CHAPTER 5.

The Hot Continental Division: Oak Forests, Fire, and Ecosystem Management Frame Fuels Management Questions

Susan L. Stout, Matthew B. Dickinson, Gregory J. Nowacki

The Hot Continental Division is one of the larger ecoregions within the continental United States (McNab and Avers 1994), incorporating portions of 19 States and extending from the eastern seacoast to areas west of the Mississippi River (chapter 1). The Division includes the Eastern (Oceanic) and Eastern (Continental) Broadleaf Forest Provinces and two Mountain Provinces (Central Appalachian Broadleaf Forest—Coniferous Forest—Meadow Province and Ozark Broadleaf Forest—Meadow Forest), which are described in chapter 6. The entire Hot Continental Division is divided into 27 sections, 5 of which are in the mountains, and occupies 449,000 square miles (1 162 950 km^2), or about 12 percent of the land area of the United States, based on U.S. land area of 3,678,190 square miles [http://www.britannica.com/EBchecked/topic/616563/United-States (Date accessed: August 8, 2011)].

The Division supports many soil types, with the vast majority having mesic temperature regimes and udic moisture regimes. To the far north and west, frigid temperature regimes can be found; aquic- through xeric-moisture regimes also occur. Annual rainfall ranges from 20 to 48 inches (510 to 1320 mm). The growing season ranges from 120 to 250 days, falling mostly between 140 and 180 days. Mean annual temperatures range from 37 to 68 °F, or 3 to 20 °C (McNab and Avers 1994).

McNab and Avers (1994) list oak-dominated (*Quercus* spp.) forests among the most important natural vegetation in all nonmountainous Hot Continental Division sections, with the exception of the northern-hardwood and beech-maple (*Fagus grandifolia–Acer* spp.) dominated Erie and Ontario Lake Plain. Northern hardwoods and beech-maple forests are second in abundance to the oak-dominated forests; and coniferous evergreen species—including shortleaf pine (*Pinus echinata*), eastern hemlock (*Tsuga canadensis*), and cedar (*Chamaecyparis* spp.)—are found primarily as components of other forests. Fire is the most common disturbance agent, at least historically. Fire regimes varied widely before European settlement and in early settlement times (Guyette and others 2006), but all oak-dominated forests (from Midwest savannas to Appalachian ridges) experienced fires. Wind, ice, and insects and diseases are other disturbance agents that interacted with fire.

History of Fire in the Hot Continental Division

A great deal of evidence, summarized in Abrams and Nowacki (2008) and other literature, suggests that oak communities in the Hot Continental Division largely owe their existence to fire regimes that favor oaks and associated species, and that the primary source of ignition for these fires was human (Abrams 2002, DeVivo 1991, Gleason 1913, Guyette and others 2002, Pyne 1982, Whitney 1994). Fire is such an important force that the boundary between this Division (fire-adapted oak systems) and the Warm Continental Division to the north (fire-sensitive northern hardwoods) was probably more attributed to regular fire occurrence than to climate (Cogbill and others 2002, Curtis 1959). The fire regimes of the Hot Continental Division included those that sustained open prairie as well as forest vegetation. Brose and others (2001) state that, "Generally, fires caused by Indians were periodic, low-intensity surface fires ignited in the spring or fall." Lightning was likely never more than a secondary source of ignition (Abrams and Nowacki 2008, Guyette and others 2006) and—in contrast to human-ignited fires—may have been most frequent in late summer and autumn when dry conditions and thunderstorms coincided (Petersen and Drewa 2006). In an analysis of presettlement and early settlement fire regimes across the central hardwoods, Guyette and others (2006) describe the spatial and temporal variability in fire regimes, attributing it to topographic resistance to fire spread, changes in human populations through time, cultural differences, drought, and continental-scale variations in climate.

Brose and others (2001), Iverson and others (2008), and Pyne and others (1996) provide evidence that early settlers used fire in ways that were similar to, and often based on, the practices they observed from local tribes, often continuing the practice of autumn or early spring burning. Although they added fires incidental to railroad logging and charcoal and iron production "fire regimes did not change enough to cause region-wide shifts in species composition" (Brose et al. 2001). As early settlers moved into topographically rough mountains, they may have increased fire frequency and the proportion of the landscape burned, compared to the final stages of the Native American period (Dey 2002, Guyette and others 2002). Frequent to annual fire favors the development of mixed oak forest types especially on high-productivity mesic sites (Brose and Van Lear 1998, Dey and Hartman 2005, Kruger and Reich 1997, Waldrop and others 1992).

The Hot Continental Division's continuum of oak forest types—from open prairies and savannas through woodlands to closed-canopy forests, all characterized by frequent, usually low-intensity surface fires and relatively high decomposition rates of woody material (Waldrop and others 2006)—resulted in continuously moderate fuel loads, ready for the next fire. More open conditions fostered fine fuels in the form of grasses and forbs that also encouraged fire. Oak foliage decays more slowly than the more mesophytic species (Hobbie and others 2006, Piatek and others 2009); as oak leaves dry on the forest floor, they curl, providing a well-aerated bed that readily supports fire spread (Loomis 1974). Stambaugh and others (2006) observed that fine fuels and litter rapidly accumulated after surface fires in hardwood-dominated forests in the Ozark Highlands. Within 4 years after burning, litter had recovered to 75 percent of the original amounts; at 12 years, litter input and decomposition reach equilibrium. A continuous cover of litter and fine fuels is essential for fire to readily move across large areas; and fuels that are able to dry in sunny, windy weather promote ignition and spread of fire in humid eastern climatic regions.

In areas with closed forests, however, fire regimes changed substantially with intensive forest harvesting and resource exploitation in the late 19th and early 20th centuries—a change fueled by the Industrial Revolution, the introduction of the railroad, and the development of railroad technology to climb steep grades and make sharp turns (Marquis 1975). The slash left by widespread industrial harvests provided unprecedented fuel loading, and the trains that transported timber provided a new ignition source. These high-intensity fires, on balance, favored chestnut oak (*Q. prinus*), although new stands could not develop until the frequency of burning subsided (during the fire suppression era that followed). Northern red oak (*Q. rubra*) was favored by the increased sunlight that followed intensive harvesting, and both red and chestnut oaks benefited from the decline of the American chestnut (*Castanea dentata*). Although red and chestnut oak experienced increases in the period between the early settlement and fire suppression eras, the once dominant white oak (*Q. alba*) declined (Abrams 2006).

Across the United States and the Hot Continental Division, the fires of the early 20th century were so intense that they produced a policy response. In Pennsylvania, nearly a million acres (400 000 ha) burned annually in the early 1900s (Banks 1960). Nationally, the fires of 1910 laid the groundwork for a policy of universal fire suppression. Lewis (2005) reports that the winter and spring of 1910 were unusually dry throughout much of the country, resulting in a fire season in which >5 million acres (2 million ha) burned, and as many as 85 firefighters died. State and Federal laws supported organizations of foresters and community volunteers to work together in fire suppression, and most fire history records show dramatic changes in fire frequency beginning around 1930 (Abrams and Nowacki 1992, Brose and others 2001, Guyette and others 2002, Iverson and others 2008). Throughout this fire suppression era, spring and autumn fires (although less frequent) continued to predominate (Haines and others 1975), a reflection that human ignition sources were still a bigger factor than lightning ignitions.

According to Nowacki and Abrams (2008), during the transition from Native American to European resource management, open systems historically maintained by frequent, human-ignited fires rapidly converted to dense, closed-canopy forests, as aged oak root stocks ("grubs") were no longer suppressed by frequent fires (Cottam 1949, Curtis 1959, Grimm 1984). In forests of the Prairie Peninsula, continued fire suppression favored increases in shade-tolerant, fire-sensitive species, such as sugar maple (*A. saccharum*) and elm (*Ulmus* spp.). Similarly, oak savannas that were widespread in the western part of the Hot Continental Division (Leach and Givnish 1999) responded to fire suppression with increases in fire-sensitive species and overall tree density (Cottam 1949, Curtis 1959, Grimm 1984). In formerly closed-canopy systems, such as Appalachian oak forests, fire suppression generally favored the establishment of dense understories and midstories of fire-sensitive and shade-tolerant species like the maples, American beech, and flowering dogwood (*Cornus florida*). Nowacki and Abrams (2008) named this process "mesophication" and spatially quantified the phenomenon in a fire regime change map (fig. 1). The map shows large reductions in fire frequency throughout the Hot Continental Division, most dramatically in areas farthest west.

Consequences of Mesophication

Changing forest conditions mean changing fuel conditions. With fire suppression, stand density increased—especially for fire-sensitive, shade-tolerant mesophytic species—which led to cool, moist understory conditions with forest floors dominated by fast-decaying, compact layers of moist leaves (Nowacki and Abrams 2008). Similarly, the amount of woody debris (fuel) decreases as decay-resistant oak logs are replaced by the more degradable logs of mesophytic species (MacMillan 1988, Tyrell and Crow 1994). Thus, the mesophication process is a kind of fuels management process, albeit largely unintended, that makes fire less likely without intervention through silviculture.

The absence of fire and the shift in forest management policies and practices have important ecological consequences for forest types that are adapted to fire. For example, ground flora accustomed to the variable sunlight conditions (including medium- and high-light conditions) commonly associated with the historic burning regime cannot persist in the uniform, low-light environment of today's closed-canopy forests (Brudvig and Asbjornsen 2009). Light is the ultimate limiting factor, such that understory plant cover and diversity are inversely related to tree density and basal area (Anderson and others 2000, Taft 2009). As tree density and shading increases, plants disappear in a predictable manner, from perennial grasses through sedges to perennial forbs (Taft 2009), or convert from high-light-requiring prairie species to shade-tolerant forest

Figure 1. Past-to-current change in fire regime across the Eastern United States, based on spatial analysis regime maps (Nowacki and Abrams 2008), derived by applying a frequency-by-intensity fire classification to past and current vegetation maps; the departure from zero relates to the extent of fire regime change [past vegetation maps based on potential natural vegetation from Schmidt and others (2002); current vegetation maps based on the Advanced Very High Resolution Radiometer Project, http://noaasis.noaa.gov/NOAASIS/ml/avhrr.html (Date accessed: June 22, 2011), and the National Map of Land-Cover Vegetation, http://www.gap.uidaho.edu/landcoverviewer.html (Date accessed: June 22, 2011)].

species (Anderson and others 2000). In most situations, tree density has progressed to the point where remaining ground plants are few, sparsely distributed, shade-tolerant, and relatively indifferent to density increases or decreases (Taft 2009). Loss of ground cover has been associated with increases in soil erosion and runoff (Wilhelm 1991). Fortunately, the negative trends of ground flora (cover, richness, and diversity) can be reversed through active management (Apfelbaum and Haney 1991, Brudvig and Asbjornsen 2009, Taft 2009), so long as viable seed banks still exist (Anderson and others 2000). Mechanical treatments coupled with prescribed burning seem to provide the best results for restoring robust ground floras, compared to prescribed burning alone (Nielsen and others 2003).

Crow (1988), Loftis and McGee (1993), and Lorimer (1993) document widespread difficulty in producing a significant oak component when regenerating oak-dominated stands, with much of the difficulty occurring across the Hot Continental Division. The loss of oak from the forests of the Hot Continental Division is important because of its effects on wildlife, on plant communities, and on the economic benefits provided by forests. McShea and Healy (2002) emphasize the importance of acorn mast as "the most important wildlife food in the deciduous forests of North American, the ecological equivalent of manna from heaven." Van Dersal (1940) lists 101 North American bird and 104 mammal species that take sustenance from oak, including direct consumption of acorns and browsing on plant material. At least 51 of these species are in the Hot Continental Division, including white-tailed deer (*Odocoileus virginianus*), black bear (*Ursa americanus*), eastern gray squirrels (*Sciurus carolinensis*), and blue jays (*Cyanocitta cristata*). Oak timber is a highly valued resource; its loss from forests results in reduced economic benefits.

The importance of oak ecosystems, their fire regimes, their value to plant and animal species, and the widespread realization that they are being replaced by more mesic forest types have prompted most national forests in the Hot Continental Division to adopt forest plans that include some elements of oak restoration, prescribed fire, and management of fire regime class (table 1), either in the goals and objectives or in vision statements of their recently revised Land and Resource Management Plans. The Eastern Region of the U.S. Department of Agriculture Forest Service has identified oak ecosystems as a focus for restoration efforts (Nowacki and others 2009), consistent with

Table 1. Oak restoration and related goals and objectives of national-forest and recreation-area lands in the Hot Continental Division.

National forest/recreation area	Oak restoration objective(s) and goals
Daniel Boone National Forest	Restore and maintain 3,000 acres of pitch pine and pitch pine-oak forest types on appropriate land-type phases.
	Reintroduce fire use across the landscape to increase biodiversity and improve resilience and stability of ecosystems.
	Move acres from FRCC 3 and 2 into FRCC 2 and 1, and reduce abundance of fire-intolerant species in fire-mediated areas.
	Provide adequate habitat to support populations of management indicator species.
Hoosier National Forest	Use prescribed fire to maintain fire-adapted ecosystems, to promote a more diverse community of plants and animals, and to manage accumulated fuels.
	Provide the diversity of habitats needed for viable populations of all native and desired nonnative species.
Land-Between-The-Lakes National Recreation Area	Use wildland fire, when practical, to protect, maintain, and enhance natural and cultural resources and, as nearly as possible, to function in its natural ecological role.
	Restore and maintain fire regimes and fire return intervals in fire-dependent communities (improve FRCC status) and use fire and other treatments to restore and manage for a healthy, predominantly oak-hickory forest type with respect to species composition, forest canopy structure, and associated wildlife species.
Mark Twain National Forest	Reestablish the role of fire in the natural communities of the Ozarks by emulating the historic fire regime.
	Restore FRCC 2 or 3 lands to condition FRCC 1.
	Facilitate restoration treatments, then emulate the range of natural variability for historical fire regimes in glades, savannas, and pine woodlands.
Shawnee National Forest	Use landscape-scale burning for oak-hickory forest management where coordinated, active vegetation management can be implemented, and for barrens management on shallow soils and poorer sites.
Wayne National Forest	Promote restoration and maintenance of the oak-hickory ecosystem by improving conditions for oak regeneration in the Historic Forest and Historic Forest with Off-Highway Vehicle Management Areas.
	Use all available silvicultural treatments, including precommercial and commercial thinning, prescribed fire, shelterwood harvests, and improvement cutting to promote the maintenance and restoration of the oak-hickory forest type.
	Use prescribed fire to conserve fire-adapted plant and animal biodiversity and to maintain and restore mixed-oak and native pine ecosystems.
	Use prescribed fire and mechanical treatments to modify current fuel composition and fire frequency, severity, and pattern.
	Use prescribed fire and mechanical treatment to maintain a current FRCC that represents a historic range of variability.

FRCC = Fire Regime Condition Classes.

the Agency's ecosystems restoration framework (Day and others 2006). There is widespread interest in coordinating these efforts through a unified monitoring approach that would allow national forest managers to share data and learn from the experiences on other forests, and that would also incorporate scientists and other land managers into the process (Yaussy and others 2008). Several States in the Hot Continental Division have also adopted oak restoration programs [http://mdc4.mdc.mo.gov/Documents/13728.pdf and http://www.dcnr.state.pa.us/forestry/sfrmp/sfrmp_update_2007.pdf (Date accessed: June 20, 2011)], and The Nature Conservancy has also embraced oak ecosystem restoration as an important goal for some of its conservation areas [http://www.nature.org/wherewework/northamerica/states/ohio/preserves/art17415.html (Date accessed: June 20, 2011)].

Fuels and Fuel Management in the Context of Oak Restoration

Forest floor fuel levels are remarkably stable across the Eastern United States because fuel deposition and decomposition are in balance (Graham and McCarthy 2006, Waldrop and others 2007). The fact that more productive (mesic) sites generate more fuel inputs than less productive (xeric) sites is offset by the higher decomposition rates on the more productive sites (Waldrop 1996). Consistent with this generality, differences in topographic position had little influence on fuel levels across the Southern Appalachians (Waldrop and others 2007) and aspect made little difference in fuel levels in the Missouri Ozarks (Kolaks and others 2003). Disturbance history and type, however, appreciably affect fuel accumulation. Fire reduces the litter layer (Graham and McCarthy 2006, Phillips and others 2000, Waldrop and others 2007). Waldrop and others (2007) found significant increases in 1-hour fuels for beetle-killed plots (compared to undisturbed plots) and 10-hour fuels for plots that had been attacked by beetles, harvested, and burned. After the first fire at the Ohio site of the National Fire and Fire Surrogates Study, increases in fine fuel loads were transient because of high decomposition rates (lasting <3 years); and large-diameter woody debris (>7.6 cm diameter) fuel loads increased, both in plots that were thinned and those that were thinned and burned (Graham and McCarthy 2006). Two subsequent fires appeared to create a positive feedback between fire intensity and woody fuel loads, with relatively high fire-line intensities on dry aspects resulting in high tree mortality and dense woody regeneration (often from sprouts), which in turn resulted in high woody fuel loads for the next fire [Iverson and others 2008, Dickinson (author observation)].

Fire regimes are profoundly affected by suppression-induced compositional changes—especially shifts from grass- and forb-dominated understories to closed-canopy oak forests in former savanna systems, and from closed-canopy oak-dominated forests to systems dominated by mesophytic species. In the absence of active silvicultural intervention and changes in forest management practices, many systems undergoing the mesophication process "may be approaching critical ecological thresholds and near-irreversible state shifts," according to Nowacki and Abrams (2008). They identify large contiguous blocks of public land as the optimal sites for restoration activities using prescribed fire, because burning larger landscapes would maximize benefit-to-cost ratios. Table 2 shows that some national forests in the Hot Continental Division have indeed seized upon this approach, and the achievement of a 40,000-acre (about 16 000-ha) burn target in 2010 by the Mark Twain shows that implementation is well underway in at least one.[1] In addition to oak and oak-pine restoration, several other forest types, all historically fire-adapted, are the targets of the restoration efforts that rely on prescribed fire. As with mesophication of closed-canopy oak-dominated forests, suppression-induced conversions of savannas to woodlands may become irreversible

[1] Personal communication. 2010. Michael Schanta, Resource Information Manager, Mark Twain National Forest, 401 Fairgrounds Road, Rolla, MO 65401.

Table 2. Target prescribed fire acreages on national-forest and recreation-area lands in the Hot Continental Division as reported in forest plans; fire acreages are given for all national forests, including the Daniel Boone, which has only a small portion of its acreage in the Hot Continental Mountain Division.

National forest/recreation area (date of plan revision)[a]	Prescribed burning planned
Daniel Boone National Forest (2004)	Increase target from 7,500 to 22,500 acres in 2004 to 25,000 to 50,000 acres in 2014
Hoosier National Forest (2006)	No targets given
Land-Between-The-Lakes National Recreation Area (2004)	Increase target from 2010 acreage to the desired long-term average of 10,000 to 21,000 acres
Mark Twain National Forest (2005)	Target of 45,000 acres
Shawnee National Forest (2006)	Target of 12,380 acres includes: 700 acres per year of site preparation/brush disposal at harvesting, 6,600 acres per year of landscape-scale burning for oak management, three burns totaling >10,000 acres per decade for barrens, and four burns (each >2,700 acres) per decade for management of open lands
Wayne National Forest (2006)	Target of 6,970 acres includes: 4,600 acres per year for oak regeneration, 20 acres per year for nonnative invasive species control, 150 acres per year for herbaceous habitat management, and 2,200 acres per year for hazardous fuel reduction

[a] Because most of the Ozark National Forest is in a Mountain Province of the Hot Continental Division, information about the Ozark is not included in this table.

once grass and forb seed and bud banks are exhausted (Nielson and others 2003, Vogl 1964).

Tables 1 and 2 reflect a diversity of approaches in scale and in context of how and why fire is being used on national forests in the Hot Continental Division. Some forests are integrating stand-level prescriptions into their silvicultural programs with a specific focus on optimizing oak regeneration responses in mesic forests, and others are embracing the landscape-scale approach to restore oak savanna and woodland systems in more xeric areas.

Stand Scale Approaches to Fuels Management and Prescribed Fire

As the growing importance of sustaining or restoring oak ecosystems has been recognized, so also has a growing body of research that combines prescribed fire with other canopy-opening treatments (Yaussy and others 2009). Van Lear and others (2000) described a silvicultural approach to regenerate oak in forests that have changed as a result of fire exclusion; the technique increases the competitive advantage of oak seedlings by introducing fire when the seedlings are the most resilient. Brose (2004), Brose and Van Lear (2000, 2003, 2004), and Brose and others (2008) elaborated on the required conditions of oak seedlings and the importance of burn-season choice and fire intensity. This work of Brose and his collaborators (2008) has been integrated into the SILVAH decision support system [http://www.nrs.fs.fed.us/tools/silvah/ (Date accessed: June 20, 2011)]. Their work has been confirmed by other research in the Hot Continental Division—such as Iverson and others (2008) and Neilson and others (2003)—showing that a combination of gap formation and prescribed fire is more effective than prescribed fire alone in promoting successful oak regeneration and reinvigorating ground flora; and that the oak regeneration period can be quite long. Ongoing research is examining combinations of mechanical thinning, herbicide application, and prescribed fire to improve oak regeneration.[2] In analogy to mechanical thinning, canopy

[2] Personal communication. 2010. Todd Hutchinson, Research Ecologist, and Joanne Rebbeck, Plant Physiologist, U.S. Forest Service, Northern Research Station, 359 Main Road, Delaware, OH 43015.

opening from the mortality of diseased, canopy white oaks in Ohio on sites that experienced multiple, low-intensity fires has led to abundant oak regeneration in contrast to unburned sites where the same canopy disturbance occurred.[3]

The techniques described in the above papers function at the stand level and require careful observation of good acorn crops and the development of oak seedlings afterwards. Understory and overstory shade is manipulated to culture oak seedlings with large root systems while competing regenerating species are growing in height. If applied in the early growing season just after leaf out—when oak seedlings still have sufficient belowground carbohydrate reserves and competitor carbohydrate reserves are at their lowest—prescribed fire favors oak, which sends out new sprouts to assume a more competitive position in the regeneration. If timber production is a principal objective, fuel management is necessary near desirable crop trees in the seed-source age class; Brose (2009) developed a photo guide to help managers conserve valuable crop trees through prescribed fires.

To control stand stocking, growth, and yield, forest managers across the Hot Continental Division use a variety of other techniques (including thinning, herbicide, and fertilization) that can affect the management of fuels. Thinning treatments and shelterwood seed-cuts add coarse woody debris to the fuel load (Kolaks and others 2004). These additions can be minor or significant depending on the size, species composition, and utilization standards of the specific locality. The persistence of high fuel loading varies by locale and depends on factors, such as climate, that control decomposition rates. Clearcuts add a large pulse of woody material to the forest floor; loadings decline rapidly over the first couple of decades until woody input from new growth produces an increase in downed biomass (Waldrop and others 2006). Like precommercial thinning, herbicide applications add fuel to the forest floor, but their other cumulative effects are small (Ristau 2010). If prescribed fire is part of the intended sequence of stand treatments, managers can achieve the silvicultural objectives of prescribed fire if they implement the other treatments in the sequence with an eye to fuels management.

When prescribed fire activities are conducted at the stand scale, their watershed cumulative effects—including effects on erosion, sedimentation, and nutrient loading—are likely to be quite small (chapter 12; Yang and others 2007, 2008). This is true whether the prescribed fires are used primarily for fuels control or natural resource management objectives, and refers to forests without an emphasis on landscape-scale burns.

Low-intensity fires to reduce canopy density in savanna and former savanna systems have been found to be less reliable than high-intensity fire combined with mechanical treatment. Haney and others (2008) found that low-intensity fires repeated over 20 years were ineffective at restoring savanna canopy species composition and structure, although evidence suggested that a longer period of low-intensity fire might be effective. In another savanna site, generally low-intensity fires repeated over 32 years incrementally reduced overstory density (Peterson and Reich 2001). Mechanical thinning is often viewed as a means to reestablish structure before fire reintroduction (Brudvig 2010). Nielsen and others (2003) found that preliminary thinning (followed by prescribed fire) was effective in reducing overstory density, but that fire alone was ineffective. High-intensity fires in former savanna sites (Haney and others 2008) and in woodlands adjacent to savannas (Anderson and Brown 1983) have resulted in substantial overstory mortality.

Landscape Scale Approaches to Fuels Management and Prescribed Fire

A number of forest managers in the Hot Continental Division are adopting landscape-scale prescribed fire treatments. They include those on the Mark Twain and Daniel Boone National Forests and the Land-Between-The-Lakes National Recreation

[3] Personal communication. 2010. Todd Hutchinson, Research Ecologist, U.S. Forest Service, Northern Research Station, 359 Main Road, Delaware, OH 43015.

Area, which are the primary practitioners of landscape-scale prescribed fire. For these forests, the objectives include restoration of oak savanna and woodland conditions with open canopy structure. They not only have high acreage targets for prescribed fire ecosystem and fuels management activities, but also have relatively short return intervals for fire—often in the 3 to 5 year range. Written interviews with the fire management officers on these forests were conducted in the autumn of 2009 and excerpts of their replies are reported in the remainder of this chapter:

- Reggie Bray, Fire Management Officer, Mark Twain National Forest, Ava/Cassville/Willow Springs Ranger District, 1103 South Jefferson, Ava, MO 65608
- Michael Davis, Fire Management Officer, Hoosier National Forest, Tell City Ranger District, 248 15th Street, Tell City, IN 47586
- Jody Eberly, Fire Management Officer, Mark Twain National Forest, 401 Fairgrounds Road, Rolla, MO 65401
- Keith Kelly, Zone Fire Management Officer, Mark Twain National Forest, 401 Fairgrounds Road, Rolla, MO 65401
- James McCoy, Fire Management Officer, Land-Between-The-Lakes National Recreation Area, 100 Van Morgan Drive, Golden Pond, KY 42211
- Paul Nelson, Forest Ecologist, Mark Twain National Forest, 401 Fairgrounds Road, Rolla, MO 65401
- Charly Studyvin, Forest Silviculturist, Mark Twain National Forest, 401 Fairgrounds Road, Rolla, MO 65401
- Bennie Terrell, Fuel Specialist, Mark Twain National Forest, 401 Fairgrounds Road, Rolla, MO 65401

When asked, "Is your prescribed fire program designed to reduce the risk of wildfire or is ecosystem management the major objective of your fire program?" all respondents identified ecosystem management or restoration components; most added that fuels reduction was an ancillary but important benefit, and some weighted both goals equally. An important implication of the Nowacki and Abrams (2008) mesophication argument is that oak-dominated forests are better adapted to fire and burn more easily; thus, although reintroduction of fire to these landscapes may have short-term fuels management benefits, they also represent a choice to manage more fire-prone forests for the associated ecosystem benefits on the landscape scale.

The landscape approach to oak ecosystem management used on the Daniel Boone National Forest involves periodic ridge ignition intended to maintain oak dominance on upper slopes. After ignition, fires move down slopes and into drainages. As much as possible, natural barriers are used and, typically, the fires self-extinguish on middle and lower slopes, although some may continue to spread for several days. The overall strategy is to restore and maintain oak dominance on the more xeric portions of the landscape where oaks have a competitive advantage, instead of attempting to convert to oak on more mesic sites. An added benefit is that fire intensities and spread rates are reduced, with lower risk expected for vulnerable wildlife populations (Dickinson and others 2009). The downside is that ridge ignition takes patience and a tolerance for smoke production over multiple days and nights.

Fuels management is an important consideration when using prescribed fire to reduce stand density in woodland and savanna restoration. Controlling overstory stocking by thinning with fire is difficult, and distribution of fuels (near trees intended for removal and away from trees that managers want to retain) is a critical factor in the achievement of desired overstory mortality and eventual return to the target woodland and savanna structure. During the dormant season, low-intensity fires often fail to reduce overstory stocking sufficiently to create open woodland or savanna structure, and high-intensity fires can cause more overstory mortality than intended (Anderson and Brown 1983). At worst, fires ignited in low humidity and hot-dry weather in high fuel loading of cured slash can cause complete overstory mortality.

Cultural and Spatial Concerns in Fuels Management and Prescribed Fire

Fire planning on national forests incorporates a suite of cultural and spatial concerns. Areas adjacent to campgrounds and administrative sites undergo priority fuels management treatment. Areas with recent natural disturbances such as ice or windstorms are monitored for fuel loading. For instance, fuel beds in mixed-oak forests in the Ohio River Valley that had been classified as fuel model 9 (Anderson 1982) for fire behavior were reclassified to slash models 10 and 12 after an ice storm, with model loadings[4] of 12 tons per acre (2.2 t/ha) and 36 tons per acre (6.6 t/ha). Dormant season wildfires in ice-storm fuels have resulted in areas of near complete overstory mortality on southerly aspects.[5]

Roads, in-holdings, and neighbors—both in the wildland-urban and the rural interfaces—are considered in laying out prescribed fires and in smoke management planning. A recent study just north of the Hot Continental Division identified strategies that forest managers can use to balance stewardship of fire-dependent ecosystems with the need to reduce fire risk for neighboring landowners. Using landscape-scale simulations, this study suggested that substantially reducing human-caused ignitions and redistributing fire-dependent forest types away from human ignition sources can offer "viable solutions for mitigating long-term fire risk and reducing land-use conflict in multi-owner landscapes" (Sturtevant and others 2009).

Habitats for species of concern are flagged for special attention; several of the surveyed managers identified the Indiana bat as a focus for prescribed-fire timing and placement. Potential direct effects from smoke, gases, and heat must be balanced by potential long-term habitat benefits (Dickinson and others 2009, Lacki and others 2009). Because rare, threatened, and endangered plants are known to benefit from prescribed fire, they also influence prescribed burn planning. For example, the smooth purple coneflower (*Echinacea laevigata*) that inhabits the eastern reaches of the Hot Continental Division and landscapes farther south "requires fire to maintain its preferred open habitat" (Owen and Brown 2005). Only 2 of the 186 species that Owen and Brown (2005) surveyed—the rock gnome lichen (*Gymnoderma lineare*) and the large flower skullcap (*Scutellaria montana*)—are found in the Hot Continental Division and have been classified as species "adversely affected by fire." Land managers must balance potential benefits of fire to threatened and endangered flora and fauna by potential risks from invasive species that are stimulated by disturbances, including fire.[6]

All respondents to the November 2009 manager survey identified some concern about wildfire on the landscapes they manage; especially when they are human caused, resulting from accidental escape of debris burning or arson. Keith Kelly reported that, "Wildfire is a concern, because it is our responsibility as land managers to suppress uncontrolled wildfires. We typically do not have catastrophic stand-replacing large-scale wildfires, but can have some small stand-replacing events."

Other managers also expressed anxiety about the impacts of wildfires. One reason for this anxiety is that firefighting resources, especially well trained fire personnel, are limited, and wildfires can exceed local capacity and consume resources needed to manage a prescribed fire program. The problem is made more acute by the relatively few windows of opportunity for prescribed burning during the spring and autumn seasons. Further, combating wildfires in other areas, especially the Western United States, reduces the ability of Hot Continental Division managers to achieve fuels management objectives by tapping local fire-trained personnel, particularly during the summer and

[4] Bowden, M.W. 2003. Dean and Shawnee State Forest ice storm 2003—fuels and fire behavior assessment. 9 p. Unpublished report. On file with: Ohio Department of Natural Resources, 1855 Fountain Square Court, Building H-1, Columbus, OH 43224-1327.

[5] Personal communication. 2010. Michael Bowden, Forest Fire Supervisor, 1855 Fountain Square Court, Building H-1, Columbus, OH 43224-1327.

[6] Personal communication. 2008. Joanne Rebbeck, Plant Physiologist, U.S. Forest Service, Northern Research Station, 359 Main Road, Delaware, OH 43015.

autumn. When this happens, local burning is not possible. Combinations of wildfire and prescribed fire can reduce public support for fuels management programs that include prescribed fire; and some organizations in the Hot Continental Division have adopted opposition positions that could reduce the ability of managers to implement fuels management or ecosystem restoration programs (Buckeye Forest Council 2009).

In the limited number of studies that measure the effects of both prescribed and wild fires on water quality in Eastern North America, the most dramatic impacts have occurred where soils are shallow and fires are severe (chapter 12). This combination is rare in the Hot Continental Division. However, water monitoring may be needed if large landscapes are being burned in single, aerial ignition events and severity varies across the burn unit.

Land managers in the western reaches of the Hot Continental Division have reported hydrological benefits from reintroducing fire in areas where fire suppression and subsequent forest densification have resulted in the loss of seeps and springs. In these instances, thinning such areas by fire and mechanical treatments can restore these important aquatic habitats. Wilhelm (1991) suggests that the loss of protective ground cover associated with increased forest density has increased soil erosion and runoff, and that restoration efforts could reverse these trends.

Large woody debris serves a critical function in riparian systems, providing a substrate for invertebrates and plant life and habitat complexity that benefits fish and wildlife (Guyette and others 2008). Most streams and flood plains of the Hot Continental Division experienced continual recruitment of large woody debris from trees migrating back onto surfaces after glaciers retreated. Guyette and others (2008) found wood accumulating in Midwest streams since the late Pleistocene (about 14,000 calibrated radiocarbon years ago). The Great Cutover that swept across the Eastern United States and the conversion to agriculture during European settlement greatly reduced inputs of large woody debris into streams. This was somewhat offset by the longevity of oak logs; once submerged and integrated into fluvial deposits, they could later be resurrected and resume functionality through stream dynamics (excavation). In Missouri, the median residence time of oak boles was found to be 3,515 years (Guyette and others 2008); thus, representing one of the most persistent carbon sinks in North America. Large oak wood has more-or-less been continually replenished over time, with a substantial dropoff only within the last 150 years of logging, conversion of riparian forests to agriculture, and channel modification. The compositional shift from rot-resistant oaks to highly degradable elm and hackberry (*Celtis occidentalis*) along stream bottoms has also been a factor (Guyette and others 2008). The consequences of these recent human impacts are still unfolding, but they hint at the importance of restoring oak ecosystems along riparian zones and allowing streams to function without human intervention, migrating within their valleys.

Maintaining oak as a component in forests of the Hot Continental Division helps to regulate carbon and nutrient stores in the forest floor. Compared to other tree species, oak leaves decompose slowly, in part because of their high-lignin content (Hobbie and others 2006); this translates to higher carbon and nutrient retention (Piatek and others 2009). Oak leaves are effective in immobilizing nitrogen (Piatek and others 2009), particularly significant in light of the number of ecosystems throughout the world that are at risk of nitrogen saturation (Aber and others 1998, Fenn and others 1998, Vitousek and others 1997). Without oak, more nitrogen would be mineralized from the litter of other species, hence increasing total nitrogen availability in the system (Piatek and others 2009, Templer and others 2005). Alexander and Arthur (2010) found winter net nitrification rates of soils to be 5 to 13 times greater beneath red maple (*A. rubrum*) than oaks. Ultimately, excess nitrogen (often in the form of nitrates) is exported into and degrades rivers, streams, lakes (Peterjohn and others 1996, Piatek and others 2009, Vitousek and others 1997), and downstream estuaries. Indeed, if left unchecked, the compositional shift from oak to maple will profoundly alter forest hydrology and nutrient availability, with many unknown cascading effects (Alexander and Arthur 2010).

Research and Operational Needs

Prescribed burning is a critical requirement for forest health across the Hot Continental Division (Nowacki and others 2009). The need arises from fire suppression during much of the 20th century, which has resulted in the mesophication of forests and the loss of savanna and woodland habitats. In response, many land and resource management agencies and conservation organizations have adopted plans to reintroduce fire to these landscapes. Emerging research further corroborates the link between fire and the ecology of oak and other fire-dependent vegetation types.

When prescribed fire is used at the stand scale, research needs revolve around its impacts on nontarget organisms—such as the timber rattlesnake (*Crotalus horridus*), the Indiana bat (*Myotis sodalis*), and a host of fire-dependent or fire-adapted plants—its interaction with invasive species, its impacts on timber growth and quality, and its continuing integration with other silvicultural practices. For example, research is needed to match the season and intensity of burn requirements for oak regeneration with the seasonal use of various bat habitats, to better understand the effects of smoke on hibernacula and roosts, and to provide a scientific basis for evaluating the tradeoffs between short-term damage to a single species and long-term, large-scale loss of oak habitat (Dickinson and others 2009, Lacki and others 2009).

The impact of projected climate change on species composition, fuels accumulation, and fire risk is daunting to imagine, but study of these interactions and impacts will be required to help managers sustain ecosystem function across the Hot Continental Division, especially those working at landscape scales. As examples, simulations with a dynamic vegetation model under climate scenarios through the 21st century suggest a general drying trend in the Eastern United States and the possible conversion of closed forests to more open ecosystems over large areas (Lenihan and others 2008). Based on current relationships between tree distribution and climate, tree distributions under future climate scenarios are projected to change significantly, with significant increases in the ranges and importance of the oak groups that favor warmer and drier conditions (Iverson and Prasad 2002). However, even under these scenarios, oaks will continue to require fire and/or fire surrogates to expand their range concomitant to shifts in climate envelopes.

Some national forest plans in the Hot Continental Division focus their goals and strategies around landscape-scale prescribed burns, repeated on 3- to 5-year cycles. Although evidence is strong that practices like these were common for hundreds—if not thousands—of years through the early 20th century, the impacts of treatments at the landscape scale have not been documented. This results in both policy and research needs.

For example, both policy guidance and new research is needed to develop methods that optimize the acreage affected by fuel-management and ecosystem-restoration treatments. Four Mark Twain National Forest (MTNF) managers articulated this need in their written interviews (Eberly, Terrell, Studyvin, and Nelson):

> The 2005 Forest Plan emphasizes restoration of fire-adapted ecosystems in MP 1.1 and 1.2 covering 19 management areas totaling 438,000 acres.[7] The objectives include treating and moving 50,000 to 150,000 acres[8] of fire-adapted ecosystems toward desired restored conditions. This ecosystem-based conservation approach is part of a statewide comprehensive wildlife strategy and follows recommendations in The Nature Conservancy's Ozark Ecoregional Conservation Assessment. The majority of the MTNF's 1.5 million acres[9] was historically fire-mediated yet we barely treat 2 percent of this total acreage annually. The present inability to substantially increase the use of fire across the MTNF will leave many areas of hazardous fuels

[7] 177 000 ha.
[8] 20 000 to 61 000 ha.
[9] 600 000 ha.

untreated and will result in the further degradation and loss of biodiversity associated with these ecosystems.

These remarks and others suggest the need for a regional and local-scale prioritization of restoration and maintenance activities for mixed-oak forests, wherein fire and other activities are only undertaken in areas where the species of interest are most favored by climate and topography.

Michael Davis of the Hoosier National Forest indicated a pressing need for prescriptive smoke-dispersion and burning standards. This need, too, is magnified in areas of the Hot Continental Division where landscape-scale burning is or will be practiced.

Another pressing research need is continued assessment of the cumulative effects that would occur should these treatments not be undertaken, and ongoing mesophication of the landscapes were allowed to continue. Although it seems quite likely that impacts of continued unabated mesophication will interact with climate change—making adaptation more difficult—a formal assessment of this risk would be beneficial. For instance, with continued fire suppression and ongoing mesophication, favorable climate shifts (in terms of oak) may not necessarily result in projected increases of oak species.

Finally, as described in chapter 12, additional study will be required to evaluate the cumulative watershed impacts of prescribed burning at the landscape scale, especially where large-scale burns include areas of high fire intensity. A watershed-scale perspective may also be needed to determine where restoration of seep and spring habitats can be accomplished by forest thinning with fire. Also needed are new metrics to measure landscape-scale intensity, and increased attention to the effects of prescribed fire at any scale on mercury transport and accumulation in the food chain (chapter 12).

Conclusions

Many forest ecosystems in the Hot Continental Division have historically depended on frequent, low-intensity fire—usually set by humans—to maintain their fire-adapted species and relatively open conditions. These ecosystems, especially the wide variety of oak savannas, woodlands, and forests, became critically important habitat for many wildlife (McShea and Healy 2002, Rodewald and Abrams 2002) and plant species (Anderson and others 2000, Apfelbaum and Haney 1991, Brudvig and Asbjornsen 2009, Nielson and others 2003, Owen and Brown 2005, Taft 2009). For example, at least 96 vertebrate species depend on acorns for some or all of their sustenance (McShea and Healy 2002). The prominent role that fire played in North American ecosystems is definitively reflected in the physiological requirements of plants. Of 186 Federal listed, proposed, and candidate plant species on National Forest System lands, 47 were found to require fire, 65 to tolerate fire, 70 to be unaffected by fire (Owen and Brown 2005), and only 4 (2 percent) to be adversely affected by fire.

With fire suppression, oak-dominated (and similar) forests have accumulated high densities of fire-sensitive, mesic species such as maple, beech, and blackgum (*Nyssa sylvatica*). The changes in density and composition that result from fire suppression, labeled mesophication by Nowacki and Abrams (2008), make these forests increasingly fire resistant. At the same time, the proportion of oak in these forests is declining, with important consequences for dependent or specialist wildlife and plant species. The demise of oak degrades aquatic systems—either directly by reducing the amount of long-lived, large woody debris (aquatic animal and plant habitat)—or indirectly through increased nitrogen exports to surface waters.

As a result, some conservation organizations and many public land management agencies, especially the national forests across the Hot Continental Division, have adopted ecosystem restoration goals to return fire-adapted species and forest community types to their previous condition and function on the landscape. Prescribed fire, with its ancillary fuels management benefits, is a primary tool to achieve these objectives. On some landscapes, prescribed fire is added to the stand-level toolkit for forest managers; all available evidence suggests that these practices have modest to no cumulative effects on water quality. Moreover, the application of fire at watershed scales may actually result in aquatic habitat improvements through increases in growing-season water yield. Management guidelines are emerging to strengthen these prescriptions with safeguards for endangered species—especially the Indiana bat—but more research is needed on these species, and similar research is needed on other species of concern. Management and policy guidelines are needed to balance the local and airshed impacts of smoke (Charney and others 2006) with the benefits of ecosystem restoration, particularly as air quality standards are tightened (Achtemeier 2009).

Most research needs are tied to the increasing adoption of landscape-level prescribed burning strategies. Some research has already suggested management practices to reduce the risk fire poses for neighbors in the wildland-urban or rural interfaces, but further tests under specific conditions across the Hot Continental Division would be desirable. Additional research on the impacts of these practices and their cumulative effects on watersheds is needed, especially in areas where fire intensity might be high. Such research should consider both potential benefits—such as aquatic habitat improvements through increases in growing season water yield—and potential risks. The need for fuels management treatments with ecosystem management benefits is very high in the Hot Continental Division. Increased understanding of the consequences of undertaking these treatments and the failure to do so are urgent needs.

Acknowledgments

The authors wish to thank Julie Arnold (Southern Research Station of the U.S. Forest Service) for conducting interviews of fire and natural resource managers from national forests in the Hot Continental Division, and to thank Reggie Bray, Michael Davis, Jody Eberly, Keith Kelly, James McCoy, Paul Nelson, Charly Studyvin, and Bennie Terrell (Eastern and Southern Regions of the U.S. Forest Service) for their informative answers.

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