient to fire. Preburn canopy cover and mortality of ponderosa pine (*Pinus ponderosa*) after the burn were linked. Mortality of tanoak (*Lithocarpus densiflorus*) after burns was modeled for the first time.	Other work has shown that combinations of tree characteristics and direct injuries provide the best prediction of postfire tree mortality (McHugh and Kolb 2003, Peterson and Arbaugh 1986, Regelbrugge and Conard 1993, Ryan and Reinhardt 1988, Saveland and Neuenschwander 1990; Stephens and Finney 2002). Stephens and Finney (2002) reported that duff consumption was an important predictor of white fir (*Abies concolor*) mortality. Susceptibility of incense cedar to bole char was previously reported by Powers and Oliver (1990).
53	Kobziar et al. 2006.	Central Sierra Nevada	Overstory vegetation	B, M, M+B	2	Mortality of tanoak (*Lithocarpus densiflorus*) and California black oak (*Quercus kelloggii*) was greater after burn treatments than other	No other studies have reported similar findings.

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						treatments, while mortality of sugar pine (*Pinus. lambertiana*) and ponderosa pine (*P. ponderosa*) was the least after burn treatments.	
53	Kobziar et al. 2006.	Central Sierra Nevada	Overstory vegetation	B, M, M+B	3	The most reliable predictors of short-term tree mortality were tree diameter and total crown damage. Bark beetles did not play a role in either immediate or delayed tree mortality.	No other studies have reported similar findings.
54	Moghaddas, J.J.; Stephens, S.L.; York, R.A. 2008. Initial response of conifer and California black oak seedlings following fuel reduction activities in a Sierra Nevada mixed conifer forest. Forest Ecology and Management. 255(8/9): 3141–3150.	Central Sierra Nevada	Overstory vegetation	B, M	1, 2	Douglas fir (*Pseudotsuga menziesii*) and ponderosa pine (*Pinus ponderosa*) seedling density increased after both burn and mechanical treatments. Seedling density for all tree species combined increased after both burn and mechanical + burn treatments. Establishment of true firs (*Abies* spp.) was inconsistent across burn treatments.	van Mantgem et al. (2006) reported that true fir seedlings easily established in both burned and unburned sites.
54	Moghaddas et al. 2008.	Central Sierra Nevada	Overstory vegetation	B, M, M+B	1, 7	California black oak (*Quercus kelloggii*) and sugar pine (*Pinus lambertiana*) seedlings likely will not survive treatments used to reduce fire hazard.	Numbers of sugar and ponderosa pine seedlings were low in dense mixed-conifer stands in the Sierra Nevada (Ansley and Battles 1998, van Mantgem et al. 2004).
55	Collins, B.M.; Moghaddas, J.J.; Stephens, S.L. 2007. Initial changes in forest structure and understory plant communities following fuel reduction activities in a Sierra Nevada mixed conifer forest. Forest Ecology and Management. 239(1–3): 102–111.	Central Sierra Nevada	Understory vegetation	B, M, M+B	1, 2	The three fuel reduction treatments decreased residual tree and seedling density, canopy cover, tree volume, and basal area.	No other studies have reported similar findings.
55	Collins et al. 2007.	Central Sierra Nevada	Understory vegetation	B, M+B	1, 2	The three treatments increased light penetration into the stands. Exposure of mineral soil increased after burn and mechanical + burn treatments. Increased exposure of mineral soil and increased light favored forbs and graminoids.	No other studies have reported similar findings.

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55	Collins et al. 2007.	Central Sierra Nevada	Understory vegetation	M, M+B	1, 2	Cover and richness of exotic plant species increased after the mechanical and mechanical + burn treatments. Using change in live tree volume as a proxy for severity, mechanical and mechanical + burn treatments represented the greatest disturbance severity.	Exotic plant species richness increased after mechanical + burn treatments in western Montana (Metlen and Fiedler 2006). Severity of silvicultural treatment, regardless of the inclusion of fire, was linked to increases in exotic plant richness (Battles et al. 2001). Little increase in exotic plant species richness and cover after burn treatments, as reported by Knapp et al. (2007), suggests that mechanical treatments may create more favorable seedbed for invasive species than burn treatments.
55	Collins et al. 2007.	Central Sierra Nevada	Understory vegetation	B, M+B	1, 2, 9	Native plant species richness declined after burn and mechanical + burn treatments. Shrub cover declined after the mechanical treatment.	No other studies have reported similar findings.
56	Stephens, S.L.; Moghaddas, J.J. 2005b. Fuel treatment effects on snags and coarse woody debris in a Sierra Nevada mixed conifer forest. Forest Ecology and Management. 214(1–3): 53–64.	Central Sierra Nevada	Fuels and fire behavior	B, M, M+B	1, 2	Volume of stand dead (snags) did not differ among treatments for all decay classes. Density of snags greater than 15 cm was higher after burn and mechanical + burn treatments.	Morrison and Raphael (1993) found similar patterns of snag recruitment.
56	Stephens and Moghaddas 2005b.	Central Sierra Nevada	Fuels and fire behavior	B, M+B	1, 2	Coarse woody debris, especially the more decayed larger logs, declined in number after burn and mechanical + burn treatments.	Reduced number of logs after burn and thin + burn treatments was reported by North

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
						Mechanical treatments had no effect on coarse woody debris.	et al. (2002). Work by Covington and Sackett (1992) and Stephens and Finney (2002) showed that between 70 and 99 percent of rotten coarse woody debris was consumed during burn treatments, suggesting that fire-prone forests likely contained low levels of rotten coarse woody debris under natural fire regimes.
56	Stephens and Moghaddas 2005b.	Central Sierra Nevada	Fuels and fire behavior	B, M+B	7	Depending upon management objectives, dry forest managers may need to balance the benefits of burn treatments for fire risk reduction with the loss of rotten coarse woody debris, an important resource for some wildlife species.	No other studies have reported similar findings.
57	Moghaddas, J.J.; Stephens, S.L. 2007b. Fire performance in traditional silvicultural and fire surrogate treatments in Sierran mixed conifer forests: a brief summary. In: Powers, R.F., ed. Proceedings of the 2005 national silviculture workshop, restoring fire-adapted ecosystems. Gen. Tech. Rep. PSW-GTR-203. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station: 251–260.	Central Sierra Nevada	Fuels and fire behavior	M+B	2, 8	Mechanical + burn treatments tended to reduce surface fuels, increase height to live crown, decrease crown density, and retain the largest trees. These characteristics may be critical for enhancing fire resiliency.	Similar characteristics may best satisfy fuel reduction objectives (Agee and Skinner 2005).
58	Stephens, S.; Rapp, V. 2008. Chainsaws or driptorches: How should fire risk be reduced? Fire Science Brief 6. Boise, ID: Joint Fire Science Program. 6 p.	Central Sierra Nevada	Fuels and fire behavior	B, M+B	1, 2	Predicted tree mortality, fireline intensity, and rate of spread were lowest after burn and mechanical + burn treatments.	No other studies have reported similar findings.
58	Stephens and Rapp 2008.	Central Sierra Nevada	Fuels and fire behavior	B, M, M+B	1, 8	Fuel reduction treatments reduced fire risk and increased what resembled historical forest structure compared to the untreated stands.	No other studies have reported similar findings.

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Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
59	Moghaddas, E.E.Y.; Stephens, S.L. 2007a. Thinning, burning, and thin-burn fuel treatment effects on soil properties in a Sierra Nevada mixed-conifer forest. Forest Ecology and Management. 250(3): 156–166.	Central Sierra Nevada	Soils	B, M, M+B	1, 2	Net rates of nitrification, nitrogen mineralization, and bulk density did not differ among treatments.	No other studies have reported similar findings.
59	Moghaddas and Stephens 2007a.	Central Sierra Nevada	Soils	B, M+B	1, 2	Burn treatments created soil chemical conditions that would be expected to enhance short-term productivity, but standing stocks of most nutrients were depleted.	Caldwell et al. (2002) reported lower losses of carbon. Gundale et al. (2005) reported lower losses of carbon and less consumption of the forest floor after spring burns. Loss of nitrogen in the forest floor was lower in work reported by Covington and Sackett (1984), Murphy et al. (2006), and Nissley (1980), and similar to that observed by Feller (1989).
59	Moghaddas and Stephens 2007a.	Central Sierra Nevada	Soils	M+B	1, 2	Inorganic nitrogen increased more after mechanical + burn treatments than other treatments.	No other studies have reported similar findings.
59	Moghaddas and Stephens 2007a.	Central Sierra Nevada	Soils	B	2	Mineral soil carbon concentration and cation exchange capacity declined after burn treatments.	No other studies have reported similar findings.
59	Moghaddas and Stephens 2007a.	Central Sierra Nevada	Soils	B, M, M+B	2, 6	Discontinuous fuels and variation in fuel consumption associated with skid trails led to spatial heterogeneity in soil pH and inorganic nitrogen.	No other studies have reported similar findings.
60	Moghaddas, E.E.Y.; Stephens, S.L. 2008. Mechanized fuel treatment effects on soil compaction in Sierra Nevada mixed-conifer stands. Forest Ecology and Management. 255(8/9): 3098–3106.	Central Sierra Nevada	Soils	M, M+B	2	Mastication equipment used in the mechanical and mechanical + burn treatments caused no detectable changes in soil bulk density or compaction off skid trails.	Few studies have examined the effects of onsite mastication of nonmerchantable material as part of a

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							fuel reduction treatment on soil compaction (Gundale et al. 2005, Hatchett et al. 2006, Moghaddas and Stephens 2007a).
60	Moghaddas and Stephens 2008.	Central Sierra Nevada	Soils	M+B	2	Soil strength (kilopascals) increased on skid trails after the mechanical + burn treatment, especially in sandy loam soils near the surface.	Hatchet et al. (2006) observed soil compaction at 10 and 25-cm depths and suggested that compaction was dispersed a broad distance from any trail and was limited to a narrow range of soil depth on sandy soils. Ampoorter et al. (2007) observed that machine traffic led to increased soil strength in sandy soils at 20- to 50-cm depths. Vazquez et al. (1991) reported that soil strength was a more sensitive indicator of soil compaction than bulk density after observing large increases in strength and only minor increases in bulk density.
61	Stephens, S.L.; Moghaddas, J.J.; Hartsough, B.R.; Moghaddas, E.E.Y.; Clinton, N.E. 2009b. Fuel treatment effects on stand-level carbon pools, treatment-related emissions, and fire risk in a Sierra Nevada mixed-conifer forest. Canadian Journal of Forest Research. 39(8): 1538–1547.	Central Sierra Nevada	Soils	B, M+B	1, 2	Burn and mechanical + burn treatments released more carbon dioxide (CO^2) than mechanical treatments.	Burning duff accounted for large emissions of carbon dioxide (Clinton et al. 2006).

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Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
61	Stephens et al. 2009b.	Central Sierra Nevada	Soils	M, M+B	1, 2	Aboveground carbon was reduced by both mechanical and mechanical + burn treatments.	No other studies have reported similar findings.
61	Stephens et al. 2009b.	Central Sierra Nevada	Soils	B	3	Management actions designed to increase wildfire resistance may be justified for long-term carbon sequestration when wildfire severity continues to increase.	Hurteau and North (2009) reported that untreated stands store more carbon but were at greater risk to high-severity wildfire.
62	Apigian, K.O. 2005. Forest disturbance effects on insect and bird communities: insectivorous birds in coast live oak woodlands and leaf litter arthropods in the Sierra Nevada. Berkeley, CA: University of California Berkeley. 178 p. Ph.D. dissertation.	Central Sierra Nevada	Vertebrates	B, M, M+B	1	Findings for this dissertation can be found in paper No. 64.	
63	Amacher, A.J.; Barrett, R.H.; Moghaddas, J.J.; Stephens, S.L. 2008. Preliminary effects of fire and mechanical fuel treatments on the abundance of small mammals in the mixed-conifer forest of the Sierra Nevada. Forest Ecology and Management. 255(8/9): 3193–3202.	Central Sierra Nevada	Vertebrates	B, M+B	1, 2	Deer mice increased after both burn and mechanical + burn treatments. Deer mice decreased after the mechanical treatment.	Deer mice have been reported to increase after fuel reduction treatments (Beck and Vogl 1972, Bock and Bock 1983, Carey and Wilson 2001, Fantz and Renken, 2005, Greenberg et al. 2006, Klenner and Sullivan 2003, Kyle and Block 2000, Muzika et al. 2004, Perry and Thill 2005, Suzuki and Hayes 2003, Tester 1965) or remain essentially unchanged (Cole et al.1998; Converse et al. 2006a, 2006b; Craig et al. 2006; Monroe and Converse 2006; Moses and Boutin 2001; Waters and Zabel 1998). Recent work has failed to detect

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
							changes in deer mouse populations associated with changes in coarse woody debris (Craig et al. 2006, Smith and Maguire, 2004). Other small mammal populations responded positively to predator exclusion (Klemola et al. 2000, Norrdahl et al. 2002, Yunger 2004).
63	Amacher et al. 2008.	Central Sierra Nevada	Vertebrates	B, M, M+B	5, 7	Brush mouse abundance was positively correlated with canopy cover, but negatively correlated with low tanoak and riparian cover.	Brush mice often are captured in dense brush or under low tree branches in stands with high canopy cover (Block et al. 2005, Grinnell and Storer 1924, Holbrook 1978, Jameson 1951, Kalcounis-Ruppell and Millar 2002, Wilson 1968).
64	Apigian, K.O.; Dahlsten, D.L.; Stephens, S.L. 2006b. Fire and fire surrogate treatment effects on leaf litter arthropods in a western Sierra Nevada mixed-conifer forest. Forest Ecology and Management. 221(1-3): 110–122.	Central Sierra Nevada	Invertebrates	B, M, M+B	1, 2	Predator beetle populations declined after burn treatments, while other beetle guilds were unaffected.	No other studies have reported similar findings.
64	Apigian et al. 2006b.	Central Sierra Nevada	Invertebrates	B, M, M+B	1, 2, 3	Fuel reduction treatments had subtle or moderate and transient effects in the short term on litter arthropods.	Baker et al. (2004) suggested that similar fuel reduction treatment effects on beetle fauna were transient.
64	Apigian et al. 2006b.	Central Sierra Nevada	Invertebrates	B, M+B	1, 2, 5, 6	Burning treatments increased the abundance of rare surface-dwelling beetle species. Many of these species responded to increased	Higher carabid beetle species richness after burning treatments was reported by Beaudry

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						heterogeneity in burned stands represented by increased exposure of mineral soil.	et al. (1997) and Villa-Castillo and Wagner (2002); other beetle species have not been studied.
65	Apigian, K.O.; Dahlsten, D.L.; Stephens, S.L. 2006a. Biodiversity of Coleoptera and the importance of habitat structural features in a Sierra Nevada mixed-conifer forest. Environmental Entomology. 35(4): 964–975.	Central Sierra Nevada	Invertebrates	B, M, M+B	1, 2, 5, 6	Species richness of ground-dwelling beetles was represented by nearly 300 species.	No other studies have documented beetle biodiversity in the Sierra Nevada, and few studies have explored beetle biodiversity in the Western United States.
65	Apigian et al. 2006a.	Central Sierra Nevada	Invertebrates	B, M, M+B	6	The ground-dwelling beetle fauna distribution occurred in fine-scale patches that were smaller than forest stands. Causes of patchiness are as yet unknown.	Niemela et al. (1996) observed carabid beetle communities structured on a fine spatial scale of 10 to 15 m.
66	Yasuda, D. 2008. Embracing “new information”: a manager’s perspective. Fire Science Manager’s Viewpoint. 6. Boise, ID: Joint Fire Science Program. 4 p.	Central Sierra Nevada	Sociology	B, M, M+B	10	An opinion piece focusing on a discussion of the initial FFS findings and management implications.	
67	Knapp, E.E.; Schwilk, D.W.; Kane, J.M.; Keeley, J.E. 2007. Role of burning season on initial understory vegetation response to prescribed fire in a mixed conifer forest. Canadian Journal of Forest Research. 37(1): 11–22.	Southern Sierra Nevada	Understory vegetation	B	2, 10	Plant species richness increased after both fall and spring burn treatments. Burns conducted in the spring after at least 120 years of fire exclusion did not cause greater mortality of understory species compared to fall burns because fuel moisture in the spring was sufficient to mitigate potential phenological effects. Managers may want to consider spring burning to mitigate effects on the understory.	Rapid recovery of understory plant species after burning was reported by Harvey et al. (1980) and Metlen et al. (2004). Increased plant species richness after burns was reported across different seasonally dry forest ecosystems (Brockway and Lewis 1997, Busse et al. 2000, Sparks et al. 1998).

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67	Knapp et al. 2007.	Southern Sierra Nevada	Understory vegetation	B	2, 3	Understory vegetation composition and structure remained similar several years after spring and fall burns were conducted.	No other studies have reported similar findings.
67	Knapp et al. 2007.	Southern Sierra Nevada	Understory vegetation	B	2, 7, 9	Data from three sites suggested that the highest levels of fuel reduction disturbance can lead to increased abundance and richness of exotic plant species, at the expense of native plant species.	No other studies have reported similar findings.
67	Knapp et al. 2007.	Southern Sierra Nevada	Understory vegetation	B	2, 9	Increased plant species richness after burning treatments was attributed to an increase in the number of native species.	Keeley et al. (2003) observed that burning led to an increase in the number of exotic plant species.
68	Knapp, E.E.; Keeley, J.E.; Ballenger, E.A.; Brennan T.J. 2005. Fuel reduction and coarse woody debris dynamics with early season and late season prescribed fire in a Sierra Nevada mixed conifer forest. Forest Ecology and Management. 208(1–3): 383–397.	Southern Sierra Nevada	Fuels and fire behavior	B, M+B	2	Burning did not reduce the number of coarse woody debris (logs); however, log length, cover, volume, and mass were reduced because logs were partially consumed by fire.	Mutch and Parsons (1998) reported similar down woody fuel loads elsewhere in the Sierra Nevada. In contrast, Kauffmann and Martin (1989) observed higher down woody fuel loads in the northern Sierra Nevada.
68	Knapp et al. 2005.	Southern Sierra Nevada	Fuels and fire behavior	B	7	More of the full fuel bed was consumed in fall burns than in spring burns. Spring burns may be beneficial when fuel loads are high because the erosion potential may be lower and more area is left in patches that can be recolonized by fire-sensitive species.	When fuel moisture is high, consumption of coarse woody debris is usually low because energy is needed to drive off excess moisture before consumption can occur (Brown et al. 1985). A modeling study by Hargrove et al. (2000) predicted

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							high patchiness with high fuel moisture levels. Similar levels of patchiness after fall burns were observed by Kilgore (1973). No other studies have reported similar findings for spring burns in the Sierra Nevada.
69	Knapp, E.E.; Keeley, J.E. 2006. Heterogeneity in fire severity within early season and late season prescribed burns in a mixed-conifer forest. International Journal of Wildland Fire. 15(1): 37–45.	Southern Sierra Nevada	Fuels and fire behavior	B	6	Despite high fuel loading and continuity in current stands owing to decades of fire suppression, prescribed fire can still create forest heterogeneity similar to wildfire. Factors that influence patchiness in fire effects include slope, live tree basal area, density of pine, percentage cover of bare ground and rock, smaller diameter surface woody fuel, and fuel moisture.	Although Slocum et al. (2003) also reported high burn patchiness with higher fuel moisture, no other study has described heterogeneity in prescribed fire effects in forest systems, nor has other work identified causal factors.
70	van Mantgem, P.J.; Schwilk, D.W. 2009. Negligible influence of spatial autocorrelation in the assessment of fire effects in a mixed conifer forest. Fire Ecology. 5(2): 116–125.	Southern Sierra Nevada	Fuels and fire behavior	B	2	Quantification of large-scale fire effects can be hampered by autocorrelation in small-scale samples, causing problems when results are extrapolated to larger scales. Certain measures of forest conditions lack autocorrelation.	Potential effects of autocorrelation should be routinely checked in ecological studies (Legendre and Legendre 1998).
70	van Mantgem and Schwilk 2009.	Southern Sierra Nevada	Fuels and fire behavior	B	6	If high patch variability is common, prefire treatments to increase heterogeneity will likely be unnecessary.	No other studies have reported similar findings.
71	Hamman, S.T.; Burke, I.C.; Knapp, E.E. 2008. Soil nutrients and microbial activity after early and late season prescribed burns in a Sierra Nevada mixed conifer forest. Forest Ecology and Management. 256(3): 367–374.	Southern Sierra Nevada	Soils	B	2	Late-season burns had greater effects on soil abiotic conditions, mineral soil carbon levels, total inorganic nitrogen, and microbial activity compared to early season	Other studies have reported an intermediate response to early-season burns compared with late-season burns.

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						burns. Total soil nitrogen pools, fluxes, and soil respiration rates were not affected by burn season. Fire severity had the greatest impact on soil variables.	Variation in responses by burning season was attributed to greater fuel consumption and fire intensity during late-season burns. (Ferrenberg et al. 2006, Knapp et al. 2007, Schwilk et al. 2006).
72	Monroe, M.E.; Converse, S.J. 2006. The effects of early season and late season prescribed fires on small mammals in a Sierra Nevada mixed conifer forest. Forest Ecology and Management. 236(2-3): 229–240.	Southern Sierra Nevada	Vertebrates	B	2	Despite profound changes in microhabitat features after burning (e.g., decreased coarse woody debris and increased bare mineral soil), burning did not adversely affect small mammal populations. Season of burn did not affect deer mouse densities or age ratios, lodgepole chipmunk densities, or total small mammal biomass, suggesting that neither burning in general nor early season burns will adversely influence native small mammal populations.	More substantial prescribed fire effects on deer mouse populations have been reported (Fisher and Wilkinson 2005, Jones 1992, Kaufman et al. 1990).
72	Monroe and Converse 2006.	Southern Sierra Nevada	Vertebrates	B	5	Interannual variation in small mammal populations explained most of the variability in model results.	Interannual variation in deer mouse populations may be caused by seed masting events, predation, or competition (Brady and Slade 2004, Pearce and Venier 2005, Wolff 1996).
73	Ferrenberg, S.M.; Schwilk, D.W.; Knapp, E.E.; Groth, E.; Keeley, J.E. 2006. Fire decreases arthropod abundance but increases diversity: early and late season prescribed fire effects in a Sierra Nevada mixed-conifer forest. Fire Ecology. 2(2): 79–102.	Southern Sierra Nevada	Invertebrates	B	2	Arthropod community structure was not affected by burn season but was affected by differences in fuel loading and vegetation and habitat heterogeneity because of burning.	Hanula and Wade (2003) reported a decrease in diversity after multiple burns.

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73	Ferrenberg et al. 2006.	Southern Sierra Nevada	Invertebrates	B	2, 5, 6	Arthropod abundance was lower and diversity was higher after burn treatments than before treatments. A mosaic of habitats created by burns may have a positive effect on arthropod diversity. All burns altered the feeding guild structure of the arthropod communities.	Apigian et al. (2006) reported that burning forest increased arthropod diversity by favoring previously rare species and decreasing the abundance of more common species. Forest arthropod diversity declined after fire because of a loss of optimal habitat (Okland et al. 1996, Yanovsky and Kiselev 1996, York 2000), whereas fire may be important in creating diverse habitat mosaics that result in a benefit to various arthropods and feeding guilds (Buddle et al. 2000, Gandhi et al. 2001, Moretti et al. 2004).
74	Schwilk, D.W.; Knapp, E.E.; Ferrenberg, S.M.; Keeley, J.E.; Caprio, A.C. 2006. Tree mortality from fire and bark beetles following early and late season prescribed fires in a Sierra Nevada mixed-conifer forest. Forest Ecology and Management. 232(1–3): 36–45.	Southern Sierra Nevada	Bark beetles	B	2	Tree mortality (all tree species) or bark beetle attack on pines did not differ between early- and late-season burns.	Similar mortality rates were reported by Thies et al. (2005). Fettig et al. (2010) reported no difference in tree mortality rates attributed to bark beetles after early- and late-season burns.
74	Schwilk et al. 2006.	Southern Sierra Nevada	Bark beetles	B	2	The probability of bark beetle attack on firs (*Abies* spp.) was greater after an early-season burn.	Fire effects may be more severe in early season burns compared to late-season burns (Harrington 1987, 1993; McHugh et al. 2003; Swezy and Agee 1991).

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74	Schwilk et al. 2006.	Southern Sierra Nevada	Bark beetles	B	2	Tree mortality, especially in the smallest tree size class, was related to fire intensity.	Mortality after fire may not return to background rates for 5 or more years (Mutch and Parsons 1998, van Mantgem et al. 2003).
75	Converse, S.J.; Dickson, B.G.; White, G.C.; Block, W.M. 2004. Estimating small mammal abundance on fuels treatment units in southwestern ponderosa pine forests. In: van Riper, C., III; Cole, K.L., eds. The Colorado Plateau: cultural, biological, and physical research. Tucson, AZ: University of Arizona Press: 113–120.	Southwestern Plateau	Vertebrates	M	2, 3	Protocols for estimating small mammal abundance within the program MARK were enhanced by using robust estimates rather than indices of population size and increased trapping efforts on a grid.	No other studies have reported similar findings.
76	Converse, S.J. 2005. Small mammal responses to forest restoration and fuel reduction. Fort Collins, CO: Colorado State University. 231 p. Ph.D. dissertation.	Southwestern Plateau	Vertebrates	M	2, 3	Findings for this dissertation can be found in paper No. 77.	
77	Converse, S.J.; White, G.C.; Block, W.M. 2006b. Small mammal responses to thinning and wildfire in ponderosa pine-dominated forests of the southwestern United States. Journal of Wildlife Management. 70(6): 1711–1722.	Southwestern Plateau	Vertebrates	M	2, 3	Wildfire produced a positive response in deer mice and an unpredicted negative response for least chipmunks.	Positive responses of deer mice to both prescribed fire and wildfire are well documented (Ahlgren 1966, Bock and Bock 1983, Krefting and Ahlgren 1974, Kyle and Block 2000, Martell 1984, Tester 1965).
77	Converse et al. 2006b.	Southwestern Plateau	Vertebrates	M	2, 3	Thinning of stands composed of small, closely spaced trees may result in the greatest short-term response of deer mice and chipmunks.	Deer mice usually respond positively to thinning (Carey and Wilson 2001, Suzuki and Hayes 2003, Wilson and Carey 2000). Chipmunk species also are known to respond positively to thinning (Carey 2000, 2001; Carey and Wilson 2001; Hadley and Wilson 2004; Sullivan et al. 2001; Wilson and Carey 2000).

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78	Hurteau, S.; Sisk, T.; Dickson, B.; Block, W. 2010. Variability in nest density, occupancy, and home range size of western bluebirds after forest treatments. Forest Science. 56(1): 131–138.	Southwestern Plateau	Vertebrates	B, M, M+B	1, 2	Western bluebird home range sizes were larger after burn treatments than other treatments. In contrast, home range sizes were 1.5 times larger after thinning and 30 percent smaller after the combined mechanical + burn treatment.	No other studies have reported similar findings. Restoration-based thinning and burning treatments that decreased ponderosa pine density and increased herbaceous cover and bare ground also increased invertebrate abundance and diversity, and may increase habitat quality for cavity-nesting birds (Germaine and Germaine 2002, Wightman and Germain 2006).
78	Hurteau et al. 2010.	Southwestern Plateau	Vertebrates	B, M, M+B	1, 2	Western bluebird nest density was higher after fuel reduction treatments even though treatments reduced snags.	Horton and Mannan (1988) reported that a reduced number of snags led to increased nest occurrence.
79	Rebbeck, J.; Long, R.; Yaussy, D. 2004. Survival of hardwood seedlings and saplings following overstory thinning and prescribed fires in mixed-oak forests of southern Ohio. Gen. Tech. Rep. SRS-GTR-73. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 275–284.	Central Appalachian Plateau	Overstory vegetation	B, M, M+B	1, 2	Sapling and seedling mortality were higher after mechanical + burn treatments than other treatments.	No other studies have reported similar findings.
79	Rebbeck et al. 2004.	Central Appalachian Plateau	Overstory vegetation	B, M, M+B	1, 3	Hardwood seedling survival, 4 months after fuel reduction treatments, ranged from 87 percent after thinning to 20 percent after burning.	No other studies have reported similar findings.
80	Yaussy, D.A.; Dickinson, M.B.; Bova, A.S. 2004. Prescribed surface-fire tree mortality in southern Ohio: equations based on thermocouple probe	Central Appalachian Plateau	Overstory vegetation	B	1, 3	Equations for bark thickness and crown volume, including bole locations below 1.37 m in height,	Hengst and Dawson (1994) and Hilt et al. (1983) developed bark

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	temperatures. In: Yaussy, D.A.; Hix, D.M.; Long, R.P.; Goebel, P.C., eds. Proceedings, 14th central hardwood forest conference. Gen. Tech. Rep. GTR-NE-316. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station: 67–75					were developed for 13 hardwood species to predict the ability of a tree to survive the heat during a fire. Equations link tree death with fire behavior and thermocouple data.	thickness equations for tree species in the central hardwoods region based on diameter outside bark at 1.37 m in height.
81	Albrecht, M.A.; McCarthy, B.C. 2006. Effects of prescribed fire and thinning on tree recruitment patterns in central hardwood forests. Forest Ecology and Management. 226(1–3): 88–103.	Central Appalachian Plateau	Overstory vegetation	B, M+B	1, 2	Burning treatments initially increased seedling densities and shifted tree regeneration dominance toward shade-intolerant tree species.	Shifts in dominance to early successional species beneath silvicultural openings also were reported by Jenkins and Parker (1998).
81	Albrecht and McCarthy 2006.	Central Appalachian Plateau	Overstory vegetation	B, M, M+B	1, 2, 3	Density of *Acer rubrum* (red maple) recovered to pretreatment levels four growing seasons after burn, mechanical, and mechanical + burn treatments. Density of *Quercus alba* (white oak) and *Q. prinus* (chestnut oak) seedlings declined, while density of *Q. velutina* (black oak) seedlings increased after treatments.	Arthur et al. (1998) and Swan (1970) reported a strong resprouting response from established *Acer rubrum* (red maple) after fire, although repeated surface fires are reported to reduce resprouting (Van Lear and Watt 1993).
81	Albrecht and McCarthy 2006.	Central Appalachian Plateau	Overstory vegetation	M, M+B	2	Four growing seasons after treatment, oak regeneration remained at a competitive disadvantage with high densities of early successional tree species present in xeric and intermediate portions of thinned stands.	Similar dynamics in tree species composition were reported after fire in closed-canopy oak forests (Arthur et al. 1998, Kuddes-Fischer and Arthur 2002) and forests where fire occurred immediately before or following thinning treatments (Franklin et al. 2003, Johnson 1974, McGee et al. 1995, Van Lear

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Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
							and Waldrop 1989, Wendel and Smith 1986). In contrast, oak regeneration has responded positively to a surface fire when stands were thinned several years before burning (Brose and Van Lear 1998, Kruger and Reich 1997).
82	Joesting, H.M.; McCarthy, B.C.; Brown, K.J. 2007. The photosynthetic response of American chestnut seedlings to differing light conditions. Canadian Journal of Forest Research. 37(9): 1714–1722.	Central Appalachian Plateau	Overstory vegetation	B, M, M+B	1, 2	The light compensation point, quantum efficiency, leaf mass per area, and leaf nitrogen concentration per unit leaf area (N^{area}) did not differ among treatments.	Increased leaf nitrogen concentration per unit leaf area (N^{area}) with more available light or decreased percentage of canopy closure was reported by Abrams and Mostoller (1995), Ellsworth and Reich (1992), Kubiske and Pregitzer (1996), Naidu and DeLucia (1998), and Wayne and Bazzaz (1993).
82	Joesting et al. 2007.	Central Appalachian Plateau	Overstory vegetation	M	2	American chestnut (*Castanea dentate*) seedlings reached light-saturating rates of photosynthesis after mechanical treatments at an irradiance level about 33 percent higher than seedlings in untreated stands.	Net photosynthesis rates increased with light availability in American chestnut (*Castanea dentate*) seedlings grown in pots at four levels of irradiance (Wang et al. 2006).
82	Joesting et al. 2007.	Central Appalachian Plateau	Overstory vegetation	M	2	American chestnut (*Castanea dentate*) seedlings had greater maximum rates of photosynthesis, dark respiration rate, and daily	Griffin (1989) found that some degree of canopy openness increased the survival of American

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
						carbon gain per seedling after the mechanical treatment than seedlings lacking mechanical treatment.	chestnut sprout clusters, and a relatively closed canopy resulted in an increase in sprout mortality.
83	Chiang, J.M.; Brown, K.J. 2007. Improving the budburst phenology subroutine in the forest carbon model PnET. Ecological Modeling. 205(3-4): 515–526.	Central Appalachian Plateau	Overstory vegetation	B, M, M+B	10	Plant phenology was an important variable in estimating ecosystem carbon balance, because it affected net annual primary production. Predicting budburst phenology for any given year is therefore important in modeling carbon production. Current carbon simulation models use growing degree days (GDD) to predict the date of budburst. In this work, GDD was a poor predictor of the date of budburst.	
84	Iverson, L.R.; Hutchinson, T.F.; Prasad, A.M.; Peters, M.P. 2008. Thinning, fire, and oak regeneration across a heterogeneous landscape in the eastern U.S: 7-year results. Forest Ecology and Management. 255(7): 3035–3050.	Central Appalachian Plateau	Overstory vegetation	M+B	2	Density of large oak (*Quercus* spp.) and hickory (*Carya* spp.) seedlings (50 to 140 cm in height) increased after mechanical + burn treatments. A second set of fires created additional landscape heterogeneity by causing additional tree mortality, and thus canopy openness, across the moisture gradient.	Hutchinson et al. (2005) reported that multiple fires without thinning did not stimulate oak (*Quercus* spp.) regeneration. In contrast, Dey and Hartman (2005) reported that oak and hickory (*Carya* spp.) were favored by multiple burns.
84	Iverson et al 2008.	Central Appalachian Plateau	Overstory vegetation	M+B	2	On dry or intermediate sites with at least 5,000 oak (*Quercus* spp.) and hickory (*Carya* spp.) seedlings per hectare, mechanical + burn treatments that left 8.5 to 19 percent canopy cover and included at least two burns promoted oak and hickory regeneration to be competitive over about 50 percent of the area. Under similar treatments on more mesic sites, however, little or no oak and hickory regeneration developed.	No other studies have reported similar findings.

Table 14—Principal citations of the national Fire and Fire Surrogate (FFS) study with their findings, by site, discipline, treatment, and theme, with supporting literature (treatment codes: B = burn, M = mechanical, M+B = mechanical + burn; theme codes: 1 = fire vs. surrogates, 2 = effect size, 3 = effect duration, 4 = regional, 5 = species adaptation, 6 = heterogeneity, 7 = tradeoffs, 8 = restoration, 9 = exotics, 10 = application) (continued)

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
84	Iverson et al 2008.	Central Appalachian Plateau	Overstory vegetation	B, M+B	2, 6	Advance regeneration of red maple (*Acer rubrum*) and American tuliptree (*Liriodendron tulipifera*), tree species that commonly compete with oak (*Quercus* spp.) and hickory (*Carya* spp.) seedlings, became abundant after the initial mechanical or burn treatments; however, a second burn reduced densities of the oak competitors.	Albrecht and McCarthy (2006) reported that oak (*Quercus* spp.) and hickory (*Carya* spp.) seedlings failed to respond to thinning and prescribed fire and suggested that additional fires would likely be necessary to reduce abundance and size of competitors.
85	Chiang, J.M.; McEwan, R.W.; Yaussy, D.A.; Brown, K.J. 2007. The effects of prescribed fire and silvicultural thinning on the aboveground carbon stocks and net primary production of overstory trees in an oak-hickory ecosystem in southern Ohio. Forest Ecology and Management. 255(5/6): 1584–1594.	Central Appalachian Plateau	Overstory vegetation	B, M+B	2	Burning increased the mortality rate of red maple (*Acer rubrum*) in the overstory, but oak (*Quercus* spp.) mortality also increased after the burn treatments. Stem growth measurements suggested that burns coincided with the initiation of growth in oaks, which may have created vulnerability in these species.	No other studies have reported similar findings.
85	Chiang et al. 2007.	Central Appalachian Plateau	Overstory vegetation	M, M+B	2, 3	Mechanical treatments removed about 30 percent of the aboveground biomass and increased recruitment of red maple (*Acer rubrum*) but had little effect on oak (*Quercus* spp.) recruitment. Aboveground net primary production declined briefly.	Recruitment of red maple (*A. rubrum*) and lack of oak (*Quercus* spp.) recruitment with thinning treatments was likely a result of insufficient oak advanced regeneration in the midstory (Abrams 1992, 1998; Hutchinson et al. 2005; McEwan et al. 2005).
86	Hutchinson, T.F.; Long, R.P.; Ford, R.D.; Sutherland, E.K. 2008. Fire history and the establishment of oaks and maples in second-growth forests. Canadian Journal of Forest Research. 38(5): 1184–1198.	Central Appalachian Plateau	Overstory vegetation	B	1	Dendrochronology was used to examine stand dynamics and past disturbances. The current overstory was the result of stand initiation	Evidence that fire was a frequent disturbance event in the central oak (*Quercus* spp.)

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						that occurred between about 1845 and 1900. Little oak (*Quercus* spp.) recruitment has occurred since about 1925. Twenty-six fires were documented from 1870 to 1933; thereafter, only two fires were identified.	hardwood region prior to organized fire control and it occurred in the dormant season was reported from other dendrochronological studies including McEwan et al. (2007), Shumway et al. (2001), and Sutherland (1997).
86	Hutchinson et al. 2008.	Central Appalachian Plateau	Overstory vegetation	B, M+B	2	Most red maples (*Acer rubrum*) established after the cessation of fires. In several units, the last major fire was followed immediately by a large pulse of red maple establishment and the cessation of oak (*Quercus* spp.) recruitment.	No other studies have reported similar findings.
87	Giuliani, R.; Brown, K.J. 2008. Within-canopy sampling of global irradiance to describe downwelling light distribution and infer canopy stratification in a broadleaf forest. Tree Physiology. 28(9): 1407–1419.	Central Appalachian Plateau	Overstory vegetation	M	10	Vertical photosynthetic photon flux sampling in broadleaf forests after mechanical treatments and in the undisturbed top canopy did not adequately represent the shaded and penumbral values. The reliability and sensitivity of the inversion of the Monsi-Saeki method (an exponential model) were sufficient to capture canopy structural differences in mechanically treated and untreated stands. This new canopy sampling and data analysis procedure may provide a fast, reliable, and inexpensive method to characterize tree crown structure and to predict plant growth and forest dynamics, and could be applied whenever vegetation absorbed radiation is a main driving force for forest canopy processes.	This finding is consistent with Parker et al. (2002).

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Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
88	Chiang, J.M.; Brown, K.J. 2010. The effects of thinning and burning treatments on within-canopy variation of leaf traits in hardwood forests of southern Ohio. Forest Ecology and Management. 260(6): 1065–1075.	Central Appalachian Plateau	Overstory vegetation	B, M, M+B	1	Leaf mass area (LMA) increased in the lower canopy after both mechanical and burn treatments, but no treatments affected LMA in the upper canopy. Similar fuel reduction treatments may affect forest net primary productivity.	No other studies have reported similar findings.
89	Huang, J.; Boerner, R.E.J. 2007. Effects of fire alone or combined with thinning on tissue nutrient concentrations and nutrient resorption in *Desmodium nudiflorum*. Oecologia. 153(2): 233–243.	Central Appalachian Plateau	Understory vegetation	B, M+B	2	Plant nutrient resorption was unaffected by burn or mechanical + burn treatments.	Similar results were reported by Boerner et al. (1988), while Latty et al. (2004) found different results.
89	Huang and Boerner 2007.	Central Appalachian Plateau	Understory vegetation	B, M+B	2, 3	Soil nitrogen and phosphorus availability was reduced both in the short- and long-term at least 3 years) by both burn and mechanical + burn treatments.	Soil nutrient pools were often reduced over the long term by fire (Monleon et al. 1997, Vance and Henderson 1984).
89	Huang and Boerner 2007.	Central Appalachian Plateau	Understory vegetation	B, M+B	2, 3	Foliar nutrient concentration, measured at 2 months and 4 years after treatment, declined after burn and mechanical + burn treatments.	Other work has shown that fires either increased or had no effect on foliar nutrient concentrations (Adams and Rieske 2003, Christensen 1997, Gilliam 1988, Kruger and Reich 1997, Reich et al. 1990).
90	Huang, J. 2007. Ecological responses of two forest understory herbs to changes in resources caused by prescribed fire alone or in combination with restoration thinning. Columbus, OH: Ohio State University. 191 p. Ph.D. dissertation.	Central Appalachian Plateau	Understory vegetation	B, M+B	1, 3	Understory light availability and soil nutrient availability shortly after burn or mechanical + burn treatments were the most important environmental drivers of ecological conditions for the forb ticktrefoil (*Desmodium nudiflorum*) and Bosc's panicgrass (*Dichanthelium boscii* [*Panicum boscii*]).	Lambers et al. (1998) also documented a link between light levels and specific leaf area. The direct, positive response of leaf nutrient content on maximum leaf photosynthetic capacity has been elsewhere (Evans 1989, Field and Mooney 1986, Reich et al. 1994).

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
90	Huang 2007.	Central Appalachian Plateau	Understory vegetation	B, M+B	2	Plant biomass, leaf mass ratio, individual seed mass, and total seed production increased in the first growing season after a second burn as part of the mechanical + burn treatment in ticktrefoil (*Desmodium nudiflorum*), while specific leaf area and plant height decreased. There were no changes to leaf area ratio and seed germination rate.	Other work has reported a lack of treatment effect on seed production (Werner and Platt 1976).
90	Huang 2007.	Central Appalachian Plateau	Understory vegetation	M+B	2	Individual plants of ticktrefoil (*Desmodium nudiflorum*) were 62 percent larger after the mechanical + burn treatment during the fourth growing season after the first burn than were plants where no fuel reduction was conducted. Mechanical + burn treatments also decreased root mass ratio and increased leaf mass ratio and specific root length.	No other studies have reported similar findings.
90	Huang 2007.	Central Appalachian Plateau	Understory vegetation	B, M+B	2, 3	Short-term nutrient levels and ramet biomass increased in Bosc's panicgrass (*Dichanthelium boscii* [*Panicum boscii*]) after mechanical and mechanical + burn treatments. Nutrient levels and ramet biomass declined with time since treatment.	Marino et al. (1997) also reported increased number of leaves per ramet after increasing light.
90	Huang 2007.	Central Appalachian Plateau	Understory vegetation	B, M+B	2, 3	Specific leaf area of ticktrefoil (*Desmodium nudiflorum*) declined in the fourth growing season after the first burn treatments.	Specific leaf area of oak (*Quercus* spp.) increased or remained unchanged after fire (Boerner et al. 1988, Reich et al. 1990).
91	Phillips, R.; Hutchinson, T.; Brudnak, L.; Waldrop T. 2007. Fire and fire surrogate treatments in mixed-oak forests: effects on herbaceous layer vegetation. In: Butler, B.W.; Cook, W., comps. Proceedings, the fire environment—innovations, management, and policy. RMRS-P-46CD. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 475–485.	Regional	Understory vegetation	B, M+B	1, 2	At the Central Appalachian Plateau site, herbaceous cover and plant species richness increased more after burn treatments than other treatments, indicating fire effects were unique disturbances that were not mimicked by alterations of the forest structure alone.	No other studies have reported similar findings.

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Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
91	Phillips et al. 2007.	Regional	Understory vegetation	B	2	Herbaceous layers did not respond to burn-only treatments at the Southern Appalachian Mountain site.	A single low-intensity fire resulted in little differences in herbaceous and shrub cover after 4 years (Kuddes-Fischer and Arthur 2002).
91	Phillips et al. 2007.	Regional	Understory vegetation	M+B	2	Plant species cover and richness increased after mechanical + burn treatments at the Southern Appalachian Mountains site.	No other studies have reported similar findings.
92	Huang, J.; Boerner, R.E.J.; Rebbeck, J. 2007. Ecophysiological responses of two herbaceous species to prescribed burning, alone or in combination with overstory thinning. American Journal of Botany. 94(5): 755–763.	Central Appalachian Plateau	Understory vegetation	B, M+B	1, 2	Photosynthetic performance, plant biomass, seed number, and mean seed mass of two understory plants, ticktrefoil (*Desmodium nudiflorum*) and Bosc's panicgrass (*Dichanthelium boscii* [*Panicum boscii*]) increased after burn and mechanical + burn treatments. Photosynthetic performance and plant biomass response was greatest after mechanical + burn treatments.	Enhanced leaf photosynthesis in oak (*Quercus* spp.) seedlings after fire was reported by Reich et al. (1990).
92	Huang et al. 2007.	Central Appalachian Plateau	Understory vegetation	B, M, M+B	2, 8	Ticktrefoil (*Desmodium nudiflorum*) responded more to the restoration treatments than did Bosc's panicgrass (*Dichanthelium boscii* [*Panicum boscii*]), thus ticktrefoil was more plastic to changes in the light environment than Bosc's panicgrass.	No other studies have reported similar findings.
93	Huang, J.; Boerner, R.E.J. 2008. Shifts in morphological traits, seed production, and early establishment of *Desmodium nudiflorum* following prescribed fire, alone or in combination with forest canopy thinning. Botany. 86(4): 376–384.	Central Appalachian Plateau	Understory vegetation	B, M+B	1, 2	Total biomass, seed size and seed production, and thus overall fitness of ticktrefoil (*Desmodium nudiflorum*) was enhanced with burn and especially mechanical + burn treatments.	Werner and Platt (1976) reported that plants growing on manipulated sites produced smaller and less numerous seeds. Reproductive output of herbaceous plant species increased after fire (Wrobleski and Kauffman 2003).

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
93	Huang and Boerner 2008.	Central Appalachian Plateau	Understory vegetation	B, M+B	1, 2	Leaf area ratio and seedling establishment remained unchanged after burn and thin + burn treatments.	No other studies have reported similar findings.
94	Yaussy, D.; Rebbeck, J.; Iverson, L.; Hutchinson, T.; Long, R. 2003. Comparison of a low-tech vs. a high-tech method to evaluate surface fire temperatures. In: Van Sambeek, J.W.; Dawson, J.O.; Ponder, F., Jr.; Loewenstein, E.F.; Fralish, J.S., eds. Proceedings, 13th central hardwood forest conference. Gen. Tech. Rep. NC-234. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station: 295.	Central Appalachian Plateau	Fuels and fire behavior	B	1	Maximum temperatures recorded by thermocouples and temperature-sensitive paints, used to monitor spatial and temporal characteristics of landscape-scale burns, were highly correlated.	Previous studies have used temperature-sensitive paints as a surrogate for fire intensity (Abrahamson and Abrahamson 1996, Cole et al. 1992, Franklin et al. 1997, Gibson et al. 1990). Heyward (1938), Miller et al. (1955), and Sackett and Haase (1992) used electronic thermocouples to measure soil temperatures during fires.
95	Iverson, L.R.; Yaussy, D.; Rebbeck, J.; Hutchinson, T.; Long, R.; McCarthy, B.; Riccardi, C.; Prasad, A. 2003. Spatial and temporal distribution of fire temperatures from prescribed fires in the mixed oak forests of southern Ohio. In: Van Sambeek, J.W.; Dawson, J.O.; Ponder, F., Jr.; Loewenstein, E.F.; Fralish, J.S., eds. Proceedings, 13th central hardwood forest conference. Gen. Tech. Rep. NC-234. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station: 293–294.	Central Appalachian Plateau	Fuels and fire behavior	B, M+B	1, 2	Simulations indicated that fires were generally cooler with a slower rate of spread in valleys, with hotter, faster fires on higher ground.	No other studies have reported similar findings.
95	Iverson et al. 2003.	Central Appalachian Plateau	Fuels and fire behavior	B, M+B	1, 2	Mixed oak (*Quercus* spp.) stands burned cooler in the mechanical + burn treatments than stands in the burn-only treatment units. Additional slash resulting from the thinning may not have dried sufficiently to increase fire intensity and thus inhibited movement of flames.	No other studies have reported similar findings.

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Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
96	Iverson, L.R.; Prasad, A.M.; Hutchinson, T.F.; Rebbeck, J.; Yaussy, D.A. 2004. Fire and thinning in an Ohio oak forest: grid-based analyses of fire behavior, environmental conditions, and tree regeneration across a topographic moisture gradient. In: Spetich, M.A. Proceedings, upland oak ecology symposium: history, current conditions, and sustainability. Gen. Tech. Rep. SRS-73. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 190–197.	Central Appalachian Plateau	Fuels and fire behavior	B, M+B	1, 2	The integrated moisture index (IMI), a geographic information system-derived index categorizing landscapes into three moisture regimes, was related to many of the measured variables: Sites modeled as topographically wetter had more soil moisture, lower fire and seasonal soil temperatures, less light penetration, and less oak and hickory regeneration.	No other studies have reported similar findings.
96	Iverson et al. 2004.	Central Appalachian Plateau	Fuels and fire behavior	M+B	2	Light, soil moisture, and growing season soil temperature were greater after mechanical + burn treatments than untreated sites in mixed-oak (*Quercus* spp.) forests. These environmental changes had no short-term effect on oak and hickory (*Carya* spp.) regeneration.	No other studies have reported similar findings.
97	Iverson, L.R.; Yaussy, D.A.; Rebbeck, J.; Hutchinson, T.F.; Long, R.P.; Prasad, A.M. 2004. A comparison of thermocouples and temperature paints to monitor spatial and temporal characteristics of landscape-scale prescribed fires. International Journal of Wildland Fire. 13(3): 311–322.	Central Appalachian Plateau	Fuels and fire behavior	B	1	Maximum temperatures recorded by thermocouples and temperature-sensitive paints, used to monitor spatial and temporal characteristics of landscape-scale burns, were highly correlated.	Previous studies used temperature-sensitive paints as a surrogate for fire intensity (Abrahamson and Abrahamson 1996, Cole et al. 1992, Franklin et al. 1997, Gibson et al. 1990). Heyward (1938), Miller et al. (1955), and Sackett and Haase (1992) used electronic thermocouples to measure soil temperatures during fires.
97	Iverson et al. 2004.	Central Appalachian Plateau	Fuels and fire behavior	B	1	Electronic thermocouples coupled with data loggers provided more information for assessing fire behavior than temperature-sensitive paints.	No other studies have reported similar findings.

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
98	Graham, J.B.; McCarthy, B.C. 2006. Forest floor fuel dynamics in mixed-oak forests of south-eastern Ohio. International Journal of Wildland Fire. 15(4): 479–488.	Central Appalachian Plateau	Fuels and fire behavior	B, M+B	2	Litter depth declined with burn treatments, duff depth increased after mechanical treatments, and duff depth was lower after mechanical + burn treatments.	Similar reductions in litter were reported by Elliot and Vose (2005).
98	Graham and McCarthy 2006.	Central Appalachian Plateau	Fuels and fire behavior	M, M+B	2, 3	Forest floor fuel dynamics varied over time; changes in large, sound fuels (1,000-hour time-lag fuels) and coarse woody debris persisted longer than changes to fine fuels (litter, duff, 1-hour, 10-hour, and 100–hour time-lag fuels) or large, unsound fuels.	Similar values for fine and large woody fuels were reported by McCarthy and Bailey (1994) and Smith and Heath (2002).
99	Boerner, R.E.J.; Brinkman, J.A. 2004. Spatial, temporal, and restoration treatment effects on soil resources in mixed-oak forests of southeastern Ohio. Yaussy, D.A.; Hix, D.M.; Long, R.P.; Goebel, P.C., eds. Proceedings, 14th central hardwood forest conference. Gen. Tech. Rep. GTR-NE-316. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station: 241–254.	Central Appalachian Plateau	Soils	M+B	1, 2	Available phosphorus and soil pH increased after some but not all mechanical + burn treatments as a result of differences in fire behavior. Patchiness in pH increased and patchiness in available phosphorus decreased after mechanical + burn treatments while nitrogen mineralization rates were unchanged.	A similar increase in pH was observed in nearby watersheds (Boerner et al. 2004). A similar lack of change in nitrogen mineralization rates was reported nearby (Boerner et al. 2004), but other work documented an increase in nitrogen availability after fire or fire plus cutting activity (Wagle and Kitchen 1972, Webb et al. 1991).
99	Boerner and Brinkman 2004.	Central Appalachian Plateau	Soils	B, M, M+B	1, 6	Mean soil properties varied more between study sites separated by many kilometers than between neighboring watersheds.	Similar scale-dependent variation has been reported (Boerner et al. 2003, 2004; Boerner and Brinkman 2003).
100	Boerner, R.E.J.; Brinkman, J.A.; Smith, A. 2005. Seasonal variations in enzyme activity and organic carbon in soil of a burned and unburned hardwood forest. Soil Biology and Biochemistry. 37(8): 1419–1426.	Central Appalachian Plateau	Soils	B, M+B	2	Non-metric multidimensional scaling ordination resulted in no clear separation of burned and unburned sample areas based on soil organic carbon and enzyme	No other studies have reported similar findings.

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Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
						activity. When soil activity was limited to late summer and early autumn, burned and unburned areas were separated on the basis of differences in soil organic carbon and L-glutaminase activity.	
100	Boerner et al. 2005.	Central Appalachian Plateau	Soils	B, M+B	2	Soil enzyme activity did not differ among sample dates in except L-glutaminase, which demonstrated a distinct maximum activity in spring.	Season variations in L-glutaminase were reported by Ratsin et al. (1998).
101	Boerner, R.E.J.; Brinkman, J.A.; Yaussy, D.A. 2007. Ecosystem restoration treatments affect soil physical and chemical properties in Appalachian mixed-oak forests. In: Buckley, D.S.; Clatterbuck, W.S., eds. Proceedings, 15th central hardwood forest conference. e-Gen. Tech. Rep. SRS-101. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 107–115.	Central Appalachian Plateau	Soils	B, M, M+B	1, 2	Soil compaction was not affected by any fuel reduction treatment.	Soil bulk density did not change after vegetation treatments in mixed-oak (*Quercus* spp.) forests (Matson and Vitousek 1981). Soil compaction after harvesting practices was reported by Berger et al. (2004) and Rummer et al. (1997).
101	Boerner et al. 2007.	Central Appalachian Plateau	Soils	B, M+B	2, 3	Soil pH increased, phosphorus availability decreased, and available calcium, potassium, and aluminum were unaffected for the first 3 years after burn treatments.	Soil pH increased after single fires (Blankenship and Arthur 1999) and after multiple fires (Boerner et al. 2004, Eivazi and Bayan 1996) in mixed-oak (*Quercus* spp.) forests.
102	Giai, C.; Boerner, R.E.J. 2007. Effects of ecological restoration on microbial activity, microbial functional diversity, and soil organic matter in mixed-oak forests of southern Ohio, USA. Applied Soil Ecology. 35(2): 281–290.	Central Appalachian Plateau	Soils	B, M, M+B	1, 2	Acid phosphatase activity increased after mechanical treatments remained unchanged after burn and mechanical + burn treatments.	Similar results were reported for other ecosystems (Boerner et al. 2007).
102	Giai and Boerner 2007.	Central Appalachian Plateau	Soils	B, M, M+B	1, 2	Chitinase activity and substrates used by either soil fungi or soil bacteria did not differ among	No other studies have reported similar findings.

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						treatments, while phenol oxidase varied among sites. Total substrate use by bacteria was greater after burn and mechanical + burn treatments than mechanical-only treatments.	
103	Miesel, J.R. 2009. Restoring mixed-conifer forests with fire and mechanical thinning: effects on soil properties and mature conifer foliage. Columbus, OH: Ohio State University. 209 p. Ph.D. dissertation.	Central Appalachian Plateau	Soils	B, M, M+B	1, 2	Findings for this dissertation can be found in papers Nos. 48, 50 and 177.	
104	Streby, H.M.; Miles, D.B. 2010. Assessing ecosystem restoration alternatives in eastern deciduous hardwood forests using avian nest survival. Open Environmental Sciences. 4: 31–40.	Central Appalachian Plateau	Vertebrates	B, M, M+B	1	Nest success of shrub-nesting avian species increased after mechanical treatments.	Lower nesting success of ground- and shrub-nesting species in burned stands was reported by Sperry et al. (2008).
104	Streby and Miles 2010.	Central Appalachian Plateau	Vertebrates	B, M, M+B	1	Nest success of understory nesting species increased after mechanical + burn treatments but not after burn or mechanical treatments.	Others have reported that nest success was poorly related to specific treatments (Artman and Downhower 2003, Duguay et al. 2001, Robinson and Robinson 2001).
105	Riccardi, C.L.; McCarthy, B.C.; Long, R.P. 2004. Oak seed production, weevil (Coleoptera: Curculionidae) populations, and predation rates in mixed-oak forests of southeast Ohio. In: Yaussy, D.A.; Hix, D.M.; Long, R.P.; Goebel, P.C., eds. Proceedings, 14th central hardwood forest conference. Gen. Tech. Rep. NE-316. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station: 10–20.	Central Appalachian Plateau	Invertebrates	B, M+B	2	Sound oak (*Quercus* spp.) acorn numbers, representing the lowest acorn weevil depredation, were greater after burning treatments. Both burn and mechanical + burn treatments increased seed production and decreased acorn weevil predation rates.	No other studies have reported similar findings. Wright (1986) found evidence of prescribed fire controlling acorn weevils.
105	Riccardi et al. 2004.	Central Appalachian Plateau	Invertebrates	M+B	2	Oak (*Quercus* spp.) species produced more acorns after mechanical + burn treatments than other treatments.	Healy et al. (1999) and McCarthy and Quinn (1989) suggested that seed production is influenced more by individual tree and annual variation than by thinning.

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Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
106	Lombardo, J.A.; McCarthy, B.C. 2008. Forest management and curculionid weevil diversity in mixed oak forests of southeastern Ohio. Natural Areas Journal. 28(4): 363–369.	Central Appalachian Plateau	Invertebrates	B, M, M+B	1, 2	Acorn weevil diversity increased after fuel reduction treatments. Neither overall abundance nor the abundance of the two major acorn infesting weevil genera was affected by treatments.	Moretti et al. (2004) reported that burning did not change the abundance of Curculionids although species richness declined. Bellocq et al. (2005) reported that thinning did not affect acorn predation by insects.
107	Giai, C. 2009. Fire, exotic earthworms and plant litter decomposition in the landscape context. Columbus, OH: Ohio State University. 151 p. Ph.D. dissertation.	Central Appalachian Plateau	Invertebrates	B, M, M+B	3	Soil-nutrient dynamics and microbial communities differed more by site characteristics and landscape position than by short-term fuel reduction treatment effects.	The role of spatial heterogeneity in soils was reported by Dolan (2002).
108	McQuattie, C.J.; Rebbeck, J.; Yaussy, D.A. 2004. Effects of fire and thinning on growth, mycorrhizal colonization, and leaf anatomy of black oak and red maple seedlings. In: Yaussy, D.A.; Hix, D.M.; Long, R.P.; Goebel, P.C., eds. Proceedings, 14th central hardwood forest conference. Gen. Tech. Rep. GTR-NE-316. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station: 200–208.	Central Appalachian Plateau	Multivariate	M+B	1	Ectomycorrhizal structures were the dominant form of fungal colonization on oak (*Quercus* spp.) roots. Endomycorrhizal structures were observed in June after mechanical + burn treatments. Endomycorrhizal colonization of maple (*Acer* spp.) roots was not affected by treatments.	Similar levels of endomycorrhizal colonization were reported for sugar maple (*Acer saccharum*) (Cooke et al. 1992, DeBellis et al. 2002, Klironomos 1995).
108	McQuattie et al. 2004.	Central Appalachian Plateau	Multivariate	B, M, M+B	1, 2	Oak (*Quercus* spp.) leaf thickness increased after burn, mechanical, and mechanical + burn treatments. Oak leaf blade thickness and starch grains in chloroplasts, measured in August, were greater after mechanical and mechanical + burn treatments than after burn treatments.	Increased leaf blade thickness, attributed to increased mesophyll thickness, was reported by Ashton and Berlyn (1992) and Igboanugo (1992). Numerous starch grains in leaf chloroplasts due to high photosynthesis were reported by Ashon and Berlyn (1992).

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
109	Phillips, R.J.; Waldrop, T.A.; Chapman, G.L.; Mohr, H.H.; Callaham, M.A.; Flint, C.T. 2004. Effects of fuel-reduction techniques on vegetative composition of Piedmont loblolly-shortleaf pine communities: preliminary results of the National Fire and Fire Surrogate study. In: Connor, K.F., ed. Proceedings, 12th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 44–47.	Southeast Piedmont	Overstory vegetation	B	1, 2	Tree stem densities were reduced more with burn treatments than other treatments. Basal area was reduced the most with mechanical + burn treatments.	No other studies have reported similar findings.
109	Phillips et al. 2004.	Southeast Piedmont	Understory vegetation	B, M+B	1, 2	Burning caused distinct compositional shifts in the understory vegetation relative to unburned units.	Miller et al. (1999) and Scherer et al. (2000) reported similar shifts in understory vegetation after burns.
110	Phillips, R.J.; Waldrop, T.A. 2008. Changes in vegetation structure and composition in response to fuel reduction treatments in the South Carolina Piedmont. Forest Ecology and Management. 255(8/9): 3107–3116.	Southeast Piedmont	Understory Vegetation	B, M, M+B	1	Mechanical treatments failed to serve as surrogates for fire, as burning tended to favor species that preferred more xeric conditions, whereas thinning tended to favor more mesic hardwood species.	No other studies have reported similar findings.
110	Phillips and Waldrop 2008.	Southeast Piedmont	Understory vegetation	B, M, M+B	1, 2, 3	Burning treatments promoted more rapid changes in the understory compared to mechanical treatments, with forb and shrub cover increasing initially and grass cover increasing in the first 3 years after treatments were applied.	Sparks et al. (1998) and Wade et al. (1989) reported that burning increased the cover of herbaceous vegetation. Halpern (1988) predicted that thinning followed by burning would elicit a faster understory response than just thinning treatments. Zenner et al. (2006) showed that understory response was dependent on intensity of thinning.

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Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
110	Phillips and Waldrop 2008.	Southeast Piedmont	Understory vegetation	M	2, 3	Changes in overstory and understory structure after fuel reduction treatments were made more complex by a southern pine beetle outbreak that killed high numbers of trees after mechanical treatments and trees in untreated areas. Shifts in understory composition were moderated by retention of high proportions of hardwoods 3 years after mechanical treatments.	Shelton and Murphy (1997) and Miller et al. (1999) reported that understory response tended to be greater with greater reductions in hardwood cover.
111	Mohr, H.H.; Waldrop, T.A.; Rideout, S.; Phillips, R.J.; Flint, C.T. 2004. Effectiveness of fire and fire surrogate treatments for controlling wildfire behavior in Piedmont forests: a simulation study. In: Connor, K.F., ed. Proceedings, 12th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 71–73.	Southeast Piedmont	Fuels and fire behavior	B, M, M+B	1, 2	Using the program BehavePlus to model the behavior of a future fire, predicted values of flame heights were shorter, rates of spread were slower, and scorch heights was lower after burn treatments than after other treatments.	Andrews et al. (2002) predicted that flame heights would be highest for thinning and thinning plus burning treatments.
111	Mohr et al. 2004.	Southeast Piedmont	Fuels and fire behavior	M, M+B	2, 3	Using the program BehavePlus to model the behavior of a future fire, predicted values of fire intensity would increase in the first growing season after mechanical and mechanical + burn treatments.	No other studies have reported similar findings.
112	Waldrop, T.A.; Glass, D.W.; Rideout, S.; Shelburne, V.B.; Mohr, H.H.; Phillips, R.J. 2004. An evaluation of fuel-reduction treatments across a landscape gradient in the Piedmont forests: preliminary results of the National Fire and Fire Surrogate study. In: Connor, K.F., ed. Proceedings, 12th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 54–59.	Southeast Piedmont	Fuels and fire behavior	B, M, M+B	1, 2	Mass of forest floor and woody fuels were reduced by burn treatments, and slash fuels increased after mechanical treatments. These patterns varied with landscape position, with litter mass reduction occurring only on mesic sites after burns.	A basis for characterizing positions on the landscape that represent different soil-moisture classes, known as Landscape Ecosystem Classification System, was described by Jones (1991).

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
113	Mohr, H.H.; Waldrop, T.A. 2006. A simulation of wildfire behavior in Piedmont forests. In: Conner, K.F., ed. Proceedings, 13th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-92. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 507–509.	Southeast Piedmont	Fuels and fire behavior	B	2	Flame length and scorch height were predicted within the program BehavePlus2 to be lower without any fuel reduction treatment or after mechanical treatments, while windspeed was predicted to be higher, and thus move fire faster in untreated areas or after burn treatments.	Andrews et al. (2002) developed the BehavePlus2 wildfire modeling program.
114	Brudnak, L.; Waldrop, T.A.; Phillips, R.J. 2010. Use of a thermocouple-datalogger system to evaluate overstory mortality. In: Stanturf, J.A., ed. Proceedings, 14th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-121. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 515–517.	Southern Appalachian Mountains	Fuels and fire behavior	B	2	Flaming front temperature, heat duration, and postfire overstory tree mortality were assessed in oak (*Quercus* spp.) woodlands by using thermocouples. Duration and average flame temperature explained 43 percent of tree mortality after the burn, while total heat output explained 45 percent of variation in tree mortality after the second burn.	Jones et al. (2006) developed a model that accounted for rate-dependent features of temperature and heat duration and their relation to tree mortality. Loomis (1973) and Regelbrugge (1994) reported that most fire-induced mortality occurred within 2 years after burning.
115	Lione, D. 2002. Effects of prescribed burning and thinning as fuel reduction treatments on the soils of the Clemson Experimental Forest. Clemson, SC: Clemson University. 87 p. M.S. thesis.	Southeast Piedmont	Soils	M, M+B	1, 2, 3	Findings for this thesis can be found in paper No. 118.	
116	Callaham, M.A.; Anderson, P.H.; Waldrop, T.A.; Lione, D.J.; Shelburne, V.B. 2004. Litter decomposition and soil respiration responses to fuel-reduction treatments in Piedmont loblolly pine forests. In: Connor, K.F., ed. Proceedings, 12th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 25–29.	Southeast Piedmont	Soils	B, M, M+B	1	Carbon was lost at a similar rate in burn, mechanical, and mechanical + burn treatments. Nitrogen concentrations were highly variable after mechanical and burn treatments, whereas nitrogen concentrations were less variable over time in untreated stands. Soil respiration was reduced after burn treatments. One year after mechanical treatment, decomposition was slower (higher carbon:nitrogen ratio), suggesting that more carbon would be stored in the forest floor after mechanical treatments than in unmanaged stands.	Blair et al. (1992) demonstrated that nitrogen and other nutrients can move in and out of litter as conditions change and become more or less favorable for decomposing organisms. Lower respiration after burning, reported by (Singh and Gupta 1977), may be due to higher soil temperature and lower moisture.

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Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
117	Shelburne, V.B.; Boyle, M.F.; Lione, D.J.; Waldrop, T.A. 2004. Preliminary effects of prescribed burning and thinning as fuel reduction treatments on the Piedmont soils of the Clemson Experimental Forest. In: Connor, K.F., ed. Proceedings, 12th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 35–38.	Southeast Piedmont	Soils	B, M, M+B	1, 2	Mechanical and burn treatments were fundamentally different, and soil nutrient effects were the most pronounced after mechanical + burn treatments. Carbon:nitrogen ratios increased after mechanical + burn treatments, while soil bulk density increased after both mechanical and mechanical + burn treatments. Proportional nitrification, carbon:nitrogen ratio in the O horizon, and nitrogen in the A/Bt horizon decreased after burn-only treatments.	Froelich (1978) found that logging with heavy machinery causes soil compaction in the first few trips into a stand. Monleon et al. (1997) observed immediate decreases in mineralization after burning, but saw a return to pretreatment levels within one year. Grogan et al. (2000) found that volatilization caused short-term losses of nitrogen after fire.
118	Boerner, R.E.J.; Waldrop, T.A.; Shelburne, V.B. 2006. Wildfire mitigation strategies affect soil enzyme activity and soil organic carbon in loblolly pine (*Pinus taeda*) forests. Canadian Journal of Forest Research. 36(12): 3148–3154.	Southeast Piedmont	Soils	M, M+B	1, 2, 3	Soil organic carbon declined the first year after mechanical and mechanical + burn treatments, and the effect persisted for at least 4 years. Soil organic carbon was reduced only in the fourth year after burn treatments.	Carter et al. (2002) reported short-term losses of soil organic carbon after clearcut harvesting. Gholz and Fisher (1982) and Knoepp et al. (2004) reported declines in soil organic carbon after combinations of mechanical and burn treatments that involved more intense harvest practices. Repeated burns generally have had little impact on soil organic carbon (McKee 1982, Moehring et al. 1966, Richter et al. 1982). Wilson et al. (2002) reported that soil organic carbon varied more from landscape position than the effects of fire.

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
118	Boerner et al. 2006.	Southeast Piedmont	Soils	B, M, M+B	1, 7	If the management objective for these southern forests is timber production, thinning may be an appropriate practice because of rapid nutrient turnover rate, while burning may be more appropriate if the management objective is to store carbon in the soil.	No other studies have reported similar findings.
118	Boerner et al. 2006.	Southeast Piedmont	Soils	B, M+B	2, 3	Soil carbon:nitrogen ratio increased in the first year after burn and mechanical + burn treatments.	No other studies have reported similar findings.
118	Boerner et al. 2006.	Southeast Piedmont	Soils	B, M, M+B	2, 3	Microbial activity, measured as soil enzyme activity, increased the fourth year after mechanical treatments with a more subtle increase in the first year.	No other studies have reported similar findings. Boerner et al. (2000) and Boerner and Brinkman (2003) reported contrasting results from oak (*Quercus* spp.) forests.
119	Kilpatrick, E.S. 2002. The effects of prescribed burning and thinning as fuel reduction treatments on herpetofauna in the upper Piedmont of South Carolina. Clemson, SC: Clemson University. 66 p. M.S. thesis.	Southeast Piedmont	Vertebrates	B, M	1, 5	Findings for this thesis can be found in paper No. 123.	
120	Zebehazy, L.A. 2002. Avian and arthropod community responses to fuel reduction treatments in the upper Piedmont of South Carolina. Clemson, SC: Clemson University. 86 p. M.S. thesis.	Southeast Piedmont	Vertebrates	B, M, M+B	7	Findings for this thesis can be found in paper No. 124.	
121	Kubacz, D.B. 2003. Effects of fire and fire surrogate treatments on small mammals in the South Carolina Piedmont. Clemson, SC: Clemson University. 73 p. M.S. thesis.	Southeast Piedmont	Vertebrates	B, M, M+B	2	Findings for this thesis can be found in paper No. 123.	
122	Kilpatrick, E.S.; Kubacz, D.B.; Guynn, D.C., Jr.; Lanham, J.D.; Waldrop, T.A. 2004. The effects of prescribed burning and thinning on herpetofauna and small mammals in the upper Piedmont of South Carolina: preliminary results of the National Fire	Southeast Piedmont	Vertebrates	B, M, M+B	1	No differences among treatments in small mammal abundance were detected, despite 9,600 trap nights. More snake species were caught after mechanical treatments than	No other studies have reported similar findings.

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	and Fire Surrogate study. In: Connor, K.F., ed. Proceedings, 12th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 18–22.					after burn treatments, although the difference was most likely the result of random encounters of traps rather than treatment. The green anole (*Anolis carolinensis*) was captured more frequently after the mechanical + burn treatments than after burn treatments or in untreated stands. The five-lined skink (*Eumeces fasciatus*) was captured more frequently after mechanical and mechanical + burn treatments than in untreated areas.	
123	Zebehazy, L.A.; Lanham, J.D.; Waldrop, T.A. 2004. Seasonal avifauna responses to fuel reduction treatments in the upper Piedmont of South Carolina: results from phase 1 of the National Fire and Fire Surrogate study. In: Connor, K.F., ed. Proceedings, 12th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 82–86.	Southeast Piedmont	Vertebrates	B, M	1, 5	Foliage-gleaning and canopy-nesting species were detected more often after mechanical treatments than after burn treatments or in untreated areas. Generally, breeding bird abundance, richness, and evenness did not differ among treatments.	Ingold and Galati (1997) reported that golden-crowned kinglets (*Regulus strapa*) decreased with treatments that opened canopies. Rodewald et al. (1999) reported that pine warblers (*Dendroica pinus*) increased with reductions in understory cover.
124	Leput, D.W. 2004. Eastern red bat (*Lasiurus borealis*) and eastern pipistrelle (*Pipistrellus subflavus*) maternal roost selection: implications for forest management. Clemson, SC: Clemson University. 86 p. M.S. thesis.	Southeast Piedmont	Vertebrates	B, M, M+B	7	Eastern red bat (*Lasiurus borealis*) females preferred to roost in mature hardwood trees surrounded by open, hardwood-dominated stands, while eastern pipistrelles (*Pipistrellus subflavus*) preferred to roost in live oak (*Quercus virginiana* Mill.) foliage surrounded by tall, large-diameter trees. Fuel reduction treatments that shifted stands from hardwood to conifer dominance likely would not be beneficial to eastern red bat maternal roosting, habitat quality for eastern pipistrelles but would likely increase roosting.	Hutchinson and Lacki (2000) and Mager and Nelson (2001) reported similar roost selection behavior of eastern red bats. Menzel et al. (1999) and Vielleux et al. (2003) reported similar roosting behavior in eastern pipistrelles.

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
125	Kilpatrick, E.S. 2006. Responses of vertebrate fauna to prescribed fire and fuel reduction treatments in the southern Piedmont. Clemson, SC: Clemson University. 198 p. Ph.D. dissertation.	Southeast Piedmont	Vertebrates	B	1	Findings for this dissertation can be found in paper No. 127.	
126	Loeb, S.C.; Waldrop, T.A. 2008. Bat activity in relation to fire and fire surrogate treatments in southern pine stands. Forest Ecology and Management. 255(8/9): 3185–3192.	Southeast Piedmont	Vertebrates	M, M+B	1, 5, 8	Habitat features such as available foraging areas and corridors for commuting increased with mechanical and mechanical + burn treatments; these practices may help preserve biodiversity of managed forests in the Piedmont region.	Similar studies have shown that bats, especially larger bodied species, tend to avoid dense forest stands (Brigham et al. 1997, Ellison et al. 2005, Erickson and West 2003). Thinned stands had higher bat activity than unthinned stands (Humes et al. 1999).
127	Kilpatrick, E.S.; Lanham, J.D.; Waldrop, T.A. 2010. Effects of fuel reduction treatments on avian nest density in the upper Piedmont of South Carolina. Open Environmental Sciences. 4: 70–75.	Southeast Piedmont	Vertebrates	B	1	Declining population levels of early successional avian species may be reversed by increasing the relative area of upland Piedmont forest receiving burn treatments.	Relative abundance of early successional songbird species may increase with forest burning (Dickson 1981).
128	Vickers, M.E. 2003. Spider (Araneae) responses to fuel reduction in a Piedmont forest in upstate South Carolina. Clemson, SC: Clemson University. 115 p. M.S. thesis.	Southeast Piedmont	Invertebrates	B, M, M+B	1, 2, 3	Abundance of funnel, dwarf, and wolf spiders initially decreased after burn treatments but recovered after 2 years. No other spider taxa were affected.	Other studies have reported no affect or only a short-term affect after fuel reduction treatments (Haskins and Shaddy 1986, Merrott 1976, New and Hanula 1998).
129	Staeben, J.C. 2003. The effects of fire and fire surrogate forest management practices on coleopterans in the Clemson Experimental Forest. Clemson, SC: Clemson University. 90 p. M.S. thesis.	Southeast Piedmont	Invertebrates	B, M, M+B	1, 2	Abundance and diversity of beetles did not differ among fuel reduction treatments.	Holliday (1991) found higher numbers of ground beetles. Muona and Rutanen (1994) suggested that land management treatments that increase complexity may lead to increased richness of carabid beetles.

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130	Boyle, M.F. 2002. Short-term response of bark beetles to fuel reduction treatments in the upper Piedmont. Clemson, SC: Clemson University. 87 p. M.S. thesis.	Southeast Piedmont	Bark beetles	B, M, M+B	1, 2, 5, 10	Findings for this thesis can be found in paper No. 131.	
131	Boyle, M.F.; Hedden, R.L.; Waldrop, T.A. 2004. Impact of prescribed fire and thinning on host resistance to the southern pine beetle: preliminary results of the National Fire and Fire Surrogate study. In: Connor, K.F., ed. Proceedings, 12th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 60–64.	Southeast Piedmont	Bark beetles	B, M, M+B	1, 2, 5, 10	Abundance of southern pine beetle did not differ among treatments. Total resin flow was inversely correlated with beetle activity on a per-tree basis, and resin flow was positively correlated with the percentage of latewood. Thus, treatments that increase the relative proportion of latewood may increase stand resistance to southern pine beetle.	Strom et al. (2002) found that progeny of pines that had previously escaped southern pine beetle attack had greater resin flow than unattacked pines from the same area. Zobel (1995) reported that the amount of latewood was an important factor for high resin flow and tree growth, and thinning may increase stand resistence to bark beetles.
132	Moody, J.M. 2002. Fire and alternative fuel treatments on soil nitrogen: a case study of Myakka River State Park. Tallahassee, FL: Florida A&M University. 52 p. M.S. thesis.	Florida Coastal Plain	Soils	M+B	1, 2	Nitrate production was greater after the mechanical + burn treatments. Ammonium production was greater after the burn-only treatments. Soil moisture levels were below levels favorable to soil microbial activity and there was a relatively high carbon:nitrogen ratio.	Matson and Vitousek (1981) reported that soil moisture and temperature were higher in clearcuts than undisturbed forests and this led to higher nitrogen mineralization and nitrification rates in clearcuts. Plymale et al. (1987) suggested that soil moisture was a strong controller of nitrogen mineralization.
133	Reetz, M.J.; Farley, E.; Contreras, T.A. 2008. Evidence for Bachman's sparrow raising brown-headed cowbirds to fledging. Wilson Journal of Ornithology. 120(3): 625–627.	Florida Coastal Plain	Vertebrates	B, M, M+B	5	First recorded evidence of a brown-headed cowbird chick raised to fledging by Bachman's sparrow.	Friedman (1963) noted only three records of brown-headed cowbird parasitism of Bachman's

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							sparrow nests, and other studies have failed to corroborate the parasitism (Kilgo and Moorman 2003, Perkins et al. 2003, Tucker et al. 2006).
134	Frank, J.H.; Foltz, J.L.; Almquist, D.T. 2005. The female of *Oxybleptes meridionalis* (Coleoptera: Staphylinidae: Staphylininae) and range extension for *Oxybleptes*. Florida Entomologist. 88(2): 199–200.	Florida Coastal Plain	Invertebrates	B, M, M+B	5	The range of the rove beetle (*Oxybleptes meridionalis*) was extended across the Florida Peninsula based on 6 females and 20 males.	No other studies have reported similar findings.
135	Outcalt, K.W. 2003. Developing management options for longleaf communities of the Gulf Coastal Plain. In: Kush, J.S., comp. Proceedings, 4th Longleaf Alliance regional conference, longleaf pine: a southern legacy rising from the ashes. Longleaf Alliance Report No. 6. Andalusia, AL: The Longleaf Alliance: 126–129.	Gulf Coastal Plain	Overstory vegetation	B, M, M+B	2, 3	Slash that was removed prior to burning minimized tree mortality and would increase cost-effectiveness over time as growing season burns would require less site preparation.	No other studies have reported similar findings.
136	Outcalt, K.W.; Foltz, J.L. 2004. Impacts of growing-season prescribed burns in the Florida pine flatwoods type. In: Connor, K.F., ed. Proceedings, 12th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 30–34.	Gulf Coastal Plain	Overstory vegetation	B, M+B	2	Crown scorch ranged from 16 to 83 percent with the lowest percentage occurring when 3 years of fuel accumulation were burned during the growing season by using mostly flanking fires.	Boyer (1993), Haywood et al. (2001), and Robbins and Myers (1992) reported that, over the long term, growing-season fuel reduction treatments could become more effective as live woody fuels are reduced and herbaceous fuels increase after repeated burns .
137	Outcalt, K.W. 2005. Restoring structure and composition of longleaf pine ecosystems of the Gulf Coastal Plains. In: Kush, J.S., comp. Proceedings, 5th Longleaf Alliance regional conference. Longleaf Alliance Report No. 8. Andalusia, AL: The Longleaf Alliance: 97–100.	Gulf Coastal Plain	Overstory vegetation	B, M, M+B	1, 2, 8	Burning was most effective in controlling understory hardwoods, whereas mechanical treatments reduced the number of large midstory hardwoods, indicating that mechanical + burn treatments may be the quickest way to restore structure and composition.	Komarek (1977) and Landers et al. (1989) reported that young hardwoods were susceptible to top kill by fire, and frequent fires can keep hardwood sprouts at low stature in longleaf pine (*Pinus palustris*) stands.

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Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
138	Rompré, G. 2003. Successful nesting of the sharp-shinned hawk (*Accipiter striatus*) in a longleaf pine stand in southern Alabama. Alabama Birdlife. 49(1): 10–13.	Gulf Coastal Plain	Vertebrates	B, M, M+B	5	A sharp-shinned hawk (*Accipiter striatus*) nest with male, female, and four hatchlings was found in a longleaf pine (*Pinus palustris*) stand in southern Alabama.	Stratford and Tucker (2002) suggested the recent extension of breeding records may be in response to restoration efforts in longleaf pine (*Pinus palustris*) ecosystems.
139	Rall, A.E. 2004. Effects of longleaf pine management practices on the herpetofauna of south Alabama. Auburn, AL: Auburn University. 61 p. M.S. thesis.	Gulf Coastal Plain	Vertebrates	B, M, M+B	2, 3	Community-level effects on amphibians and reptiles did not differ among treatments.	Current amphibian monitoring projects extend for 6 to 21 years (Pechmann et al. 2001).
140	Sharp, N.W. 2005. Demography of small mammal populations in longleaf pine undergoing restoration. Auburn, AL: Auburn University. 84 p. M.S. thesis.	Gulf Coastal Plain	Vertebrates	B, M, M+B	2, 5	Survival of golden mice (*Ochrotomys nuttalli*) declined after burn treatments. Small mammal recruitment was affected by both habitat alteration within stands, and the availability of immigrants from source habitat outside stands.	No other studies have reported similar findings.
141	Sharp, N.W.; Mitchell, M.S.; Grand, J.B. 2009. Sources, sinks, and spatial ecology of cotton mice in longleaf pine stands undergoing restoration. Journal of Mammalogy. 90(6): 1440–1448.	Gulf Coastal Plain	Vertebrates	B	2	Habitat quality for cotton mice (*Peromyscus gossypinus*) increased after mechanical + burn and mechanical + herbicide treatments. Habitat quality after mechanical-only treatments was similar to untreated stands. Bottomland hardwood forests adjacent to longleaf pine (*Pinus palustris*) stands may have served as a source of immigrants.	No other studies have reported similar findings.
142	Steen, D.A.; McGee, A.E.R.; Hermann, S.M.; Stiles, J.A.; Stiles, S.H.; Guyer, C. 2010. Effects of forest management on amphibians and reptiles: generalist species obscure trends among native forest associates. Open Environmental Sciences. 4: 24–30.	Gulf Coastal Plain	Vertebrates	B, M, M+B	1	Total amphibian species richness was unaffected by treatments, but richness of amphibian fauna known to be associated with longleaf pine forests increased after active treatments.	Means et al. (2004) suggested that effects studies should focus on those amphibian species that are found to be associated with longleaf

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
							pine (*Pinus palustris*) stands; otherwise, treatment effects may be masked by generalist species.
142	Steen et al. 2010.	Gulf Coastal Plain	Vertebrates	B, M, M+B	2	Total lizard and snake species richness and richness of lizard and snake species associated with longleaf pine (*Pinus palustris*) forests did not differ among treatments.	Mushinsky (1985, 1992) reported that richness of lizard and snake species increased after fire.
143	Robinson, W.D.; Rompré, G. 2010. Nest survival of understory birds in longleaf pine forests exposed to fire and fire-surrogate treatments. Open Environmental Sciences. 4: 63–69.	Gulf Coastal Plain	Vertebrates	B, M, M+B	2	Treatment plot size was too small to draw conclusions, but there was some evidence that nest mortality rates of eastern towhee were higher in treated stands than in untreated stands.	Rotella et al. (2007) reported that the minimum size area for sampling for nest predation in longleaf pine (*Pinus palustris*) stands was 100 ha.
144	Phillips, R.J.; Waldrop, T.A.; Simon, D.M. 2010. Third-year responses of understory woody regeneration to fuel reduction treatments in the Southern Appalachian Mountains. In: Stanturf, J.A., ed. Proceedings, 14th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–121. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 289–293.	Southern Appalachian Mountains	Understory vegetation	B, M, M+B	2, 3, 8	Density of shade-intolerant tree species 3 years after treatment increased the most after mechanical + burn treatments, and shrub cover had decreased the most. Burning favored oak (*Quercus*) species. Repeated entries likely will be needed to restore stands to presettlement conditions.	Dolan and Parker (2004) and Hutchinson et al. (2005) reported increased density of shade-tolerant tree species after burning.
145	Phillips, R.J.; Waldrop, T.A.; Simon, D.M. 2006. Assessment of the FARSITE model for predicting fire behavior in the Southern Appalachian Mountains. In: Connor, K.F., ed. Proceedings, 13th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-92. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 521–525.	Southern Appalachian Mountains	Fuels and fire behavior	B, M+B	10	The fire behavior and growth simulator FARSITE was calibrated for the Southern Appalachian Mountains by using postburn data. Adjustments led to realistic rates of spread, although predicted flame lengths were excessive. Fuel moistures and the presence of ericaceous shrubs proved difficult to simulate.	Grupe (1998) showed that FARSITE was sensitive to small spatial variations in fuel models (areas that occupied only 10 percent of the landscape) and these could affect the predicted average rate of spread, flame length, and fire-line intensity.

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Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
146	Gambrell, H.E.; Waldrop, T.A.; Wang, G.G. [In press]. Fuel dynamics across southern Appalachian landscapes. In: 15th biennial southern silvicultural research conference. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station.	Southern Appalachian Mountains	Fuels and fire behavior	B, M, M+B	1, 5	Leaf litter and fine woody fuel did not differ across different topographic positions while the mass of coarse woody debris was greater on northeast-facing slopes than other topographic positions.	Waldrop et al. (2007) and Kolaks et al. (2003) reported similar slope effects on fuel mass. Clinton (2004) reported that cover of ericaceous shrubs on north slopes could account for greater fuel mass because volatile chemicals in the shrubs contribute to decay resistence.
147	Waldrop, T.; Phillips, R.; Simon, D. 2010. Fuels and predicted fire behavior in the southern Appalachian Mountains after fire and fire surrogate treatments. Forest Science. 56(1): 32–45.	Southern Appalachian Mountains	Fuels and fire behavior	B, M, M+B	1, 3	Litter and simulated fire behavior were decreased for 1 year after burn treatments but returned to pretreatment levels by the third year. Vertical fuels declined and litter and woody fuels increased after mechanical treatments, and simulated fire behavior was more intense for 5 years.	No other studies have reported similar findings.
147	Waldrop et al. 2010.	Southern Appalachian Mountains	Fuels and fire behavior	M+B	1, 8	Flame temperatures were higher and the mass of woody fuel consumed greater after combined mechanical + burn treatments than other treatments. Mechanical + burn treatments were the most effective in reducing simulated fire behavior and meeting restoration objectives.	No other studies have reported similar findings.
148	Mohr, H.H.; Waldrop, T.A.; Simon, D.M. 2010. Using BEHAVEPlus for predicting fire behavior in southern Appalachian hardwood stands subjected to fuel reduction treatments. In: Stanturf, J.A., ed. Proceedings, 14th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-121. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 565–567.	Southern Appalachian Mountains	Fuels and fire behavior	B, M, M+B	2	Wildland fire behavior was predicted by using the model BEHAVEPlus. Potential posttreatment fire intensities were highest for mechanical-only treatments, intermediate for burn-only treatments, and lowest for the mechanical + burn treatments.	No other studies have reported similar findings.

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
149	Coates, T.A.; Shelburne, V.B.; Waldrop, T.A.; Smith, B.R.; Hill, H.S., Jr.; Simon, D.M. 2010. Forest soil response to fuel reduction treatments in the southern Appalachian Mountains. In: Stanturf, J.A., ed. Proceedings, 14th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-121. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 283–287.	Southern Appalachian Mountains	Soils	B, M, M+B	1, 3	Forest floor carbon:nitrogen ratio was lower during the first year after mechanical + burn treatments, but was no different from other treatments after 4 years. Soil extractable iron and pH 4 years after mechanical treatments was lower than untreated stands.	Johnson and Curtis (2001), Knoepp and Swank (1993), and Wells et al. (1979) reported that most forest floor variables in eastern deciduous forests change little in response to fuel reduction treatments.
150	Tomcho, A.L. 2004. Effects of prescribed fire and understory removal on bird communities in a southern Appalachian forest. Clemson, SC: Clemson University. 72 p. M.S. thesis.	Southern Appalachian Mountains	Vertebrates	B, M, M+B	2	Findings for this thesis can be found in paper No. 153.	
151	Greenberg, C.H.; Otis, D.L.; Waldrop, T.A. 2006. Response of white-footed mice (*Peromyscus leucopus*) to fire and fire surrogate fuel reduction treatments in a southern Appalachian hardwood forest. Forest Ecology and Management. 234(103): 355–362.	Southern Appalachian Mountains	Vertebrates	B, M, M+B	2, 3	Age structure and male-female ratio of white-footed mice (*Peromyscus leucopus*) were not affected by fuel reduction treatments. Average adult body mass declined least during the first year after mechanical treatments than other treatments. Population levels increased equally the first year after treatments, while population levels increased more after mechanical + burn treatments than other treatments during the second season.	Wolff (1985) reported similar adult body masses. Ford et al. (1999) and Keyser et al. (2001) reported similar *Peromyscus* species abundance in both burned and unburned hardwood forest floors. Kirkland et al. (1996) reported a lower abundance of white-footed mice (*Peromyscus leucopus*) in stands with little shrub cover after burning than in unburned stands. Krefting and Ahlgren (1974) reported higher densities of *Peromyscus* species in burned mixed-conifer-hardwood stands than unburned stands.

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Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
151	Greenberg et al. 2006.	Southern Appalachian Mountains	Vertebrates	B, M, M+B	5	The proportion of white-footed mice (*Peromyscus leucopus*) captured near coarse woody debris did not differ from that captured in open areas, indicating that they did not use coarse woody debris preferentially or change their use patterns in response to fuel reduction treatments.	Greenberg (2002) found that white-footed mice (*Peromyscus leucopus*) preferentially used coarse woody debris, but relative densities of mice were similar among sites with different levels of coarse woody debris loading. Others have reported that white-footed mice use coarse woody debris preferentially for travel, orientation, foraging, nesting and refuge sites (Kirkland 1990, McCay 2000, Tallmon and Mills 1994).
152	Greenberg, C.H.; Tomcho, A.L.; Lanham, J.D.; Waldrop, T.A.; Tomcho, J.; Phillips, R.J.; Simon, D. 2007. Short-term effects of fire and other fuel reduction treatments on breeding birds in a southern Appalachian upland hardwood forest. Journal of Wildlife Management. 71(6): 1906–1916.	Southern Appalachian Mountains	Vertebrates	M+B	1, 2	Many bird species did not change in abundance with treatments. Species richness, total bird density and abundance in some species, including indigo buntings (*Passerina cyanea*) and eastern bluebirds (*Sialia sialis*), increased 1 or 2 years after mechanical + burn treatments. Eastern wood-pewees (*Contopus virens*) increased immediately after mechanical + burn treatments. Hooded warblers (*Wilsonia citrina*), black-and-white warblers (*Mniotilta varia*), and worm-eating warblers (*Helmitheros vermivorus*) declined temporarily in some or all treatments. High snag availability, open conditions, and a higher density of flying insects in the mechanical + burn treatment likely contributed to increased bird density and species richness.	Hejl (1994) reported that bird response to fire varies according to fire severity and the corresponding postburn conditions. Campbell et al. (2007b) reported an increased density of flying insects and visibility after mechanical + burn treatments.

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
153	Greenberg, C.H.; Miller, S.; Waldrop, T.A. 2007. Short-term response of shrews to prescribed fire and mechanical fuel reduction in a Southern Appalachian upland hardwood forest. Forest Ecology and Management. 243(2–3): 231–236.	Southern Appalachian Mountains	Vertebrates	B, M, M+B	5	Relative abundance of all shrews, including northern short-tailed shrews (*Blarina brevicauda*), smokey shrews (*Sorex fumeus*), pygmy shrews (*S. hoyi*), and southeastern shrews (*S. longirostris*) was lower in the mechanical + burn treatments than other treatments, but differed only from the mechanical treatments where the leaf litter depth was high. Low-intensity fuel reduction treatments, with little change in canopy cover or leaf litter depth, have little impact on shrews, while high-intensity treatments that reduce shading and leaf litter depth can result in short-term declines in shrew abundance.	Ford et al. (1999) reported that a high-intensity burn in a xeric pitch pine (*Pinus rigida*) forest did not affect the relative abundance of masked shrews (*Sorex cinereus*), smokey shrews, pygmy shrews, and northern short-tailed shrews. Ford et al. (1997) reported a linkage between leaf litter depth and abundance of northern short-tailed shrews and smokey shrews. Ford and Rodrigue (2001) reported that shrew abundance did not change after partial overstory removal.
154	Greenberg, C.H.; Waldrop, T.A. 2008. Short-term response of reptiles and amphibians to prescribed fire and mechanical fuel reduction in a southern Appalachian upland hardwood forest. Forest Ecology and Management. 255(7): 2883–2893.	Southern Appalachian Mountains	Vertebrates	B, M, M+B	2	Relative abundance of salamanders, amphibians, lizards, and reptiles was not changed by fuel reduction treatments. High-intensity burning could be used to increase reptile abundance.	Floyd et al. (2002), Ford et al. (1999), and Keyser et al. (2004) reported that burning did not affect relative abundance of salamanders. Floyd et al. (2002) reported that reptiles were not affected by burning, while Keyser et al. (2004) reported that reptile abundance increased with burning owing to reduced leaf litter, more bare ground, and higher light levels that facilitate movement and thermoregulation (Russel et al. 1999, Renken 2006).

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Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
155	Matthews, C.E. 2008. Long-term response of herpetofauna and soricid populations to fire and fuel reduction treatments in the southern Appalachian Mountains. Raleigh, NC: North Carolina State University. 57 p. MS thesis.	Southern Appalachian Mountains	Vertebrates	B, M, M+B	1, 2	Findings for this thesis can be found in papers Nos. 156 and 157.	
156	Matthews, C.E.; Moorman, C.E.; Greenberg, C.H.; Waldrop, T.A. 2009. Response of soricid populations to repeated fire and fuel reduction treatments in the southern Appalachian Mountains. Forest Ecology and Management. 257(9): 1939–1944.	Southern Appalachian Mountains	Vertebrates	B, M, M+B	1, 2	Abundance of shrews did not differ among treatments.	Several studies have reported little or no response by shrews to minor habitat disturbances (Ford et al. 1999, Ford and Rodrigue 2001, Greenberg and Miller 2004).
156	Matthews et al. 2009.	Southern Appalachian Mountains	Vertebrates	B, M, M+B	1, 2	Southeastern shrews (*Sorex longirostris*) declined in abundance the first year after mechanical + burn treatments because leaf litter, duff depth, and canopy cover were decreased, thereby decreasing ground-level moisture. Abundance rebounded the second year after treatments.	Dense herbaceous cover and deep leaf litter favor southeastern shrews (*Sorex longirostris*) (French 1980).
157	Matthews, C.E.; Moorman, C.E.; Greenberg, C.H.; Waldrop, T.A. 2010. Response of reptiles and amphibians to repeated fuel reduction treatments. Journal of Wildlife Management. 74(6): 1301–1310.	Southern Appalachian Mountains	Vertebrates	B, M, M+B	1, 2	Both reptile and amphibian communities were unchanged by mechanical or burn treatments. Salamander abundance declined and lizard abundance increased after mechanical + burn treatments.	Reduction in overstory canopy cover may negatively affect salamanders (Harpole and Hass 1999; Petranka et al. 1993, 1994; Pough et al. 1987), and retention of full canopy cover may positively affect salamanders (Harpole and Hass 1999, Homyack and Hass 2009, Knapp et al. 2003). Little or no change in salamander abundance occurred after burns (Floyd 2003, Ford et al. 1999,

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
							Greenberg and Waldrop 2008, Moseley et al. 2003). Salamander abundance remained unchanged after midstory canopy removal with herbicides (Harpole and Haas 1999, Homyack and Haas 2009, Knapp et al. 2003). A single burn increased abundance of reptiles and had no effect on numbers of amphibians in the short term (Ford et al. 1999, Greenberg and Waldrop 2008).
158	Campbell, J.W.; Hanula, J.L.; Waldrop, T.A. 2007a. Effects of prescribed fire and fire surrogates on floral visiting insects of the Blue Ridge Province in North Carolina. Biological Conservation. 134(3): 393–404.	Southern Appalachian Mountains	Invertebrates	B, M, M+B	1, 2	Floral visitors increased in abundance and species richness after mechanical + burn treatments that reduced the density of overstory trees and increased the amount of herbaceous plant growth. Plant pollinator abundance and species diversity increased more after mechanical + burn treatments than other treatments.	No other studies have reported similar findings.
159	Campbell, J.W.; Hanula J.L.; Waldrop, T.A. 2007b. Observations of *Speyeria diana* (Diana Fritillary) utilizing forested areas in North Carolina that have been mechanically thinned and burned. Southeastern Naturalist. 6(1): 179–182.	Southern Appalachian Mountains	Invertebrates	B, M, M+B	1, 2	Male Diana fritillaries (*Speyeria diana*) were observed feeding on sourwood (*Oxydendrum arboretum*) after mechanical + burn treatments, likely a result of greater cover of herbaceous plants than other treatments.	Thill et al. (2004) reported that the Diana fritillary increased in abundance after thinning and burning because of a greater abundance of nectar resource.

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Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
160	Greenberg, C.H.; Forrest, T.G.; Waldrop, T. 2010. Short-term response of ground-dwelling arthropods to prescribed fire and mechanical fuel reduction in a southern Appalachian upland hardwood forest. Forest Science. 56(1):112–121.	Southern Appalachian Mountains	Invertebrates	B, M, M+B	2	Abundance, dry biomass of all species, or species composition of ground-dwelling arthropods did not differ in the short-term among fuel reduction treatments. Hymenoptera (predominantly Formicidae) dry biomass was greater with mechanical + burn treatments than mechanical treatments.	Apigian et al. (2006) reported taxon-specific changes in relative abundance in response to fuel reduction treatments. Negligible or very transient reductions in relative abundance or richness of macroarthropods after fire was reported by Abbott et al. (2003), New and Hanula (1998), and Siemann et al. (1997). More substantial impacts were reported by Hanula and Wade (2003), Moretti et al. (2006), and Paquin and Coderre (1997).
161	Waldrop, T.A.; Yaussy, D.A. 2007. Delayed mortality of eastern hardwoods after prescribed fire. In: Stanturf, J.A., ed. Proceedings, 14th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-121. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 609–612.	Regional	Overstory vegetation	B, M, M+B	3	Tree mortality continued for 4 years after burning, probably owing to prior tree health. Accurate assessment of stand response to treatments requires several years of posttreatment monitoring.	Delayed tree mortality may be related to drier soils after treatments when forest floor depth is decreased and the amount of sunlight reaching the forest floor is increased (Waldrop et al. 2002).
162	Phillips, R.J.; Waldrop, T.A. [In press]. Fuel loading after fuel reduction treatments and impacts from natural disturbances. In: Proceedings, 15th biennial southern silvicultural research conference. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station.	Regional	Fuels and fire behavior	B, M, M+B	1, 2, 3	An ice storm in 2005 increased fine fuels by 13 $m^3 \cdot ha^{-1}$ after mechanical treatments and in untreated stands; 2 years later, fine fuel mass remained greater than after burn and mechanical + burn treatments. Fire behavior may be managed, and the detrimental effects of natural disturbances reduced, by fuel reduction treatments.	Estimates of biomass input resulting from ice storms include 5.1 $m^3 \cdot ha^{-1}$ (Rebertus et al. 1997), 19.4 $m^3 \cdot ha^{-1}$ (Bruderle and Steams 1985), and 33.6 $m^3 \cdot ha^{-1}$ (Hooper et al. 2001).

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
162	Phillips and Waldrop [In press].	Regional	Fuels and fire behavior	B, M, M+B	2, 3	Fine fuel mass, 8 years after treatment, was lower after mechanical + burn treatments than other fuel reduction treatments, and fine fuel mass after mechanical treatments did not differ from untreated stands.	No other studies have reported similar findings.
162	Phillips and Waldrop [In press].	Regional	Fuels and fire behavior	B, M, M+B	2, 4	After 8 years, predicted future fire behavior was lowest after mechanical treatments at the Southeastern Piedmont site, and after mechanical + burn treatments at the southern Appalachian Mountains site.	Fire behavior projections likely may change rapidly in both types of forests, because fuels tend to accumulate rapidly after each fire entry (Wade et al. 2000). Examining interactions over time among multiple natural and human-induced disturbances can provide valuable information for land managers relevant to long-term restoration goals (Lundquist 2007).
163	Coates, T.A. 2006. Response of forest soil resources to fuel reduction in the southeastern Piedmont and southern Appalachian Mountains. Clemson, SC: Clemson University. 91 p. M.S. thesis.	Regional	Soils	B, M, M+B	1, 2	Findings for this thesis can be found in papers Nos. 164 and 179.	
164	Coates, T.A.; Boerner, R.E.J.; Waldrop, T.A.; Yaussy, D.A. 2008. Soil nitrogen transformations under alternative management strategies in Appalachian forests. Soil Science Society of America Journal. 72(2): 558–565.	Regional	Soils	B, M, M+B	1, 2	Nitrogen transformation rates were 2 to 10 times higher at the Central Appalachian Plateau site than at the Southern Appalachian Mountains site, likely owing to the presence of ericaceous shrubs including mountain laurel (*Kalmia latifolia* L.) and rhododendron (*Rhododendron* spp.).	Decomposition and soil organic matter consumption rates were lower in forests with dense ericaceous understories because the litter contained high levels of recalcitrant tannins and phenols (DeLuca et al. (2002, Waterman and Mole 1994).

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Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
164	Coates et al. 2008.	Regional	Soils	B, M, M+B	1, 2, 3	Extractable total inorganic nitrogen (N), N mineralization, and nitrification increased during the first year after mechanical treatments at the Central Appalachian Plateau site and total inorganic nitrogen was greater in the third year after mechanical and mechanical + fire treatments at the Southern Appalachian Mountains site.	Total inorganic nitrogen and nitrogen transformation rates typically increase after burning, and eastern forests generally have lower rates of nitrogen transformation than western forests (Wan et al. 2001).
164	Coates et al. 2008.	Regional	Soils	B, M+B	2	Mineralization rates initially declined after burn treatments at the Central Appalachian Plateau site but were unaffected at the Southern Appalachian Mountains site.	No other studies have reported similar findings.
165	Kilpatrick, E.S.; Waldrop, T.A.; Lanham, J.D.; Greenberg, C.H.; Contreras, T.H. 2010. Short-term effects of fuel reduction treatments on herpetofauna from the southeastern United States. Forest Science. 56(1): 122–130.	Regional	Vertebrates	B, M+B	1, 2	Lizard and reptile abundances were higher after the burn and mechanical + burn treatments at the Southern Appalachian Mountains and Southeastern Piedmont sites, and were best predicted by native herbaceous cover.	Burning in many southeastern forests increased light penetration to the forest floor and stimulated herbaceous cover (Conner et al. 2002, Wilson et al. 1995, Wood et al. 2004). Burning provided greater heat for basking by lizards and reptiles (Perison et al. 1997, Zug 1993). Fire is generally a positive process for native reptiles and amphibians (Johnson and Hale 2000).

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
165	Kilpatrick et al. 2010.	Regional	Vertebrates	B, M, M+B	2	Lizard and reptile abundance was higher after burn and mechanical + burn treatments at the Southeastern Piedmont and Southern Appalachian Mountains sites than other fuel reduction treatments, and this increased abundance was linked to higher native herbaceous cover after treatment.	Increased lizard and reptile abundance was linked to increased insolation in burned units, which increased heat available at the forest floor used by these poikilothermic animals for basking and attainment of necessary active body temperatures (Perison et al. 1997, Phelps and Lancia 1995).
166	Zwart, D.C. 2004. Effects of fuel reduction treatments on the incidence of two root pathogens of forest trees. Clemson, SC: Clemson University. 114 p. M.S. thesis.	Regional	Pathology and fungi	B, M, M+B	1, 2	The plant-killing diseases *Phytophthora heveae* and *P. cinnamomi* were pathogenic to white pine (*Pinus strobes*), mountain laurel (*Kalmia latifolia*), and rhododendrons (*Rhododendron* spp.), yet fuel reduction treatments had no effect on the incidence of the root pathogens *Leptographium* spp. and *Phytophthora* spp.	These plant diseases tend to be resistant to disturbances including fuel reduction treatments (Erwin and Ribeiro 1996).
167	McLaughlin, I.M. 2008. Effects of fuel reduction treatments on species of *Phytophthora* and *Leptographium* in forest ecosystems. Clemson, SC: Clemson University. 162 p. M.S. thesis.	Regional	Pathology and fungi	B, M, M+B	1, 2, 3	Incidence of the forest tree pathogen *Leptographium* species in roots of southern pine trees was initially lower after fuel reduction treatments at the Southeastern Piedmont site, but rebounded to pretreatment levels after 5 years.	Otrosina et al. (1997) reported the presence of *Leptographium* species in tree roots was associated with high stand basal area and suggested that reducing basal area may help maintain lower levels of this pathogen.
167	McLaughlin 2008.	Regional	Pathology and fungi	B, M, M+B	2, 10	Incidence of the forest tree pathogen *Phytophthora* species in soils did not differ among fuel reduction treatments at the Southern Appalachian Mountains site.	*Phytophthora* species were shown to be resilient to various fuel reduction treatments (Hansen and Sutton 2005, Marks et al. 1975).

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Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
168	Knapp, E.E.; Stephens, S.L.; McIver, J.D.; Moghaddas, J.J.; Keeley, J.E. 2004. Fire and fire surrogate study in the Sierra Nevada: evaluating restoration treatments at Blodgett Forest and Sequoia National Park. In: Murphy, D.D.; Stine, P.A., eds. Proceedings, Sierra Nevada science symposium 2002: science for management and conservation. Gen. Tech. Rep. PSW-GTR-193. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station: 79–85.	Regional	Multivariate	B	1, 2	Fewer small trees were killed, less fuel was consumed, and more heterogeneous patterns of effects resulted after spring burns than after fall burns at the Southern Sierra Nevada site. Fuel loads were reduced from 150.0 to 101.9 $tons{\cdot}ha^{-1}$ by using mechanical treatments at the Central Sierra Nevada site.	No other studies have reported similar findings.
169	Yaussy, D.A.; Waldrop, T.A. 2009. Fire and fire surrogate study: annotated highlights from oak-dominated sites. In: Hutchinson, T.F., ed. Proceedings, 3rd fire in eastern oak forests conference. Gen. Tech. Rep. NRS-P-46. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station: 40–50.	Regional	Multivariate	B, M, M+B	1	Annotated highlights of short-term findings from Central Appalachian Plateau and Southern Appalachian Mountains sites are provided.	No other studies have reported similar findings.
170	Waldrop, T.A.; Boerner, R.E.J.; Yaussy, D.A. [In press]. Restoration treatments in eastern hardwoods: impacts and interactions of multiple ecosystem components. In: 15th biennial southern silvicultural research conference. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station.	Regional	Multivariate	M+B	2, 3, 8	Stand-level shifts toward restoration were greater after mechanical + burn treatments than other treatments at both the Central Appalachian Plateau and Southern Appalachian Mountains sites, yet overstory and understory vegetation remained too dense, soils were largely unaffected, and bird species richness showed only ephemeral changes. Treatments should be repeated if the management goal is to replicate historical structure and function.	No other studies have reported similar findings.
171	Waldrop, T.A.; Yaussy, D.A.; Phillips, R.J.; Hutchinson, T.A.; Brudnak, L., Boerner, R.E.J. 2008. Fuel reduction treatments affect stand structure of hardwood forests in western North Carolina and southern Ohio, USA. Forest Ecology and Management. 255(8/9): 3117–3129.	Network	Overstory vegetation	M+B	1, 2	Overstory stand structure was modified more by mechanical + burn treatments that included two burns than other fuel reduction treatments at both the Central Appalachian Plateau and Southern Appalachian Mountains sites, yet no set of treatments restored stand structure to historical conditions.	No other studies have reported similar findings.

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
171	Waldrop et al. 2008.	Network	Overstory vegetation	B, M, M+B	8, 10	Results from the two study sites in the Appalachian Mountains indicated the rapid sprouting and growth of undesirable eastern species, and suggested the need for frequently repeated treatments during the restoration phase.	Van Lear (1998) reported that burns conducted after yellow poplar (*Liriodendron tulipifera*) was established favored oak (*Quercus*) establishment. Zenner et al. (2006) reported that intensive harvesting may be necessary to cause marked changes in the understory, especially in the forb and grass components.
172	Bartuszevige, A.M.; Kennedy, P.L. 2009. Synthesis of knowledge on the effects of fire and thinning treatments on understory vegetation in U.S. dry forests. Special Report 1095. Corvallis, OR: Oregon State University Press. 159 p.	Network	Understory vegetation	B, M, M+B	1, 10	Information on the effects of fuel reduction treatments in seasonal dry forests is presented by region and by plant functional group and plant species.	No other studies have reported similar findings.
172	Bartuszevige and Kennedy 2009.	Network	Understory vegetation	B, M, M+B	2, 9	Landscape context, or the proximity of proposed treatments to nearby roads, wildland-urban interface, or previous plant invasions, will influence the effectiveness of treatments.	Exotic or nonnative invasive plant species richness increased after mechanical + burn treatments (Collins et al. 2007, Dodson et al. 2008, Dodson and Fiedler 2006, Griffis et al. 2001, Metlen and Fiedler 2006, Nelson et al. 2008).
172	Bartuszevige and Kennedy 2009.	Network	Understory vegetation	B, M, M+B	3	Long-term studies are needed to capture fully understory response to treatments.	Busse et al. (2000) and Laughlin et al. (2008) reported lasting long-term effects after fuel reduction treatments, while Fulé et al. (2002) failed to detect similar long-term effects.

Table 14—Principal citations of the national Fire and Fire Surrogate (FFS) study with their findings, by site, discipline, treatment, and theme, with supporting literature (treatment codes: B = burn, M = mechanical, M+B = mechanical + burn; theme codes: 1 = fire vs. surrogates, 2 = effect size, 3 = effect duration, 4 = regional, 5 = species adaptation, 6 = heterogeneity, 7 = tradeoffs, 8 = restoration, 9 = exotics, 10 = application) (continued)

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
172	Bartuszevige and Kennedy 2009.	Network	Understory vegetation	B, M, M+B	8	Multiple or repeated treatments will be required to restore understory structure and bring forests back into the historical range of variability.	Multiple entries are needed to restore understories to the historical range of variability (Harrington and Edwards 1999, Metlen and Fiedler 2006, Waldrop et al. 2008). Laughlin et al. (2008) reported that multiple burns conducted over 11 years were needed to restore historical understory community structure in a southwestern forest.
172	Bartuszevige and Kennedy 2009.	Network	Understory vegetation	B, M, M+B	8	Many rare, threatened, and endangered plant species are adapted to fire and often respond positively to burns.	Rare, threatened, and endangered plant species often maintain their population level through repeated exposure to fire (Menges et al. 2006, Norden and Kirkman 2004, Satterthwaite et al. 2002).
173	Kennard, D.K.; Outcalt, K.W.; Jones, D.; O'Brien, J.J. 2005. Comparing techniques for estimating flame temperature of prescribed fires. Fire Ecology. 1(1): 75–84.	Network	Fuels and fire behavior	B, M+B	10	Simple fire behavior observations taken during burns and indicators of fire severity taken after the burn were inexpensive and revealed useful differences among fires.	No other studies have reported similar findings.
173	Kennard et al. 2005.	Network	Fuels and fire behavior	B, M+B	10	Thermocouples provided the most detailed spatial and temporal information on temperatures during a burn. Pyrometers were the most effective in characterizing spatial heterogeneity in temperatures during a fire. Calorimeters generally were disadvantageous owing to lack of precision and high labor cost.	Perez and Moreno (1998) reported that calorimeters were more precise than pyrometers, while Wally et al. (2006) reported that pyrometers outperformed calorimeters as a cheap method for describing relative temperature regimes

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
							that are a function of both temperature and residence time.
173	Kennard et al. 2005.	Network	Fuels and fire behavior	B, M+B	10	Thermocouples, pyrometers, and calorimeters all underestimated maximum flame temperatures, yet several devices were useful for characterizing other metrics of fire behavior.	Iverson et al. (2004) noted the relative imprecision of thick thermocouples for capturing fast short-term temperature dynamics.
174	Stephens, S.L.; Moghaddas, J.J.; Edminster, C.; Fiedler, C.E.; Haase, S.; Harrington, M.; Keeley J.E.; Knapp, E.E.; McIver, J.D.; Metlen, K.; Skinner, C.N.; Youngblood, A. 2009a. Fire treatment effects on vegetation structure, fuels, and potential fire severity in western U.S. forests. Ecological Applications. 19(2): 305–320.	Network	Fuels and fire behavior	B, M, M+B	1, 2	Potential fire severity under severe fire weather conditions was reduced by using burn, mechanical, or mechanical + burn treatments with whole tree harvest systems. Fire resistance was increased when the largest trees within the stands were retained.	No other studies have reported similar findings.
174	Stephens et al. 2009a.	Network	Fuels and fire behavior	M, M+B	1, 2	Potential for crown fire was reduced by using mechanical or mechanical + burn treatments with whole tree harvest systems.	Similar results were reported by Graham (2003), Ritchie et al. (2007), and Skinner et al. (2004).
174	Stephens et al. 2009a.	Network	Fuels and fire behavior	B, M+B	2	The torching index increased after burn and mechanical + burn treatments, which reduced vulnerability of individual trees.	No other studies have reported similar findings.
175	Boerner, R.E.J.; Waldrop, T.A.; Skinner, C.N.; Callaham, M.A.; Brinkman, J.A.; Smith, A. 2004. Ecosystem restoration and wildfire management treatments affect soil organic matter and microbial activity in four contrasting forests. In: Yaussy, D.A.; Hix, D.M.; Long, R.P.; Goebel, P.C., eds. Proceedings, 14th central hardwood forest conference. Gen. Tech. Rep. NE-316. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station: 499.	Network	Soils	B, M, M+B	3, 4, 8	Short-term changes in soil microbial activity after fuel reduction treatments varied among sites, and were more closely related to soil organic carbon than to variation in vegetation, climate, or geology.	No other studies have reported similar findings.

Table 14—Principal citations of the national Fire and Fire Surrogate (FFS) study with their findings, by site, discipline, treatment, and theme, with supporting literature (treatment codes: B = burn, M = mechanical, M+B = mechanical + burn; theme codes: 1 = fire vs. surrogates, 2 = effect size, 3 = effect duration, 4 = regional, 5 = species adaptation, 6 = heterogeneity, 7 = tradeoffs, 8 = restoration, 9 = exotics, 10 = application) (continued)

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
176	Boerner, R.E.J.; Huang, J.; Hart, S.C. 2008c. Impacts of fire and fire surrogate treatments on ecosystem nitrogen storage patterns: similarities and differences between eastern and western North America. Canadian Journal of Forest Research. 38(12): 3056–3070.	Network	Soils	M, B, M+B	1, 2	Losses of vegetation nitrogen were greatest after mechanical + burn treatments, intermediate after mechanical treatments, and were weakest after burn treatments.	Clinton et al. (1996) and Mann et al. (1988) reported estimates of nitrogen loss in vegetation after clearcutting that were about 30 to 50 percent higher than FFS estimates.
176	Boerner et al. 2008c.	Network	Soils	B, M, M+B	2, 4	Total nitrogen did not decline more than 15 percent after any of the fuel reduction treatments at any site. Western sites lost relatively more nitrogen after treatment than did eastern sites.	No other studies have reported similar findings.
176	Boerner et al. 2008c.	Network	Soils	B, M, M+B	4	Total ecosystem nitrogen averaged 4480 $kg{\cdot}ha^{-1}$ across the FFS network, with about 80 percent in the soil, 9 percent each in vegetation and forest floor, and 2 percent in dead wood. Ten sites showed the same pattern of nitrogen distribution among ecosystem components; the Central Sierra Nevada and Southern Sierra Nevada sites had relatively more nitrogen in vegetation.	Finer et al. (2003) reported similar patterns of nitrogen distribution among ecosystem components. Clinton et al. (1996), Finer et al. (2003), Gessel et al. (1973), Johnson et al. (1982) reported similar differences among various sites in the range of nitrogen in the vegetation.
176	Boerner et al. 2008c.	Network	Soils	B, M, M+B	4	Management strategies that maximize ecosystem carbon gain by minimizing nitrogen loss may be an important focus for western forests, where carbon and nitrogen are tightly linked, but may be less important in eastern forests where atmospheric nitrogen deposition has decoupled carbon and nitrogen cycles.	Clinton et al. (1996) reported that more nitrogen was captured by atmospheric deposition than by regrowth 2 years after clearcutting in eastern deciduous forests. Gessel et al. (1973), Johnson et al. (1997), and Hart et al. (2006) reported that most western forests were nitrogen limited and thus logging residues retained may

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
							be important to preserve nitrogen needed for vegetation regrowth.
177	Boerner, R.E.J.; Giai, C.; Huang, J.; Miesel, J.R. 2008d. Initial effects of fire and mechanical thinning on soil enzyme activity and nitrogen transformations in eight North American forest ecosystems. Soil Biology and Biochemistry. 40(12): 3076–3085.	Network	Soils	B, M, M+B	1, 2	Soil carbon:nitrogen ratios increased after mechanical treatments, while forest floor carbon:nitrogen ratios decreased after burn, mechanical, and mechanical + burn treatments.	Black and Harden (1995) reported increased soil carbon:nitrogen ratios after fire, while Antos et al. (2003) reported decreased ratios.
177	Boerner et al. 2008d.	Network	Soils	B, M, M+B	1, 2	Phenol oxidase activity was lower after burn treatments than after other treatments, and was lower at the Southern Cascades, Blue Mountains, and Central Appalachian Plateau sites.	Boerner and Brinkman (2003) and Boerner et al. (2004, 2007) reported that interannual variation in phenol oxidase may eclipse treatment effects and may lead to conflicting treatment effects.
177	Boerner et al. 2008d.	Network	Soils	B, M, M+B	1, 2	Phosphatase levels differed between pre- and postmechanical + burn treatments at most sites across the FFS network. Microclimate of the forest floor was changed more by mechanical + burn treatments than other treatments.	No other studies have reported similar findings.
177	Boerner et al. 2008d.	Network	Soils	B, M, M+B	2	Phosphatase activity was reduced by burn and mechanical + burn treatments in four of five western sites, while this enzyme was reduced only by the mechanical + burn treatments at the Central Appalachian Plateau site.	Saa et al. (1993) reported reductions in phosphatase activity after fire in seasonally dry conifer forests in Europe.
177	Boerner et al. 2008d.	Network	Soils	B, M, M+B	2, 8	Large-scale restoration treatments used in the FFS study produced only subtle effects on soil microbial activity and nitrogen transformations.	No other studies have reported similar findings.

Table 14—Principal citations of the national Fire and Fire Surrogate (FFS) study with their findings, by site, discipline, treatment, and theme, with supporting literature (treatment codes: B = burn, M = mechanical, M+B = mechanical + burn; theme codes: 1 = fire vs. surrogates, 2 = effect size, 3 = effect duration, 4 = regional, 5 = species adaptation, 6 = heterogeneity, 7 = tradeoffs, 8 = restoration, 9 = exotics, 10 = application) (continued)

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
178	Boerner, R.E.J.; Huang, J.; Hart, S. 2008b. Fire, thinning, and the carbon economy: effects of fire and fire surrogate treatments on estimated carbon storage and sequestration rate. Forest Ecology and Management. 255(1): 3081–3097.	Network	Soils	B, M, M+B	1, 2	Total ecosystem carbon storage (defined as the sum of carbon in aboveground vegetation, forest floor, dead wood, and mineral soil to 30 cm) across the FFS network was greater at eastern sites than at western sites.	Heath et al. (2003) reported similar values for average carbon stored in eastern and western forests. Hurtt et al. (2002) and Turner et al. (1995) reported that eastern forests were the largest carbon sink, where regrowth after fire, harvesting, or land use changes caused rapid carbon uptake, while the second largest carbon sink was in western forests, where fire suppression led to increased detrital carbon. Values for soil carbon reported by Dixon et al. (1994), Heath et al. (2003), and Turner et al. (1995) were higher because these studies estimated soil carbon to 1 m depth.
178	Boerner et al. 2008b.	Network	Soils	B, M, M+B	2	Total ecosystem carbon across the FFS network did not differ among treatments, although total carbon initially increased after burns at the Blue Mountains site and decreased initially at the Southern Cascades, Central Sierra Nevada, and Northern Rocky Mountains sites. Total ecosystem carbon declined after mechanical and mechanical + burn treatments in the first year after treatments but was partially offset by enhanced net carbon uptake during the next 1 to 3 years.	No other studies have reported similar findings.

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
178	Boerner et al. 2008b.	Network	Soils	B, M, M+B	2	Vegetation carbon across the FFS network declined after mechanical and mechanical + burn treatments. Forest floor carbon across the network declined after burn and mechanical + burn treatments. Across the network, dead wood and soil organic carbon did not differ among treatments.	Page-Dumroese et al. (2003) reported that the forest floor carbon pool was the most susceptible carbon component for losses after fires. Hall et al. (2006) reported that the forest floor carbon pool returned to pretreatment levels unless vegetation biomass was reduced for extended periods of time. Moehring et al. (2006) and Richter et al. (1982) reported that soil organic carbon was unaffected by fuel reduction treatments, while Wilson et al. (2002) reported that it varied more by landscape position than by treatment.
179	Boerner, R.E.J.; Coates, A.T.; Yaussy, D.A.; Waldrop T.A. 2008a. Assessing ecosystem restoration alternatives in eastern deciduous forests: the view from belowground. Restoration Ecology. 16(3): 425–434.	Network	Soils	B, M+B	2	Soil organic carbon content, carbon:nitrogen ratios, and overall microbial activity (measured as acid phosphatase activity) did not differ after burn and mechanical + burn treatments at the Central Appalachian Plateau site. These same measures declined after burn, mechanical, and mechanical + burn treatments at the Southern Appalachian Mountains site. Only the effect on microbial activity persisted into the fourth year after treatment.	No other studies have reported similar findings.

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Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
179	Boerner et al. 2008a.	Network	Soils	B, M, M+B	2, 3	Soil organic carbon increased and both carbon:nitrogen ratios and microbial activity decreased after mechanical treatments at the Central Appalachian Plateau site, yet these measures returned to pretreatment levels by the fourth year after treatments.	No other studies have reported similar findings.
180	Boerner, R.E.J.; Huang, J.; Hart, S.C. 2009. Impacts of fire and fire surrogate treatments on forest soil properties: a meta-analytical approach. Ecological Applications. 19(2): 338–358.	Network	Soils	B, M+B	1, 2	Mineral soil exposure across the FFS network was greater after burn and mechanical + burn treatments than in untreated areas.	Klepac et al. (1999) and Rummer et al. (1997) reported higher levels of soil exposure after mechanical treatments than those found across the FFS network.
180	Boerner et al. 2009.	Network	Soils	B, M, M+B	1, 2, 3	Overall, treatment effects on soil properties across the FFS network were modest and transient. More site-by-treatment-by-year effects were detected after mechanical + burn treatments than after burn or mechanical treatments. Some changes persisted longer after mechanical + burn treatments, such as greater soil exposure and more calcium, and decreased total inorganic nitrogen.	No other studies have reported similar findings.
180	Boerner et al. 2009.	Network	Soils	B, M, M+B	2	Soil bulk density, soil organic carbon, and carbon:nitrogen ratio were unaffected by treatments across the FFS network.	Agee (1993) and Moehring et al. (1966) reported that soil bulk density was unchanged after low-severity fires. Matson and Vitousek (1981) reported little or no change in soil bulk density after timber harvesting, while Rummer et al. (1997) found increased bulk density after harvesting in hardwood forests.

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
180	Boerner et al. 2009.	Network	Soils	B, M+B	2	The greatest changes in soil pH, total inorganic nitrogen, soil organic carbon content, and soil carbon:nitrogen ratios were related to fire severity at the Northern Rocky Mountains, Central Sierra Nevada, and Southern Sierra Nevada sites, and these changes explained most of the variation in standardized effect sizes among sites.	Wan et al. (2001) reported that fire severity was a factor in explaining variation in soil chemical effects.
180	Boerner et al. 2009.	Network	Soils	B, M, M+B	2, 3	Across the FFS network, net mineralization, a measure of soil productivity, was unaffected by burn, mechanical, and mechanical + burn treatments.	Net mineralization often increased after single fires (Boerner et al. 2006, Raison 1979, Wan et al. 2001).
180	Boerner et al. 2009.	Network	Soils	B, M, M+B	2, 3	Soil total inorganic nitrogen levels across the FFS network initially increased after burn, mechanical, and mechanical + burn treatments, but the effect did not persist.	Soil total inorganic nitrogen levels decline after fire (Covington et al. 1991, Covington and Sackett 1992). Soil total inorganic nitrogen levels were relatively unchanged after prescribed burns with low fire severity (Wan et al. 2001.
181	Converse, S.J.; White, G.C.; Farris, K.L.; Zack, S. 2006a. Small mammals and forest fuel reduction: national-scale responses to fire and fire surrogates. Ecological Applications. 16(5): 1717–1729.	Network	Vertebrates	B, M, M+B	1	Total small mammal biomass was best predicted by an information-theoretic model with treatment type as the top ranked variable (untreated vs. treated). Higher small mammal biomass occurred after burn, mechanical, and mechanical + burn treatments.	Overall increased abundance in small mammal communities was linked to increased habitat complexity (Carey and Harrington 2001, Goodwin and Hungerford 1979).

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Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
181	Converse et al. 2006a.	Network	Vertebrates	B, M, M+B	2	Small mammal taxa did not differ among burn, mechanical, and mechanical + burn treatments.	Critical features of small mammal habitat, such as understory vegetation and coarse woody debris, respond differently to alternative fuel reduction treatments (Carey and Harrington 2001, Kyle and Block 2000).
181	Converse et al. 2006a.	Network	Vertebrates	B, M, M+B	2, 5, 10	Individual species and genera of small mammals across the FFS network did not respond consistently to treatments, indicating a high degree of site specificity. Adaptive management methods may help to reduce the uncertainty in choosing treatments that are locally optimal for meeting management objectives for small mammals.	Deer mouse and chipmunk populations increased after forest thinning (Hadley and Wilson 2004) and burning (Kyle and Block 2000).
182	Kennedy, P.L.; Fontaine, J.B. 2009. Synthesis of knowledge on the effects of fire and fire surrogates on wildlife in U.S. dry forests. Special Report 1096. Corvallis, OR: Oregon State University. 132 p.	Network	Vertebrates	B, M, M+B	1	Information on the effects of fuel reduction treatments in seasonal dry forests is presented by region and by animal taxa. Information is more available for birds and small mammals than for reptiles, amphibians, and large mammals. Fire-effects information is categorized by fire severity and time since fire.	No other studies have reported similar findings.
182	Kennedy and Fontaine 2009.	Network	Vertebrates	B, M, M+B	1, 3, 10	Wildlife species responded to both year and site effects, thus it was not possible to predict responses for many species. Future experimental research should focus on longer term studies in which large experimental plots are used.	The strongest factor in explaining variation in response to treatment was site, thus adaptive management methods may help to reduce the uncertainty in choosing treatments that are locally optimal for meeting

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
							management objectives for wildlife (Converse et al. 2006).
182	Kennedy and Fontaine 2009.	Network	Vertebrates	B, M, M+B	2	Most wildlife species that were fire-adapted responded favorably to burn treatments.	Wildlife species that were fire dependent responded favorably to fire, with or without mechanical treatment (Saab et al. 2007, Saab and Dudley 1998).
183	Farris, K.L.; Converse, S.J.; Zack, S.; Robinson, W.D.; Amacher, A.J.; Contreras, T.; Gaines, W.L.; Kilpatrick, E.S.; Lanham, J.D.; Miles D.; Rompré, G.; Sieving, K.E.; Pierson, J.C. 2010a. Short-term effects of fire and fire surrogate treatments on avian nest survival: a national-scale analysis. Open Environmental Sciences. 4: 53–62.	Network	Vertebrates	B, M, M+B	2	Daily nest survival of ground, shrub, tree, and snag-nesting bird species across the FFS network are described. Avian species generally failed to respond to treatments. Only two species had best fit models that included treatment effects.	Siegal and DeSante (2003) reported that American robins (tree-nesters) had higher abundances in thinned stands than in untreated stands.
183	Farris et al. 2010a.	Network	Vertebrates	B, M, M+B	3	Larger plot sizes and longer timeframes would provide better information on passerine bird response to fuel reduction treatments.	No other studies have reported similar findings.
184	Farris, K.L.; Zack, S.; Amacher, A.J.; Pierson, J.C. 2010b. Microhabitat selection of bark-foraging birds in response to fire and fire surrogate treatments. Forest Science. 56(1): 100–111.	Network	Vertebrates	B, M, M+B	1	Bark-foraging birds generally responded positively to fuel reduction treatments at western sites. Woodpeckers (*Picoides* spp.) increased in abundance after burn and mechanical + burn treatments while the red-breasted nuthatch, mountain chickadee, and brown creeper did not respond consistently.	No other studies have reported similar findings.

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Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
184	Farris et al. 2010b.	Network	Vertebrates	B, M, M+B	5	Tree and snag diameter were the strongest and most consistent features that influenced bark-foraging birds across all treatments.	Adams and Morrison (1993), Raphael and White (1984), and Weikel and Hayes (1999) reported that bark-foraging birds responded positively to increased average tree diameters. Bark-foraging birds, especially woodpeckers, are consistently linked to large-diameter snags (Bull et al. 1997) in both burned and unburned forests where they feed primarily on bark and wood-boring beetles (Murphy and Lehnhausen 1998).
185	Robinson, W.D. 2010. The challenges of studying vertebrates in habitat treatment plots. Open Environmental Sciences. 4: 21–23.	Network	Vertebrates	B, M, M+B	10	Experimental wildlife studies are often hampered by small treatment plot sizes, but reliable information can be obtained by focusing on intensive behavioral work and by making well-documented data sets available for future meta-analyses.	New modeling methods are more suitable for working with data sets hampered by small sample size (Steby and Miles 2010). Use of cameras at nests may increase information about how treatments influence predator success (Klug et al. 2010, Weatherhead et al. 2010). Resampling methods may provide new insights (Simon 1992).
186	Chalmers, S.R.; Hartsough, B.R. 2001. Thinning and prescribed fire as methods to reduce fuel loading-a cost analysis. In: Thinnings, a valuable forest management tool proceedings of an international conference. (CD-ROM). Pointe-Claire, QC: Forest Engineering Research Institute of Canada.	Network	Economics	M, M+B	1, 10	In a cost analysis of fuel reduction methods, mechanical treatments were likely cost-neutral or income-generating. Costs of burn treatments will likely be determined by expert opinion. Costs of mechanical	No other studies have reported similar findings.

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
						treatments will likely be determined by measuring production or schedule hours, operation costs, and the volume of wood removed.	
187	Hartsough, B.R.; Abrams, S.; Barbour, R.J.; Drews, E.S.; McIver J.D.; Moghaddas, J.J.; Schwilk, D.W.; Stephens, S.L. 2008. The economics of alternative fuel reduction treatments in western United States dry forests: financial and policy implications from the National Fire and Fire Surrogate Study. Forest Policy and Economics. 10(6): 344–354.	Network	Economics	B, M, M+B	1	On federal lands, giving contract officers and administrators flexibility to decide on the details of fuel reduction (e.g., whether to remove small trees or treat on site) makes sense given the volatility of both dimension lumber and chip markets.	No other studies have reported similar findings.
187	Hartsough et al. 2008.	Network	Economics	M, M+B	1	Net costs of mechanical treatments varied owing to market conditions at the time of harvest, but in general, revenue gained by bringing products to market lowered the net costs of fuel reduction.	Haynes et al. (1998) reported that stumpage prices in the Western United States varied by more than six-fold.
187	Hartsough et al. 2008.	Network	Economics	B, M, M+B	3, 7	Financial analyses of costs and revenues of fuel reduction treatments provided only a partial picture; a complete cost-benefit analysis involves both short- and long-term ecological effects and monetary values assigned to nonmarket issues.	No other studies have reported similar findings.
187	Hartsough et al. 2008.	Network	Economics	B, M+B	4	Costs for burn treatments at the western FFS sites generally were higher than at southeastern sites because burning conditions were drier in the West, resulting in higher risk of fire escaping and greater smoke production.	Cleaves et al. (2000) reported that prescribed fire costs in the Southern United States were substantially lower than costs reported at FFS sites.
188	Youngblood, A.; Bigler-Cole, H.; Fettig, C.J.; Fiedler, C.; Knapp, E.E.; Lehmkuhl, J.F.; Outcalt, K.W.; Skinner, C.N.; Stephens, S.L.; Waldrop, T.A. 2007. Making fire and fire surrogate science available: a summary of regional workshops with clients. Gen. Tech. Rep. 727. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 59 p.	Network	Sociology	B, M, M+B	1, 2, 7	Participatory evaluation was used to design four regional workshops to identify effective and efficient means of communicating FFS results to clients. Most manager participants favored the use of existing electronic platforms (e.g.,	No other studies have reported similar findings.

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Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
	Tech. Rep. 727. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 59 p.					FRAMES, FEIS) within which to place FFS information, favored the synthesis of scientific publications by topic (e.g., prescribed fire) and discipline (e.g., wildlife), and emphasized the value of one-on-one contacts with researchers.	
189	McCaffrey, S.; Moghaddas, J.J.; Stephens, S.L. 2008. Different interest group views of fuels treatments: survey results from fire and fire surrogate treatments in a Sierran mixed conifer forest, California, USA. International Journal of Wildland Fire. 17(2): 224–233.	Network	Sociology	B, M, M+B	1	Most individuals had more acceptable opinions of burning as a treatment, and this pattern applied as well to mechanical treatments for those groups having more experience with logging.	Monroe et al. (2006) reported the importance of effective outreach for educating and informing the public about the value of fuel reduction programs.
189	McCaffrey et al. 2008.	Network	Sociology	B, M, M+B	1, 7	Most respondents understood and valued the role of fuel reduction treatments for reducing wildfire hazard, yet fewer individuals found mechanical treatments to be as acceptable as burn treatments.	A majority of the public generally found fuel reduction treatments acceptable (Blanchard 2003, Brunson and Shindler 2004, Winter et al. 2005).
189	McCaffrey et al. 2008.	Network	Sociology	B, M+B	1, 7, 10	Few people were concerned about smoke production as a prescribed fire issue, while more were concerned about risks of losing control of burns.	Brunson and Shindler (2004) reported that smoke was not considered by many to be a problem associated with prescribed fire.
190	Weatherspoon, C.P. 2000. A proposed long-term national study of the consequences of fire and fire surrogate treatments. In: Neuenschwander, L.F.; Ryan, K.C.; Goldberg, G.E., eds. Proceedings, crossing the millennium: integrating spatial technologies and ecological principles for a new age in fire management, 1999 Joint Fire Science conference. Moscow, ID: University of Idaho Press: 117–126.	Network	General and study description	B, M, M+B	1, 2	The need for the proposed FFS study is discussed and the study design is described.	No other studies have reported similar findings.

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
191	McIver, J.D.; Youngblood, A.; Niwa, C.; Ottmar, R.; Smith, J. 2000a. Hypotheses on the ecological effects of alternative fuel reduction methods. In: Proceedings, Society of American Foresters 1999 national convention. Bethesda, MD: Society of American Foresters: 552–555.	Network	General and study description	B, M, M+B	1, 2	Initial hypotheses of FFS treatment responses are listed and discussed.	No other studies have reported similar findings.
192	Edminster, C.B.; Weatherspoon, C.P.; Neary, D.G. 2000. The fire and fire surrogates study: providing guidelines for fire in future watershed management decisions. In: Ffolliott, P.F.; Baker, M.B., Jr.; Edminster, C.B.; Dillon, M.C.; Mora, K.L., tech. coords. Proceedings, land stewardship in the 21st century: the contributions of watershed management. RMRS-P-13. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 312–315.	Network	General and study description	B, M, M+B	1, 2	The proposed FFS study is described in the context of watershed management.	No other studies have reported similar findings.
193	McIver, J.; Weatherspoon, P.; Edminster, C. 2001. Alternative ponderosa pine restoration treatments in the western United States. In: Vance, R.K.; Edminster, C.B.; Covington, W.W.; Blake, J.A., comps. Proceedings, ponderosa pine ecosystems restoration and conservation: steps toward stewardship. RMRS-P-22. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 104–109.	Network	General and study description	B, M, M+B	1, 2	The proposed FFS study is described in the context of ponderosa pine restoration.	No other studies have reported similar findings.
194	Youngblood, A.; Metlen, K.L.; Knapp, E.E.; Outcalt, K.W.; Stephens, S.L.; Waldrop, T.A.; Yaussy, D. 2004. Implementation of the fire and fire surrogate study, a national research effort to evaluate the consequences of fuel reduction treatments. In: Peterson, C.E.; Maguire, D.A., eds. Proceedings, balancing ecosystem values: innovative experiments for sustainable forestry. Gen. Tech. Rep. PNW-GTR-635. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 315–321.	Network	General and Study description	B, M, M+B	1, 2, 3, 4	Height to live crown ratio was not increased within the first year after treatment at several FFS sites, yet a network-wide response was expected 3 years after treatments.	No other studies have reported similar findings.
195	McIver, J.D.; Boerner, R.E.J.; Hart, S.C. 2008. The national fire and fire surrogate study: ecological consequences of alternative fuel reduction methods in seasonally dry forests. Forest Ecology and Management. 255(8–9): 3075–3080.	Network	General and study description	B, M, M+B	1, 2	This paper introduced a set of 11 papers that discuss short-term results of the national FFS study, including 4 papers on vegetation, 2 papers on fuels, 2 papers on soils, and 3 papers on wildlife.	No other studies have reported similar findings.

Table 14—Principal citations of the national Fire and Fire Surrogate (FFS) study with their findings, by site, discipline, treatment, and theme, with supporting literature (treatment codes: B = burn, M = mechanical, M+B = mechanical + burn; theme codes: 1 = fire vs. surrogates, 2 = effect size, 3 = effect duration, 4 = regional, 5 = species adaptation, 6 = heterogeneity, 7 = tradeoffs, 8 = restoration, 9 = exotics, 10 = application) (continued)

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
196	McIver, J.; Stephens, S.L.; Youngblood, A. 2009. The national fire and fire surrogate study: ecological consequences of fuel reduction methods in seasonally dry forests. Ecological Applications. 19: 283–284.	Network	General and study description	B, M, M+B	1, 2	This paper introduced a set of four papers that discuss short-term results of the national FFS study, including multisite papers on vegetation, fire performance, and soils, and a multivariate paper linking delayed tree mortality to bark beetles and fire severity.	No other studies have reported similar findings.
197	McIver, J.D.; Fettig, C.J. 2010. Ecological consequences of alternative fuel reduction treatments in seasonally dry forests: the national fire and fire surrogate study. Forest Science. 56(1): 2–3.	Network	General and study description	B, M, M+B	1, 2, 3	This paper introduced a set of 11 papers that discuss short-term results of the national FFS study, including 1 paper on the development of the study; 3 papers on changes in stand structure, fuels, or fire behavior; 2 papers on bark beetle dynamics; and 5 papers on vertebrate and invertebrate community response.	No other studies have reported similar findings.
198	McIver, J.D.; Weatherspoon, C.P. 2010. On conducting a multisite, multidisciplinary forestry research project: lessons from the national fire and fire surrogate study. Forest Science. 56(1): 4–17.	Network	General and study description	B, M, M+B	1, 2	The national FFS study was designed to improve understanding of ecosystem response to alternative fuel reduction treatment in dry forests of the United States and allow comparison of treatment responses across a wide variety of conditions. The FFS is one example of a complex multidisciplinary management experiment focused on natural resource issues. Seven key features of the FFS were necessary to achieve success: adequate funding, design, partnerships, organization, standardization, data management, and outreach.	No other studies have reported similar findings.
199	Hart, S.C.; DeLuca, T.H.; Newman, G.S.; MacKenzie, M.D.; Boyle, S.I. 2005. Post-fire vegetative dynamics as drivers of microbial community structure and function in forest soils. Forest Ecology and Management. 220(1–3): 166–184.	Network	Multivariate	B, M+B	2, 3	Low-intensity fires caused transient changes in soil microbial communities across the FFS network of sites. More permanent changes would be predicted	No other studies have reported similar findings.

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
						if understory plant species composition changed. Few long-term studies have examined links among fire, plant and microbial communities, and ecosystem function.	
200	Waldrop, T.A.; McIver, J. 2006. The national fire and fire surrogate study: early results and future challenges. In: Conner, K.F., ed. Proceedings, 13th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-92. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 526–530.	Network	Multivariate	B, M, M+B	1	The national FFS study was designed to provide information on the effects of alternative fuel reduction treatments in dry forests. Different types of analyses were planned, including univariate comparisons at a single site, univariate comparisons at multiple sites, multivariate comparisons at a single site, and multivariate comparisons across multiple sites.	No other studies have reported similar findings.
201	Boerner, R.E.J. 2005. Soil, fire, water, and wind: How the elements conspire in the forest context. In: Dickinson, M.B., ed. Proceedings: fire in eastern oak forests: delivering science to land managers. Gen. Tech. Rep. GTR-NRS-P-1. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station: 104–122.	Network	Multivariate	B, M+B	2, 3, 6	Fires in oak (*Quercus* spp.)-dominated forests occur primarily during the dormant season, and generally are of low intensity. Principal effects of these fires included (1) direct soil heating, which alters soil properties and kills soil organisms; (2) volatilization and ash convection of nitrogen, phosphorus, and cations; (3) mineral soil exposure, which may lead to sheet erosion if slope is sufficient; (4) subtle and transient changes in nitrogen availability, organic carbon, and soil microorganisms; (5) complex effects owing to heterogeneous geomorphology of most oak-dominated forests.	No other studies have reported similar findings.
202	Gundale, M.J.; Metlen, K.L.; Fiedler, C.E.; DeLuca, T.H. 2006. Nitrogen spatial heterogeneity influences diversity following restoration in a ponderosa pine forest, Montana. Ecological Applications. 16(2): 479–489.	Northern Rocky Mountains	Multivariate	B, M, M+B	1, 6, 8	Net increase in species richness was correlated with total inorganic nitrogen standard deviations 1 and 2 years after restoration treatments, supporting the resource heterogeneity hypothesis. Within	Baer et al. (2004) reported the influence of nitrogen heterogeneity on diversity in the context of burn treatments,yet found no link between

Table 14—Principal citations of the national Fire and Fire Surrogate (FFS) study with their findings, by site, discipline, treatment, and theme, with supporting literature (treatment codes: B = burn, M = mechanical, M+B = mechanical + burn; theme codes: 1 = fire vs. surrogates, 2 = effect size, 3 = effect duration, 4 = regional, 5 = species adaptation, 6 = heterogeneity, 7 = tradeoffs, 8 = restoration, 9 = exotics, 10 = application) (continued)

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
						burn treatments, total inorganic nitrogen heterogeneity was positively correlated with fine fuel consumption, a variable reflecting burn severity.	total inorganic nitrogen heterogeneity and diversity. The resource heterogeneity hypothesis was supported by work showing that species composition was dissimilar on different resource patches (Fitter 1982, Inouye and Tilman 1995, Reynolds et al. 1997, Sulkava and Huhta 1998, Vivian-Smith 1997).
202	Gundale et al. 2006.	Network	Multivariate	B, M, M+B	1, 6, 9	Native and exotic plant species responded positively to increased heterogeneity in total inorganic nitrogen after burn treatments.	Burnett et al. (1997) and Nichols et al. (1998) described factors that caused heterogeneity at different patch scales.
203	Schwilk, D.W.; Keeley, J.E.; Knapp, E.E.; McIver, J.; Bailey, J.D.; Fettig, C.J.; Fiedler, C.E.; Harrod, R.J.; Moghaddas, J.J.; Outcalt, K.W.; Skinner, C.N.; Stephens, S.L.; Waldrop, T.A.; Yaussy, D.A.; Youngblood, A. 2009. The national fire and fire surrogate study: effects of fuel reduction methods on forest vegetation structure and fuels. Ecological Applications. 19(2): 285–304.	Network	Multivariate	B, M, M+B	1, 2, 7, 9	Across the network of FFS sites, key ecological variables including fewer and larger diameter trees, less surface fuel mass, and greater herbaceous species richness were obtained after mechanical + burn treatments, but this set of treatment also favored alien species invasion at some sites.	Riegel et al. (1995) and Wayman and North (2007) reported understory vegetation responded favorably to light and suggested that a change in forest floor microclimate improved conditions for herbaceous species and thereby increased species richness. Alien species often responded to disturbance (Collins et al. 2007, Dodson and Fiedler 2006, Keeley et al. 2003, Kerns et al. 2006). Increases of alien species may be short-lived when soil disturbance is ephemeral (Keeley and McGinnis 2007).

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
203	Schwilk et al. 2009.	Network	Multivariate	B, M, M+B	2	Across the network of FFS sites, treatments that included burns were more effective at creating snags, killing seedlings, elevating height to live crown, and reducing surface woody fuels than treatments lacking burns.	No other studies have reported similar findings.
203	Schwilk et al. 2009.	Network	Multivariate	M, M+B	2	Across the network of FFS sites, mechanical treatments were more effective at reducing overstory tree density and basal area, and increasing quadratic mean tree diameter in the first year after treatment than treatments lacking a mechanical component.	Burns conducted under relatively cool conditions do not thin large trees (Miller and Urban 2000). Burning may increase mineral soil exposure and initiate tree regeneration (Moghaddas et al. 2008) and germination of herbaceous species (Moghaddas and Stephens 2007a). Burning caused patchiness, which may increase species richness (Connell 1978, Pickett 1980).
203	Schwilk et al. 2009.	Network	Multivariate	B, M+B	2, 3	Across the network of FFS sites, shrub cover generally declined after burn treatments and then recovered to previous levels 2 to 4 years after burning.	Shrub growth after burn treatments was linked to increased light in the openings of the overstory canopy and species-specific resprouting capabilities (Knapp et al. 2007).
204	Knapp, E.E.; Estes, B.L.; Skinner, C.N. 2009. Ecological effects of prescribed fire season: a literature review and synthesis for managers. Gen. Tech. Rep. PSW-GTR-224. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 80 p.	Network	Multivariate	B	10	Burning may be conducted at times of the year when fires were infrequent historically, leading to concerns about potential adverse effects on vegetation and wildlife. In regions and vegetation types where considerable differences	No other studies have reported similar findings.

Table 14—Principal citations of the national Fire and Fire Surrogate (FFS) study with their findings, by site, discipline, treatment, and theme, with supporting literature (treatment codes: B = burn, M = mechanical, M+B = mechanical + burn; theme codes: 1 = fire vs. surrogates, 2 = effect size, 3 = effect duration, 4 = regional, 5 = species adaptation, 6 = heterogeneity, 7 = tradeoffs, 8 = restoration, 9 = exotics, 10 = application) (continued)

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
						in fuel consumption exist among burning seasons, the effects of prescribed fire season appears, for many ecological variables, to be driven more by fire intensity differences among seasons than by phenology or growth stage of organisms at the time of fire. Most species in ecosystems that evolved with fire appear resilient to one or a few out-of-season (i.e., external to the historical fire regime window) prescribed burns.	
204	Knapp et al. 2009.	Network	Multivariate	B	10	Where fuel consumption differs little among seasons, the effect of phenology or growth stage is typically more apparent, because it is not overwhelmed by fire intensity differences.	No other studies have reported similar findings.
204	Knapp et al. 2009.	Network	Multivariate	B	10	There is compelling evidence that growing-season burns in eastern pine and pine-oak woodland lead to shifts in the understory plant community relative to dormant-season fire.	No other studies have reported similar findings.
205	Grace, J.B.; Youngblood, A.; Scheiner, S.M. 2009. Structural equation modeling and ecological experiments. In: Miao, S.; Carstenn, S.; Nungesser, M., eds. Real world ecology: large-scale and long-term case studies and methods. New York: Springer Science+Business Media: 19–45. Chapter 2.	Network	Multivariate	B, M, M+B	1, 2	Structural equation modeling is a framework representing a wide range of models that emphasizes the study of pathways to learn about causal processes. It can be used to evaluate theoretically specified models rather than null hypotheses, and can contribute to a system-level understanding by informing the simultaneous functioning of multiple processes.	No other studies have reported similar findings.

Number	Citation	Site	Discipline	Treatment	Theme	Finding	Supporting literature
205	Grace et al. 2009.	Network	Multivariate	B, M, M+B	1, 2	As an example of structural equation modeling, work from the Blue Mountains FFS site was used to demonstrate causal pathways for large tree mortality. Delayed mortality of large-diameter ponderosa pine from bark beetles and wood borers was directly related to surface fire severity and bole charring, which in turn depended on fire intensity, which in turn was greater where thinning increased slash fuels.	Youngblood et al. (2009) reported the structural equation modeling pathway leading to large tree mortality.
206	Campbell, J.W.; Hanula, J.L.; Outcalt, K.W. 2008. Effects of prescribed fire and other plant community restoration treatments on tree mortality, bark beetles, and other saproxylic Coleoptera of longleaf pine, *Pinus palustris* Mill., on the coastal plain of Alabama. Forest Ecology and Management. 254: 134–144.	Gulf Coastal Plain	Multivariate	M+B	1, 7	Mechanical + burn treatment caused the highest mortality of trees, with fire being the primary cause of death; most mortality occurred within 1 year after treatment.	No other studies have reported similar findings.
206	Campbell et al. 2008.	Gulf Coastal Plain	Multivariate	B, M, M+B	1, 7	Beetle species richness was highest in stands receiving both mechanical and burn treatments.	No other studies have reported similar findings.
206	Campbell et al. 2008.	Gulf Coastal Plain	Multivariate	B, M, M+B	1, 7	Bark beetle response was variable among species, but number generally increased when stands were burned; most other beetles were less responsive to fire.	No other studies have reported similar findings.
206	Campbell et al. 2008.	Gulf Coastal Plain	Multivariate	B, M, M+B	1, 7	Abundance of wood-boring beetles increased with increasing numbers of dead trees.	No other studies have reported similar findings.

English Equivalents

When you know:	Multiply by:	To get:
Centimeters (cm)	.394	Inches
Meters (m)	3.28	Feet
Hectares (ha)	2.47	Acres
Square meters (m^2)	10.76	Square feet
Cubic meters per hectare (m^3/ha)	14.29	Cubic feet per acre
Kilograms per hectare (kg/ha)	.893	Pounds per acre
Tons per hectare (t/ha)	893	Pounds per acre

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