Chapter 1

Introduction, Study Area Description, and Experimental Design

Elaine Kennedy Sutherland[1], Todd F. Hutchinson[2], and Daniel A. Yaussy[2]

[1]USDA Forest Service, Rocky Mountain Research Station, Missoula, Montana
[2]USDA Forest Service, Northeastern Research Station, Delaware, Ohio

Abstract

Throughout much of the Eastern Deciduous Forest, the sustainability of oak-dominated forests is threatened by poor oak regeneration as other tree species increase in abundance. Historically, fire was a frequent process in oak-dominated ecosystems (savannas, woodlands, open-structured forests) as Native Americans and then Euro-American settlers used fire for a variety of purposes. Oaks are well adapted to fire and aggressive fire suppression since ca. 1930 is considered a key factor contributing to the reduced sustainability of oak ecosystems today. As forests become more dense and oak abundance decreases, species adapted to open-structured forests and dependent on hard-mast will likely be affected as well. In 1994, we initiated a multidisciplinary study of prescribed fire as a tool to restore structure, composition, and function to mixed-oak forest ecosystems in southern Ohio. In this chapter we introduce the problem and the rationale for the study. We also describe the experimental design and general characteristics of the climate, physiography, land-use history, fire regimes, and forests of the study areas.

Introduction

Sustainability of Oak Forest Ecosystems

The most abundant forest type in the United States is oak-hickory (Smith et al. 2001). However, in historically oak-dominated landscapes throughout the eastern deciduous forest, tree species other than oak, including red maple (*Acer rubrum*), sugar maple (*Acer saccharum*), blackgum (*Nyssa sylvatica*) yellow poplar (*Liriodendron tulipifera*), and beech (*Fagus grandifolia*), are increasing in abundance (Abrams 1992). The advance reproduction of closed canopy oak stands and the re-growth following canopy disturbance are often dominated by these species. Written accounts prior to Euro-American settlement often described open-structured oak forests and the use of fire by Native Americans (Whitney 1994; Bonnickson 2000). The long-term abundance of oak in eastern deciduous forests has been associated with fire, as evidenced by palynology studies of charcoal and oak pollen from lake sediments (Clark and Royall 1995; Delcourt and Delcourt 1997; Maenza-Gmelch 1997; Delcourt et al. 1998; Fuller et al. 1998). Studies of fire-scarred trees indicate frequent fire (return intervals less than 10 years) in oak forests and woodlands before and after Euro-American settlement, until organized fire suppression began, ca. 1930 (Guyette and Cutter 1991; Cutter and Guyette 1994; Sutherland 1997; Shumway et al. 2001). Aggressive fire suppression over the last 70 years is widely considered to be the most important factor contributing to the reduced sustainability of oak-dominated forests today (Lorimer 1984; Abrams 1992; Lorimer 1993; Van Lear and Watt 1993).

Oaks possess a suite of physical adaptations that render them both resistant and resilient to fire, thus likely improving their competitive status in a disturbance regime characterized by frequent surface fires (Van Lear and Watt 1993). Oak seedlings and sprouts are highly resilient to top-killing; the large rootstocks can remain viable and continue to sprout after repeated fires. Larger oak trees have thick bark, limiting damage to cambial tissue during fire (Hengst and Dawson 1994). When fire-caused wounding does occur, damage is rapidly compartmentalized (Smith and Sutherland 1999). Van Lear and Watt (1993) and Wade et al. (2000) summarized the functional role of fire in the ecology of oak regeneration: fire creates optimal seedbeds and encourages seed caching; fire reduces acorn and seedling predators; fire reduces the abundance of fire-sensitive competitors, thus increasing light availability for oak seedling growth; fire dries soils, favoring oaks over more mesic species; fire promotes the production of fine fuels (grasses and forbs) that increases the probability of future fires. Frequent long-term burning can also reduce nitrogen availability, which should favor oaks over more nutrient-demanding species, e.g., sugar maple and beech (Boerner et al. 1988; Eivasi and Bryan 1996).

In contrast, species that are increasing in abundance in oak forests possess traits that suggest a competitive disadvantage in a regime of frequent fire, including thin-bark (red maple, beech, yellow poplar), high degree of shade tolerance (sugar maple, red maple, blackgum, beech), and high shoot-to-root ratio (red maple, yellow poplar). In southern Ohio, all of these species were common historically only on mesic to hydric landscape positions, including lower north-facing slopes, ravines, and larger bottomlands; areas that likely burned less frequently and intensely (Dyer 2001).

Reduced oak abundance has many ramifications. Historically, oaks have been dominant components of the region's forests for millenia (Delcourt and Delcourt 1991; Abrams 2002). As oak forests shift in structure and composition, other ecosystem components likely will be affected. In mixed-mesophytic forests, with oak as a component, tree diversity has been shown to decrease with increasing sugar maple dominance (Schuler and Gillespie 2000). Midwestern oak savannas and woodlands maintained with fire contain highly diverse plant communities, often harboring threatened and endangered species (Taft et al. 1995; Anderson et al. 1999; Leach and Givnish 1999). As oak woodlands and forests become more dense with shade-tolerant trees, plant diversity may decline with the loss of species adapted to frequent disturbance and more open conditions. For example, in tallgrass prairie, the removal of fire from the landscape can cause significant plant species' loss (Leach and Givnish 1996).

Also, the hard mast produced in oak-hickory forests is consumed by numerous species of mammals and birds and thus a major contributing factor to community functioning (McShea 2000; McShea and Healy 2002). In the eastern U.S., bird species adapted to open habitats maintained by disturbance (grasslands, savannas, woodlands, open-structured forests) are declining at higher rates than species adapted to closed-canopied forests (Brawn et al. 2001; Hunter et al. 2001). In the central hardwoods region, declining species that are adapted to open-structured forests include the cerulean warbler (*Dendroica cerulea*), red-headed woodpecker (*Melanerpes erythrocephalus*), and eastern wood-pewee (*Contopus virens*) (Hunter et al. 2001). Oak-dominated forests also have been shown to support a greater abundance of birds than maple-dominated forests (Rodewald and Abrams 2002). In addition to bird species dependent on acorns, e.g., red-bellied woodpecker (*Melanerpes carolinus*), and tufted titmouse (*Baeolophus bicolor*), the bark and foliage structure of oaks may provide better foraging for bark- and foliage-gleaning species (Rodewald and Abrams 2002). In addition to these ecological ramifications, economic losses may be significant as well because of the high commercial value of oak lumber.

Forests and Fire in Southern Ohio

Written accounts of the Ohio Valley prior to Euro-American settlement described park-like forests ("open woods", "clear woods") and the frequent use of fire by Native Americans in some areas for the purposes of hunting and landscape management (Chapter 2). However, specific fire regimes in the presettlement landscape are poorly understood.

At the onset of Euro-American settlement (ca. 1795-1805), witness trees recorded for the original land surveys indicated forests dominated by oak covered much of the Unglaciated Allegheny Plateau in southeastern Ohio (Gordon 1969; Dyer 2001). Throughout the 19th century, nearly all forests in southern Ohio were harvested, primarily for agriculture and the production of timber and fuel (Williams 1989).

Dendroecological studies of second-growth oak forests indicate fire return intervals ranging from 5 to 15 years, with fires becoming much less frequent after the establishment of organized fire suppression in 1923 (Sutherland 1997; Sutherland, unpublished data). Fire statistics (ca. 1910-2001) for 10 counties in southern Ohio indicate a steep decline in the annual acreage burned after 1923 (Fig. 1).

Currently, forests cover approximately 55% of the land in southeastern Ohio with 68% of the forestland classified as oak-hickory (Griffith et al. 1993). However, from 1968 to 1991, oak and hickory volume have declined relative to that of maple, black cherry, and yellow poplar (Chapter 3). Mature secondary forests have densities of 350 to 400 trees per hectare (Chapter 9). From land surveys in southern Illinois, Anderson and Anderson (1975) estimated an average density of only 160 trees per hectare for presettlement oak-hickory forests, forests similar in composition to the presettlement forests of southern Ohio (Chapter 2).

Similar to regional trends, the density of oak advance reproduction (large seedlings and saplings) is likely inadequate for successful oak regeneration after disturbance (Goebel and Hix 1997; Chapter 8). Indeed,

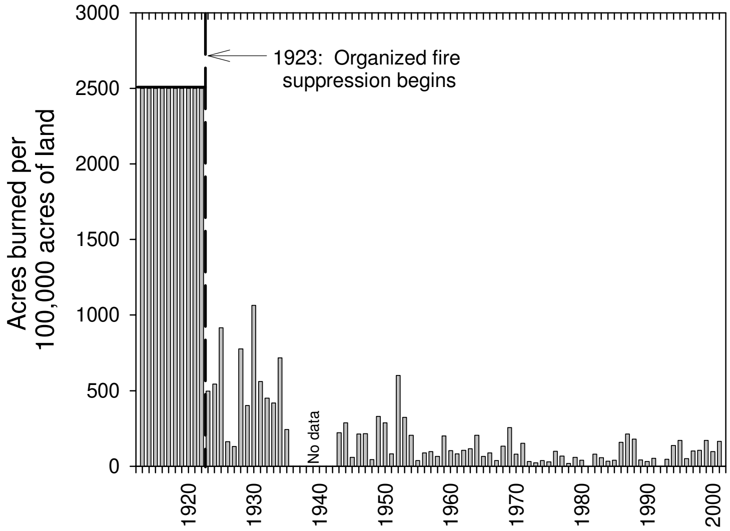

Figure 1.-- The annual acreage burned per 100,000 acres of land for 10 counties (Adams, Athens, Gallia, Hocking, Jackson, Lawrence, Pike, Ross, Scioto, Vinton) in southeastern Ohio. The 1913-1922 annual value is based on an estimate that 333,546 acres (of 1.3 million total forest acres) had burned within the previous 10 years. The estimate is from a 1920-1922 forest survey of the 10 counties and is contained in a 1931 Ohio Division of Forestry unpublished report titled "Forest fire control plan for Ohio". The 1923-1935 data are from Leete (1938). All other fire statistics (1943-2001) are from Ohio Division of Forestry records.

following timber harvest, the relative abundance of oak has been shown to decrease significantly, particularly on mesic sites. (Heiligman et al. 1985; Norland and Hix 1996; Iverson et al. 1997).

Objectives of the Ecosystem Management Study: Effectiveness of Prescribed Burning in the Ecological Restoration of Mixed-Oak Forest Ecosystems

On many public forestlands, management has shifted towards an ecosystem management approach. The main objective of ecosystem management is to sustain ecosystem composition, structure, and function by applying sound ecological knowledge (Christensen et al. 1996). For ecosystems that have shifted away from desired conditions, restoration is often a key component of ecosystem management. Ecological restoration is an elusive goal. Restoration often focuses on a historical reference point, such as the conditions encountered prior to Euro-American settlement (Stephenson 1999). Restoring composition often requires the restoration of processes, such as disturbance regimes and resource supply rates.

In southern Ohio, forest structure and composition almost certainly varied considerably in past millennia, in response to climatic variation and human land use. Landscapes cannot be fully restored to the presettlement conditions of the late 18th century, after extensive harvesting, introduced tree diseases (e.g., chestnut blight), and the extirpation of animal species (e.g., the timber wolf, woodland bison, passenger pigeon). However, given the evidence that fire has played an important role in the development and maintenance of oak-dominated ecosystems, we initiated a large-scale study of prescribed fire as a restoration tool in mixed-oak forests.

For this study, the desired future condition is a more open-structured and more functionally sustainable mixed-oak forest ecosystem. We hypothesize that frequent fires of low to moderate intensity will alter forest structure, composition, and function, enhancing the regeneration potential of oak while also promoting species adapted to open-structured forests in which fire is a frequent disturbance process. The frequency and intensity of fire will be directly related to the degree of change in plant and animal communities.

The application of any management tool on public lands, particularly Federal lands, requires supporting documentation concerning potential effects on the ecosystem (Christensen et al. 1996; Thomas 1996). To aid in the management of oak-dominated ecosystems, our objective is to provide land managers with quantitative information on how fire affects sustainability, biodiversity, and ecosystem functioning.

In this chapter, we describe the study areas and experimental design. As Sheriff and He (1997) stated, manipulative experiments must include defined treatments, randomization, and replication to infer cause-and-effect relationships. The study includes pretreatment monitoring of conditions on all sites as well as unburned control areas and will include monitoring of the following ecosystem components:

- Overstory: structure, composition, productivity, foliar nutrient status.
- Tree regeneration: structure and composition.
- Understory vegetation: composition and diversity, threatened and endangered species.
- Light availability: canopy openness and light environment.

Table 1.--General characteristics of the four study areas. Values for slope, stand age, tree basal area and oak basal area are means (+/- 1 SE) from the 27 vegetation plots in each study area.

Study Area County Latitude, Longitude	Area (ha)	Elevational range (m)	Percent slope	Primary soil series	Stand age (years)	Tree basal area (m^2/ha)	Oak basal area (%)
Watch Rock Vinton County 39°12' N, 82°23' W	76.8	210-281	29.2 (2.5)	Steinsburg- Gilpin Association	112 (4.6)	25.3 (0.7)	68.9 (4.5)
Arch Rock Vinton County 39°11' N, 82°22' W	80.1	214-266	33.4 (2.3)	Steinsburg- Gilpin Association	108 (2.1)	27.2 (0.7)	72.5 (4.3)
Young's Branch Lawrence County 38°43' N, 82°41' W	75.3	242-298	31.6 (1.2)	Steinsburg- Shelocta Association	121 (5.3)	27.8 (0.8)	67.1 (4.3)
Bluegrass Ridge Lawrence County 38°36' N, 82°31' W	109.3[1]	222-295	23.7 (1.0)	Upshur-Gilpin- Steinsburg Association	100 (3.9)	27.1 (0.9)	70.0 (5.9)

[1]Includes an area of approximately 10 ha in the infrequent burn unit that was clearcut within the last 20 years and thus was not included in the study.

- Belowground: soil nutrient status and cycling rates; organic matter quantity and turnover; abundance and activity of key soil microbial groups.
- Fauna: community composition, diversity, and functioning, with emphasis on breeding birds and arthropods.

Experimental Design and Study Area Description

The study was designed to test the effects of prescribed fire on various ecosystem components at five separate study areas. The dissected topography of southern Ohio causes significant variability in microclimate and soil moisture across the landscape, which in turn affects vegetation structure and composition. A split-plot design was thus established to incorporate soil moisture as a factor. The study areas are replicate blocks, fire treatment is the whole plot factor, and soil moisture class the subplot factor.

Study Areas

In cooperation with our management partners, MeadWestvaco Corporation and The Wayne National Forest, a pool of potential study areas was selected based on the following criteria: 1) areas have been continuously forested, historically (forests on abandoned agricultural lands were excluded); 2) areas have at least 75 ha of contiguous land to delineate three separate treatment units of 25 ha for adequate monitoring of avian populations (Chapter 12); 3) stands within the areas are at least 80 years of age, in the understory reinitiation stage of stand development (Oliver and Larson 1996); 4) areas contain adequate land modeled as xeric, intermediate, and mesic in soil moisture (described below); 5) oak is a major component of the overstory in all moisture classes; and 6) parent materials are sandstones and shales that produce the relatively acidic, well-drained soils typical of the unglaciated Allegheny Plateau.

After field reconnaissance, the five most-suitable study areas were selected, two in Vinton County (Arch Rock and Watch Rock) and three in Lawrence County (Young's Branch, Bluegrass Ridge, and Sharp's Creek). However, pilot data indicated that soil pH and fertility were much greater in some portions of Bluegrass Ridge and Sharp's Creek, which contained significant interbedded limestone. Because of the close proximity of the two areas, we selected three (two at Bluegrass Ridge; one at Sharp's Creek) of the six units that were most similar to the other study areas in soil chemistry to combine into one study area (Bluegrass Ridge), eliminating the other three units and resulting in four study areas.

Watch Rock and Arch Rock are located in the Raccoon Ecological Management Area (REMA), a 6,900 ha tract

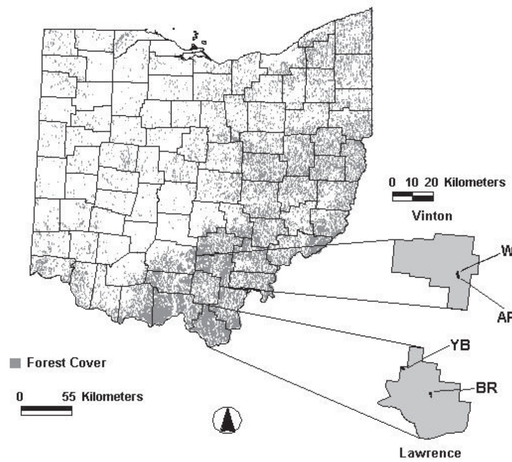

Figure 2.--Map of Ohio showing the location of the four study areas in Vinton and Lawrence Counties. WR = Watch Rock, AR = Arch Rock, YB = Young's Branch, BR = Bluegrass Ridge.

of contiguous forest owned by MeadWestvaco Corporation (Fig. 2). Young's Branch and Bluegrass Ridge are located in the Ironton District of the Wayne National Forest. In general, the terrain, soils, and forests are similar among the four study areas (Table 1).

The study areas are located in the Southern Unglaciated Allegheny Plateau Section of the Eastern Broadleaf Forest Province, which is characterized as a maturely dissected plateau of high hills, sharp ridges and narrow valleys (McNab and Avers 1994). The sites are underlain predominantly by sandstones and shales of Pennsylvanian age and soils are mostly loams and silt loams that are acidic and well-drained. Physiography, geology and soils are described in Chapters 4 and 5.

Lawrence County is slightly warmer and wetter than Vinton County with a mean annual temperature difference of 1.6 °C and a mean annual precipitation difference of 35 mm (Fig. 3). Also, Lawrence County averages 27 more frost-free days than Vinton County. Both counties always attain freezing temperatures in April and sometimes in May. The first date of freezing temperatures in fall occurs between September and November in both counties. Moderate to severe droughts (Palmer Drought Severity Indices of -2 to –3) have occurred infrequently since 1930. It should be noted that for Lawrence County, all weather stations were located along the Ohio River. Thus, these data likely describe more moderate weather conditions than the uplands where the two study areas are located. Given the dissected topography common in this landscape, microclimate variation at the local scale (within study areas) is greater than macroclimate variation at the regional scale (among study areas).

The species composition of presettlement forests and the subsequent land use history of the study areas are similar to many forested uplands in southern Ohio. Witness trees recorded for the original land surveys (ca. 1795-1805) indicate that forests were oak-dominated, with white oak (*Quercus alba*) the most abundant species (Chapter 2). Vinton and Lawrence Counties remained largely forested until the rise of the charcoal iron industry (ca. 1830-1860). Iron furnaces were established near each study area and the forests were clearcut for charcoal until the industry declined in the late-1800s (Chapter 2). Forests have since been relatively undisturbed; stand-level disturbances are interpreted with dendroecological methods in Chapter 2. Presently, the most abundant species in the overstory (trees > 10 cm diameter at breast height) are white oak, red maple, chestnut oak (*Q. prinus*), hickories (*Carya* spp.), sugar maple, and black oak (*Q. velutina*) (Chapter 9).

Fire Regimes and Fire Treatments

Though lighting-caused fires do occur in the central hardwoods region (Haines et al. 1975; Ruffner 1998), the great majority of fires are human-caused (Yaussy and Sutherland 1994). Despite human-caused ignitions, seasonal weather patterns dictate the occurrence of fires in southern Ohio (Leete 1938; Yaussy and Sutherland 1994). During spring (March-April) and fall (October-November), weather conditions can cause rapid fuel drying, increasing the probability of fire ignition and spread. The peak of the spring fire season occurs in mid- to late-March in Lawrence County and late-March to early-April in Vinton County (Fig. 4), likely tied to the minor differences in climate. In the winter months, temperatures are generally too low and humidities too high for adequate drying of surface fuels. From leaf expansion (early May) through summer, the forest floor is shaded, covered with lush vegetation, and humidities are high, also reducing the probability of fire propagation. In the Ohio Valley region, fire occurrence is related more strongly to these annual weather cycles than to periodic circulation phenomenon such as the El Nino/Southern Oscillation (Yaussy and Sutherland 1994).

Fires in oak forests are confined to surface fuels such as leaf litter, small woody debris, and understory vegetation (Little 1974; Anderson 1982). Studies of prescribed fire indicate that flame lengths usually are less than 1 m, causing minimal overstory mortality (Brose and Van Lear 1998; Elliot et al. 1999). However, high intensity surface fires can cause significant patches of overstory mortality, particularly when highly flammable tall understory

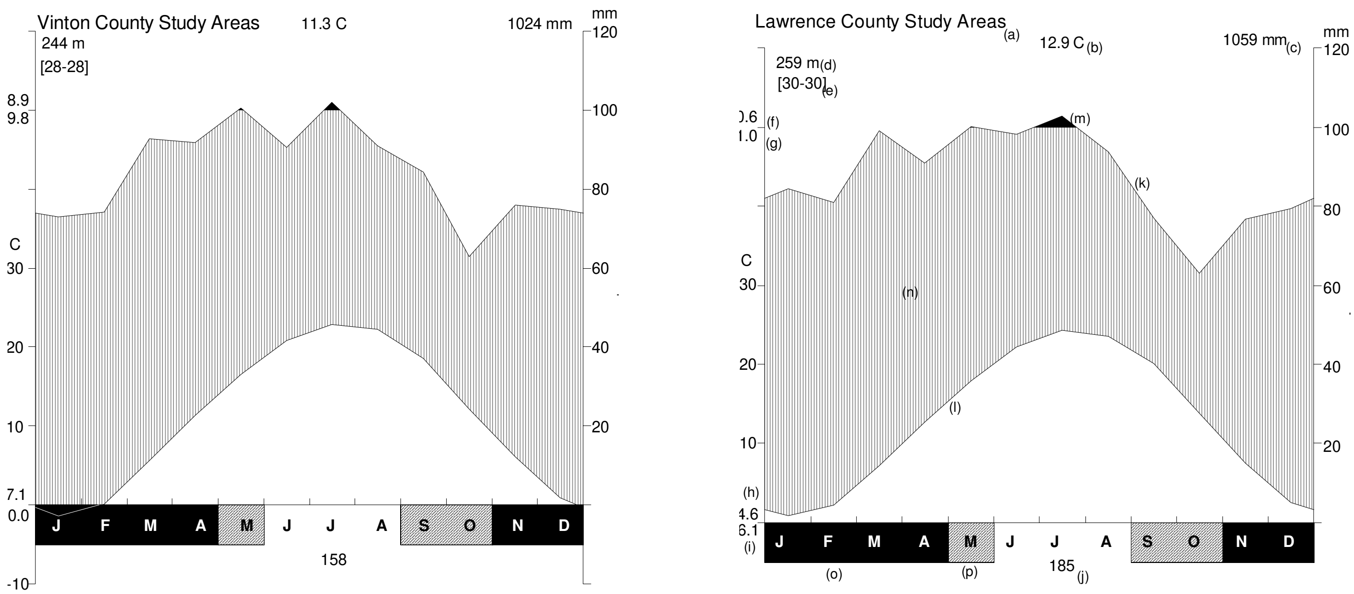

Figure 3.--Climate diagrams for Vinton County and Lawrence county study areas: (a) plot location, (b) mean annual temperature, (c) mean annual precipitation, (d) average elevation of study areas, (e) number of years of record used in computing mean monthly temperature and precipitation respectively, (f) extreme maximum monthly temperature, (g) mean maximum monthly temperature of the warmest month, (h) mean minimum monthly temperature for the coldest month, (i) extreme mean minimum monthly temperature, (j) mean frost-free period, (k) mean monthly precipitation, (l) mean monthly temperature, (m) period when precipitation usually exceeds water holding capacity of soil, (n) period of adequate available moisture, (o) months when temperatures always fell below freezing, (p) months when temperatures sometimes fell below freezing. Data presentation follows Walter (1984).

vegetation (e.g., laurel [*Kalmia*], greenbriar [*Smilax*]) is abundant (Regelbrugge and Smith 1994; Ducey et al. 1996).

For a number of sites in southern Ohio, fire return intervals before the suppression era (ca. 1850-1925) were in the range of 3-7 years (Sutherland 1997; Sutherland, unpublished data). However, the mere imitation of fire regimes that may have sustained mixed-oak forests will not necessarily achieve our objective to alter stand structure. These sites have experienced more than 70 years with little or no fire, during which significant populations of non-oak species have become established in the understory and midstory (Chapters 8 and 9). A single prescribed fire rarely has much effect on the overstory and midstory strata of eastern hardwood communities. Tree species considered susceptible to fire (e.g., yellow-poplar and maples) generally are resistant to fire-caused injury when stems are at least 15 cm in diameter at breast height (d.b.h.), that is, when bark is sufficiently thick to protect the cambium and crowns are sufficiently high to avoid heat-caused injury (Van Lear and Watt 1993). Any attempt to alter forest structure significantly is likely to require multiple fires.

For the initial stage of the project (1995-1999), we chose to evaluate annual and periodic spring-season fires. Thus the three experimental treatment units (approximately 25 ha each) per study area were designated as control (no fire), frequent burn, and infrequent burn. The frequent burn units were to be burned annually, 1996-1999. The infrequent burn units were to be burned twice, in 1996 and 1998 or 1999. After 1999, we plan to evaluate the initial effects, then continue burning with two distinct long-term treatments; fire applied every 2-3 years (frequent units) and fire applied every 5-6 years (infrequent units).

Fire treatment units were assigned nonrandomly to meet logistical needs. For WR and AR, populations of *Calamagrostis porteri* subsp. *insperata*, a state-endangered grass, were located in the central unit of each study area. To protect these populations from the unknown effects of fire, each central unit was designated a control (Figs. 5a and 5b). For YB and BR, the frequent and infrequent burn units were located adjacent to one another to facilitate burning as one large unit in years when both units are burned (Figs. 5c and 5d).

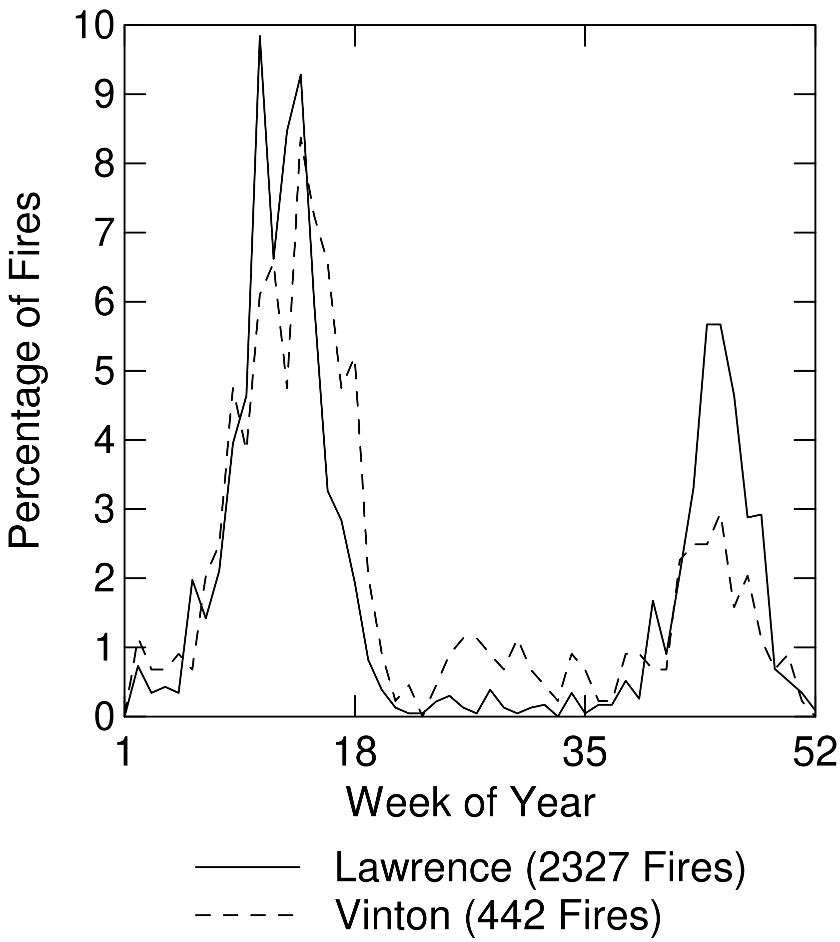

Figure 4.--Weekly percentage of total fires from October 1981 to October 2001 in Lawrence and Vinton Counties, Ohio.

Table 2.—Size of treatment units in each study area and the distribution of vegetation plots by IMI (integrated moisture index) class in each treatment unit.

Study Area	Treatment Unit	Area (ha)	Xeric plots	Intermediate plots	Mesic plots
Watch Rock	Control	20.4	3	2	4
	Infrequent burn	25.7	3	2	4
	Frequent burn	30.7	2	5	2
Arch Rock	Control	24.1	3	1	5
	Infrequent burn	24.0	3	3	3
	Frequent burn	32.0	4	2	3
Young's Branch	Control	24.1	3	3	3
	Infrequent burn	22.2	2	3	4
	Frequent burn	29.1	3	3	3
Bluegrass Ridge	Control	28.3	1	7	1
	Infrequent burn	49.8[1]	3	3	3
	Frequent burn	31.2	4	4	1
Total	Control	96.9	10	13	13
	Infrequent burn	123.0	11	11	14
	Frequent burn	121.6	13	14	9

[1]Includes an area of approximately 10 ha that was clearcut within the last 20 years and thus was not included in the study.

Soil Moisture (Integrated Moisture Index)

In the topographically dissected terrain of the region, aspect and slope position (rather than elevation) cause significant variability in microclimate, soil moisture, and nutrient cycling due to differential solar radiation and hillslope drainage patterns (Wolfe et al. 1949; Hutchins et al. 1976; Plymale et al. 1987; Garten et al. 1994). In turn, forest composition and productivity vary primarily along topographic gradients of moisture and fertility (Hutchins et al. 1976; Adams and Anderson 1980; Muller 1982; Fralish 1994).

To account for variation in soil moisture and vegetation, a geographic information system (GIS) was used in conjunction with forest-plot data to develop an Integrated Moisture Index (Chapter 3; Iverson et al. 1997). The integrated moisture index (IMI) was designed to integrate topography and soils into a single index that can be related to a number of ecological attributes across the landscape. The components of the IMI were a slope-aspect shading index (40 percent), cumulative flow of water downslope (30 percent), soil water-holding capacity (20 percent), and curvature of the landscape (10 percent). From the calculated IMI scores, 30 by 30-m cells were classified as xeric, intermediate, or mesic across the landscape (Figs. 5a-d). Chapter 3 provides a thorough description of the IMI and its application over the study areas.

Vegetation Sample Plots

We established vegetation plots within the treatment units to sample vegetation and soils. For each treatment unit, IMI maps were used to field-locate three 50 x 25 m (0.125 ha) vegetation plots in each of the IMI categories (Figs. 5a-d). Thus, there were three vegetation plots per IMI class, three IMI classes per treatment unit, and three treatment units per study area for a total of 27 plots per study area. During plot installation, slope corrections were made to locate plot corners, which were established permanently with reinforcement bar. Nearly all plots were located on sloping terrain; no plots were located in stream valleys or side-slope drainages and only a few plots were located on ridgetops. The plots were designed to sample trees >10 cm d.b.h. on the entire plot, tree saplings (1.4 m height to 9.9 cm d.b.h.) and seedlings (<1.4 m height) on one-half of the plot (25 x 25 m) and understory vegetation on the other half (25 x 25 m). Soil samples were collected adjacent to the vegetation plots (Chapter 5) and light measurements were taken at plot center (Chapter 6).

Established Design and Statistical Analysis

In summary, four study areas (Watch Rock, Arch Rock, Young's Branch, Bluegrass Ridge) were established as replicate blocks, each with three fire treatment units (control, infrequent burn, frequent burn) as whole plots. The whole plots were divided into subplots (split-plots) composed of three IMI classes (xeric, intermediate, mesic), resulting in 36 experimental units (four study areas X three fire treatments X three IMI classes). The three vegetation plots (sampling units) per IMI class in each treatment unit were designed as pseudoreplicates (Hurlbert 1984). When the established vegetation plots were georeferenced, 22 of 108 were located in an IMI class different from that intended. Thus, within each treatment unit, the number of vegetation plots per IMI class ranged from one to seven rather than three per IMI class (Table 2). However, 31 of the 36 experimental units contain two to five vegetation plots. Because all 36 experimental units contain at least one vegetation plot, the design is balanced at both the whole plot and subplot levels even though the number of pseudoreplicates is not balanced. Fauna sampling was not stratified by the IMI and was not linked to the vegetation plots; the experimental units were the 12 fire treatment units (Chapters 11 and 12).

For this volume, data collected on the vegetation plots were analyzed with a mixed-model analysis of variance (ANOVA) to determine whether there were significant pretreatment differences among fire treatments, among IMI classes, and fire*IMI interactions (PROC MIXED; SAS Institute 1999). Study area (block) was treated as a random effect, considered a random sample from a larger population of similar oak forests that can't be replicated exactly in other studies (Steel et al. 1997). Fire treatment and IMI class are treated as repeatable fixed effects. The statistical model assumes no interaction between block (study areas) and treatment (fire). The analyses presented in the chapters that follow will serve as a baseline to evaluate the subsequent effects of fire and IMI on many different ecosystem attributes.

Acknowledgements

Funding was provided by the Washington Office of the USDA Forest Service to Elaine Kennedy Sutherland (Principal Investigator) for the ecosystem management research project 'Effectiveness of Prescribed Burning in the Ecological Restoration of Mixed-oak Forests in Southern Ohio'. We thank Jeffrey Gove, Martin Jones, Ward McCaughey, Stephen Shifley, and Thomas Waldrop for editorial and technical reviews of this chapter. We thank Thomas Jacob for statistical guidance while establishing the experimental design. We also thank our management cooperators, Ralph Miller (Wayne National Forest) and Wayne Lashbrook, Steve Mathey, and Walt Smith (MeadWestvaco Corporation) for providing the study sites and logistical support.

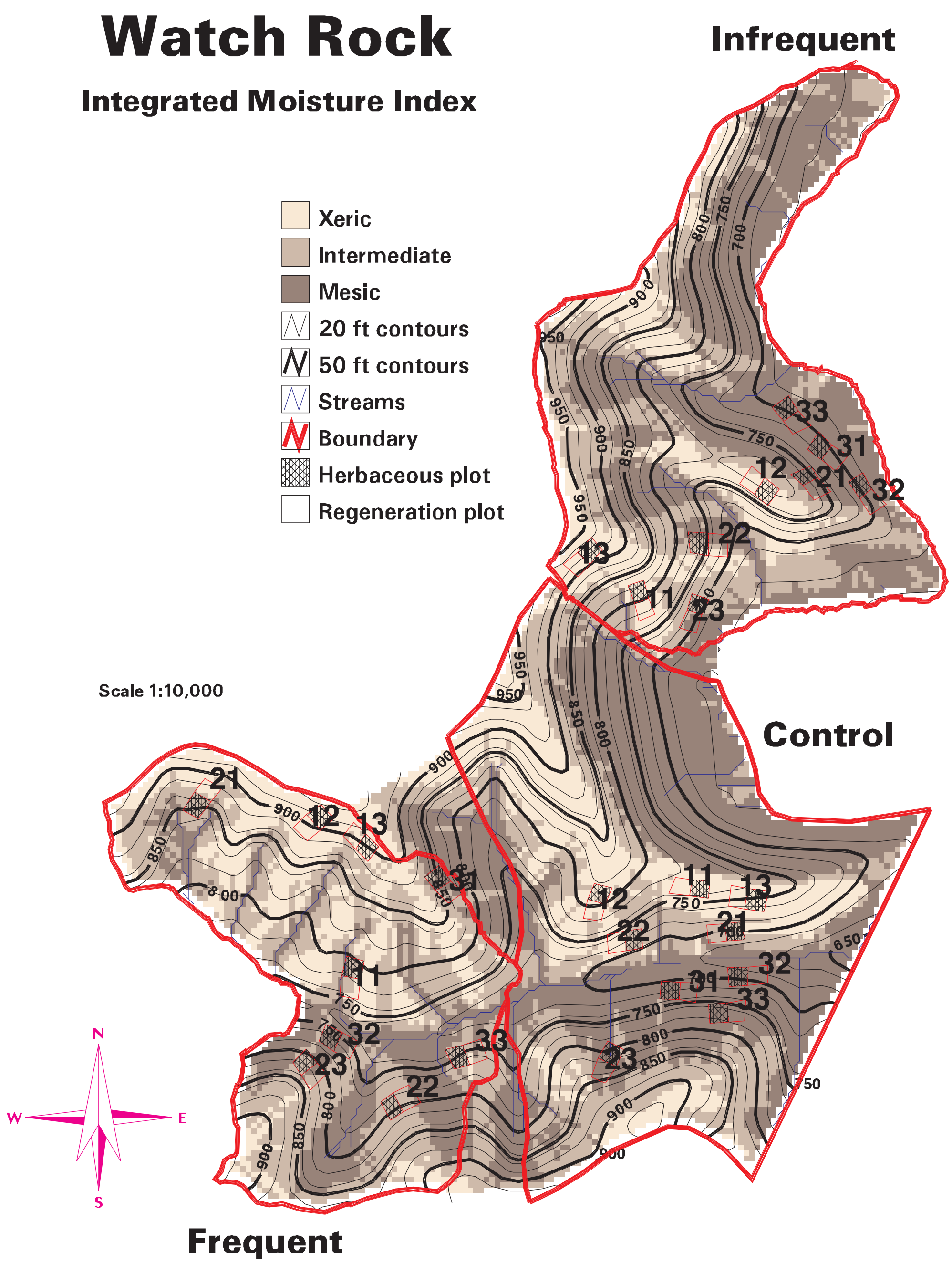

Figure 5a.-- Map of Watch Rock study area with fire treatment units, IMI classes, and vegetation plots. The total area comprises 76.8 ha.

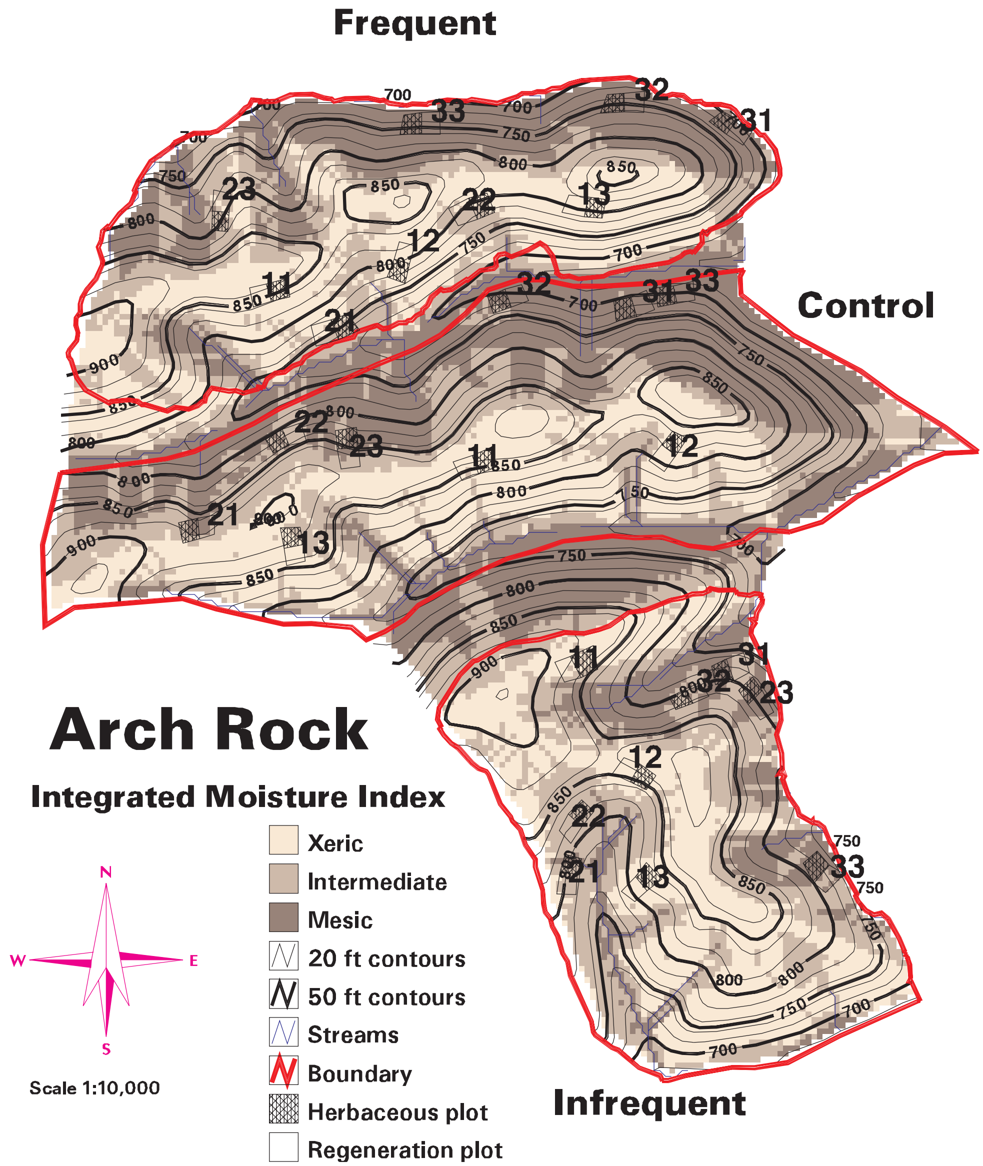

Figure 5b.-- Map of Arch Rock study area with fire treatment units, IMI classes, and vegetation plots. The total area comprises 80.1 ha.

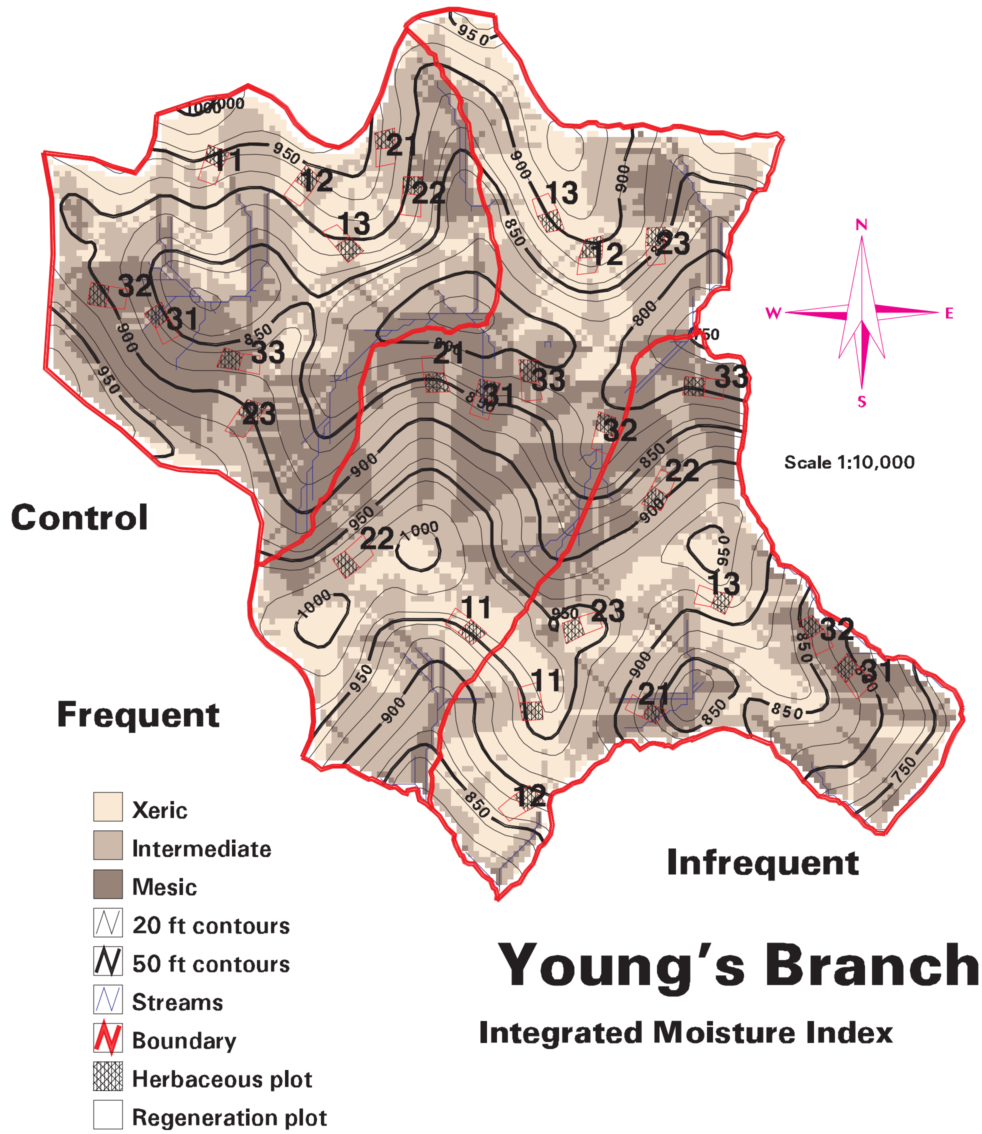

Figure 5c.-- Map of Young's Branch study area with fire treatment units, IMI classes, and vegetation plots. The total area comprises 75.3 ha.

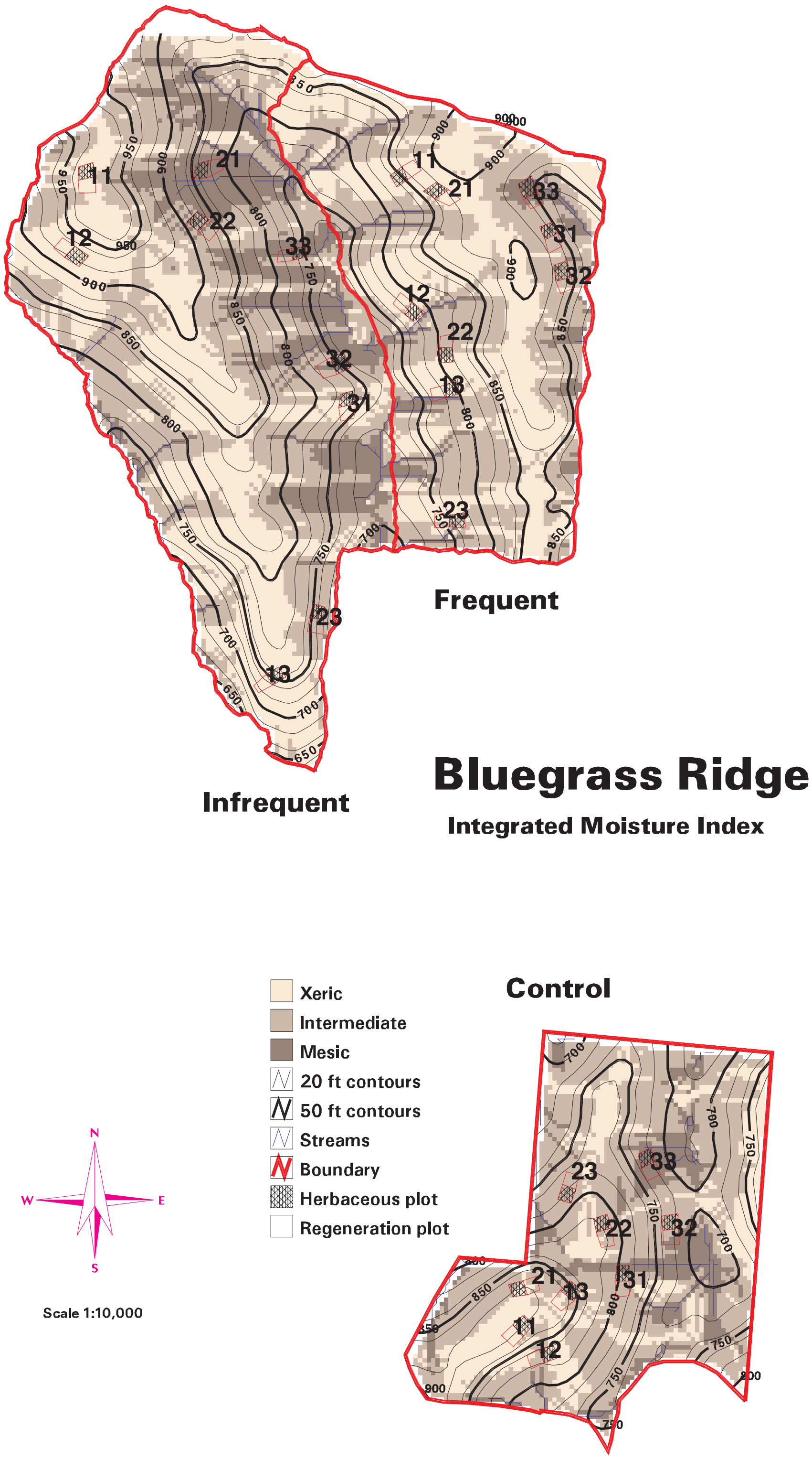

Figure 5d.-- Map of Bluegrass Ridge Study area with fire treatment units, IMI classes, and vegetation plots. In the infrequent burn unit, a recent clearcut (less than 20 years old) occupies approximately 10 ha of the unit in the west central portion. No vegetation plots are located in this area. The total area comprises 109.3 ha.

Literature Cited

Abrams, M. D. 1992. **Fire and the development of oak forests.** Bioscience. 42: 346-353.

Abrams, M. D. 2002. **The postglacial history of oak forests in Eastern North America.** In: McShea, W. J.; Healy, W. M., eds. Oak forest ecosystems. Ecology and management for wildlife. Baltimore: The Johns Hopkins University Press: 34-45.

Adams, D.; Anderson, R. C. 1980. **Species response to a moisture gradient in central Illinois forests.** American Journal of Botany. 67: 381-392.

Anderson, H. E. 1982. **Aid to determining fuel models for estimating fire behavior.** Gen. Tech. Rep. INT-122. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Range and Experiment Station. 22 p.

Anderson, R. C.; Anderson, M. R. 1975. **The presettlement vegetation of Williamson County, Illinois.** Castanea. 40: 345-363.

Anderson, R. C.; Fralish, J. S.; Baskin, J. M. 1999. **Savannas, barrens, and rock outcrop plant communities of North America.** Cambridge: Cambridge University Press. 497 p.

Boerner, R. E. J.; Lord, T. R.; Peterson, J. C. 1988. **Prescribed burning in the oak-pine forest of the New Jersey Pine Barrens: effects on growth and nutrient dynamics of two *Quercus* species.** American Midland Naturalist. 120: 108-119.

Bonnickson, T. M. 2000. **America's ancient forests. From the ice age to the age of discovery.** New York: John Wiley and Sons, Inc. 594 p.

Brawn, J. D.; Robinson, S. K.; Thompson III, F. R. 2001. **The role of disturbance in the ecology and conservation of birds.** Annual Review of Ecology and Systematics. 32: 251-276.

Brose, P. H.; Van Lear, D. H. 1998. **Responses of hardwood advance regeneration to seasonal prescribed fires in oak-dominated shelterwood stands.** Canadian Journal of Forest Research. 28: 331-339.

Christensen, N. L.; Bartuska, A. M.; Brown, J. H.; Carpenter, S.; D'Antonio, C.; Francis, R.; Franklin, J. F.; MacMahon, J. A.; Noss, R. F.; Parsons, D. J.; Peterson, C. H.; Turner, M. G.; Woodmansee, R. G. 1996. **The report of the Ecolgical Society of America committee on the scientific basis for ecosystem management.** Ecological Applications. 6: 665-691.

Clark., J. S.; Royall, P. D. 1995. **Transformation of a northern hardwood forest by aboriginal (Iroquois) fire: charcoal evidence from Crawford Lake, Ontario, Canada.** The Holocene. 5: 1-9.

Cutter, B. E.; Guyette, R. P. 1994. **Fire frequency on an oak-hickory ridgetop in the Missouri Ozarks.** American Midland Naturalist. 132: 393-398.

Delcourt, H. R.; Delcourt, P. A. 1991. **Quaternary ecology: a paleoecological perspective.** London: Chapman & Hall. 242 p.

Delcourt, H. R.; Delcourt, P. A. 1997. **Pre-Columbian Native American use of fire on southern Appalachian landscapes.** Conservation Biology. 11: 1010-1014.

Delcourt, P. A.; Delcourt, H. R.; Ison, C. R.; Sharp, W. E.; Gremillion, K. J. 1998. **Prehistoric human use of fire, the eastern agricultural complex, and Appalachian oak-chestnut forests: paleoecology of Cliff Palace Pond, Kentucky.** American Antiquity. 63: 263-278.

Ducey, M. J.; Moser, W. K.; Ashton, P. M. S. 1996. **Effect of fire intensity on understory composition and diversity in a Kalmia-dominated oak forest, New England, U.S.A.** Vegetatio. 123: 81-90.

Dyer, J. M. 2001. **Using witness trees to assess forest change in southeastern Ohio.** Canadian Journal of Forest Research. 31: 1708-1718.

Eivasi, F.; Bryan, M. R. 1996. **Effects of long-term prescribed burning on the activity of selected soil enzymes in an oak-hickory forest.** Canadian Journal of Forest Research. 26: 1799-1804.

Elliot, K. J.; Hendrick, R. L.; Major, A. E.; Vose, J. M.; Swank, W. T. 1999. **Vegetation dynamics after prescribed fire in the southern Appalachians.** Forest Ecology and Management. 114: 199-213.

Fralish, J. S. 1994. **The effect of site environment on forest productivity in the Illinois Shawnee Hills.** Ecological Applications. 4: 134-143.

Fuller, J. L.; Foster, D. R.; McLachlan, T. S.; Drake, N. 1998. **Impact of human activity on regional forest**

composition and dynamics in central New England. Ecosystems. 1: 76-95.

Garten, C. T.; Huston, M. A.; Thoms, C. A. 1994. **Topographic variation of soil nitrogen dynamics at Walker Branch Watershed, Tennessee.** Forest Science. 40: 497-512.

Goebel, P. C.; Hix, D. M. 1997. **Changes in the composition and structure of mixed-oak, second-growth forest ecosystems during the understory reinitiation stage of stand development.** Ecoscience. 4: 327-340.

Gordon, R. B. 1969. **The natural vegetation of Ohio in pioneer days.** Bulletin of the Ohio Biological Survey, New Series, Vol. 3, No. 2. Columbus, OH: Ohio State University. 113 p.

Griffith, D. M.; DiGiovanni, D. M.; Witzel, T. L.; Wharton, E. H. 1993. **Forest statistics for Ohio, 1991.** Resour. Bull. NE-128. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 169 p.

Guyette, R. P.; Cutter, B. E. 1991. **Tree-Ring analysis of fire history of a post oak savanna in the Missouri Ozarks.** Natural Areas Journal. 11: 93-99.

Haines, D. A.; Johnson, V. J. 1975. **Wildfire atlas of the northeastern and north central States.** Gen. Tech. Rep. NC-16. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Experiment Station. 25 p.

Heiligmann, R. B.; Norland, E. R. 1985. **28-year-old reproduction on five cutting practices in upland oak.** Northern Journal of Applied Forestry. 2: 17-22.

Hengst, G. E.; Dawson, J. O. 1994. **Bark properties and fire resistance of selected tree species from the central hardwood region of North America.** Canadian Journal of Forest Research. 24: 688-696.

Hunter, W. C.; Buehler, D. A.; Canterbury, R. A. ; Confer, J. L.; Hamel, P. B. 2001. **Conservation of disturbance-dependent birds in eastern North America.** Wildlife Society Bulletin. 29: 440-455.

Hurlbert, S. H. 1984. **Pseudoreplication and the design of ecological field experiments.** Ecological Monographs. 54: 187-211.

Hutchins, R. B.; Blevins, R. L.; Hill, J. D.; White, E. H. 1976. **The influence of soils and microclimate on vegetation of forested slopes in eastern Kentucky.** Soil Science. 121: 234-241.

Iverson, L. R.; Dale, M. E.; Scott, C. T.; Prasad, A. 1997. **A GIS-derived integrated moisture index to predict forest composition and productivity of Ohio forests (U.S.A.).** Landscape Ecology. 12: 331-348.

Leach, M. K.; Givnish, T. J. 1996. **Ecological determinants of species loss in remnant prairies.** Science. 273: 1555-1558.

Leach, M. K.; Givnish, T. J. 1999. **Gradients in the composition, structure, and diversity of remnant oak savannas in southern Wisconsin.** Ecological Monographs. 69: 353-374.

Leete, B. E. 1938. **Forest fires in Ohio 1923 to 1935.** Bull. 598. Wooster, OH: Ohio Agricultural Experiment Station. 54 p.

Little, S. 1974. **Effects of fires on temperate forests.** In: Kozlowski, T. T.; Ahlgren, C. E., eds. Fire and ecosystems. New York: Academic Press: 225-250.

Lorimer, C. G. 1984. **Development of the red maple understory in northeastern oak forests.** Forest Science. 30: 3-22.

Lorimer, C. G. 1993. **Causes of the oak regeneration problem.** In: Loftis, D.; McGee, C. E., eds. Oak regeneration: serious problems, practical recommendations; 1992 September 8-10; Knoxville, TN. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 14-39.

Maenza-Gmelch, T. E. 1997. **Holocene vegetation, climate, and fire history of the Hudson Highlands, southeastern New York, USA.** The Holocene. 7: 25-37.

McNab, W. H.; Avers, P. E. 1994. **Ecological subregions of the United States: section descriptions.** Administrative Publication WO-WSA-5. Washington, D.C.: U.S. Department of Agriculture, Forest Service. 267 p.

McShea, W. J. 2000. **The influence of acorn crops on annual variation in rodent and bird populations.** Ecology. 81: 228-238.

McShea, W. J.; Healy, W. H. 2002. **Oak forest ecosystems. Ecology and management for wildlife.** Baltimore: The Johns Hopkins University Press. 432 p.

Muller, R. N. 1982. **Vegetation patterns in the mixed mesophytic forest of eastern Kentucky.** Ecology. 63: 1901-1917.

Norland, E. R.; Hix, D. M. 1996. **Composition and structure of a chronosequence of young, mixed-species forests in southeastern Ohio, USA.** Vegetatio. 125: 11-30.

Oliver, C. D.; Larson, B. C. 1996. **Forest stand dynamics.** New York: John Wiley & Sons. 520 p.

Plymale, A. E.; Boerner, R. E. J.; Logan, T. J. 1987. **Relative nitrogen mineralization and nitrification in soils of two contrasting hardwood forests: effects of site microclimate and initial soil chemistry.** Forest Ecology and Management. 21: 21-36.

Regelbrugge, J. C.; Smith, D. W. 1994. **Postfire tree mortality in relation to wildfire severity in mixed oak forests in the Blue Ridge of Virginia.** Northern Journal of Applied Forestry. 11: 90-97.

Rodewald, A. D.; Abrams, M. D. 2002. **Floristics and avian community structure: implications for regional changes in eastern forest composition.** Forest Science. 48: 267-272.

Ruffner, C. M.; Abrams, M. D. 1998. **Lightning strikes and resultant fires from archival (1912-1917) and current (1960-1997) information in Pennsylvania.** Journal of Torrey Botanical Society . 125: 249-152.

SAS Institute Inc. 1999. **SAS/STAT® user's guide, version 8.** Cary, NC: SAS Institute. 3884 p.

Schuler, T. M.; Gillespie, A. R. 2000. **Temporal patterns of woody species diversity in a central Appalachian forest from 1856 to 1997.** The Journal of the Torrey Botanical Society. 127: 149-161.

Sheriff, S. L.; He, Z. 1997. **The experimental design of the Missouri Ozark Forest Ecosystem Project.** In: Brookshire, B. L.; Shifley, S. R., eds. Proceedings of the Missouri Ozark Forest Ecosystem Project: an experimental approach to landscape research; 1997 June 3-5; St. Louis, MO. Gen. Tech. Rep. NC-193. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 26-40.

Shumway, D. L.; Abrams, M. D.; Ruffner, C. M. 2001. **A 400-year history of fire and oak recruitment in an old-growth oak forest in western Maryland, U.S.A.** Canadian Journal of Forest Research. 31: 1437-1443.

Smith, K. T.; Sutherland, E. K. 1999. **Fire-scar formation and compartmentalization in oak.** Canadian Journal of Forest Research. 29: 166-171.

Smith, W. B.; Vissage, J. S.; Darr, D. R.; Sheffield, R. M. 2001. **Forest resources of the United States, 1997.** Gen. Tech. Rep. NC-219. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station. 190 p.

Steel, R. G. D.; Torrie, J. H.; Dickey, D. A. 1997. **Principles and procedures of statistics. A biometrical approach. Third edition.** Boston, MA: WCB McGraw-Hill. 666 p.

Stephenson, N. L. 1999. **Reference conditions for giant sequoia forest restoration: structure, process, and precision.** Ecological Applications. 9: 1253-1265

Sutherland, E. K. 1997. **The history of fire in a southern Ohio second-growth mixed-oak forest.** In: Pallardy, S. G.; Cecich, R. A.; Garrett, H. E.; Johnson, P. S., eds. Proceedings, 11th central hardwoods forest conference; 1997 March 23-26 ; Columbia, MO. Gen. Tech. Rep. NC-188. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 172-183.

Taft, J. B.; Schwartz, M. W.; Loy, R. P. 1995. **Vegetation ecology of flatwoods on the Illinoian till plain.** Journal of Vegetation Science. 6: 647-666.

Thomas, J. W. 1996. **Forest Service perspective on ecosystem management.** Ecological Applications. 6: 703-705.

Van Lear, D. H.; Watt, J. M. 1993. **The role of fire in oak regeneration.** In: Loftis, D. L.; McGee, C. E., eds. Oak regeneration: serious problems, practical recommendations; 1992 September 8-10; Knoxville, TN. Gen. Tech. Rep. SE-84. Asheville, NC : U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 66-78.

Wade, D. D.; Brock, B. L.; Brose, P. H.; Grace, J. B.; Hoch, G. A.; Patterson, W. A. 2000. **Fire in eastern ecosystems.** In: Brown, J. K.; Smith, J. K., eds. Wildland fire in ecosystems: effects of fire on flora. Gen. Tech. Rep. RMRS-42-vol. 2. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 53-96.

Walter, H. 1984. **Vegetation of the earth.** New York: Springer. 318 p.

Whitney, G. G. 1996. **From coastal wilderness to fruited plain. A history of environmental change in temperate North America from 1500 to present.** Cambridge, UK: Cambridge University Press. 451 p.

Williams, M. 1989. **Americans and their forests. A historical geography.** Cambridge: Cambridge University Press. 599 p.

Wolfe, J. N.; Wareham, R. T.; Scofield, H. T. 1949. **Microclimates and macroclimate of Neotoma: a small valley in central Ohio.** Bulletin of the Ohio Biological Survey, Vol. 8, Issue 41. Columbus, OH: Ohio Biologial Survey. 169 p.

Yaussy, D. A.; Sutherland, E. K. 1994. **Fire history in the Ohio River Valley and its relation to climate.** In: Proceedings of the 12th conference on fire and forest meterology; 1993 October 26-28; Jekyll Island, GA. Bethesda, MD: Society of American Foresters: 777-786.