Chapter 7
Herbaceous Response to Type and Severity of Disturbance

Katherine J. Elliott, Craig A. Harper, and Beverly Collins

Abstract The herbaceous layer varies with topographic heterogeneity and harbors the great majority of plant diversity in eastern deciduous forests. We described the interplay between disturbances, both natural and human-caused, and composition, dynamics, and diversity of herbaceous vegetation, especially those in early successional habitats. Management actions that create low to moderate disturbance intensity can promote early successional species and increase diversity and abundance in the herb layer, although sustaining communities such as open areas, savannahs, and woodlands may require intensive management to control invasive species or implement key disturbance types. A mixture of silvicultural practices along a gradient of disturbance intensity will maintain a range of stand structures and herbaceous diversity throughout the central hardwood forest.

7.1 Introduction

The herbaceous layer, made up of all herbaceous species and woody species under a meter height, harbors the great majority of plant diversity in eastern deciduous forests (Gilliam and Roberts 2003). In landscapes with significant topographic

K.J. Elliott (✉)
USDA Forest Service, Southern Research Station, Center for Forest Watershed Research, Coweeta Hydrologic Laboratory, Otto, NC, USA
e-mail: kelliott@fs.fed.us

C.A. Harper
Department of Forestry, Wildlife, and Fisheries, University of Tennessee, Knoxville, TN, USA
e-mail: charper@utk.edu

B. Collins
Department of Biology, Western Carolina University, Cullowhee, NC, USA
e-mail: collinsb@email.wcu.edu

C.H. Greenberg et al. (eds.), *Sustaining Young Forest Communities*, Managing Forest Ecosystems 21, DOI 10.1007/978-94-007-1620-9_7,

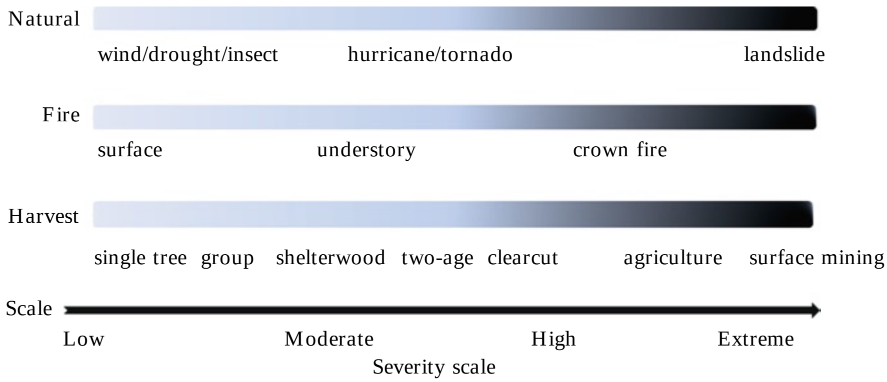

Fig. 7.1 Conceptual diagram of disturbance severity scale for natural and human-induced events

heterogeneity, herb layer composition and diversity vary with gradients of microclimate, soil moisture, and soil fertility (Hutchinson et al. 2005). Herb layer vegetation also is affected by natural and anthropogenic disturbances. Disturbances to the tree canopy, including individual tree falls, catastrophic wind events, catastrophic wildfire, and timber harvesting, result in moderate to large increases in resource availability (Small and McCarthy 2002; Roberts and Gilliam 2003). Low severity disturbances, such as surface fires, usually cause minor damage to overstory trees but affect herb layer vegetation directly by killing aboveground stems and indirectly by altering the forest floor and the availability of light, water, and nutrients (Elliott et al. 2004; Knoepp et al. 2009). At the highest end of a severity scale (Fig. 7.1), disturbances such as agriculture, landslides, and surface mining remove vegetation and till or entirely remove the soil, even down to bedrock. In this chapter, we examined the interplay between disturbance, both natural and human-caused, and composition, dynamics, and diversity of herbaceous vegetation. We briefly discuss herb layer contribution to early successional habitats in different communities, and then focus mostly on herbaceous layer response to specific types and severities of disturbance.

7.2 Early Successional Communities

The herb layer composition of open areas such as abandoned pastures, savannahs, and woodlands affects the quality of early successional habitats these communities provide to wildlife (Jones and Chamberlain 2004; Donner et al. 2010). Desirable plants provide protective cover and nutritious food sources, and allow travel, feeding, and loafing by wildlife within and under the cover. Conversely, undesirable plants provide suboptimal cover, seed, or forage that is not palatable or digestible and inhibit mobility of small animals. When undesirable plants dominate an area, usable space is limited and the abundance and species richness of wildlife may be

Fig. 7.2 An open field (**a**) and woodland (**b**) in eastern Tennessee with abundant native warm season grasses and forbs (photo by C.A. Harper)

relatively low. Management actions that increase diversity and abundance of desirable herb layer species can help sustain quality early successional habitats in these communities (Fig. 7.2).

In open areas and abandoned pastures, for example, eradicating non-native plant cover such as tall fescue (*Festuca elatior*) and bermudagrass (*Cynodon dactylon*), may be necessary before more desirable plant species can be established (Harper et al. 2007; Harper and Gruchy 2009). Tall fescue, which became the most important cultivated pasture grass in the Central Hardwood Region by the 1970s, develops a dense, sod-forming structure near the ground and deep thatch that restricts mobility of several birds (Harper and Gruchy 2009), including young Eastern Wild Turkey (*Meleagris gallopavo*), Northern Bobwhite (*Colinus virginianus*), Field Sparrows (*Spizella pusilla*) and Grasshopper Sparrows (*Ammodramus savannarum*). Its dense growth and thatch can suppress germination of more desirable ground layer plants such as broomsedge (*Andropogon virginicus*), big bluestem (*Andropogon gerardii*), little bluestem (*Schizachyrium scoparium*), blackberry (*Rubus* spp.), American pokeweed (*Phytolacca americana*), native lespedezas (*Lespedeza* spp.), ticktrefoil (*Desmodium* spp.), and partridge pea (*Chamaecrista fasiculata*). Desirable open areas have a mixture of native warm-season grasses and forbs with scattered patches of shrubs, such as wild plum (*Prunus* spp.), sumac (*Rhus* spp.), and crabapple (*Malus* spp.).

Prescribed fire, particularly growing season fires, may be necessary to reduce woody encroachment and maintain early successional grasses and forbs (Klaus et al. 2005; Harper 2007; Gruchy et al. 2009) in savannahs and woodlands. These communities are found throughout tropical and temperate portions of the world and are characterized by scattered overstory trees and a continuous herbaceous understory rich in grasses and forbs. Frequent fire, grazing, and periodic drought or relatively low annual precipitation maintain the open canopy of savannahs and woodlands (Brudvig and Asbjornsen 2008), and the vast majority of these communities in the eastern USA have been lost over the past century as a result of fire suppression, agriculture, and development (Scholes and Archer 1997; Abrams 2003; Spetich et al., Chap. 4). Management using late-dormant season fire at 3 year intervals led to dramatic increases in both richness and density of small mammals and songbirds, and provided more than adequate high-quality forage for white-tailed deer and elk in mature shortleaf pine (*Pinus echinata*) – bluestem sites (Masters 2007).

7.3 Disturbance and Forest Herb Layer Vegetation

In forests, herbaceous vegetation response depends on the type and severity of disturbances, which regulate supplies of resources such as light, soil nutrients, and moisture (Clinton 1995). Stand-replacing, high-severity disturbances (Fig. 7.1) create relatively homogeneous resource availability while low- to moderate-severity disturbances (Fig. 7.1) partially remove the canopy and generally result in greater resource heterogeneity (Gravel et al. 2010; White et al., Chap. 3). Silvicultural systems used in central hardwood forests represent a gradient of disturbance severity, from the least intense single-tree selection (harvesting individual selected trees from most of all size classes) to the most intense clear-cutting (complete removal of the stand in a single harvest) (Loftis et al., Chap. 5). In the following sections, we discuss human-caused and natural disturbances that commonly affect herbaceous vegetation in forests of the Central Hardwood Region.

7.3.1 Harvests

Herbaceous response to forest harvests differs among ecoregions within the Central Hardwood Region. In the Southern Appalachians and adjacent areas, high growth rates and nutrient concentrations of herbaceous plants result in faster recovery of aboveground biomass following clearcutting (Boring et al. 1988; Elliott et al. 2002a) compared to northern hardwood forests (Federer et al. 1989; Reiners 1992; Mou et al. 1993). For example, 1 year after harvest, aboveground biomass of herbs in clearcuts ranged from 0.18 to 0.40 Mg ha^{-1} in a hardwood watershed in western North Carolina (Elliott et al. 2002a) compared to only 0.09 Mg ha^{-1} in a northern hardwood forest in New Hampshire (Mou et al. 1993). However, herbaceous layer diversity in the harvested North Carolina watershed was lower than that in a nearby mature (≈70-years-old) forest (Table 7.1). In addition, it can take decades for herb layer diversity to recover from clearcut harvests. For example, flatter dominance diversity curves for reference and pre-harvest compared to post-harvest stands in two clearcut watersheds in the Coweeta Basin in western North Carolina show the herbaceous layer has not recovered diversity 30 years after disturbance (Fig. 7.3).

In contrast to the Southern Appalachians, all measures of herbaceous abundance and diversity in young (ca. 7 years old) clearcuts were greater than those in mature (more than 125 years old) stands in the Central Appalachians of Ohio (Small and McCarthy 2005), including mean cover (10.94% ± 1.42 versus 4.89 ± 0.57), richness, and H′ diversity (Table 7.1). Clearcut and mature forests shared high importance of several species, including white wood aster (*Aster divaricatus*), hog peanut (*Amphicarpaea bracteata*), whorled loosestrife (*Lysimachia quadrifolia*), Christmas-fern (*Polysticum acrostichoides*), and dooryard violet (*Viola sororia*). At the same time, younger stands showed greater importance of annual or shade-intolerant graminoids, such as sedges (*Carex digitalis*, *Carex laxiflora*), panic grass (*Panicum clandestinum*), and *Poa* spp., and non-native herbs (e.g., hoary bitter-cress (*Cardamine hirsuta*) and sulphur cinquefoil (*Potentilla recta*)), while mature stands showed greater importance of shade-tolerant perennials such as black cohosh (*Cimicifuga racemosa*), bland sweet cicely (*Osmorhiza claytonia*), Solomon's seal (*Polygonatum pubescens*), false Solomon's seal *(Smilacina racemosa)*, and bellwort (*Uvularia perfoliata*) (Small and McCarthy 2005).

Other studies from sites within the Central Hardwood Region show diverse herb layer responses to forest harvests. Belote et al. (2009) used sites in Virginia and West Virginia to investigate how a gradient in disturbance intensity caused by different levels of timber harvesting influenced plant diversity through time and across spatial scales ranging from a square meter to 2 ha. The gradient of tree canopy removal and associated forest floor disturbance ranged from clearcut (95% basal area removed), leave-tree harvest (74% basal area removed leaving a few dominants), shelterwood harvest (56% basal area removed), understory herbicide (suppressed trees removed via basal application of herbicide), to uncut control. In the first year after disturbance, herbaceous species diversity increased at all spatial scales, but after 10 years of forest development shading by the canopy once again

Table 7.1 Mean (SE) herbaceous layer diversity (S = species richness; H′ = Shannon's diversity index; E′ = Pielou's evenness index) for different types and severities of disturbance for numerous studies across the Central Hardwood Region. S, H′ and E were calculated at the small plot ($1.0\ m^2$) level with means and standard errors presented for each treatment and study location

Treatment	Location	Community	Time since last disturbance	Diversity[a]			References
				S	H′	E	
Silviculture Rx							
Mature forest [precut forest]	Coweeta WS7	Mixed deciduous, low elevation, south-facing	50+ years	16.1 (1.3)	2.11 (0.10)	0.79 (0.02)	Elliott et al. 1997[b]
Clearcut	Coweeta WS7	Mixed deciduous, low elevation, south-facing	1 year	3.6 (0.3)	0.91 (0.09)	0.80 (0.02)	Elliott et al. 1997[b]
Clearcut	Coweeta WS7	Mixed deciduous, low elevation, south-facing	17 years	4.4 (0.4)	0.80 (0.08)	0.62 (0.04)	Elliott et al. 1997[b]
Clearcut	Coweeta WS7	Mixed deciduous, low elevation, south-facing	30 years	4.8 (0.5)	0.78 (0.08)	0.59 (0.04)	Elliott, unpublished
Mature forests [reference]	Allegheny Plateau, OH	Mixed-oak, low elevation (< 320 m)	>125 years	4.7 (0.4)	1.08 (0.09)		Small and McCarthy 2005
Clearcuts	Allegheny Plateau, OH	Mixed-oak, low elevation (< 320 m)	7 years	6.0 (0.4)	1.34 (0.07)		Small and McCarthy 2005
Mature forest [reference]	Wine Spring, NC	*Quercus rubra*, high elevation (> 1,200 m)	50+ years	15.0 (0.7)	2.12 (0.06)	0.79 (0.01)	Elliott and Knoepp 2005[b]
Two-age cut	Wine Spring, NC	*Quercus rubra*, high elevation (> 1,200 m)	2 years	14.9 (0.8)	2.12 (0.08)	0.80 (0.02)	Elliott and Knoepp 2005[b]

Group selection	Wine Spring, NC	*Quercus rubra*, high elevation (> 1,200 m)	2 years	16.8 (0.7)	2.25 (0.07)	0.81 (0.02)	Elliott and Knoepp 2005[b]
Shelterwood	Wine Spring, NC	*Quercus rubra*, high elevation (> 1,200 m)	2 years	18.8 (0.8)	2.40 (0.06)	0.82 (0.01)	Elliott and Knoepp 2005[b]
Mature forest [reference]	Ray Branch, NC	Mixed deciduous, mid elevation (850–950 m)	50+ years	21.0 (1.0)	1.89 (0.07)	0.63 (0.02)	Elliott, unpublished
Two-age cut	Ray Branch, NC	Mixed deciduous, mid elevation (850–950 m)	2 years	31.5 (1.7)	2.38 (0.06)	0.70 (0.01)	Elliott, unpublished
Abandoned pasture or old field							
Mature forest [reference]	Coweeta WS14	Mixed deciduous, low elevation, north-facing	70 years	12.1 (1.6)	1.51 (0.15)	0.70 (0.04)	Elliott et al. 1998[b]
Grass-to-forest	Coweeta WS6	Mixed deciduous, low elevation, north-facing	1 year	11.6 (0.58)	1.54 (0.08)	0.63 (0.03)	Elliott et al. 1998[b]
Grass-to-forest	Coweeta WS6	Mixed deciduous, low elevation, north-facing	28 years	11.6 (0.58)	1.54 (0.08)	0.63 (0.03)	Elliott et al. 1998[b]
Old Field	Wayne County, WV	Stream floodplain, bottomland hardwoods	20 years	13.4 (0.5)	2.21 (0.05)	0.86 (0.01)	Gilliam and Dick 2010
Pasture	Wayne County, WV	Stream floodplain,	< 1 year	5.9 (0.2)	1.38 (0.03)	0.78 (0.01)	Gilliam and Dick 2010
Fire							
Mature forest [pre-burn]	Wine Spring, NC	Pine-oak-heath	50+ years	5.8 (1.4)	1.02 (0.22)	0.35 (0.03)	Elliott et al. 1999[b]

(continued)

Table 7.1 (continued)

Treatment	Location	Community	Time since last disturbance	Diversity[a]			References
				S	H′	E	
Rx fire (single burn)	Wine Spring, NC	Pine-oak-heath	2 years	5.9 (0.3)	1.35 (0.05)	0.80 (0.02)	Elliott et al. 1999[b]
Rx fire (single burn)	Wine Spring, NC	Pine-oak-heath	10 years	7.0 (0.4)	1.53 (0.06)	0.81 (0.02)	Elliott et al. 2009[b]
Mature forest [reference]	Ocoee, TN	Shortleaf pine-mixed oak	50+ years	5.2 (0.4)	1.12 (0.10)	0.71 (0.04)	Elliott, unpublished
Rx fire (repeated 2X)	Ocoee, TN	Shortleaf pine-mixed oak	2 years	5.4 (0.5)	1.19 (0.10)	0.76 (0.03)	Elliott, unpublished
Cut + Rx fire (repeated 2X)	Ocoee, TN	Shortleaf pine-mixed oak	2 years	6.3 (0.4)	1.36 (0.08)	0.76 (0.02)	Elliott, unpublished
Cut + Rx fire (repeated 2X)	Ocoee, TN	Mesic, mixed oak-pine	2 years	11.8 (0.5)	1.90 (0.06)	0.78 (0.02)	Elliott, unpublished
Mature forest [reference]	Smoky Mountains, TN	Mixed deciduous	50+ years	22	2.4 (0.2)	0.74 (0.02)	Holzmueller et al. 2009
Wildfire (single burn)	Smoky Mountains, TN	Mixed deciduous	~20 years	27	2.5 (0.2)	0.75 (0.03)	Holzmueller et al. 2009
Wildfire (repeated 2X)	Smoky Mountains, TN	Mixed deciduous	~20 years	27	2.3 (0.3)	0.70 (0.03)	Holzmueller et al. 2009
Wildfire (repeated 3X)	Smoky Mountains, TN	Mixed deciduous	~20 years	27	2.0 (0.4)	0.62 (0.05)	Holzmueller et al. 2009
Mature forest [reference]	Allegheny Plateau, OH	Oak-hickory	50+ years	14 (0.8)	3.73 (0.04)	0.91 (0.01)	Hutchinson et al. 2005[c]

Rx fire (repeated 2X)	Allegheny Plateau, OH	Oak-hickory	2 years	17 (0.8)	3.82 (0.03)	0.92 (0.01)	Hutchinson et al. 2005[c]
Rx fire (annual 4X)	Allegheny Plateau, OH	Oak-hickory	1 year	17 (0.8)	3.81 (0.03)	0.91 (0.01)	Hutchinson et al. 2005[c]
Mature forest [reference]	Monongahela National Forest, WV	Mixed deciduous	50+ years		1.06 (0.11)		Royo et al. 2010
Rx fire + gap + grazing	Monongahela National Forest, WV	Mixed deciduous	5 years	5.6 (1.1)	1.31 (0.09)		Royo et al. 2010
Fire + gap	Monongahela National Forest, WV	Mixed deciduous	5 years	2.9 (0.7)			Royo et al. 2010
Post-burn, 2-year fire interval	Fort Benning, GA	Mixed oak-pine	postburn	4.7 (0.7)	3.63[e] (0.15)	0.49 (0.003)	Collins, unpublished[d]
Post-burn, 4-year fire interval	Fort Benning, GA	Mixed oak-pine	postburn	4.1 (0.3)	3.55[e] (0.09)	0.54 (0.01)	Collins, unpublished[d]
2-year fire interval	Fort Benning, GA	Mixed oak-pine	1 year	5.4 (0.9)	3.8 (0.17)	0.49 (0.04)	Collins, unpublished[d]
4-year fire interval	Fort Benning, GA	Mixed oak-pine	3 year	5.0 (0.54)	3.7 (0.11)	0.50 (0.02)	Collins, unpublished[d]
Wind disturbance							
Mature forest [reference]	Massac County, IL	Bottomland hardwoods	60+ years		0.92		Nelson et al. 2008[e]
Wind	Massac County, IL	Bottomland hardwoods	3 years		1.47		Nelson et al. 2008[e]
Wind + salvage	Massac County, IL	Bottomland hardwoods	3 years		1.72		Nelson et al. 2008[e]

(continued)

Table 7.1 (continued)

Treatment	Location	Community	Time since last disturbance	Diversity[a] S	H′	E	References
Mature forest [reference]	Coweeta	High elevation (> 1,100 m), Mixed-oak	70+ years	9.5 (1.0)	1.49 (0.14)	0.70 (0.04)	Elliott et al. 2002b[b]
Wind + salvage	Coweeta	High elevation (> 1,100 m), Mixed-oak	2 years	14.5 (0.7)	1.87 (0.07)	0.71 (0.02)	Elliott et al. 2002[b]
Mature forest [reference]	Northwestern, CO	Subalpine, high elevation (> 1,260 m), spruce-fir	>200 years	14.6 (1.5)	2.2 (0.2)	0.75 (0.04)	Rumbaitis del Rio 2006
Wind	Northwestern, CO	Subalpine, high elevation (> 1,260 m), spruce-fir	4 years	17.8 (1.6)	2.2 (0.1)	0.76 (0.02)	Rumbaitis del Rio 2006
Wind + salvage	Northwestern, CO	Subalpine, high elevation (> 1,260 m), spruce-fir	4 years	6.3 (0.7)	1.3 (0.1)	0.74 (0.02)	Rumbaitis del Rio 2006

[a]Shannon index was calculated as: $H' = pi \ln pi$, where pi = proportion of total percent cover or total aboveground biomass (g) of species i. Species evenness was calculated as: $E = H'/H'_{MAX}$, where H'_{MAX} = maximum level of diversity possible within a given population = ln(number of species) (Magurran 2004). Standard errors are in parentheses

[b]S, H, and E were re-calculated at a finer spatial scale (1.0 m^2 plot) than presented in the original manuscripts (≥100 m^2 plot) for comparisons among other studies listed in the table

[c]Hutchinson et al. (2005) used a 2.0 m^2 plot for herbaceous layer sampling

[d]Collins (unpublished) based calculations on twelve 12 m line intercept samples in each of 10 sites, significantly different ($p = 0.039$)

[e]Newman et al. (2008) found no significant differences ($p = 0.082$) among treatments

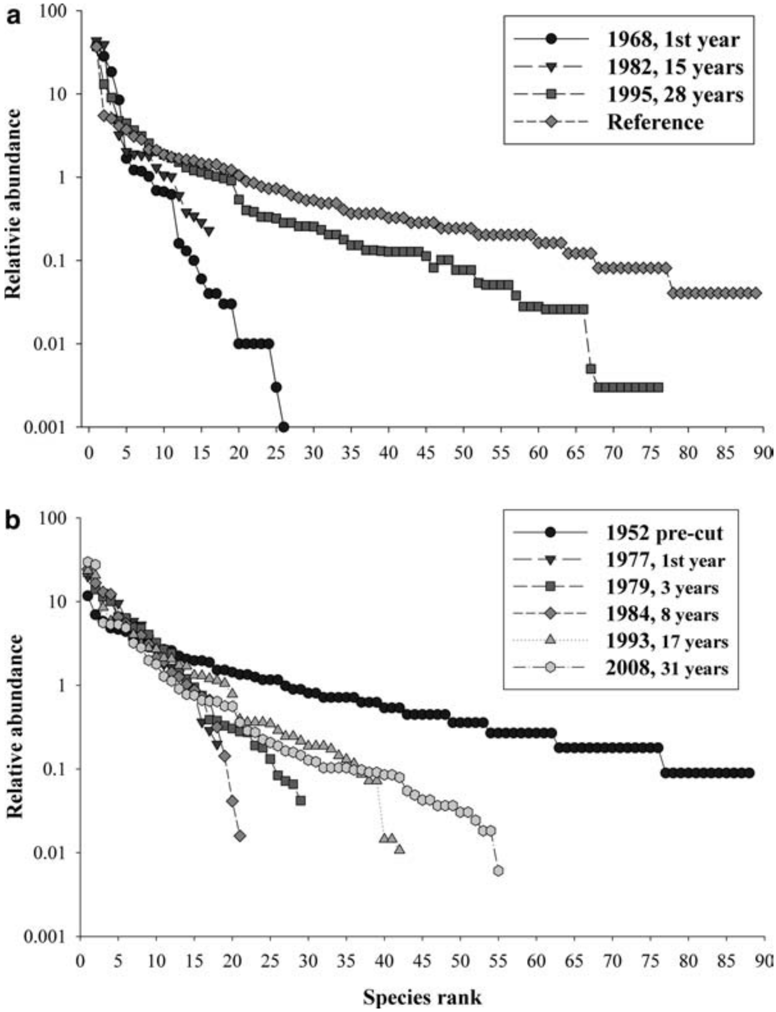

Fig. 7.3 Dominance-diversity curves for two clearcut watersheds, WS6 and WS7, in the Coweeta Basin, western North Carolina (Adapted from Elliott et al. 1997, 1998 and Elliott, unpublished). Curves were based on percent cover for (**a**) WS6 at 1, 15, and 28 years after the final disturbance and (**b**) WS7 prior to clearcutting in 1952, and 1, 3, 8, 17, and 31 years after cutting. Flatter curves represent high species diversity or low dominance by a few species; in contrast, steep curves represent low species diversity or a high degree of dominance (Whittaker 1965)

controlled diversity (Belote et al. 2009). Zenner et al. (2006) compared five harvest treatments in upland mixed oak hardwoods in the Missouri Ozarks. The harvest treatments caused overstory canopy reductions from 12.8% in controls to 83.6% in clearcuts. Herb layer vegetation showed a clear response that increased in proportion to harvest treatment intensity, with relative species composition and abundance of life forms increasing in proportion to harvest intensity. Dominance of legumes and tree seedlings decreased while woody vines, graminoids, and annuals/biennials increased along the harvest intensity gradient. Elliott and Knoepp (2005) found a similar pattern in herbaceous layer diversity in the Southern Appalachians; group selection (24% canopy reduction) and shelterwood harvests (68% canopy reduction) had higher species richness and diversity (Shannon's index of diversity, Magurran 2004) than the heavier two-age cut (80% canopy reduction) and reference forests (Table 7.1). In partial cuts, shade from the residual overstory trees created a mosaic of environmental conditions, which provided suitable microsites for a mix of shade-intolerant and shade-tolerant herbaceous species, and higher species richness and diversity than an undisturbed forest.

Taken together, the research shows that harvesting central hardwood forests affects diversity and species composition of herbaceous layer vegetation. Diversity can increase or decrease following harvest, then recovers, but the recovery can take decades to reach pre-harvest or reference values. In addition, harvests can increase abundance of shade-intolerant species associated with early successional habitats in proportion to intensity of the harvest treatment.

7.3.2 Abandoned Agricultural Lands

Abandoned agricultural land is common in the eastern USA (Parker and Merritt 1994; Bellemare et al. 2002), but is declining as oldfields shift to forest lands. In the Southern Appalachians, for example, agricultural lands have declined by an average 13% from the 1950s to the 1990s (Wear and Bolstad 1998). In fact, major portions of today's eastern National Forests were once abandoned agricultural land (Jenkins and Parker 2000; Thiemann et al. 2009).

Agricultural use has had a definite and severe effect on native plant communities (Flinn and Vellend 2005). Forests growing on former agricultural land often have lower frequencies of many native forest herbs than forests that were never cleared for agriculture. A leading explanation for this pattern is that many forest herbs are dispersal-limited, but environmental conditions can also hinder colonization (Fraterrigo et al. 2009a, b). Abandoned agricultural areas have a species composition that is highly variable and distinct from other disturbance types. For example, in southern Indiana, several typical disturbance species, such as blackberry (*Rubus* spp.) and northern groundcedar (*Lycopodium complanatum*), and many non-native species such as grass pink (*Dianthus armeria*), meadow fescue (*Festuca pratensis*), and oxeye daisy (*Leucanthemum vulgare*), were associated with abandoned agriculture plots (Jenkins and Parker 2000). Abandoned agriculture plots had significantly greater cover of giant ragweed (*Ambrosia trifida*, federally listed as a noxious-weed and common in oldfields) than four other stands types (Jenkins and Parker 2000).

In Great Smoky Mountains National Park, abandoned agricultural plots were associated with species normally found in dry and sub-mesic communities, including ebony spleenwort (*Asplenium platyneuron*), ribbed sedge (*Carex virescens*), poverty oatgrass (*Danthonia spicata*), hillside blueberry (*Vaccinium palladium*), and dwarf dandelion (*Krigia biflora*) (Thiemann et al. 2009). They also were associated with an influx of non-native and non-forest species such as northern ground-cedar (*Lycopodium complanatum*), Japanese honeysuckle (*Lonicera japonica*), and heart-leaved groundsel (*Senecio aureus*) (Thiemann et al. 2009). In addition, many other indicators of mesic forests, including star chickweed (*Stellaria pubera*), Canadian woodnettle (*Laportea canadensis*), bloodroot (*Sanguinaria canadensis*), celandine-poppy (*Stylophorum diphyllum*), and five-parted bitter-cress (*Cardamine concatenate*) were not found in the abandoned agriculture plots (Thiemann et al. 2009).

In general, abandoned agricultural fields can maintain early successional vegetation on the landscape from open site through young forest conditions. Early successional species that establish in the herbaceous layer can persist for several decades. At the same time, these sites may promote invasive species and have slow establishment of forest understory herbs.

7.3.3 Surface Mining and Mountain-Top Removal

Surface mining, particularly mountain-top removal, is the most severe disturbance type in the Central Hardwood Region, with the exception of landslides (Hales et al. 2009). Some coal surface mines have been reclaimed for more than 40 years, and reclamation has been mandated by USA federal law for almost 30 years (Surface Mining Control and Reclamation Act, Public Law 95–87 Federal Register 3 Aug 1977, 445–532). Coal surface mine reclamation practices are similar to those of other large-scale land reclamation projects: a few aggressive plant species are seeded or planted in an effort to achieve legal requirements for minimum ground cover and prevent soil erosion. Many mine reclamation efforts focus on establishing rapid-growing non-native species that control erosion but may slow or prevent the establishment of later-successional, native species (Holl 2002). Until recently, this seeded ground cover consisted of Kentucky-31 tall fescue (*Festuca elatior*), red clover (*Trifolium pratense*), sericea lespedeza (*Lespedeza cuneata*), and birdsfoot trefoil (*Lotus corniculatus*), all of which are non-native and dense.

Although efforts are underway to establish native species, many recently mined mountain tops are still hydro-seeded with a non-native mixture of species. Once these species are established, it can be difficult to reduce their cover and replace them with native species. In addition, these non-native plant communities may be susceptible to establishment of invasive woody species. For example, 50 years after being reclaimed with sericea lespedeza, red clover, and Kentucky-31 tall fescue beneath planted eastern white pine (*Pinus strobus*), autumn olive (*Eleagnus umbellata*), privet (*Ligustrum* spp.), and dying white pines made up a significant component of the woody understory and forest edge vegetation on a coal surface mine in eastern Kentucky (Collins, unpublished).

7.3.4 Fire

Prescribed burning is used by the USDA Forest Service, USDI National Park Service, The Nature Conservancy and other land owners to reduce fuel loads, improve wildlife habitat, and restore ecosystem structure and function. However, less is known about its effects on eastern hardwood ecosystems than on southern pine dominated ecosystems. There, prescribed fire has been used as a silvicultural tool for over 50 years (see review: Carter and Foster 2004). In general, vegetation is responsive to prescribed fire, but the magnitude of response depends on initial forest condition and fuel load, topography, and season and characteristics of the fire, among other factors (Spetich et al., Chap. 4). In the following sections, we discuss herbaceous vegetation response to fire in two major forest types of the Central Hardwood Region: oak forests and hardwood pine forests.

7.3.4.1 Fire in Oak Forests

Perennial herbs in oak forests usually emerge each season from rhizomes, but they are dormant during the spring and fall burning periods. Because little heat penetrates into the soil to the dormant rhizomes when leaf litter burns, resprouting usually is not affected by burning in either season. Any changes in herb layer species composition or abundance would more likely be due to indirect effects such as reduced competition with top-killed midstory shrubs, or consumption of the litter layer. Keyser et al. (2004) found plant cover and species richness in an oak-dominated forest increased following fire regardless of whether burning occurred in February, April, or August. However, the more intense spring and summer burns led to a shift toward herbaceous species, whereas the winter burn resulted in dominance by woody species (Keyser et al. 2004).

In some cases in central hardwood forests, prescribed fire resulted in increased cover and diversity of herbaceous layer species (Arthur et al. 1998; Elliott et al. 1999; Clinton and Vose 2000; Clendenin and Ross 2001). In mixed-oak communities, herbaceous layer species tend to be more diverse after moderate-severity fire (Elliott et al. 1999; Glasgow and Matlack 2007), partly due to removal of the litter layer, increased nutrient cycling rates, and increased light levels. However, low severity, dormant season fires often have little effect on plant community composition (McGee et al. 1995; Kuddes-Fischer and Arthur 2002), and in some cases they have little effect on diversity (Franklin et al. 2003; Dolan and Parker 2004; Hutchinson et al. 2005; Elliott et al. 2004; Phillips et al. 2007; Elliott and Vose 2010).

Although single prescribed burns may have little effect, repeated dormant-season fire may affect herbaceous layer diversity, particularly warm-season grasses and forbs (Holzmueller et al. 2009; Pyke et al. 2010) in oak forests. For example, Bowles et al. (2002) found a significant shift in herbaceous layer vegetation toward greater abundance of warm-season plants, without decline of cool-season plants, after 17 years of annual fires. They suggested repeated burning can increase forest herbaceous layer diversity in a predictable manner: repeated, annual burns reduce shrubs and saplings, which subsequently increases understory light levels. They also found a positive relationship between canopy light levels with warm-season herb cover and richness (Bowles et al. 2002).

7.3.4.2 Fire in Pine-Hardwood Forests

Mixed pine-hardwood forests on dry ridges are thought to be sustained by fire (Barden 2000; Lafon et al. 2007). Fire suppression and few natural fires in dry-to-xeric pine-hardwood forests have promoted dominance of hardwoods and decline of the pine component of these forests for the last three decades (Smith 1991; Vose et al. 1999; Elliott and Vose 2005). In addition, substantial drought-related insect populations (primarily southern pine beetle [*Dendroctonus frontalis*]) (Elliott et al. 1999; Elliott and Vose 2005) and previous forestry practices, such as high-grading, have contributed to changes such as a significant increase in acreage of stands with a dense understory of mountain laurel (*Kalmia latifolia*) on upper, drier slopes of the Southern Appalachians. Competition with mountain laurel inhibits reproduction and growth of woody and herbaceous vegetation, so changes in species composition and stand structure are likely to persist without management intervention.

Herbaceous species respond to direct and indirect effects of fire. An initial increase in nitrogen availability after fire can contribute to increased herbaceous cover (Elliott et al. 2004; Knoepp et al. 2009). In addition, low severity prescribed fires, coupled with dormant season ignition, allow the root systems and seed banks of herbaceous layer species to survive; thus, plants are able to re-emerge in the spring and summer after the burn treatments. The herbaceous layer includes several life forms that may respond differently to fire disturbance: tree seedlings, shrubs, forbs, ferns, and graminoids. In a Southern Appalachians pine-oak community, Elliott et al. (2009) found evergreen shrubs decreased, while deciduous shrubs, forbs, and grasses increased after a moderate-severity prescribed fire (Fig. 7.4). After 10 years, forbs and grasses were more abundant than they were before the prescribed fire treatment (Elliott et al. 2009).

In another site in the Southern Appalachians (Linville Gorge; Dumas et al. 2007), post-disturbance colonizers such as fireweed (*Erichtites hieracifolia*), daisy fleabane (*Erigeron annuus*), and white snakeroot (*Eupatorium rugosum*) were present only in burned plots, where they likely flushed from the seed bank. Greater diversity and abundance of herbs and tree seedlings in the first post-fire growing season were likely a response to the combination of forest floor removal by fire and increased penetration of light associated with the loss of the mountain laurel. These findings are consistent with Reilly et al. (2006), who argued that changes in species diversity after the Linville Gorge fire were the result of local scale phenomena, and not long distance dispersal. Fire would favor seed bank species and species able to propagate from protected meristems.

Dilustro et al. (2002, 2006) and Collins et al. (2006a, b) examined herb layer response to prescribed fire and land use (military) in pine and mixed pine-hardwood

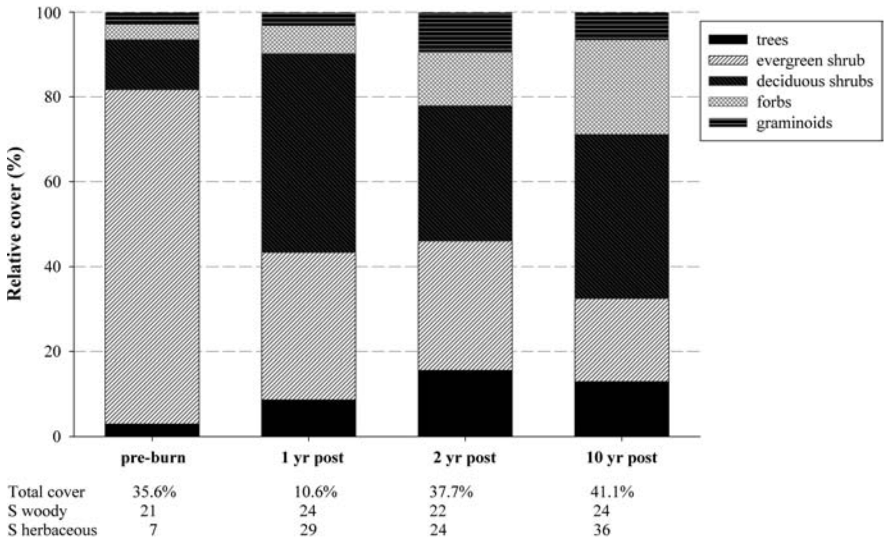

Fig. 7.4 Relative cover of the herbaceous layer (all herbaceous species and woody species <1.0 m height) by growth forms for Wine Spring Creek, western North Carolina; a dormant season, moderate-to-high intensity prescribed burn. Total cover (%), S_{woody} (number of woody species), $S_{herbaceous}$ (number of herbaceous species) for pre-burn (1994), 1-year post-burn (1995), 2-years post-burn (1996), and 10-years post-burn (2006) (adapted from Elliott et al. 2009)

forests at Fort Benning, GA. In a subset of these sites with a significant hardwood component, neither species richness nor evenness differed between 2 year and 4 year fire treatments, either in the post-burn season or after one (2-year treatment) or three (4-year treatment) years. Overall diversity (H′) was higher in 2-year burn treatments in the post-burn season, but this difference was not apparent 1–3 years(s) post-burn (Table 7.1). Across all sites, however, fire, harvests, and disturbances associated with mechanized military training favor pine dominance and maintain early successional or fire-tolerant species in the ground layer (Dilustro et al. 2002).

Positive response of some herb layer species provides evidence that growing season fire is an important part of the natural disturbance regime in pine-hardwood forests. However, what is best for one species may not be for all; other species respond more to dormant-season than growing-season burns (Sparks et al. 1998; Hiers et al. 2000; Liu and Menges 2005). In addition, many species do not appear to be influenced by burning season. For example, in a shortleaf pine-grassland community in Arkansas, fewer than 10% of 150 plant species evaluated for response to late growing-season (September–October) and late dormant-season (March–April) burns were differentially affected by burning season (Sparks et al. 1998). The variable response of understory species to fire season suggests a heterogeneous fire regime (including variation in the seasonal timing of fire) may help conserve biodiversity (Hiers et al. 2000; Liu et al. 2005) and maintain early successional stages of pine-hardwood forests on the landscape.

7.3.5 Drought

Canopy gaps, created by wind or death of canopy trees, are widely known to influence woody seedling and sapling species recruitment and abundance through their effect on resource availability and heterogeneity (Clinton et al. 1993; Elliott and Swank 1994; Kneeshaw and Bergeron 1998; Kloeppel et al. 2003; Gravel et al. 2010). Less is known about the effects of gaps created by drought on the herbaceous layer in temperate forested ecosystems (Roberts and Gilliam 2003; Neufeld and Young 2003). Information is especially lacking on how interactions among drought-induced canopy gaps and other disturbances, such as herbivory and fire, affect herbaceous vegetation (sensu Royo et al. 2010).

One long-term study conducted in the Southern Appalachians provides an example of the complex interactions among disturbances. Webster et al. (2008) investigated effects of Japanese stilt grass (*Microstegium vimineum*), an invasive grass, and deer herbivory on native herbaceous layer species in Cades Cove, Great Smoky Mountains National Park. A severe drought occurred in 2000, partway through their 10 year study (1997–2006). With deer herbivory, Japanese stilt grass populations rebounded quickly following drought and native herbaceous and woody species were unable to capitalize on the ephemeral release of growing space. In contrast, in the absence of deer herbivory (i.e., in exclosure plots), there was an increase in cover of woody plants and native species richness (Webster et al. 2008).

7.3.6 Windthrow and Salvage Logging

Canopy gaps caused by windthrow have different consequences for herb layer vegetation than gaps caused by drought. Windthrow uproots trees and breaks or kills surrounding trees, which, in turn, creates pit and mound topography (Clinton and Baker 2000) and generally creates larger canopy openings (Greenberg and McNab 1998; Peterson 2000; Elliott et al. 2002b; Peterson and Leach 2008) than drought-created gaps. Elliott et al. (2002b) reported a greater number of both early and late successional herb species in forests with windthrow and subsequent salvage logging than in an undisturbed forest (Table 7.1). In addition, some late successional species that were found in both forests were more abundant in the disturbed forest; these included Jack-in-the-pulpit (*Arisaema triphyllum*), black cohosh (*Cimicifuga racemosa*), wild licorice (*Galium lanceolatum*), common yellow wood-sorrel (*Oxalis stricta*), and violets (*Viola* spp.).

In a bottomland hardwood forest in southern Illinois, Nelson et al. (2008) investigated differences in vegetation composition and diversity among undisturbed, wind disturbed, and wind + salvage areas. They found species diversity (H′) generally increased as a function of soil disturbance (based on soil disturbance severity classes ranging from undisturbed < compressed < ruts < churned), with no significant differences between wind and wind + salvage areas (Table 7.1). Significantly less herbaceous cover in undisturbed and transition areas was attributed to having at least partial canopy cover in these sites versus wind and wind + salvage areas. Nelson et al. (2008) argued that large yearly variation in herbaceous cover among soil disturbance classes was due to creation of ruts, berms, pits, and mounds, which led to variation in moisture availability on a fine spatial scale. Three years after the wind disturbance, herbaceous cover in all soil disturbance classes declined rapidly as the canopy closed.

In subalpine forests of northwestern Colorado, Rumbaitis (2006) compared windthrow, windthrow + salvage logging, and undisturbed forests. Species richness and diversity were lower in the wind + salvage logged areas than the windthrow or undisturbed areas (Table 7.1). Species growing in the wind + salvage logged areas primarily were early successional specialists, whereas mixtures of early and late successional species grew in the windthrow only areas (Rumbaitis 2006). In contrast to the results of Elliott et al. (2002b), few shade-tolerant forbs were found in the wind + salvage logged areas. Rumbaitis (2006) concluded differences in understory disturbance severity were likely responsible for the observed differences in species diversity and composition between the windthrow only and wind + salvage logged areas.

In general, windthrow generates microsite heterogeneity that can facilitate species diversity and abundance in the herb layer. For example, pits and mounds associated with treefalls can have higher species diversity and greater herb cover than adjacent undisturbed areas (Peterson and Campbell 1993). Changes in light quality and quantity associated with gaps generate the greatest responses in understory herbs because many species are light limited (Whigham 2004). Woodland herbs often show greater growth and reproduction in response to increased light (Collins and Pickett 1988; Neufeld and Young 2003); however, positive responses may depend on gap size (Collins and Pickett 1988) and negative impacts associated with competition (Hughes 1992). Overall, windthrow gaps can increase herb layer species diversity and abundance, but may increase abundance of early successional or light-demanding species only when the canopy is removed and there is considerable soil disturbance.

7.4 Summary

Over the landscape, open areas, savannahs, and woodlands can provide early successional habitats for numerous wildlife species, but maintaining or restoring these vegetation types can require intensive management, such as removing invasive grasses with herbicide applications, increasing fire, and mechanical disturbance (e.g., disking). Herb layer response to disturbance varies with the type and severity of the disturbance, but also among ecoregions and forest types within the Central Hardwood Region. Low to moderate fire severity can increase herb cover and diversity and promote emergence from the seed bank and protected meristems in oak and pine-hardwood forests. Windthrow, at the low end of a canopy and soil disturbance gradient, can promote diversity of native species in the understory. At the other end of the spectrum, abandoned agricultural land and surface mining, especially mountain top removal, create early successional communities, but can also promote non-native species, especially if initially seeded with these species. Although herbaceous response differs over ecoregions, a mixture of silvicultural practices along a gradient of disturbance severity will maintain a range of stand ages and structures, and subsequently maximize landscape level herbaceous diversity.

Literature Cited

Abrams MD (2003) Where has all the white oak gone? Bioscience 53:927–939

Arthur MA, Paratley RD, Blankenship BA (1998) Single and repeated fires affect survival and regeneration of woody and herbaceous species in an oak-pine forest. J Torrey Bot Soc 125:225–236

Barden LS (2000) Population maintenance of *Pinus pungens* Lam. (table mountain pine) after a century without fire. Nat Areas J 20:227–233

Bellemare J, Motzkin G, Foster DR (2002) Legacies of the agricultural past in the forested present: an assessment of historical land-use effects on rich mesic forests. J Biogeogr 29:1401–1420

Belote RT, Sanders NJ, Jones RH (2009) Disturbance alters local–regional richness relationships in Appalachian forests. Ecology 90:2940–2947

Boring LR, Swank WT, Monk CD (1988) Dynamics of early successional forest structure and processes in the Coweeta Basin. In: Swank WT, Crossley DA Jr (eds) Forest hydrology and ecology at Coweeta, ecological studies 66. Springer, New York, pp 161–180

Bowles ML, Jacobs KA, Mengler JL (2002) Long-term changes in an oak forest's woody understory and herb layer with repeated burning. J Torrey Bot Soc 134:223–237

Brudvig LA, Asbjornsen H (2008) Patterns of oak regeneration in a Midwestern savanna restoration experiment. For Ecol Manage 255:3019–3025

Carter MC, Foster CD (2004) Prescribed burning and productivity in southern pine forests: a review. For Ecol Manage 191:93–109

Clendenin MA, Ross WG (2001) Effects of cool season prescribed fire on understory vegetation in a mixed pine hardwood forest of east Texas. Tex J Sci 53:65–78

Clinton BD (1995) Temporal variation in photosynthetically active radiation (PAR) in mesic Southern Appalachian hardwood forests with and without Rhododendron understories. In: Gottschalk KW, Fosbroke SL (eds) Proceedings of the 10th Central Hardwood forest conference, 5–8 Mar 1995, Morgantown WV. Gen Tech Rep NE-197, USDA Forest Service Northeastern Forest Experiment Station, Radnor, pp 534–540

Clinton BD, Baker CR (2000) Catastrophic windthrow in the Southern Appalachians: characteristics of pits and mounds and initial vegetation responses. For Ecol Manage 126:51–60

Clinton B D, Vose JM (2000) Plant succession and community restoration following felling and burning in the Southern Appalachians. In: Moser WK, Moser CF (eds) Fire and forest ecology: innovative silviculture and vegetation management, Proceedings of the 21st tall timbers fire ecology conference. Tall Timbers Research Station, Tallahassee, pp 22–29

Clinton BD, Boring LR, Swank WT (1993) Canopy gap characteristics and drought influences in oak forests of the Coweeta Basin. Ecology 74:1551–1558

Collins BS, Pickett STA (1988) Response of herb layer cover to experimental canopy gaps. Am Midl Nat 119:282–290

Collins B, Minchin P, Dilustro J, Duncan L (2006a) Land use effects on groundlayer composition and regeneration of mixed pine hardwood forests in the Fall Line Sandhills, S.E. USA. For Ecol Manage 226:181–188

Collins B, Sharitz R, Madden K, Dilustro J (2006b) Comparison of sandhills and mixed pine hardwood communities at Fort Benning, Georgia. SE Nat 51:92–102

Dilustro J, Collins B, Duncan L, Sharitz R (2002) Soil Texture, land use intensity, and vegetation of Fort Benning upland forest sites. J Torrey Bot Soc 129:280–297
Dilustro J, Collins B, Duncan L (2006) Land use history effects in mixed pine hardwood forests at Fort Benning. J Torrey Bot Soc 133:460–467
Dolan B J, Parker GR (2004) Understory response to disturbance: an investigation of prescribed burning and understory removal treatments. In: Spetich MA (ed) Upland oak ecology symposium: history, current conditions, and sustainability. Gen Tech Rep SRS-73, USDA Forest Service Southern Research Station, Asheville, pp 285–291
Donner DM, Ribic CA, Probst JR (2010) Patch dynamics and the timing of colonization–abandonment events by male Kirtland's Warblers in an early succession habitat. Cons Biol 143:1159–1167
Dumus S, Neufeld HS, Fisk MC (2007) Fire in a thermic oak-pine forest in Linville Gorge wilderness area, North Carolina: importance of the shrub layer to ecosystem response. Castanea 72:92–104
Elliott KJ, Knoepp JD (2005) The effects of three regeneration harvest methods on plant diversity and soil characteristics in the Southern Appalachians. For Ecol Manage 211:296–317
Elliott KJ, Swank WT (1994) Impacts of drought on tree mortality and growth in a mixed hardwood forest. J Veg Sci 5:229–236
Elliott KJ, Vose JM (2005) Effects of understory burning on shortleaf pine (*Pinus echinata* Mill.) /mixed-hardwood forests. J Torrey Bot Soc 132:236–251
Elliott KJ, Vose JM (2010) Short-term effects of prescribed fire on mixed oak forests in the Southern Appalachians: vegetation response. J Torrey Bot Soc 137:49–66
Elliott KJ, Boring LR, Swank WT, Haines BR (1997) Successional changes in diversity and composition in a clearcut watershed in Coweeta Basin, North Carolina. For Ecol Manage 92:67–85
Elliott KJ, Boring LR, Swank WT (1998) Changes in vegetation diversity following grass-to-forest succession. Am Midl Nat 140:219–232
Elliott KJ, Hendrick RL, Major AE, Vose JM, Swank WT (1999) Vegetation dynamics after a prescribed fire in the Southern Appalachians. For Ecol Manage 114:1–15
Elliott KJ, Boring LR, Swank WT (2002a) Aboveground biomass and nutrient pools in a Southern Appalachian watershed 20 years after clearcutting. Can J For Res 32:667–683
Elliott KJ, Hitchcock SL, Krueger L (2002b) Vegetation response to large scale disturbance in a Southern Appalachian forest: hurricane opal and salvage logging. J Torrey Bot Soc 129:48–59
Elliott KJ, Vose JM, Clinton BD, Knoepp JD (2004) Effects of understory burning in a mesic mixed-oak forest in the Southern Appalachians. In: Engstrom RT, Galley KEM, de Groot WJ (eds) Proceedings of the 22nd tall timbers fire ecology conference: fire in temperate, boreal, and montane ecosystems. Tall Timbers Research Station, Tallahassee, pp 272–283
Elliott KJ, Vose JM, Hendrick RL (2009) Long-term effects of prescribed wildland fire on vegetation dynamics in the Southern Appalachians. Fire Ecol 5:66–85
Federer CA, Hornbeck JW, Tritton LM, Martin CW, Pierce RS, Smith CT (1989) Long-term depletion of calcium and other nutrients in eastern US forests. Environ Manage 13:593–601
Flinn KM, Vellend M (2005) Recovery of forest plant communities in post-agricultural landscapes. Front Ecol Environ 3:243–250
Franklin SB, Robertson PA, Fralish JS (2003) Prescribed burning effects on upland *Quercus* forest structure and function. For Ecol Manage 184:315–335
Fraterrigo JM, Pearson SM, Turner MG (2009a) The response of understory herbaceous plants to nitrogen fertilization in forests of different land-use history. For Ecol Manage 257:2182–2188
Fraterrigo JM, Turner MG, Pearson SM (2009b) Interactions between past land use, life-history traits and understory spatial heterogeneity. Landsc Ecol 21:777–790
Gilliam FS, Dick DA (2010) Spatial heterogeneity of soil nutrients and plant species in herb-dominated communities of contrasting land use. Plant Ecol 209:83–94
Gilliam FS, Roberts MR (2003) Conceptual framework for studies of the herbaceous layer. In: Gilliam FS, Roberts MR (eds) The herbaceous layer in forests of Eastern North America. Oxford University Press, Oxford, pp 3–11
Glasgow LS, Matlack GR (2007) Prescribed burning and understory composition in a temperate deciduous forest, Ohio, USA. For Ecol Manage 238:54–64

Gravel D, Canham CD, Beaudet M, Messier C (2010) Shade tolerance, canopy gaps and mechanisms of coexistence of forest trees. Oikos 119:475–484
Greenberg CH, McNab WH (1998) Forest disturbance in hurricane-related downbursts in the Appalachian mountains of North Carolina. For Ecol Manage 104:179–191
Gruchy JP, Harper, Gray MA (2009) Methods for controlling woody invasion into CRP fields in Tennessee. Proceedings of the Gamebird 2006: Quail VI and Perdix XII 6: 315–321
Hales TC, Ford CR, Hwang T, Vose JM, Band LE (2009) Topographic and ecologic controls on root reinforcement. J Geophys Res 114:F03013. doi:10.1029/2008JF001168
Harper CA (2007) Strategies for managing early succession habitat for wildlife. Weed Tech 21:932–937
Harper CA, Gruchy JP (2009) Conservation practices to promote quality early successional habitat. In: Burger LW, Evans KO (eds) Managing working lands for northern bobwhite: the USDA NRCS Bobwhite Restoration Project, Washington, DC, pp 87–114
Harper CA, Bates GE, Hansbrough MP, Gudlin MJ, Gruchy JP, Keyser PD (2007) Native warm-season grasses: identification, establishment, and management for wildlife and forage production in the Mid-South. UT Extension, PB 1752, Knoxville, 189 pp
Hiers JK, Wyatt R, Mitchell RJ (2000) The effects of fire regime on legume reproduction in longleaf pine savannas: is a season selective? Oecologia 125:521–530
Holl KD (2002) Long-term vegetation recovery on reclaimed coal surface mines in the Eastern USA. J Appl Ecol 39:960–970
Holzmueller EJ, Jose S, Jenkins MA (2009) The response of understory species composition, diversity, and seedling regeneration to repeated burning in Southern Appalachian oak-hickory forests. Nat Areas J 29:255–262
Hughes JW (1992) Effects of removal of co-occurring species on distribution and abundance of *Erythronium americanum* (Liliaceae), a spring ephemeral. Am J Bot 790:1329–1336
Hutchinson TF, Boerner REJ, Sutherland S, Sutherland EK, Ortt M, Iverson LR (2005) Prescribed fire effects on the herbaceous layer of mixed-oak forests. Can J For Res 35:877–890
Jenkins MA, Parker GR (2000) The response of herbaceous-layer vegetation to anthropogenic disturbance in intermittent stream bottomland forests of southern Indiana, USA. Plant Ecol 151:223–237
Jones JDJ, Chamberlain MJ (2004) Efficacy of herbicides and fire to improve vegetative conditions for northern bobwhites in mature pine forests. Wildl Soc Bull 32:1077–1084
Keyser PD, Sausville DJ, Ford WM, Schwab DJ, Brose PH (2004) Prescribed fire impacts to amphibians and reptiles in shelterwood-harvested oak-dominated forests. Va J Sci 55:159–168
Klaus NA, Buehler DA, Saxton AM (2005) Forest management alternatives and songbird breeding habitat on the Cherokee National Forest, Tennessee. J Wildl Manage 69:222–234
Kloeppel BD, Clinton BD, Vose JM, Cooper AR (2003) Drought impacts on tree growth and mortality of Southern Appalachian forests. In: Greenland D, Goodin DG, Smith RC (eds) Climate variability and ecosystem response at long-term ecological research sites. Oxford University Press, New York, pp 43–55
Kneeshaw DD, Bergeron Y (1998) Canopy gap characteristics and tree replacement in the southeastern boreal forest. Ecology 79:783–794
Knoepp JD, Elliott KJ, Vose JM, Clinton BD (2009) Effects of prescribed fire in mixed-oak forests of the Southern Appalachians: forest floor, soil, and soil solution nitrogen responses. J Torrey Bot Soc 136:380–391
Kuddes-Fischer LM, Arthur MA (2002) Response of understory vegetation and tree regeneration to a single prescribed fire in oakpine forests. Nat Areas J 22:43–52
Lafon CW, Waldron JD, Cairns DM, Tchakerian MD, Coulson RN, Klepzig KD (2007) Modeling the effects of fire on the long-term dynamics and restoration of yellow pine and oak forests in the Southern Appalachian Mountains. Rest Ecol 15:400–411
Liu H, Menges ES (2005) Winter fires promote greater vital rates in the Florida keys than summer fires. Ecology 86:1483–1495
Liu H, Menges ES, Snyder JR, Koptur S, Ross MS (2005) Effects of fire intensity on vital rates of an endemic herb of the Florida keys, USA. Nat Areas J 25:71–76

Magguran AE (2004) Measuring biological diversity. Blackwell, Oxford
Masters RE (2007) The importance of shortleaf pine for wildlife and diversity in mixed oak-pine forests and pine-grassland woodlands. In: Kabrick JM, Dey DC, Gwaze D (eds) Shortleaf pine restoration and ecology in the Ozarks. Gen Tech Rep NRS-P-15, USDA Forest Service Northern Research Station, Newtown Square, pp 35–46
McGee GG, Leopold DJ, Nyland RD (1995) Understory response to springtime prescribed fire in two New York transition oak forests. For Ecol Manage 76:149–168
Mou P, Fahey TJ, Hughes JW (1993) Effects of soil disturbance on vegetation recovery and nutrient accumulation following whole-tree harvest of a Northern Hardwood ecosystem. J Appl Ecol 30:661–675
Nelson JL, Groninger JW, Battaglia LL, Ruffner CM (2008) Bottomland hardwood forest recovery following tornado disturbance and salvage logging. For Ecol Manage 256:388–395
Neufeld HS, Young DR (2003) Ecophysiology of the herbaceous layer in temperate deciduous forests. In: Gilliam FS, Roberts MR (eds) The herbaceous layer in forests of eastern North America. Oxford University Press, Oxford, pp 38–90
Parker GR, Merritt C (1994) The central region. In: Barren JW (ed) Regional silviculture of the United States. Wiley, New York, pp 129–172
Peterson CJ (2000) Catastrophic wind damage to North American forests and the potential impact of climate change. Sci Total Environ 262:287–311
Peterson CJ, Campbell JE (1993) Microsite differences and temporal change in plant communities of treefall pits and mounds in an old-growth forest. Bull Torrey Bot Club 120:451–460
Peterson CJ, Leach AD (2008) Limited salvage logging effects on forest regeneration after moderate-severity windthrow. Ecol Appl 18:407–420
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 BW, Cook W (comps) The fire environment-innovations, management, and policy. Gen Tech Rep RMRS-P-46, USDA Forest Service Rocky Mountain Research Station, Fort Collins, pp 1–11
Pyke DA, Brooks ML, D'Antonio C (2010) Fire as a restoration tool: a decision framework for predicting the control or enhancement of plants using fire. Restor Ecol 18:274–284
Reilly MJ, Wimberly MC, Newell CL (2006) Wildfire effects on plant species richness at multiple spatial scales in forest communities of the Southern Appalachians. J Ecol 94:118–130
Reiners WA (1992) Twenty years of ecosystem reorganization following experimental deforestation and regrowth suppression. Ecol Monogr 62:503–523
Roberts MR, Gilliam FS (2003) Response of the herbaceous layer to disturbance in Eastern forests. In: Gilliam FS, Roberts MR (eds) The herbaceous layer in forests of eastern North America. Oxford University Press, Oxford, pp 302–320
Royo AA, Collins R, Adams MB, Kirschbaum C, Carson WP (2010) Pervasive interactions between ungulate browsers and disturbance regimes promote temperate forest herbaceous diversity. Ecology 91:93–105
Rumbaitis del Rio CM (2006) Changes in understory composition following catastrophic windthrow and salvage logging in a subalpine forest ecosystem. Can J For Res 36:2943–2954
Scholes RJ, Archer SR (1997) Tree-grass interactions in savannas. Annu Rev Ecol Syst 28:517–544
Small CJ, McCarthy BC (2002) Spatial and temporal variation in the response of understory vegetation to disturbance in a Central Appalachian oak forest. J Torrey Bot Soc 129:136–153
Small CJ, McCarthy BC (2005) Relationship of understory diversity to soil nitrogen, topographic variation, and stand age in an eastern oak forest, USA. For Ecol Manage 217:229–243
Smith RN (1991) Species composition, stand structure, and woody detrital dynamics associated with pine mortality in the Southern Appalachians. Thesis, University of Georgia, Athens
Sparks JC, Masters RE, Engle DM, Palmer MW, Bukenhofer GA (1998) Effects of late growing-season and late dormant-season prescribed fire on herbaceous vegetation in restored pine-grassland communities. J Veg Sci 9:133–142
Thiemann JA, Webster CR, Jenkins MA, Hurley PM, Rock JH, White PS (2009) Herbaceous-layer impoverishment in a post-agricultural Southern Appalachian landscape. Am Midl Nat 162:148–168

Vose JM, Swank WT, Clinton BD, Knoepp JD, Swift LW Jr (1999) Using prescribed fire to restore Southern Appalachian pine-hardwood ecosystems: effects on mass, carbon, and nutrients. For Ecol Manage 114:215–226

Wear DN, Bolstad P (1998) Land-use changes in Southern Appalachian landscapes: spatial analysis and forecast evaluation. Ecosystems 1:575–594

Webster CR, Rock JH, Froese RE, Jenkins MA (2008) Drought-herbivory interaction disrupts competitive displacement of native plants by *Microstegium vimineum*, 10-year results. Oecologia 157:497–508

Whigham DF (2004) Ecology of woodland herbs in temperate deciduous forests. Annu Rev Ecol Evol Syst 35:583–621

Whittaker RH (1965) Dominance and diversity in land plant communities. Science 147:250–260

Zenner EK, Kabrick JM, Jensen RG, Peck JE, Grabner JK (2006) Responses of ground flora to a gradient of harvest intensity in the Missouri Ozarks. For Ecol Manage 222:326–334