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Rule-based Mapping of Fire-adapted Vegetation and Fire Regimes for the Monongahela National Forest

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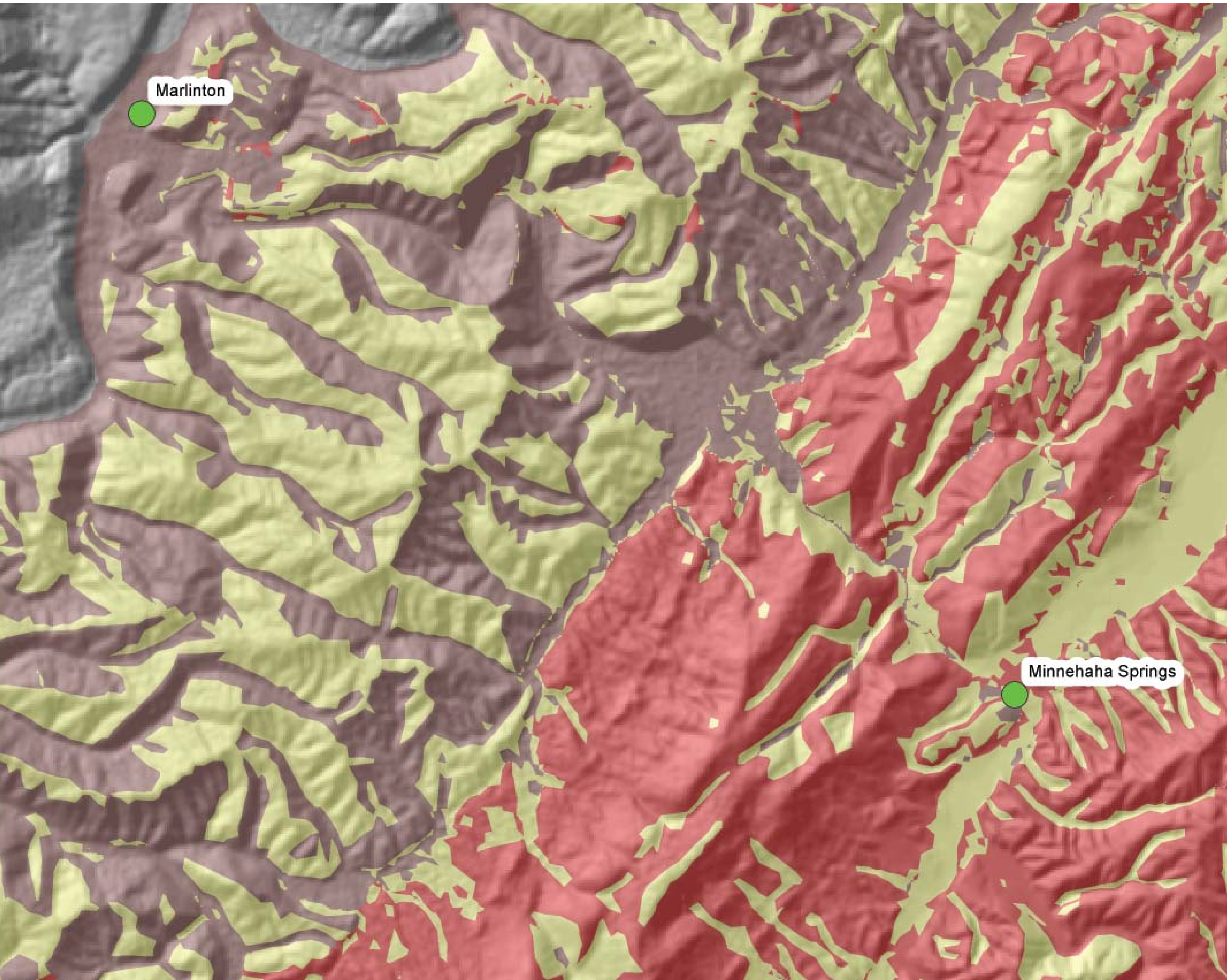

Abstract

The use of prescribed fire is expected to increase as efforts to restore fire-dependent ecosystems gain momentum nationally. The documentation of historical fire regimes is essential for setting restoration objectives that include prescribed burning. To aid the Monongahela National Forest in this endeavor, a rule-based approach was employed in GIS to map fire-adapted vegetation and fire regimes. Spatial analyses and maps were generated using ArcMap 9.1 using the proclamation boundary of the Monongahela National Forest as our study area. Based on current knowledge of fire-vegetation-site relationships, we reviewed available data sets for relevancy in estimating fire regimes. Four themes were selected: landtype association, potential natural vegetation (primary and secondary), and current forest type. All themes were converted to 20 m^2 grids. Selected features of each theme were scaled from 1 through 5 according to their relationship to fire, with 1 representing conditions most conducive to fire and 5 the least. Each theme was weighted to reflect its inferred effect on system fire adaptation. The resulting fire-adaptation scores were then categorized into standard fire regime groups. Fire regime group V (200+ yrs fire frequency) was the most common, assigned to more than 510,000 ha, primarily in the Allegheny Mountains Section. Fire regime group I (low & mixed severity, 0-35 yrs) and III (low & mixed severity, 35 -200 yrs) were assigned to nearly 198,000 ha, primarily in the Ridge and Valley Section and one subsection within the Allegheny Mountains Section. The resultant maps are intended to identify fire-adapted systems for land management purposes. These systems likely will require active silviculture using fire and/or fire surrogates for their maintenance or restoration. The transparent rule-based procedure can be easily modified and, as such, possesses the flexibility for application to other ecosystems with similar spatial databases

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INTRODUCTION

Increasing public concern over recurrent large wildfires in the western United States spurred government action in the form of the National Fire Plan, President's Healthy Forest Initiative, and Healthy Forest Restoration Act. These federal policies fully acknowledge the current wildfire situation, the contributing factors leading to the problem (including 20th century fire suppression and fuel build-up), and the need to reintroduce fire into fire-dependent systems. Collectively, this represents a philosophical shift in the way we view and manage wildfire. Instead of a continuation of fire suppression policies of the past, policies which some believe may have led to the current wildfire problem, more balanced approaches are being sought, including embracing fire as a management tool.

To adequately implement legislation, there is an immediate need for information about fire and its effects (historical and current fire regimes, fire risk/hazard maps, wildland-urban interface, etc.). Considerable research has ensued to fill this void including one effort, spanning the conterminous United States conducted by Schmidt and others (2002). This multifaceted project produced maps of fire regimes and condition classes at a very broad scale (1:2 million). This undertaking resulted in products that were suitable for regional and national level planning efforts. However, at this scale (1-km^2 cell size) the products lacked the specificity to meet management needs of individual national forests.

Although attention to restoring fire to landscapes has focused predominantly on the western United States, there is ample evidence that public lands in the eastern United States are in similar need of restoration (Brose and others 2001, Abrams 2005). Information on fire regimes and their departure from the natural/historical range is even more deficient in this part of the country. Recognizing the needs of national forests, we followed the approach of Schmidt and others (2002), with appropriate modifications, to generate landscape-scale products for the Monongahela National Forest (hereafter referred to as the Monongahela). The stepwise procedure Schmidt and others (2002) employed proved particularly instructive and spurred us to use rule-based mapping in a GIS (Morgan and others 2001). Our original goal was management based: to generate a map showing the best locations to restore fire to the landscape given historical and current conditions. Areas that have pyrogenic origins (potential natural vegetation) and still possess those characteristics in their current vegetation are considered the best candidates for prescribed burning. Those areas possessing mesophytic characteristics, either currently or in the past, are poor candidates for prescribed burning. This publication explains our approach for selecting resource themes, assigning scores and weights, and generating maps and associated tabular data. The process used here to create fire-adapted landscape and fire-regime maps can be easily transferred to other locales where similar spatial databases exist.

STUDY AREA

The spatial extent of this study is approximately the proclamation boundary for the Monongahela, which covers about 710,000 ha. National Forest System lands comprise about 371,000 ha of this area; the remainder is held in state, private, or other federal ownership. The Monongahela's noted biodiversity stems from its rugged topography, which in turn affects primary ecosystem drivers of temperature, solar radiation, and precipitation. Moreover, it is located in the central portion of the Appalachians where plant and animal species with southern and northern affinities coexist. The Monongahela spans portions of two ecological sections with different geomorphologies and climates: the Allegheny Mountains and Northern Ridge and Valley (Cleland and others 2005a). Because of these differences, conditions allow for a wide range of vegetation types from wet, sub-alpine red spruce (*Picea rubens* Sarg.) through species-rich, mixed mesophtyic forests to dry, pine-oak barrens (McCay and others 1997).

Most of the Monongahela lies in the Allegheny Mountains Section (DeMeo and others 1995, Abrams and McCay 1996, McCay and others 1997). The Allegheny Mountains Section has a wet and cool climate, with 114 to 152 cm of precipitation per year (about 20 percent as snow; 30 percent at higher elevations), an annual temperature of 4 to 12 °C, and a growing season of 140 to 160 days. Küchler (1964) mapped this section as northeastern spruce-fir, northern hardwoods, mixed mesophytic, and oak-hickory-pine. Braun (1950) classified the area as part of the mixed mesophytic forest region; however others have noted that hemlock-white pine-northern hardwoods would be more appropriate (Abrams and McCay 1996). The vegetation of the Allegheny Mountains is strongly influenced by elevation and aspect and forms four broad bands or zones: oaks, mixed mesophytic, northern hardwoods, and red spruce. The lowest elevations (valleys and foothills) are dominated by oaks, which associate with sycamore (*Platanus occidentalis* L.), river birch (*Betula nigra* L.), and various mesophytes along riparian corridors and in floodplains. Upslope, the vegetation transitions into mixed mesophytic forests, which include yellow-poplar (*Liriodendron tulipifera* L.), basswood (*Tilia americana* L.), white ash (*Fraxinus americana* L), sugar maple (*Acer saccharum* Marsh.) and northern red oak (*Quercus rubra* L.). The rich, mesic cove hardwoods are diagnostic of this group. The northern hardwood group is found on upper slopes and ridge tops and features sugar maple, yellow birch (*Betula alleghaniensis* Britt.), American beech (*Fagus grandifolia* Ehrh.), eastern hemlock (*Tsuga canadensis* (L.) Carr.), and black cherry (*Prunus serotina* Ehrh). Red spruce forests occur at the highest elevations (above 1,000 m) often mixing with American beech, yellow birch, and eastern hemlock.

Much of the Northern Ridge and Valley Section lies in the rain shadow of the Allegheny Mountains and supports vegetation reflective of drier conditions (Abrams and McCay 1996, McCay and others 1997). Annual precipitation ranges from 76 to 102 cm and may be as high as 152 cm near the Allegheny Plateau. Annual temperature ranges from 4 to 14 °C and the growing season ranges from 120 to 180 days. Küchler (1964) mapped this section as Appalachian oak forest, oak-hickory-pine forest, and some northern hardwoods forest. Braun (1950) classified much of the area as oak-American chestnut (*Castanea dentata* (Marsh.) Borkh.), although oaks now dominate since chestnut blight effectively eliminated American chestnut as an overstory species. In general, northern red oak and white oak (*Quercus alba* L.) occur on productive mesic sites, often intermixed with eastern white pine (*Pinus strobus* L.) on side slopes. Scarlet (*Q. coccinea* Muenchh.) and black oak (*Q. velutina* Lam.) increase in representation on progressively drier sites. On the driest sites (e.g., shale barrens), pitch (*P. rigida* P. Mill.), Table Mountain (*P. pungens* Lam), or Virginia (*P. virginiana* Mill.) pines predominate, either in pure stands or mixed with scrub oak (*Q. ilicifolia* Wangenh.).

METHODS

Mapping Approach

We applied aspects of the nationwide approach of Schmidt and others (2002) to the landscape scale. Schmidt and others (2002) mapped historical fire regimes at a regional scale by assigning rankings to combinations of biophysical and vegetation spatial data layers. We used their approach and substituted best available local data sources, making appropriate modifications based on these databases and local environment, and employing weighted averaging and rule-based mapping.

A geographic information system (GIS) was used to couple available spatial data with expert opinion on Appalachian disturbance regimes for graphical display and analysis. We used ArcMap 9.1 (Environmental Systems Research Institute, Redlands, CA) in a manner similar to Hiers and others (2003) for spatial analyses,

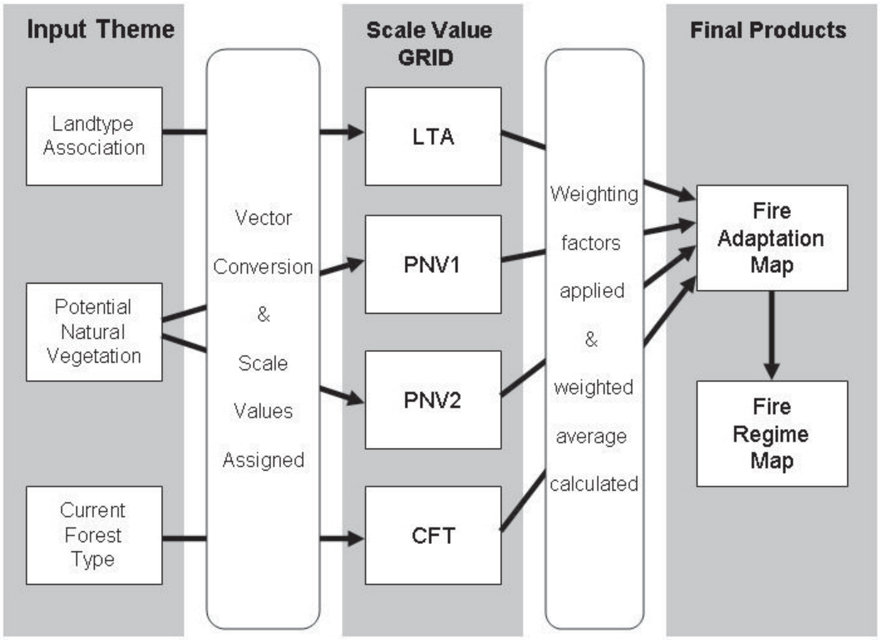


Figure 1.—Schematic showing the stepwise procedure of rule-based mapping. Input themes (far left column) are converted from polygons to 20 m^2 grids and scale values are assigned to each grid cell from the score values (rules) shown in Tables 5, 6, and 7. Weighting factors are then applied to these grids resulting in the weighted average overlay map (far right column).

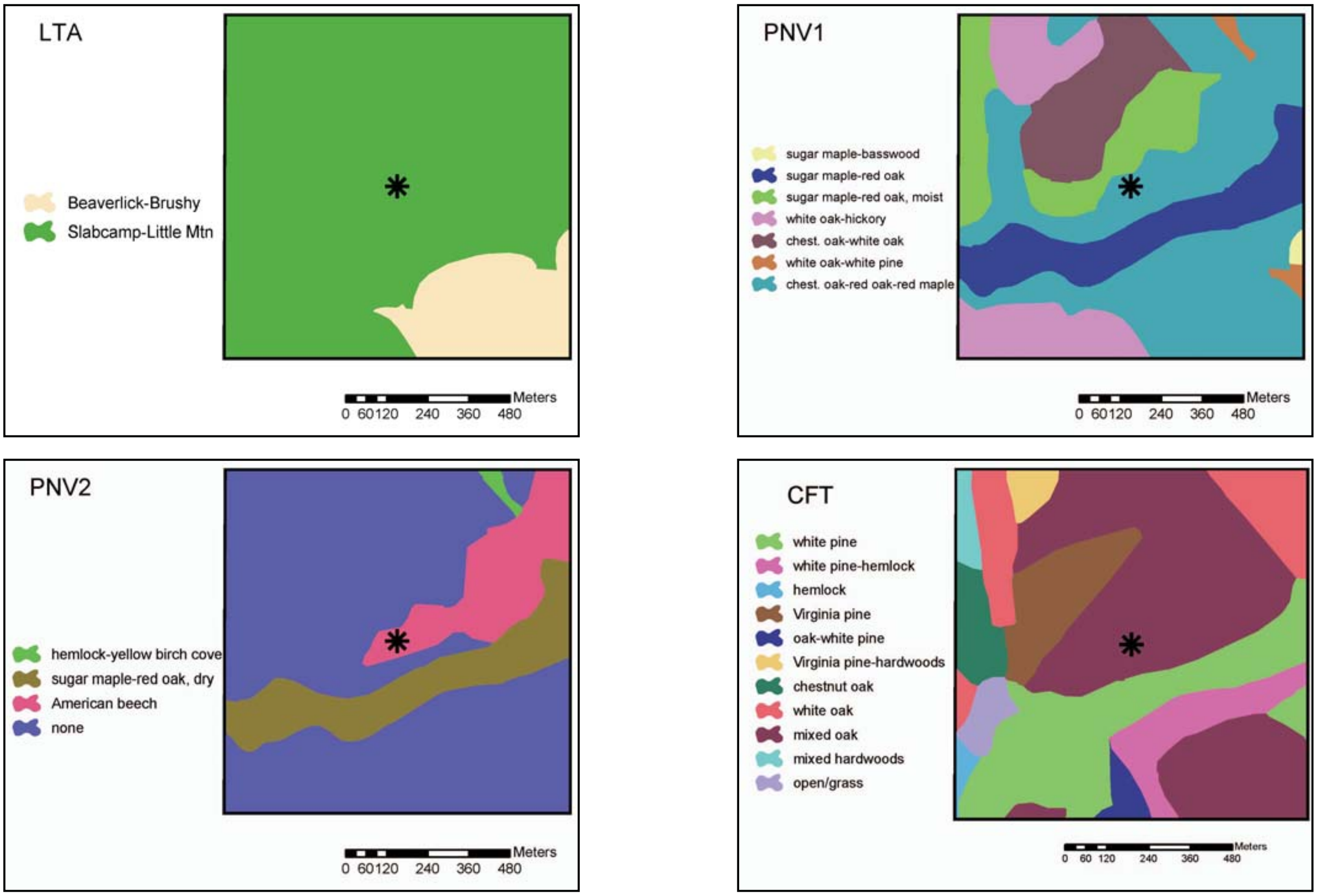
Table 1.—Weighting values by input theme to produce the fire-adaptation landscape map

Theme	Weight (percent)
Land type association (LTA)	20
Potential natural vegetation, primary association (PNV1)	30
Potential natural vegetation, secondary association (PNV2)	20
Current forest types - overstory (CFT)	30

applying weights and scale values to determine scores (weighted averaging) resulting in map generation.

Four input themes were selected: landtype associations (LTA), potential natural vegetation primary (PNV1) and secondary (PNV2), and current forest type (CFT) (Fig. 1). Primary PNV plant associations are the dominant plant association for a given area, whereas secondary plant associations are less prevalent inclusions that provide additional ecological information within a map unit. All themes were converted to 20 m^2 grids and weights were assigned to each (Table 1) according to their estimated influence on fire adaptation based on expert opinion of the authors. Figure 2 provides an example of how scale values (assigned from Tables 5, 6, and 7) and weights (Table 1) were applied to individual themes to generate a fire-adaptation score for a given cell.

To determine the final input themes and their weights, an analysis was made of the relationships among themes, weights, and outputs. This sensitivity analysis was an iterative process, where different theme weights were applied (from equal weighting to various combinations) and output maps compared and scrutinized (Fig. 3 and 4 and Tables 2 and 3). Equal weighting (25 percent to all themes) gave the most conservative estimate of fire adaptation (higher scores; less fire), whereas higher weights to either CFT or PNV1 (60 percent weighting) returned more liberal estimates of fire adaptation (lower scores; more fire). The final output (Fig. 2 and 5) was based on equal weighting of CFT and PNV1 (30 percent each), and equal weighting (20 percent each) of PNV2 and LTA. Themes PNV1 and PNV2 make up 50 percent of the weighting because these themes cover all land in the study area in finer detail than the other themes.



Input theme	Scale value	Weight %	Score
LTA	5	20	1
PNV1	2	30	0.6
PNV2	5	20	1
CFT	2	30	0.6
Weighted average			3.2

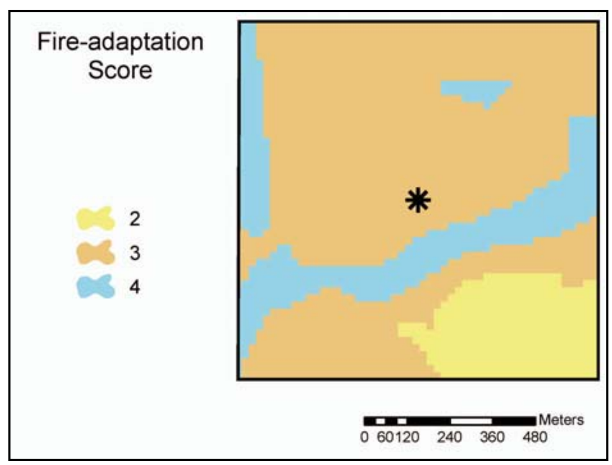


Figure 2.—Example of weighted averaging for a point on the Monongahela. Square represents 1,000 m^2 with the centroid displayed as an asterisk. Input values for landtype association (LTA), potential natural vegetation (primary and secondary; PNV1 and PNV2, respectively), and current forest type (CFT) are displayed. The table of values within the figure shows the steps made through the application of the assigned rules to determine the weighted average fire-adaptation score.

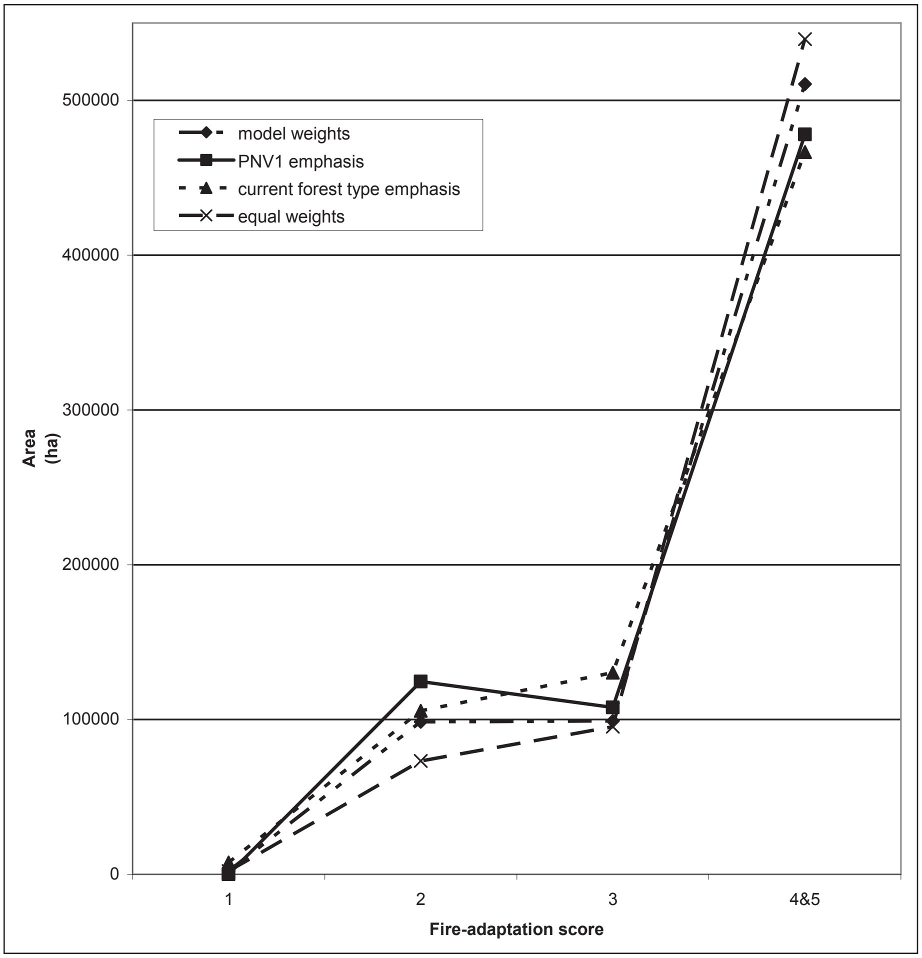


Figure 3.—Comparison of fire-adaptation score totals for different weighting schemes. See also Table 2.

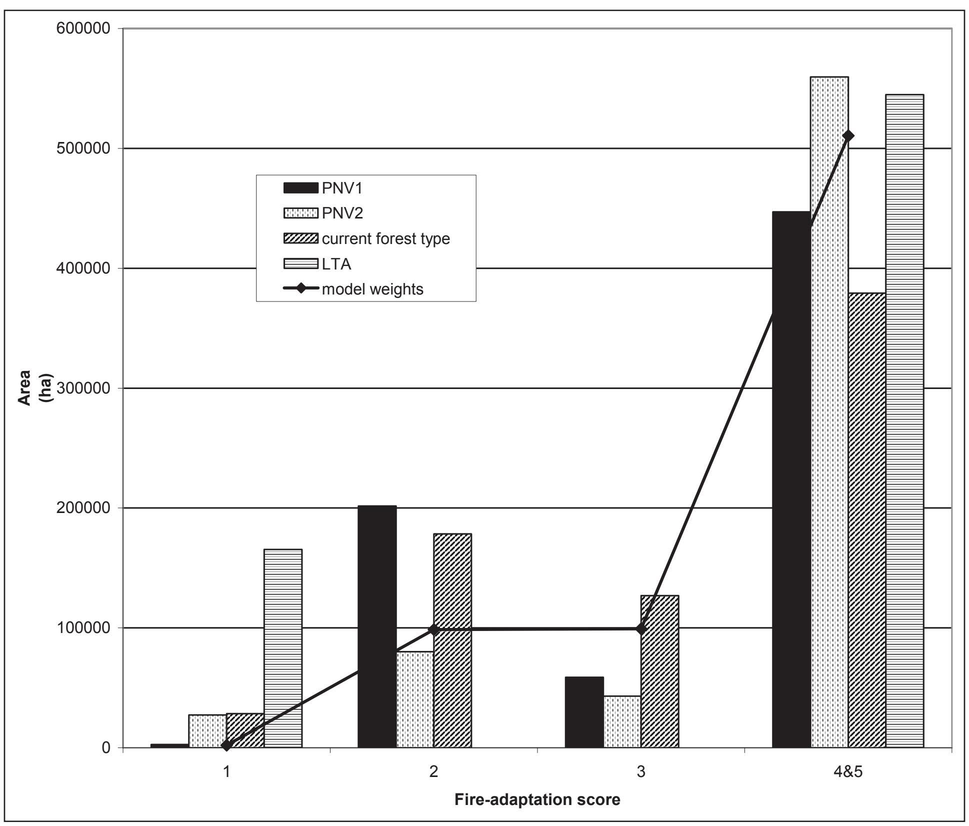


Figure 4.—Comparison of fire-adaptation score totals for input themes (unweighted, not averaged) and results of weighted averaging. See also Table 3.

Table 2.—Results of sensitivity analysis. Fire-adaptation score totals after changing weights

Weighting scheme	Area (ha) by score			
	1	2	3	4 and 5
Equal weights for current forest type and primary potential natural vegetation (LTA - 20%, PNV1- 30%, PNV2 20%, CFT - 30%)	2,100	98,513	99,147	510,521
Equal weights all themes (LTA - 25%, PNV1 - 25%, PNV2 - 25%, CFT - 25%)	2,098	73,154	95,452	539,577
Current forest type emphasized (LTA - 14%, PNV1 - 13%, PNV2 - 13%, CFT - 60%)	7,656	105,661	130,264	466,701
Primary potential natural vegetation emphasized (LTA - 13%, PNV1 - 60%, PNV2 - 14%, CFT - 13%)	0	124,467	107,857	477,957

Table 3.—Results of sensitivity analysis. Area (ha) by fire-adaptation score from individual input themes compared to weighted average of all themes

Score	PNV1	PNV2	LTA	CFT	Model weights
1	2,750	27,403	165,497	28,593	2,100
2	201,613	80,215	0	178,492	98,513
3	58,799	43,139	0	126,886	99,147
4&5	447,119	559,525	544,784	379,328	510,521

Features in each of the input themes were scaled from 1 through 5 in accordance to fire-adaptation characteristics of the landscape (primarily vegetation-based) with 1 representing characteristics most adapted to fire and 5 the least. Weights and rules (scale values) were applied to each cell in the GIS and the resulting weighted averages were rounded to whole numbers using the default rounding function to produce the fire-adapted score for each cell. Scale values and weighting factors were based on literature and expert opinion of the authors. Null values were assigned a 5, thus being conservative in areas with little information. This GIS rule-based approach provides an effective way to locate and summarize fire-adapted landscapes based on commonly held notions regarding fire-vegetation-site relations.

The map and associated database applies but does not test these theories of fire ecology. As research advances and our knowledge of fire ecology improves, the map can easily be modified to reflect those changes. The stepwise logic behind the weighted averaging is illustrated in Figure 1.

Literature Review

The assignment of fire-adapted values to LTA, CFT, PNV1, and PNV2 was based on review of literature on historical disturbance regimes, tree-life histories, and silvical characteristics (Table 4). We used the Central Appalachian Broadleaf Forest-Coniferous Forest-Meadow Province (M221) (Cleland and others 2005a) as the focus for literature review and reconstructing presettlement disturbance regimes.

Presettlement and Historical Disturbance Regimes

Presettlement disturbance regimes, and land-use alterations since, are well documented across the eastern United States (Frost 1998, Wade and others 2000, Brose and others 2001). The ecological role of fire is particularly well established for oak and pine systems (Abrams 1992, 2001, 2005; Brose and others 2001).

Native American ignitions were prevalent prior to European settlement, considering the unfavorable seasonality (mainly during green leaf-out) and conditions (wet and rainy) associated with most lightning storms—

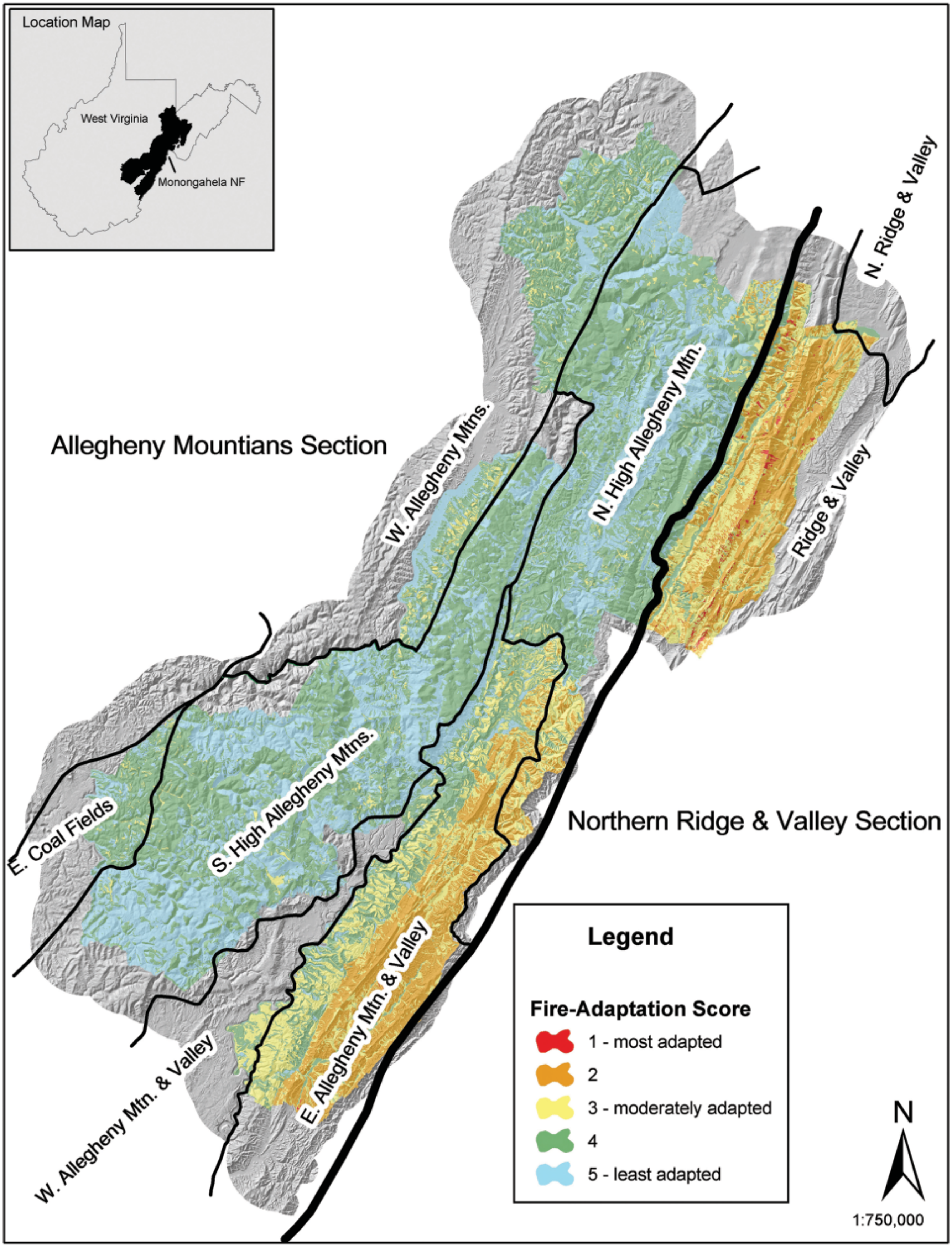


Figure 5.—Fire-adapted vegetation within the study area. Ecological divisions shown are subsections; section break between the Allegheny Mountains and Northern Ridge and Valley sections is the thicker line.

Table 4.—Information sources for presettlement and historical disturbance regimes for major forest types

General disturbance regimes	Brown 2000 Brown and Smith 2000 Chapman and others 1982 Delcourt and Delcourt 1997, Delcourt and Delcourt 1998 DeVivo 1991 Frost 1998 Guyette and others 2002 Ison 2000 Maxwell 1910 Patterson and Sassaman 1988 Rentch and Hicks 2005 Russell 1983 Schmidt and others 2002 Seymour and others 2002 Wade and others 2000 Williams 1989
Red spruce and spruce-hardwood forests	Chandler and others 1983 Gorman 2005 Hopkins 1899 Rentch and others 2007 Schuler and others 2002 White and others 1985
Northern hardwood forests	Canham and Loucks 1984 Cleland and others 2005b Fahey and Reiners 1981 Frelich and Lorimer 1991 Lorimer 1977 Lorimer and White 2003 Marks and Gardescu 1992 Nowacki and others 2004 Parshall and Foster 2002 Patterson and Backman 1988 Seischab and Orwig 1991 Wade and others 2000 Whitney 1986, Whitney 1987, Whitney 1990
Mixed mesophytic forests	Abrams and others 1998 Davenport 2005 Lorimer 1980 McCarthy and others 2001 Schuler and Fajvan 1999
Oak and oak-pine forests	Abrams 1992, Abrams 2001, Abrams 2003, Abrams 2005 Abrams and others 1995 Brose and Van Lear 2004 Brose and others 2001 Collins and Carson 2003 Croy and Frost 2005 Fryar 2004 Lorimer 1985, Lorimer 1989 Lorimer and White 2003 Randles and others 2002 Rentch and others 2003 Schuler and McClain 2003 Shumway and others 2001 Signell and others 2005 Spetich 2004 Sutherland 1997 Van Lear 1991, Van Lear 1993 Waldrop and others 2002 Welch and Waldrop 2001

the primary natural ignition source in the East (Bratton and Meier 1998, Dey and Guyette 2000, Lorimer 2001). For instance, fossil pollen and charcoal particle records preserved in a North Carolina peat bog indicated that local, presumably Native-caused, fires increased to 30 percent of the charcoal record during the Woodland period (3,000 to 1,000 years BP). This corresponds with documented lifestyle changes toward agriculture and hunting-based habitat manipulation by Native Americans (Delcourt and Delcourt 1997). Delcourt and Delcourt (1997, 1998) speculate that Native American activities including burning would have heightened differences between vegetation types. In eastern Kentucky, pond fossil pollen and charcoal records and archaeological records of prehistoric sites near the pond demonstrate the central role anthropogenic fires played in shaping forest composition (Ison 2000). Sediment core studies at Cliff Palace Pond track the changes in vegetation due to climate and human influence, including the increase in fire-tolerant plant taxa even as a wetter climate developed (Ison 2000).

The earliest historical accounts of the landscape of Virginia (and some areas later to become West Virginia) are documented in Maxwell (1910). Maxwell recounts the 1671 Thomas Batts expedition where "…meadows and old fields…" indicative of Native habitation were reported in a valley near the New River, near the present Virginia - West Virginia border. The time that elapsed between Native depopulation (ca.1672) and European arrival (mid-1700s) probably greatly obscured the scope and magnitude of Native American impacts in West Virginia (Maxwell 1910). Some ancillary accounts do exist, however, such as small areas of sod and young, pole-sized forests found by early settlers (1753) in Tygart Valley (Maxwell 1910).

Red Spruce and Allied Forests

Red spruce occurs on high elevation (>1000 m) ridges and plateaus within the Allegheny Mountains Section, often mixing with yellow birch, sugar maple, American beech, black cherry, and eastern hemlock (Rentch and others 2007). These topographically exposed locations are driven largely by weather-related disturbances, particularly wind and ice-storm events. These disturbances affect forests in a variety of ways, from frequent single-tree mortality and occasional partial canopy removal to infrequent catastrophic blowdowns (White and others 1985). This disturbance regime of principally gap-phase dynamics is conducive to the life history of red spruce—a shade tolerant species that can persist in deep shade for long periods and quickly respond to canopy gaps.

The prevailing cool, foggy, and wet conditions greatly suppresses fire, with stand replacement burns recurring at an estimated 650 years (Gorman 2005). Pre-European settlement fire events probably were restricted to times of extended drought, especially in the presence of dead or dying timber due to insect infestations or blowdowns (Hopkins 1899). This forest type was greatly affected by late 19th /early 20th century logging and subsequent fires, converting many stands to northern hardwoods (Schuler and others 2002).

Northern Hardwood Forests

Northern hardwoods occur on upper elevations of the Allegheny Mountains Section below 1000 m in elevation, forming a transition between mixed mesophytic at lower elevations and red spruce forests at the highest elevations. Diagnostic species, including yellow birch and black birch (*Betula lenta* L.), sugar maple and red maple (*Acer rubrum* L.), and American beech, are well suited to the prevailing cool, damp climate of this zone. The inherently moist site conditions coupled with the fire-retarding tendencies of the dominant species (dense understory shade; rapid decomposition of moisture-retaining leaves and woody debris) strongly inhibit fire. The low incidence of presettlement fire is firmly established in historical, dendroecological, and palaeoecological records (Lorimer 1977, Fahey and Reiners 1981, Whitney 1987, Patterson and Backman 1988, Frelich and Lorimer 1991, Parshall and Foster 2002). Instead, wind and ice-related events are the primary disturbances of this forest type.

Throughout their range, northern hardwoods are renowned for their long-term stability and old-growth character driven by gap-phase dynamics (single-tree and small multiple-tree gap creation). This gap-based disturbance regime reinforces the long-term dominance of the species of this forest type. Occasionally, intense disturbance events (hurricane-force winds, rime icing) lead to partial or full canopy destruction. However, stand-replacing disturbances are exceedingly infrequent, with return intervals averaging more than 1,000 years (Lorimer 1977, Canham and Loucks 1984, Whitney 1986, Whitney 1990, Seischab and Orwig 1991, Marks and Gardescu 1992). At this rate, several tree generations of gap-phase-origin can cycle between catastrophic episodes.

Mixed Mesophytic Hardwood Forests

The mixed mesophytic hardwood forests are found mainly in the Allegheny Mountains Section and are distinguished by a diverse mix of tree species found generally on moist, nutrient-rich sites. Common tree species include basswood, yellow-poplar, sugar maple, northern red oak, American beech, and white ash. Weather-based and disease-caused single and small multiple-tree gaps are the primary disturbance agents, although infrequent, low-intensity fire is possible in stands embedded in fire-prone landscapes (Davenport 2005). Frequent canopy disturbance was confirmed on a unique talus slope in the study area, with release events occurring every decade from 1870 to 1990 (Abrams and others 1998). Fire scars also were noted on some sugar maples in the study. On the Fernow Experimental Forest in West Virginia, partial canopy disturbance occurred approximately every 31 years between 1797 and 1983 (Schuler and Fajvan 1999). This return interval fell within the range found in southwestern North Carolina of 30 to 40 years (Lorimer 1980).

Oak and Oak-Pine Forests

Oak forests dominate parts of the study area, especially in the Northern Ridge and Valley section. A variety of oak species occur, including white oak, chestnut oak (*Quercus prinus* L.), black oak, scarlet oak, and northern red oak. Hickories (*Carya* spp) and pines (*Pinus* spp) are common associates. Frequent, low-intensity surface fires are considered the principal disturbance that historically maintained these forest types. Local fire-scar studies have calculated fire-return intervals of 8 years (Shumway and others 2001) and 7 to 15 years (Schuler and McClain 2003). Fire scars on one old-growth white oak in Ohio showed a median fire interval of 2 years between 1731 and 1881 (McCarthy and others 2001). Large canopy disturbances (involving multiple trees) from various origins (wind, fire, ice) occurred every 16 years in oak-dominated old-growth stands in the central hardwoods region (Rentch and others 2003).

Oaks are well suited to frequent surface burning because they possess a number of fire adaptations, including thick bark, high resistance to rotting after injury, deep rooting, vigorous sprouting abilities, and increased germination and survival on fire-created seedbeds (Abrams 2000). Also, oak leaves dry quickly, resist decay, and curl to provide a fuel bed for surface fires, as opposed to the leaves of northern hardwoods that decay faster and lie flat (Van Lear 2004). Maple and beech litter often do not carry surface fire on prescribed fires in the study area, especially if allowed to decay and flatten under winter snow packs (personal observation of the authors). Oak is a disturbance-dependant genus that prefers high light conditions to germinate and recruit to the overstory. Although they will regenerate in forested understories, oaks are often relegated to small seedlings that do poorly against shade-tolerant competitors (Lorimer 1985, Lorimer 1989). Oaks and hickories respond to fire by sprouting from root collar buds located deeper in the soil than their shade-tolerant competitors (Brose and Van Lear 2004). The connection between oak and fire is strong, based on multiple lines of evidence (paleoecology, historical records, tree-life histories, ecophysiological traits) (Abrams 1992). Without fire, oak forests readily succeed to fire-sensitive, shade-tolerant species on all but the most xeric of sites.

Input Themes

Landtype associations are ecological units that represent biogeoclimatic relations at the landscape scale (Cleland and others 1997). Landtype associations were digitally mapped by DeMeo and others (1995) for the study area prior to this study. We appended fire-history descriptions to each LTA and assigned scale values of 1 or 5 (Table 5). Landtype associations with documented fire events, drier site conditions, and pyrogenic species were assigned a value of 1, whereas LTAs having little or no documented fire history, moister conditions, and mesophytic (fire-avoiding) species were assigned a value of 5. The majority of LTAs within the study area (about 443,200 ha) have an unknown fire history. As such, many LTAs received

Table 5.—Assigned scale values for landtype associations (LTA)

Landtype association	Scale value	Fire history
Allegheny Front Foothills (Fore Knobs)	1	Frequent, low intensity
Allegheny Mountain System	1	Frequent, low intensity
Beaverlick-Brushy System	1	Frequent
Cave Mountain System	1	Frequent, low intensity
Germany Valley	1	Frequent, low intensity
North Fork Mountain/River Knobs	1	Frequent, low intensity
Allegheny Front Sideslopes	5	Unknown
Allegheny Plateau	5	Unknown
Allegheny Plateau Block, Red Spruce, Frigid Soils	5	Low occurrence
Allegheny Plateau Red Spruce - Frigid Soils	5	Low occurrence
Burner Mountain - Laurel Fork Virginia System	5	Unknown
Canaan Valley	5	Unknown
Cheat Mountain Backslopes	5	Unknown
Cheat River	5	Riparian, low frequency
Cheat River Hills	5	Unknown
Cheat-Shaver's-Back Allegheny Mountain System	5	Low occurrence
Cloverlick System	5	Unknown
Deer Creek	5	Unknown
Dolly Sods	5	Low occurrence, high severity
Middle Mountain System	5	Unknown
Northern Allegheny Mountain	5	Unknown
Potomac Riparian	5	Riparian, low frequency
Slabcamp - Little Mountain System	5	Unknown
Spruce Knob System	5	Low occurrence
Tygart Valley River Riparian	5	Low occurrence, riparian
Upper Tygart Valley	5	Unknown
Water	5	None

a scale value of 5, which contributed to the conservative tendency of our results. Using Figure 2 as an example, the Slabcamp-Little Mountain LTA had a scale value of 5 based on its unknown fire history (Table 5).

Potential natural vegetation for land of all ownership types was taken from the Monongahela's landtype inventory to form two input variables. Primary potential natural vegetation plant associations (PNV1) were assigned scale values based on the fire adaptation of their component trees (Table 6). Secondary plant associations (PNV2) are composed of the same associations as PNV1 and were assigned the same scale values as PNV1, but remained a separate theme in the model. As shown in Figure 2, if an area has a PNV2 assigned, it will be different than the area's PNV1, by definition; however the same list of plant associations is used (Table 6).

Current forest types (CFT) on National Forest System (NFS) lands were assigned scale values based on the current stand-level forest type inventory (Table 7). There were about 28,400 stands in the database, representing data collected from 1950 (one stand) through the present. This database, maintained by the Monongahela for ongoing management, is the best approximation of current vegetation available for NFS lands. A continuum of value assignments (1 through 5) were based on the life histories and physiological traits of the dominant overstory trees (Burns and Honkala 1990a, Burns and Honkala 1990b, Brown and Smith 2000). Using Figure 2 as an example, the CFT of the point is mixed oak and receives a scale value of 2 (Table 7).

For land in other ownerships, the 1993 West Virginia Gap Analysis data for Land Use/Land Cover (West

Table 6.—Assigned scale values for plant associations (PNV1 and PNV2)

Scale value	Plant association
1	Dry pines (Virginia, pitch, and/or Table Mountain pine), Heathland (blueberry/mountain laurel), Rock with blueberry
2	Chestnut oak-red oak-red maple, Chestnut oak-white oak, Chestnut oak-white pine, Goldenrod/sedges, Hypericum glades, Limestone glades, Mountain hairgrass/hayscented fern, Red oak, Red oak/mountain laurel, Scarlet oak-black oak, Shale barrens, White oak, White oak-Eastern red cedar, White oak-hickory, White oak-white pine
3	Spirea thicket, Sugar maple-red oak (dry phase), White oak-yellow poplar, White pine-hemlock, Yellow birch, Yellow birch/rhododendron, Yellow birch/rhododendron
4	Cotton grass-beaked rush, Hemlock cove, Hemlock-yellow birch cove, Red spruce, Red spruce/balsam fir, Red spruce/hay scented fern, Red spruce, American beech, Red spruce-Eastern hemlock, Red spruce-eastern hemlock/rhododendron, Sedges, Sphagnum bogs, Sugar maple-hemlock cove, Sugar maple-red oak, Sugar maple-red oak (moist phase), Sugar maple-red oak/blue cohosh, Sugar maple-red oak/New York fern
5	Alluvial riparian, American beech, American beech-basswood, Rock, Speckled alder/willow thickets, Sugar maple, Sugar maple-American beech, Sugar maple-basswood, Sugar maple-basswood/wood nettle, Sugar maple-blue cohosh, Sugar maple-yellow- poplar, Unknown, Water

Table 7.—Assigned scale values for current forest type (CFT)

Scale value	Forest type
1	Open, Pitch pine, Red pine, Red pine-oak, Shrubland, Virginia pine, Virginia pine-hardwoods, Woodland
2	Bigtooth aspen, Birch, Black locust, Black oak/scarlet oak/hickory, Chestnut oak, Eastern white pine, Eastern white pine-hemlock, Hardwood/conifer forest, Mixed oaks, Northern red oak, Oak dominant forest, Oak-Eastern white pine, Quaking aspen, Scarlet Oak, Upland shrubs, White oak, Yellow-poplar/white oak/Northern red oak
3	Hemlock, Mixed upland hardwoods, Paper birch, White pine – northern red oak
4	Black cherry-white ash/yellow-poplar, Black walnut, Cove hardwood forest, Diverse/mesophytic hardwood, Herbaceous wetland, Lowland shrubs, Mountain conifer forest, Norway spruce, Red maple (dry site), Red spruce-balsam fir, Spruce, Sugar maple-beech-yellow birch/red spruce, Tamarack
5	Barren land (mining, construction), Beech, Conifer plantation, Floodplain forest, Forested wetland, Intensive urban, Light intensity urban, Major power lines, Moderately intense urban, Mountain hardwood forest, Mountain hardwood/conifer forest, Pasture/grassland, Planted grassland, Red maple (wet site), River birch/sycamore, Row crop agriculture, Shrub wetland, Sugar maple, Sugar maple – beech/yellow-poplar, Sugar maple-basswood, Surface water, Unknown, White ash, White spruce-balsam fir

Virginia University 2006a) was used to estimate CFT. These data include NFS lands as well, however we used only those polygons not in NFS ownership. Current land-cover types were mapped at the alliance level from a combination of LANDSAT imagery, FIA plot data, and aerial photos (Strager and Yuill 2002, West Virginia University 2006b).

Map Validation

Validation of the resultant fire-adaptation map proved difficult, given that efforts were geared to identify and use the best available spatial data in its creation. What could be considered “the truth,” especially since multiple interacting variables influence fire regimes? Solely concentrating on biophysical parameters as theme inputs enabled us to use meteorological data as an independent check. Due to its strong control on fire regimes, precipitation was selected as a prime validation measure. We used a PRISM-based average annual precipitation cover (1961-1990) for West Virginia provided by the Natural Resources Conservation Service's National Water and Climate Center and the Spatial Climate Analysis Service at Oregon State University (USDA NRCS 2007). Precipitation classes ranged from somewhat dry to very wet, lending themselves well for fire-adaptation score assignment. The full range of fire-adaptation scores (1-5) were assigned to precipitation classes along this moisture (inferred fire) gradient. The 14 pre-determined precipitation classes in the data set were assigned fire-adaptation scores as follows: 1 = ≤86 cm precipitation classes; 2 = 87-102 cm precipitation classes; 3 = 103-112 cm precipitation classes; 4 = 113-137 cm precipitation classes, and 5 = >138 cm precipitation classes (Fig. 6). Fire-adaptation scores generated by the model and precipitation data were geospatially compared at a 20-m pixel resolution and a correspondence matrix and Kappa statistic produced (Monserud and Leemans 1992).

Fire-regime Map Creation

The fire-adaptation scores generated by our rule-based approach do not directly correspond to nationally standardized fire regime groups (USDA FS 2003). Based on literature review, our fire-adaptation scores were cross-walked and assigned to the standardized fire regime groups as follows: 1 (most fire-adapted areas) = fire regime group IV (replacement, 35-200 years); 2 = fire regime group I (low and mixed severity, 0-35 years); 3 (moderately fire-adapted areas) = fire regime group III (low and mixed severity, 35-200 years), and 4 and 5 (least fire-adapted areas) = fire regime group V (200+ years).

Fire regime group II (replacement, 0-35 years) represents highly pyrogenic ecosystems such as grass and shrub lands—systems that are rare in the central Appalachians. As such, no landscapes on the Monongahela were categorized as fire regime group II. The fire regime map was substantiated by comparing it to site specific stand dynamic studies within the study area.

RESULTS

A rule-based, multifactor approach was used to generate a fire-adaptation map and database that spatially identifies and quantifies vegetation-fire patterns of the Monongahela landscape (Fig. 4 and Table 8). Our final output (Fig. 2 and 5) was based on equal weighting of CFT and PNV1 (30 percent), resulting in a distribution generally between the two extremes from the other weighting schemes described previously and displayed in Table 2. These two themes were given equal weight since they were consistent with the original intents of the mapping effort: to identify and map those areas where prescribed fire could be best applied to perpetuate current forest types or restore historical (PNV) forest types. By combining and weighting themes to generate fire-adaptation scores, the model has a moderating effect relative to using individual "unweighted" themes (Fig. 4 and Table 3).

Table 8.—Fire-adaptation scores as a result of the mapping from rule-based weighted averaging

Fire-adaptation score	Area (ha)
1 – most fire adapted	2,100
2	98,513
3 – moderately fire adapted/neutral	99,147
4	308,129
5 – least fire adapted	202,392
Total	710,281

For validation, we compared our model-based fire-adaptation scores to those generated by an independent factor, precipitation. A strong correspondence was found between the two spatial covers analyzed at the 20-m pixel resolution. The direct correspondence between the cells is 44 percent with a Kappa statistic of 0.17. As Table 9 shows, this correspondence is based on exact agreement between the two maps (main diagonal of the table). When near correspondence is computed (secondary diagonals off the main diagonal, outlined area in Table 9) the correspondence increases to about 92 percent with a Kappa statistic of 0.88.

Since fire-adaptation scores of 4 and 5 were combined when we assigned fire regime groups, another analysis of correspondence was made involving the main diagonal (direct correspondence) and cells for fire-adapted rankings of either 4 or 5 (bold numbers in

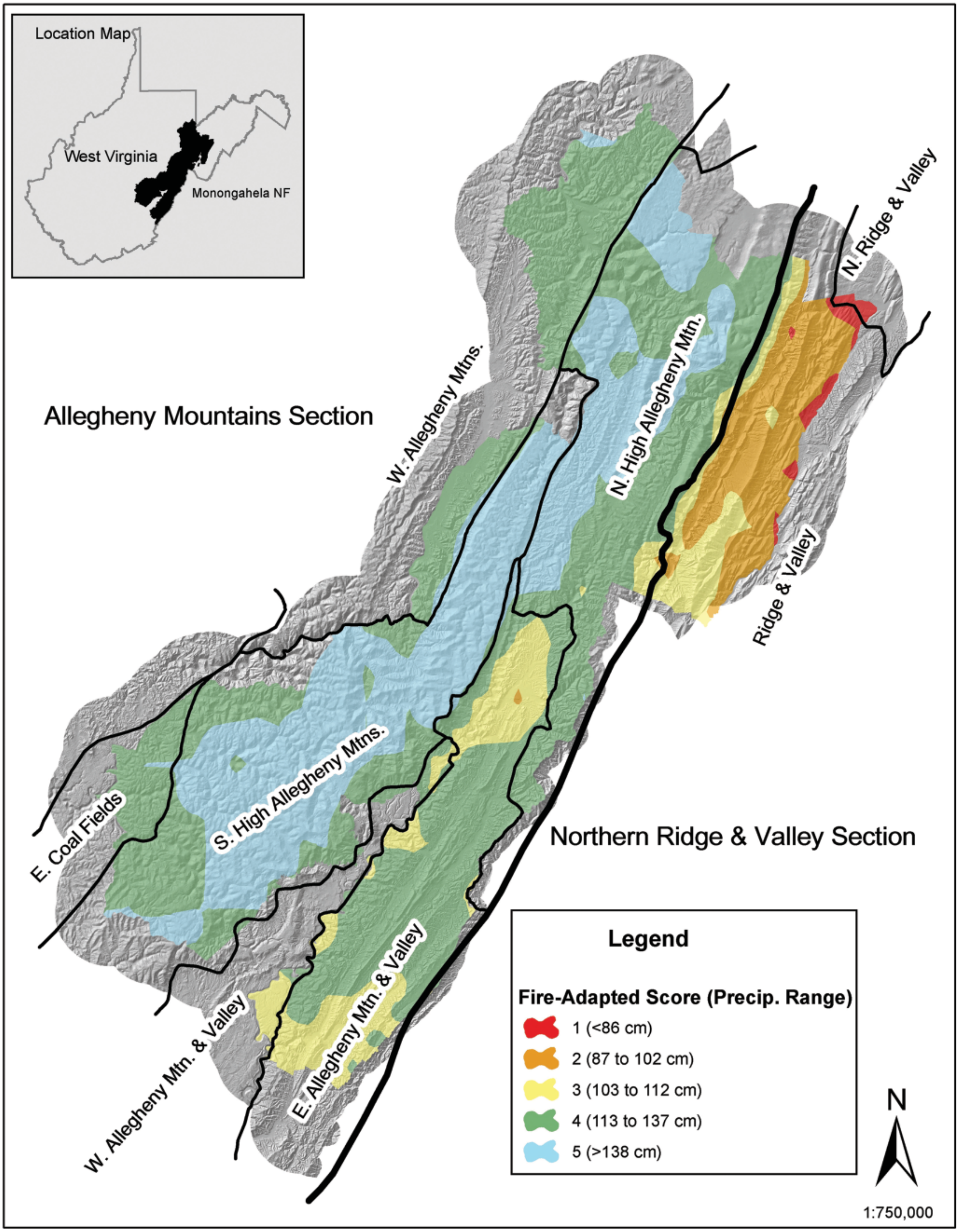


Figure 6.—Average annual precipitation data and assigned fire-adaptation scores. Ecological divisions shown are subsections; section break between the Allegheny Mountains and Northern Ridge and Valley sections is the thicker line.

Table 9.—Matrix produced from cell-by-cell comparison of average annual precipitation and our rule-based model. The grey highlighted area represents about 44 percent correspondence between the two layers with a Kappa statistic of 0.17. The outlined area represents about 92 percent correspondence with a Kappa statistic of 0.88. Numbers in bold were used to calculate correspondence based on the fire-regime groups and show a correspondence of 75 percent with a Kappa statistic of 0.37.

	Result from precipitation layer					
Result from our model	1	2	3	4	5	Total
	Number of cells					
1	**1,329**	26,431	22,796	2,335	0	52,891
2	69,031	**777,183**	577,238	1,048,575	752	2,472,779
3	51,660	458,762	**675,457**	1,221,769	70,103	2,477,751
4	24,585	127,828	595,722	**3,942,389**	**3,003,431**	7,693,955
5	463	10,584	125,229	**2,434,005**	**2,488,013**	5,058,294
Total	147,068	1,400,788	1,996,442	8,649,073	5,562,299	17,755,670

Table 10.—Fire-regime group as cross-walked by fire-adaptation scores

Fire regime group	Fire-adaptation score	Area (ha)
I - Low & mixed severity, 0-35 yr	2	98,513
II - Replacement, 0-35 yrs	NA	0
III - Low & mixed severity, 35-200 yrs	3	99,147
IV - Replacement, 35-200 yrs	1	2,100
V - Any severity, 200+ years	4 & 5	510,521
Total		710,281

Table 10). With this comparison, there was a 75 percent correspondence and a Kappa statistic of 0.37, indicating fair agreement between the maps (Monserud and Leemans 1992). Although precipitation is only one of many factors affecting fire regimes, this correspondence provided some assurance of model validity. It should be noted that absolute correspondence was not attainable due to scale differences between the two layers; i.e., our fire-adaptation map shows smaller inclusions associated with topographic variation (slope, aspect, elevation). Given its higher resolution, we consider our map superior to the precipitation-based fire adaptation layer that was used for evaluation.

The fire-adaptation map showed that much of the study area was not strongly adapted to fire (fire-adaptation scores of 4 and 5). This was especially true of the Allegheny Mountains Section, except for its far southeastern portion. In total, landscapes least adapted to fire comprised 72 percent of the study area (Table 8). Scattered within this pyrophobic matrix were small areas of moderately fire-prone areas (fire-adaptation score of 3). These areas often reflected the influence of aspect, which creates drier conditions more conducive to fire-adapted vegetation. About 14 percent of the landscape was classified in the two most fire-adapted categories (1 and 2), having strong spatial ties to the Ridge and Valley Section and the Eastern Allegheny Mountains and Valley subsection.

The fire-regime map (Fig. 7) is a direct derivative of the fire-adaptation map and represents a conversion of fire-adaptation scores into standardized fire regimes (Table 10). As such, similar spatial distributions exist between the two maps, differing only in their categorization. Fire regime V dominated the study area landscape with 510,500 ha (Table 10). Fire regime groups I and III, concentrated in the drier portions of the study area,

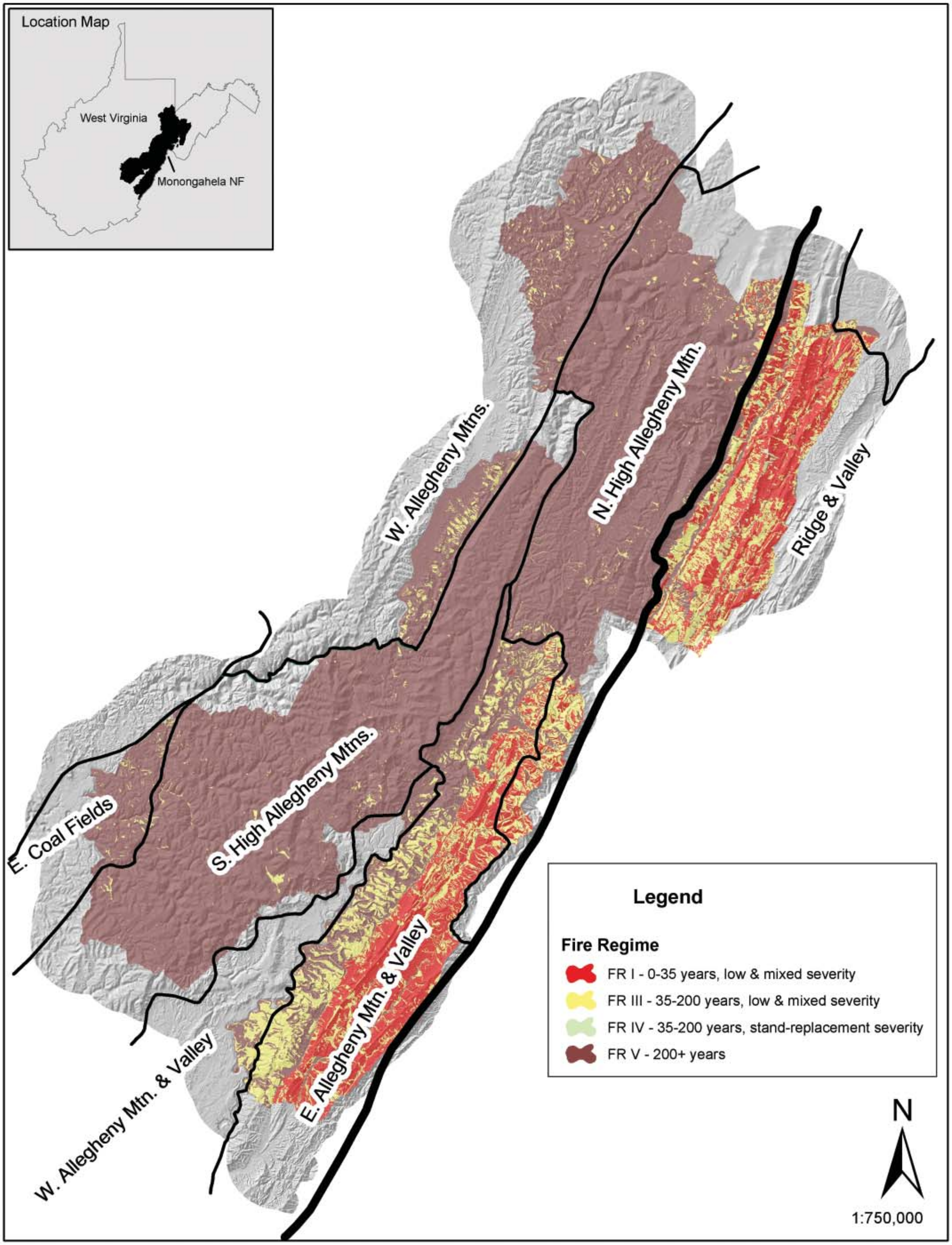


Figure 7.—Fire-regime groups within the study area. Ecological divisions shown are subsections; section break between the Allegheny Mountains and Northern Ridge and Valley sections is the thicker line.

had similar areal extents at 98,500 and 99,100 ha, respectively. Fire regime group IV covered only 2,100 ha of the study area.

To validate our rule-based procedures and resultant fire-regime map, we compared the latter with four sites in the study area with known dendrochronological records. Three of the comparison sites are somewhat atypical of conditions within the Monongahela and were from remnant old-growth, talus slope forest, or extremely dry sites with unique vegetation. As such, these areas may not be wholly representative of general disturbance regimes or forest types of the study area (see Table 4 for other references). However, these are the only known published dendrochronological studies from the project area with which to compare our inferred fire regimes.

Fire-return intervals were estimated for a site in the Ridge and Valley Province on North Fork Mountain in eastern West Virginia (Schuler and McClain 2003). The site, referred to as Pike Knob, is one of the driest areas of the state, being in the eastern rain shadow of the Allegheny Plateau. Vegetation includes a mixture of oak-pine forest, northern hardwood forest, grass bald, and the southern-most stand of red pine. The area sampled lies within the transition of the oak-pine forest and grass bald communities, dominated by northern red oak. Before widespread, organized fire suppression, fire-return intervals were found to be between 7 and 15 years. Most of the area around Pike Knob was modeled as fire regime III (low & mixed severity, 35-200 years) which is slightly longer than the fire return interval documented by Schuler and McClain (2003) although the study site may extend into areas mapped as fire regime I (low & mixed severity, 0-35 years) adjacent just west and south.

Abrams and others (1995) conducted a dendrochonological study of a presettlement-origin white pine-mixed oak forest on the Monongahela. Recruitment patterns and release dates were determined to describe the history of this study area. Fire scars were noted on tree cores; however, all releases were grouped together regardless of disturbance agent. All species and age classes showed a series of major or moderate releases at regular intervals of every 20 to 30 years. This disturbance regime was corroborated by recruitment periodicity of white pine and various oaks until 1900. The site is assigned to fire regime group III (low & mixed severity, 35-200 years) based on our map. Considering that disturbances (fire, wind, ice storms, insects, and diseases) were not differentiated, fire regime group III seems to be a reasonable fit to the overall disturbance regime of the stand.

In contrast to these drier areas, a dendroecological analysis to determine recruitment patterns in an area of the Fernow Experimental Forest (Schuler and Fajvan 1999) was compared to our GIS map of fire regimes. In this mixed mesophytic forest, the standwide median canopy disturbance interval was found to be about 31 years between 1797 and 1983. The study area was assigned a fire regime group V (200+ years). No fire scars were reported from the 170 stems studied. While canopy disturbance is shown in this area through the release of residual trees, fire was not identified as the disturbance mechanism. Although mesic portions of the study area may have been influenced by fire in the past, we reiterate that our model was designed to identify areas of highest priority for reintroduction of prescribed fire to restore fire-adapted characteristics.

Dendroecological study of a unique talus slope forest of oak, maple, and basswood on the Monongahela documented a disturbance history of moderate releases every decade from 1870 to 1990 (Abrams and others 1998). The site is a steep, high elevation, talus over a rich silt loam soil. Fire scars were noted on the boles of standing trees, although no fire scars were reported specifically from the tree cores taken to reconstruct disturbance history. Our map shows the study area to be in fire regime group V. The authors conclude that continuous recruitment of red oak (until 1940) can be explained by the complex interaction of climatic, edaphic, and disturbance factors particular to this site. Decadal canopy disturbance is shown through the release of residual trees. Fire is not the primary disturbance mechanism, though it may be one of many.

DISCUSSION

Vegetation-fire relationships differ sharply over the Monongahela landscape, and larger study area, (Figs. 5 and 7), generally aligning with broad-scale ecological units: 1) the pyrophobic Allegheny Mountains Section; and 2) the pyrophillic Northern Ridge and Valley Section. The only exception is the Eastern Allegheny Mountain and Valley subsection, which is more similar to the Northern Ridge and Valley Section. This reconfirms local land managers' and researchers' suspicions that this area is transitional in nature based on climate, vegetation, and disturbance types. Armed with this information, section boundaries (Cleland and others 2005a) should be evaluated and possibly moved based on the results of our analysis. Others have used different section boundaries to describe the study area (Abrams and McCay 1996); those boundaries seem to fit better with results of our analyses.

Our fire-regime map contradicts the coarse-scale historic natural fire regime map of Schmidt and others (2002), which shows the Monongahela as a mix of fire regime groups I (45 percent), III (46 percent), IV (5 percent), and V (4 percent). Their results suggest a landscape heavily influenced by fire with more than 90 percent of the study area experiencing a fire at least once per century and almost half experiencing a fire at least every 35 years. In stark contrast, our analysis generated area percentages as follows: 14 percent (I), 14 percent (III), <1 percent (IV), and 72 percent (V). The differences between these two efforts are striking and primarily are due to differences in the spatial scale of databases. Schmidt and others (2002, Appendix G) used very broad potential natural vegetation units based on Küchler (1964, 1975) to assign fire regimes. As such, fire characteristics were averaged over much larger geographic areas, causing higher fire frequencies (lower return intervals) to be used in their categorization. Our efforts better represent local conditions by concentrating on stand- and landscape-level data. We focused on more detailed data to specifically identify the extent and location of areas where fire could be most effectively reintroduced. We acknowledge that some of the mesic portions of the Monongahela may have been influenced by both prehistoric and historical fires, but these areas would require greater investments of resources to perpetuate or restore fire-adapted communities.

Historical fire regimes mapped through LANDFIRE Rapid Assessment more closely align with our analysis. LANDFIRE Rapid Assessment projections estimate about 16 percent of the study area as fire regime group I, 9 percent fire regime group III, and 74 percent fire regime group V (USDI GS 2006). LANDFIRE Rapid Assessment data are intended for use at the national and regional levels while LANDFIRE National Products (applicable at landscape levels) are being produced. The close correspondence between the two maps is encouraging, but not surprising as both models were created primarily based on vegetation data and expert opinion about successional pathways. The increased reliance on local data sets and expertise of our rule-based products should prove superior to previous efforts for on-the-ground planning of management activities.

The maps and associated data tables we developed allow for quick identification of pyrogenic landscapes. Fire periodicity, as shown by fire-regime groups (Fig. 7), allows managers to estimate the resources (personnel, time, funding) needed to plan and schedule prescribed burning over the long term. For example, to maintain the estimated 99,000 ha in fire regime group I, all lands within this class should experience low and mixed severity burns at least once every 35 years. Assuming this is the management objective, about 2,800 ha of land in this class should be treated each year with prescribed fire. Alternatively, more achievable goals (if resources are limiting) can be set by concentrating on smaller areas of the Monongahela with specific management scenarios. For example, fire regime group I lands within an area designated for ecosystem restoration could be specifically targeted for prescribed burning. Within this context, the map could be queried for the total area and location of the fire regime group I and annual estimates of prescribed burning could be calculated. Our spatial products also can be used to identify potential conflicts or hazards (e.g., proximity of fire regime I lands to towns or other developments), however fire-regime maps are not synonymous with fire-hazard maps or rankings.

This first effort focused on landscape and vegetation factors; however, management concerns and opportunities also could be added to the input themes and factored in the scoring or the results could be scaled up and bounded by features such as roads or streams to create efficient landscape-scale blocks for prescribed burning (Hiers and others 2003). For instance, management could focus on reintroducing fire in areas where fire-adapted oaks are being aggressively replaced by shade-tolerant competitors such as maple – a common phenomenon on the Monongahela and throughout the East (Abrams 1992). In this scenario, plot data could be queried for stands having oak-dominated overstories and maple-dominated understories and used to identify and prioritize locations for restoration activities using prescribed fire and/or fire surrogates. Plot data also could be queried for the presence of mountain laurel (*Kalmia latifolia* L.), blueberry (*Vaccinium* spp.), or other fire-prone species of interest to determine prescribed fire needs for ecological reasons and/or fuel reduction.

Application of rule-based mapping is not limited to determination of fire-adapted landscapes. Other resource questions and concerns could be addressed by gathering information, forming expert panels, and incorporating all into a rule-based GIS map. Using an existing component of a readily available software package to create a rule-based, spatially referenced map allows for future flexibility (Hiers and others 2003). The inputs can be easily modified as spatial information is updated. Moreover, scale values and weighting factors can easily be changed and other input themes could be added if necessary.

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A rule-based approach was employed in GIS to map fire-adapted vegetation and fire regimes within the proclamation boundary of the Monongahela National Forest. Spatial analyses and maps were generated using ArcMap 9.1. The resulting fire-adaptation scores were then categorized into standard fire regime groups. Fire regime group V (200+ yrs) was the most common, assigned to more than 510,000 ha, primarily in the Allegheny Mountains Section. Fire regime group I (low & mixed severity, 0-35 years) and fire regime group III (low & mixed severity, 35-200 yrs) were assigned to almost 198,000 ha, primarily in the Ridge and Valley Section and one subsection of the Allegheny Mountains Section. These systems will likely require active silviculture using fire and/or fire surrogates for their maintenance or restoration. The transparent rule-based procedure can be easily modified and, as such, possesses the flexibility for universal application to other ecosystems with similar spatial databases.

KEY WORDS: historical fire frequency, GIS, prescribed fire

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