Chapter 3

A GIS-Derived Integrated Moisture Index

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Abstract

A geographic information system (GIS) approach was used in conjunction with forest-plot data to develop an integrated moisture index (IMI) that is being used to stratify and help explain landscape-level phenomena in the four study areas. Several landscape features (a slope-aspect shading index, cumulative flow of water downslope, curvature of the landscape, and water-holding capacity of the soil) were used to create the IMI in the GIS. The IMI can be used to better manage forest resources where moisture is limiting and to predict how the resource will change under different forms of ecosystem management. In this study, the IMI was used to stratify the study areas into three moisture regimes: xeric, intermediate, and mesic. Of the 108 plots established across the four study areas (27 per study area), roughly a third fell into each of the three moisture classes. The proportion of land in each IMI class was similar among study areas. The Watch Rock site had the highest proportion area in the mesic class, while Bluegrass Ridge had the highest proportion of land in the xeric class. Among treatment areas within each study area, the distribution of IMI classes was similar, so that treatment effects can be attributed to the treatments rather than a priori landscape variation. Analysis of IMI by vegetation plot revealed that these plots well represent the entire treatment areas.

Introduction

Trends in Forest Composition in Ohio

Ohio is typical among many Midwestern and Eastern States in that oaks, e.g., white (*Quercus alba*), chestnut (*Q. prinus*), scarlet (*Q. coccinea*), black (*Q. velutina*), and northern red (*Q. rubra*), are being replaced by maples (*Acer rubrum* and *A. saccharum*) and other species in historically oak-dominated forests. Data from USDA Forest Service inventories between 1968 and 1991 (Kingsley and Mayer 1970; Dennis and Birch 1981; Griffith et al. 1993) indicate that the proportion of total overall volume in oak and hickory *(Carya* spp.) declined substantially compared to maple, black cherry (*Prunus serotina*), and yellow-poplar (*Liriodendron tulipifera*) (Fig. 1). Although absolute growing-stock volumes tended to increase for most species in Ohio as the secondary forests matured, there was a shift in the relative importance of species: red oaks declined by 41 percent relative to total volume, while white oaks and hickories showed a relative decline of 31 and 22 percent, respectively. By contrast, relative increases (as a proportion of total volume) were documented for red maple (70 percent), sugar maple (44), black cherry (129), and yellow-poplar (38). This trend corroborates a pattern seen regionwide, e.g., in Illinois (Iverson et al. 1989; Iverson 1994), Pennsylvania (Abrams and Nowacki 1992), and several other Eastern States (Powell et al. 1993). This trend has prompted a large scientific effort to assess the problem and search for management solutions (e.g., Loftis and McGee 1993). In southern Ohio, a large-scale ecosystem management project was established in four study areas to study the effectiveness of using prescribed fire for oak ecosystem restoration. In this chapter we describe the development and application of an Integrated Moisture Index (IMI) across the study sites.

Tree Species Regeneration Related to Environmental Factors

It has been shown that the success of oak regeneration is related to light and moisture gradients. Oaks do not regenerate well under moist, shady conditions in the absence of fire, and thus are declining in importance across the Eastern United States while more shade-tolerant, mesophytic species are gaining (Heiligmann et al. 1985; Hilt 1985; Loftis and McGee 1993; Barton and Gleeson 1996). Oaks generally are classed as intermediate in tolerance to shade. Compared to tolerant species such as red maple, oaks have a higher light compensation

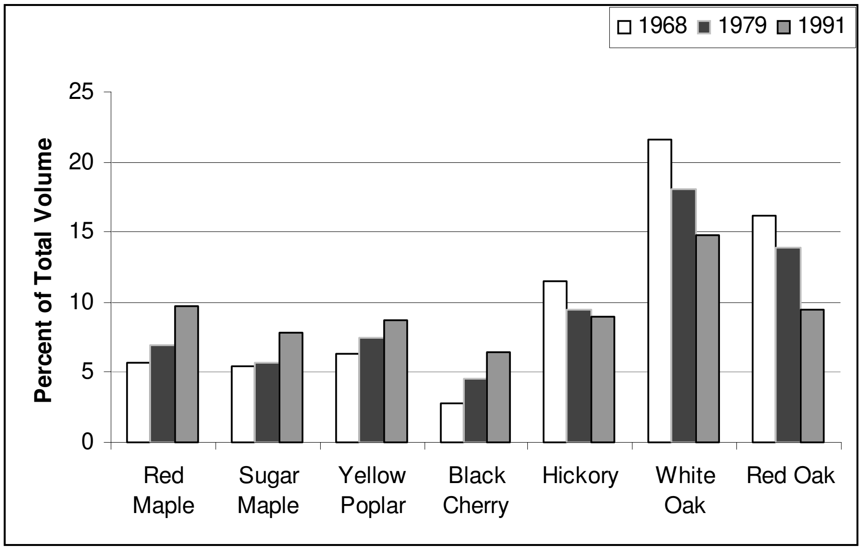

Figure 1.—Forest-inventory trends for seven primary species or species groups in Ohio, 1968-91 (Source: Kingsley and Mayer 1970; Dennis and Birch 1981; Griffith et al. 1993).

point, use light flecks less efficiently, have similar or lower rates of net photosynthesis, higher rates of respiration, and lower biomass yields (Hodges and Gardiner 1993). Yet oak also is at a disadvantage when light is not limiting (e.g., following a clearcut); in this case, yellow-poplar and other intolerant species tend to grow faster and outcompete the oaks (Beck 1990; Marquis 1990). Net photosynthesis is significantly greater in intolerant species than in oak; photosynthesis in oak saturates at one-third of full sunlight, much less than that for intolerant species (Beck 1990; Marquis 1990). Intolerants also allocate a greater portion of photosynthate to shoot growth, giving them a height advantage over oaks (Hodges and Gardiner 1993).

Oaks are relatively more tolerant of moisture stress due to morphological and anatomical characteristics of oak leaves and xylem and patterns of carbon allocation that favor root growth. These factors enhance growth and give oaks a competitive advantage under moisture-stressed conditions (Hodges and Gardiner 1993).

Thus, conditions for oak regeneration are best where light levels are intermediate and where long-term soil moisture levels are limited (Loftis and McGee 1993). For much of the mixed-oak region of the United States, future oak-dominated natural stands likely will be concentrated in relatively dry landscape positions where competition from more mesic and shade-tolerant species will be minimized. If a high level of oak in the stand is a desired condition, management activities should be concentrated in areas with intermediate to mesic moisture levels, i.e., where oak regeneration is low, but where fire and/or silvicultural practices such as group selection cuts could shift the balance in favor of oaks.

If current trends continue, red maple likely will be the dominant future canopy tree over much of the mixed-oak forest type as it grows on a wider range of soil types, textures, moisture, pH, and elevation than other forest species in North America (Hepting 1971; Golet et al. 1993; Iverson et al. 1999). It is expanding in dominance throughout its range (Abrams 1998) and can thrive following many kinds of disturbance (Bowersox and Ward 1972; Good and Good 1972). However, red maple is highly susceptible to fire because of its thin bark (Hengst and Dawson 1994).

Several other ecosystem properties are correlated to moisture gradients. Nitrogen availability and pH both tend to be higher with higher moisture regimes (Hairston and Grigal 1994; Garten et al. 1994; Morris and Boerner 1998), and long-term soil moisture has been used to predict organic matter, phosphorus, and depth of the A horizon (Gessler et al. 1995). Plant composition also is strongly related to these gradients, including overall biological diversity which tends to be greater under higher moisture regimes (Host et al 1987; Iverson et al. 1999; Hutchinson et al. 1999). These gradients are increasingly being related to animal distributions as well. For example, Dettmers and Bart (1999) used moisture regimes derived from landscape parameters to predict suitable habitat for several species of birds in Ohio.

Moisture Models and Tree Growth

The distribution and growth (i.e., site index) of trees in this geographic region are correlated with local topography and soils, but these relationships are difficult to quantify and map (Merz 1953; Trimble and Weitzman 1956; Trimble 1964; Carmean 1965; Tajchman and Boyles 1993). McNab (1993) devised a topographic index based on eight slope gradients that was related to yellow-poplar site index in the southern Appalachians. Fralish (1994) found a strong relationship between stand basal area and soil and topographic factors in southern Illinois. He found this association related mostly to the soil-water reservoir. Slope angle, aspect, and position, and effective soil depth were the primary factors controlling the amount of water in the soil-water reservoir. White (1958) also concluded that any measure of site productivity is mostly an estimate of the amount of available soil water, the exception being when the site has a prevailing water table within 2 m of the surface where ground water would be available for tree growth (Loucks 1962). In British Columbia, Wang and Klinka (1991) found that the site index for lodgepole pine (*Pinus contorta*) could be estimated reasonably well with a soil-moisture model. Host et al. (1987) reported that forest successional pathways in Michigan were strongly related to topographic and edaphic conditions, again, largely via variations in moisture availability.

These relationships indicate that geographic information system (GIS) technology may be ideally suited to model moisture level across landscapes, and, by extension, the ecosystem patterns and processes correlated to moisture, including oak regeneration. Predictive vegetation mapping has advanced rapidly in recent years because of the increased availability of digital maps of topography and soils, and tools for processing them (Franklin 1995). Digital elevation models (DEM) (U.S. Geol. Surv. 1987) have been useful in deriving topographic features associated with landscape processes (Jenson and Domingue 1988; Skidmore 1990; Twery et al. 1991; Garten et al. 1994; Mitasova et al. 1996). Digital elevation data also have been used in combination with remotely sensed and other data to map forest composition and biomass (Fox et al. 1985; Frank and Thorne 1985; Iverson et al. 1994).

The objectives of this study were to: 1) create a model predicting an integrated moisture index (IMI) based on DEM and soils data; 2) apply the model across the study areas of the ecosystem management project to stratify the landscape into moisture classes; and 3) summarize IMI and other landscape features prior to prescribed fire treatments.

Methods

Integrated Moisture Index

The IMI was developed to integrate GIS-derived topographic and soil features of the landscape into a single index that can be statistically related to a number of ecological processes across a landscape (Iverson et al. 1996; Iverson et al. 1997). The intention was to provide a relative rating of moisture that can be related to specific processes wherever moisture is seen as the primary driving factor. Assuming reasonably similar climate, elevation, disturbance history, and soil fertility among upland sites, variation in plant distribution and productivity is driven primarily by moisture availability. Moisture levels are higher where direct solar radiation is minimized (the hillshade variable in the IMI model), in lower positions on slopes (flow accumulation) or in depressions (curvature), and in soils capable of storing large amounts of water (total water-holding capacity). Therefore, IMI is modeled here as a function of:

solar radiation potential, or hillshade +
flow accumulation of water downslope +
curvature of the landscape +
total available water capacity of soil

The first three factors (hillshade, flow accumulation, and curvature) were generated from U.S. Geological Survey (USGS) 7.5-minute DEM data (1:24,000 scale, 30x30 m cell size). This method is described in detail in Iverson et al. (1997).

Hillshade captures the effects of differential solar radiation due to variation in slope angle, aspect, and position, and accounts for shading from adjacent hills. The latter component of hillshade was minimal because, although dissected heavily, the maximum relief change was less than 100 m and cliffs are rare in the area. Cumulative solar radiation is greatest on steep, south-facing slopes (Lee and Baumgartner 1966). Because of the added drying potential of higher afternoon temperatures, drying of soil is greatest on aspects slightly west of south (SSW). Thus, the highest moisture levels will be on NNE aspects, a solar azimuth of 22 degrees. A solar altitude of 45 degrees was used to approximate a growing season average. The "hillshade" command in Arc/Info Grid (Environ. Syst. Res. Inst. 1994), operating on the digital elevation data for the sites, was used to create hillshade maps with increasing scores contributing to increasing moisture content.

Flow accumulation represents the accumulated flow of water downslope as water moves via gravity. Thus, it is related to position on the slope where the bottoms of slopes accumulate much more moisture than ridgetops. The Arc/Info Grid command "flow accumulation" (Environ. Syst. Res. Inst. 1994) counts the number of cells sending water downslope to the cell being evaluated; ridgetops would have a flow accumulation of only one while the valley bottoms would have maximum accumulation. Thus, higher flow accumulation scores contribute to higher IMI values.

Curvature is a measure of shape of the topography. The Arc/Info program "curvature" assesses surrounding cells to calculate a curvature, with increasing positive scores representing increasing concavity. Concave surfaces will accumulate moisture and contribute positively to the IMI. The curvature map generally assigns small coves and depressions with higher scores, and small knolls with lower scores. Algorithms for flow accumulation and curvature are given in Jenson and Domingue (1988).

Total available water capacity was derived from digitized soil-series maps originally compiled at a scale of 1:15,840 by the USDA Natural Resources Conservation Service. Using the attributes from these soil maps, soil depth (A plus B horizons) and available water capacity (per unit depth) were multiplied to estimate the total amount of water available to plants in the A and B horizons. In several instances, the mapping unit was a soil complex consisting of two or more soil series; in these cases, weighted averages were calculated based on the percentage of each soil series in the complex. There was a large difference in total water-holding capacity between bottomland and upland soils. The latter are mostly shallow soils with bedrock close to the surface, which severely restricted the total water-holding capacity. Soils in the valleys generally were deeper with higher silt content. These maps generated for total available water capacity had sharp boundaries with large differences in water capacity depending on the mapped soil series/ complex. A continuous soil-property map developed using GIS and fuzzy logic would be preferable, and is being developed by some researchers (e.g., Zhu 1994; Ramlal and Beard 1996).

Each of the four factors cited were standardized to a score of 0 to 100 to facilitate calculation of the IMI. After numerous iterations associated with on-site visits and field experience, the weights selected for use in the GIS model for the IMI were hillshade (40 percent), flow accumulation (30), total water-holding capacity (20), and curvature (10). The final IMI score has a theoretical range of zero to 100, with higher scores indicating higher soil moisture levels.

Stratification of Study Sites

The resulting IMI scores, along with minimum size requirements were used to stratify the sites into four classes:

1. **xeric**: IMI scores 0-35.0
2. **intermediate**: 35.0-50.6
3. **mesic**: 50.6-100
4. **too small**: < 4000 m^2

Obviously, these class breaks are artificial and were selected in order to achieve good representation of each class. These classes were mapped and used in the field to position the vegetation and soil plots into the approximate moisture regime. Later, when a global positioning system (GPS) became available to us, precise calculation of IMI and IMI class was performed for plots.

Map Generation and Georeferencing

Maps were generated for each site and IMI classes were mapped as described. Topographic lines were generated from the DEM via an ARC/INFO GRID program (Contour) (Environ. Syst. Res. Inst. 1994).

GPS technology was used to georeference unit boundaries and plot locations (108 plots across the four study areas, three treatment units, three IMI classes, and three replicates) (see Chapter 1). A Trimble ProXL GPS was used to acquire the line data for the firelines for the fire-treatment units. The data were then differentially corrected with Pathfinder software (Trimble Navigation Ltd. 1995) and imported into Arc/Info, where the data were edited to remove spurious vertices, and built into polygon coverages. Because the control treatment unit boundary lines were generated via digitization of lines drawn on 1:24,000 scale topographic maps, these data are therefore not as accurate as the GPS data.

As discussed in Chapter 1, the individual plots measure 25 x 50 m and are bounded by six metal stakes. Each stake was positioned with 150 GPS points and later was differentially corrected to within ~3 m with the Pathfinder software. The points were transferred to the GIS and converted to plot-boundary polygons for GIS mapping and analysis. Understory vegetation and regeneration subplots were identified separately in the GIS for later analysis.

Analysis by Study Site

The GPS and GIS efforts allowed calculation of area and proportions of each IMI class for each study area: Arch Rock (AR), Watch Rock (WR), Young's Branch (YB), and Bluegrass Ridge (BR). This analysis resulted in overall statistics on area and perimeter of each treatment area in each study area, along with average IMI scores and percentages in each IMI class.

Analysis by Treatment Area

The GIS was used to assess the following characteristics for each treatment unit: area, average IMI, hillshade, flow accumulation, curvature and soil water-holding-capacity scores, average slope angle, average, minimum, maximum and range of elevation, and length of streams and ridges within the treatment units. Site index for oak also was estimated based on regression relations developed earlier between IMI and young forest stands near the Vinton County sites (AR and WR) (Iverson et al. 1997). These characteristics were used to assess landscape variability within and between study areas.

Analysis by Plot

Each of 108 plots was located accurately in the GIS via GPS. The plots were subsampled to 2-m pixel cells and overlaid via Arc/Info Grid on a series of map layers to generate weighted-average statistics for each plot. Thus, statistics were generated for the following landscape characteristics: IMI, hillshade, flow accumulation, soil water-holding capacity, curvature, aspect in degrees, slope angle, elevation, distance to nearest stream and to nearest ridge, and estimated oak site index. The aspect in degrees was simply an average aspect in degrees, with proper accounting when pixels within a plot had a mixture of aspects east (< ˉ45°) or west (> 315°) of due north.

Results and Discussion

IMI Generation

The resulting models of IMI for the four study areas reveal the heterogeneous nature of the landscape. For example, within any 10-ha area, one can find a wide range of IMI scores (Fig. 5, Chapter 1). There is also a general pattern of low scores (drier conditions) on ridgetops and south-southwest facing slopes, especially where soils are shallow. The deep soils and high flow accumulation along stream bottoms such as the Elk Fork (the eastern boundary of AR FREQ (frequent burn unit) and WR INFR (infrequent burn unit) are apparent with the highest IMI scores.

Descriptive Statistics by Study Area, Treatment Area, and IMI Category

The average IMI score, and the proportions of each treatment or study area within the three IMI classes were reasonably consistent across study areas (Table 1). These sites encompassed 341.5 ha, 244.6 of which were FREQ or INFR treatment areas. Except for the 49.8-ha INFR treatment area on BR, all treatment units range in size from 20.4 to 32 ha. Weighted-average IMI scores by treatment unit ranged from 39.2 on AR INFR to 50.1 on WR CONT (Table 1). WR was the most mesic with 41 percent of its area in that class, while BR was the least mesic with only 15 percent of its land being in that class (Table 1). AR and YB had 29 and 31 percent of the area classified as mesic, respectively. An underlying reason for the smaller proportion of mesic land at BR was that its ridgelines generally run north to south, while the other sites have generally east to west ridgelines. North-south ridges result in less north-facing terrain; hence, IMI values are lower. This trend also was apparent for the AR INFR treatment area, with only 18 percent mesic land (Table 1).

Landscape features, including the variables used in creating IMI, also were calculated for each IMI class within the treatments and study areas (Table 2). For three of the four components of IMI (except for several instances of water-

Table 1.—Summary information by study and treatment area.

Study Area	Treatment	Area	Perimeter	Average IMI	Xeric	Inter-mediate	Mesic
		ha	*m*			*Percent*	
Arch Rock	Control (B)	24.1	2451	46.3	32	31	37
	Frequent (A)	32.0	2898	44.2	39	29	33
	Infrequent (C)	24.0	2123	39.2	43	39	18
	Total/Average	80.1	7472	43.3	38	33	29
Watch Rock	Control (B)	20.4	2223	50.1	23	28	49
	Frequent (A)	30.7	2592	42.3	31	45	25
	Infrequent (C)	25.7	2650	49.4	19	32	49
	Total/Average	76.8	7465	46.7	24	35	41
Young's Branch	Control (A)	24.1	2340	45.2	21	44	35
	Frequent (B)	29.1	3161	44.9	27	44	29
	Infrequent (C)	22.2	2584	44.2	25	46	28
	Total/Average	75.3	8085	44.8	24	45	31
Bluegrass Ridge	Control (A)	28.3	2509	42.2	25	59	16
	Frequent (B)	31.2	2586	48.8	47	44	09
	Infrequent (C)	49.8	3534	40.1	39	41	20
	Total/Average	109.3	8629	43.1	37	48	15
All Areas	Control	96.9	9523	46.0	25	41	34
	Frequent	123.0	11237	45.1	36	41	24
	Infrequent	121.6	10891	43.2	32	40	29

Table 2.—Summary information of treatment-level landscape features, by IMI class, for each study area (all averages are weighted) except for lengths of streams or ridges.

ITEM	Control			Frequent			Infrequent			Average		
	Xeric	Inter.	Mesic	Xeric	Inter.	Mesic	Xeric	Inter.	Mesic	Control	Frequent	Infreq.
						Arch Rock						
IMI	29.4	43.1	63.4	28.8	41.7	64.3	28.8	42.3	57.1	46.3	44.2	39.2
Flow	23.7	30.8	48.9	24.2	29.4	47.1	18.9	35.5	62.3	35.3	33.2	33.3
Hillshade	37.3	60.2	80.8	36.7	62.0	83.3	41.9	58.3	70.8	60.6	59.2	53.6
Curvature	37.3	47.4	54.5	36.1	41.7	51.2	35.7	50.8	65.5	46.8	42.7	47.0
WHC[a] (cm)	2.53	2.93	4.71	2.42	2.60	4.94	2.29	2.40	2.49	3.5	3.3	2.4
Slope (degrees)	15.5	16.7	19.8	17.6	17.5	20.6	14.5	15.5	15.3	17.5	18.5	15.1
Elevation (m)	253.8	247.4	234.6	247.7	246.7	234.6	250.1	247.7	241.1	244.7	243.1	247.5
Minimum	201.2	199.8	199.9	208.2	206.3	209.0	207.8	206.6	207.3	200.3	207.9	207.2
Maximum	281.3	280.7	273.9	279.6	278.4	270.5	280.5	279.5	273.9	278.4	276.3	278.9
Range	80.1	80.9	74.0	71.4	72.2	61.4	72.7	73.0	66.5	78.1	68.3	71.7
Site Index	60.5	66.0	74.4	60.3	65.5	74.7	60.3	65.7	71.8	67.4	66.5	64.5
Streams (m)	0	8	1479	0	16	545	0	58	1203	496	187	420
Ridges (m)	1994	862	533	1553	636	326	2734	548	9	1130	838	1097
						Watch Rock						
IMI	28.0	43.4	64.3	29.3	42.6	57.8	28.1	43.5	61.7	50.1	42.3	49.4
Flow	19.0	32.8	54.6	15.2	34.8	62.3	20.4	29.2	49.1	40.3	30.3	37.2
Hillshade	37.0	57.9	75.6	35.7	53.6	68.6	35.7	56.1	68.8	61.8	51.9	58.4
Curvature	35.3	47.3	58.4	37.6	49.2	66.2	37.8	46.2	58.7	50.0	45.6	50.7
WHC[a] (cm)	2.64	3.12	4.96	3.43	3.18	2.94	2.63	3.72	5.47	3.9	3.8	4.4
Slope (degrees)	16.8	18.9	17.1	15.4	15.8	14.2	20.3	17.3	16.1	17.6	16.7	17.3
Elevation (m)	249.5	245.6	223.3	259.4	250.0	240.6	250.7	238.9	223.2	235.6	246.2	233.5
Minimum	204.1	199.5	196.8	218.3	217.5	217.1	201.0	201.0	201.0	199.2	208.0	201.0
Maximum	293.6	292.3	277.3	287.4	280.2	272.0	292.2	291.6	288.4	285.3	285.7	290.2
Range	89.5	92.9	80.6	69.1	62.7	54.9	91.2	90.6	87.4	86.1	77.8	89.2
Site Index	60.0	66.2	74.7	60.5	65.9	72.1	60.0	66.2	73.7	68.9	65.8	68.7
Streams (m)	0	18	1496	0	0	949	0	0	1007	505	316	336
Ridges (m)	1529	661	194	1586	675	0	1035	1195	329	795	754	853

Table 2.—Cont.

ITEM	Control			Frequent			Infrequent			Average		
	Xeric	Inter.	Mesic	Xeric	Inter.	Mesic	Xeric	Inter.	Mesic	Control	Frequent	Infreq.
Youngs Branch												
IMI	29.9	42.8	57.7	30.1	42.7	56.8	30.6	43.2	57.9	45.2	44.9	44.2
Flow	16.3	38.4	65.3	17.8	36.5	62.5	15.2	34.3	61.1	43.1	43.0	37.1
Hillshade	42.0	55.5	69.7	42.8	58.0	71.6	45.7	58.0	70.6	57.6	57.3	58.4
Curvature	42.2	51.8	61.0	40.9	50.3	56.8	39.0	49.4	58.3	53.0	52.0	49.3
WHC[a] (cm)	2.63	2.59	2.66	2.50	2.49	2.52	2.64	2.87	3.07	2.6	2.6	2.9
Slope (degrees)	12.5	12.0	11.5	12.3	13.3	12.6	10.8	12.5	13.5	11.9	11.9	12.4
Elevation (m)	276.3	270.2	264.6	278.3	271.6	263.7	275.8	266.2	254.3	269.5	270.5	265.2
Minimum	243.8	235.3	234.8	241.3	230.1	228.4	223.1	219.6	220.4	236.9	237.2	220.7
Maximum	305.4	301.4	294.8	308.3	306.7	300.0	295.0	295.0	291.3	300.0	300.9	293.9
Range	61.6	66.1	60.0	66.9	76.6	71.5	71.9	75.4	70.9	63.0	63.7	73.2
Site Index	60.7	65.9	72.1	60.8	65.9	71.7	61.0	66.1	72.2	66.9	66.8	66.5
Streams (m)	0	5	2155	0	0	1478	0	0	1215	720	493	405
Ridges (m)	1410	319	21	1667	966	9	1780	762	7	583	881	850
Bluegrass Ridge												
IMI	30.9	43.2	56.4	29.3	42.0	55.1	29.4	42.5	55.7	42.2	48.8	40.1
Flow	12.1	40.2	73.8	19.9	48.0	84.2	22.7	44.2	74.0	38.4	56.8	41.9
Hillshade	55.4	63.0	68.1	45.6	53.6	56.4	43.6	57.9	66.8	61.9	63.3	54.2
Curvature	41.2	51.1	62.6	42.7	52.3	64.2	43.2	50.5	57.7	50.4	56.5	49.1
WHC[a] (cm)	1.74	1.68	1.65	1.69	1.73	1.71	1.71	1.75	1.74	1.7	1.7	1.7
Slope (degrees)	10.5	12.0	10.2	10.9	11.3	10.1	12.2	11.9	11.5	11.4	10.8	11.9
Elevation (m)	242.0	233.7	223.7	255.4	251.6	245.3	252.4	250.8	242.5	234.2	231.3	249.8
Minimum	207.5	204.4	204.2	217.0	211.6	215.3	194.7	196.2	199.7	205.2	206.3	196.4
Maximum	272.0	273.2	268.4	279.9	278.6	269.5	296.4	295.8	292.2	272.1	271.4	295.3
Range	64.5	68.8	64.2	62.8	67.0	54.2	101.6	99.5	92.5	66.9	65.1	98.9
Site Index	61.2	66.1	71.5	60.5	65.6	71.0	60.6	65.8	71.2	65.7	68.4	64.9
Streams (m)	0	44	1081	31	185	1405	11	228	2486	375	540	908
Ridges (m)	1927	420	0	3158	210	8	4200	731	21	782	1125	1651

[a] WHC = Water-holding capacity. Maximum capacity of water (cm) in A and B soil horizons.

Table 3.—Summary information for plot-level landscape, by IMI class, for each study area (all averages are weighted).

	Control			Frequent			Infrequent			Average		
Item	**Xeric**	**Inter.**	**Mesic**	**Xeric**	**Inter.**	**Mesic**	**Xeric**	**Inter.**	**Mesic**	**Control**	**Frequent**	**Infreq.**
						Arch Rock						
IMI	30.0	46.5	62.4	27.9	37.7	73.5	29.7	44.8	53.4	46.3	46.4	42.6
Flow	22	25	42	30	44	50	22	39	37	29	41	33
Hillshade	34	78	88	28	46	90	40	63	85	67	54	62
Curvature	34	41	56	44	64	44	38	51	38	44	51	42
WHC[a] (cm)	2.71	2.24	4.36	2.49	2.07	6.83	2.24	2.43	2.24	3.10	3.79	2.30
Slope, degrees	15	26	21	20	19	23	15	19	19	21	21	17
Aspect, degrees	178	330	1	164	223	15	191	191	36	[b]	[b]	[b]
Elevation, m	259	251	235	248	235	223	259	246	240	249	235	248
D-Streams, m	66	80	57	73	50	111	49	34	60	68	78	48
D-Ridges, m	19	21	31	26	56	58	17	30	28	24	47	25
Est. Site Index, ft	60	67	74	60	64	79	60	67	70	67	68	66
						Watch Rock						
IMI	30.7	37.3	62.4	27.0	42.8	57.9	27.0	47.8	63.4	43.4	42.6	46.1
Flow	16	40	49	17	30	39	18	48	29	35	29	31
Hillshade	39	24	88	21	62	81	31	55	84	50	54	57
Curvature	29	54	57	48	44	54	36	44	46	47	49	42
WHC[a] (cm)	3.04	4.47	3.80	3.37	2.69	4.08	2.72	3.04	6.41	3.77	3.38	4.06
Slope, degrees	13	22	22	19	18	19	19	24	19	19	19	21
Aspect, degrees	174	165	0	207	b	56	169	107	47	[b]	[b]	[b]
Elevation, m	236	218	228	276	244	243	254	222	218	227	254	231
D-Streams, m	78	37	37	66	40	62	48	44	94	51	56	62
D-Ridges, m	13	47	48	8	26	20	17	41	34	36	18	31
Est. Site Index, ft	60	64	74	59	66	72	59	67	74	66	66	67

Table 3.—Cont.

	Control			Frequent			Infrequent			Average		
Item	**Xeric**	**Inter.**	**Mesic**	**Xeric**	**Inter.**	**Mesic**	**Xeric**	**Inter.**	**Mesic**	**Control**	**Frequent**	**Infreq.**
						Youngs Branch						
IMI	33.1	46.1	55.2	30.6	43.1	59.9	36.8	40.1	57.2	44.8	44.6	44.7
Flow	35	38	50	31	33	57	17	25	50	41	40	31
Hillshade	34	67	77	33	61	83	30	60	76	59	59	55
Curvature	48	47	50	40	50	53	40	42	52	48	48	45
WHC[a] (cm)	2.67	2.19	2.67	2.53	2.67	2.67	2.37	2.45	3.45	2.51	2.62	2.76
Slope, degrees	15	14	13	15	11	15	16	10	16	14	14	14
Aspect, degrees	186	85	38	210	258	14	199	287	60	[b]	[b]	[b]
Elevation, m	280	277	267	279	268	255	275	284	252	275	267	270
D-Streams, m	64	83	36	79	51	38	35	73	33	61	56	47
D-Ridges, m	28	30	72	31	18	35	5	29	51	43	28	28
Est. Site Index, ft	62	67	71	61	66	73	59	65	72	67	67	65
						Bluegrass Ridge						
IMI	32.9	42.3	53.1	31.5	43.2	55.3	29.1	43.6	54.9	42.8	43.4	42.5
Flow	20	35	57	43	43	72	24	37	61	37	53	41
Hillshade	49	65	75	36	59	68	41	66	75	63	54	60
Curvature	43	44	50	49	49	65	41	47	55	46	54	48
WHC[a] (cm)	2.06	1.75	1.63	1.63	1.68	1.64	1.63	1.64	0.10	1.81	1.65	1.63
Slope, degrees	12	12	14	14	13	11	11	16	14	13	13	14
Aspect, degrees	137	*	65	231	165	82	241	92	67	[b]	[b]	[b]
Elevation, m	268	248	222	251	251	261	268	241	239	246	255	249
D-Streams, m	91	70	23	37	45	10	92	53	23	61	31	56
D-Ridges, m	27	20	64	48	33	81	21	33	51	37	54	35
Est. Site Index, ft	62	66	70	62	66	71	60	66	71	66	66	66

[a] WHC = Water-holding capacity. Maximum capacity of water (cm) in A and B soil horizons.

[b] Average aspect not reasonable calculated because of high variability.

holding capacity), the scores increased as moisture level increased. Water-holding capacity was highest at the Vinton County sites, particularly the treatment areas with deep bottomland soils of the Elk Fork (WR CONT and INFR and AR FREQ and INFR). Slope angle also was generally higher at the Vinton County sites, with several treatment units averaging more than 20 degrees in slope. Elevation was highest at YB as several ridgetops exceeded 300 m. The average for the other three sites was 230 to 250 m. As expected, total ridge length was higher for the xeric classes than for the more mesic zones, while stream length was almost exclusively in the latter.

The treatment units generally were equivalent with respect to landscape variables (Table 1). Ideally, the weighted averages among control, frequent, and infrequently burned plots should be similar so that treatment effects can be attributed to the treatment rather than other variables. Similar scores among treatment units is the case in most instances, though there are exceptions. For example, WR FREQ has a lower IMI and flow accumulation than the other treatment units at WR. Given that these are weighted averages, most of the difference is attributed to the disproportionately lower amount of mesic area relative to the other units (25 percent for WR FREQ versus 49 percent for WR CONT and INFR; Table 1).

Landscape Features of Plots

A precise location of the 108 plots allows for a more detailed analysis of the biotic and abiotic factors associated with the landscape features. The plot data also provide information that will allow extrapolation to landscape scales. Reported data are similar to those reported in the previous section for the treatment and IMI classes, but also include estimates of the distances to the nearest ridge and stream as well as estimates of aspect in degrees (Table 3).

The plots are representative of the entire treatment areas, as the mean values for the plots correspond well with the weighted averages for the treatment areas (Tables 2-3). Therefore, we can be confident that the results obtained from plot investigations can be reasonably extrapolated to the entire treatment area and beyond.

At the plot level, the weighted average overall IMI scores were similar among treatments, ranging only from 42.5 for BR INFR to 46.4 for AR FREQ (Table 3). However, variability was higher among the four components used to derive IMI. For example, average flow accumulation is higher for BR FREQ and AR FREQ than for the other treatments because of long hillslopes. Hillshade values were lower on those same units. Because hillshade and flow accumulation account for 70 percent of the IMI score, these variables tend to compensate for each other in the distribution.

Plots classified as xeric tended to be southerly in aspect and higher in elevation, while mesic plots generally faced north and were lower in position. The intermediate plots were intermediate in these traits but varied in average aspect in degrees (some averages were not reasonably calculated due to the high variability among plots). The intermediate plots were on a variety of slopes but often faced east or west.

Plot center distances to the nearest ridge or stream generally were as expected, with xeric plots nearest ridges and mesic plots nearest streams. However, these data were variable and not always easily understood. Because of the extremely dissected nature of the study areas, a plot can be near a stream or ridge horizontally, but not if corrected for slope. The dissected landscape also yielded many small streams or ridgelines so that plots were rarely more than 75 m from either.

Conclusion

The IMI can be developed from readily available topographic data and soils maps. It requires no field assessments, is time invariant (excluding geologic time), and is consistent between areas to be assessed. The IMI is related to site productivity (site index) and to species composition (Iverson et al. 1996, 1997). It also is useful for predicting ecosystem attributes such as understory vegetation patterns (Iverson et al. 1996; Hutchinson et al. 1999), species richness (Hutchinson et al. 1999), soil pH and available nitrogen (Morris and Boerner 1998), root production (Dress and Boerner 2001) and distributions of bird species (Dettmers and Bart 1999). The IMI is recommended as a site attribute for ecosystems where moisture is limiting.

The GIS analysis showed that the plots are highly representative of the entire treatment area, as the mean values of many landscape variables for the plots are similar to the weighted averages for the entire treatment area. Therefore, the results obtained from plot investigations can be reasonably applied to all treatment units. We are confident that the results of our prescribed-burning experiments can be extrapolated to other locations in southern Ohio and beyond.

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