FOREST SITE-COMMUNITY RELATIONSHIPS IN THE SHAWNEE HILLS REGION, SOUTHERN ILLINOIS

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ABSTRACT

Forest site-community relationships were investigated in 30 relatively undisturbed, near steady-state stands of the Shawnee Hills, a region of sandstone bedrock covered by a thin loess deposit. Site conditions ranged from dry, hot rock outcrops and southwest slopes with thin soil to moist, cool northeast slopes and protected stream terraces with deep soil. The general sequence of forest types across these site conditions is: red cedar, post oak, white oak, northern red oak, and sugar maple. The forest types are generally restricted to a range of site conditions although site characteristics between types overlap slightly and result in gradations between communities. The distribution of these types appears primarily related to soil available water capacity, exposure to or protection from the desiccating effects of wind, and aspect which influences the impact of solar radiation on a site. Available water capacity is a function of stoniness, bulk density and soil depth to bedrock or the fragipan.

Multiple linear regression analyses indicate that available soil water, effective soil depth, aspect, slope position and site protection may be the most important variables for predicting basal area. The amount of variation in stand basal area accounted for by four MLR models ranged from 71 to 87 percent.

INTRODUCTION

A prerequisite to the management of forests as a renewable resource is an understanding of the basic ecological relationships between the forest community and the physical environment of the sites. In an area that has received heavy disturbance, as has the Shawnee Hills Region of Southern Illinois, it is difficult, if not impossible, to sort out the original relationships from those that presently exist. Severe perturbations such as widespread unrestricted cutting, or "high grading", and fire have substantially disrupted the basic relationships so that species composition is entirely different from and basal area levels are lower than those of the undisturbed forest. In the Shawnee Hills Region, many forest stands are in various stages of composition change (succession) and often are young developing stands. The result is that the forester

has difficulty evaluating a site for potential basal area level or species composition. This problem can be resolved by studying scattered remnants of relatively undisturbed fully stocked stands that are approaching a steady-state condition, characteristics of sites on which these stands are found, and then applying the relationships to disturbed communities and sites.

Few quantitative studies of the site environment and nature of the plant communities have been done for the region. Voigt and Mohlenbrock (1964) briefly described the upland forest communities of southern Illinois, but did not distinguish between forests of different physiographic provinces. Ashby (1968) investigated the plant communities of Lusk Creek but did not relate vegetation to soil and site factors, nor were successional communities excluded.

This paper summarizes data from six years of research on steady-state stands and their environment. The objectives of this paper are to (1) examine the range of site and stand characteristics found in the Shawnee Hills, (2) relate stand basal area level and species composition to these site characteristics, and (3) provide multiple regression models for predicting potential basal area from site characteristics.

THE STUDY AREA

The Shawnee Hills division is a physiographically distinct region crossing southern Illinois in an east-west direction. It is bordered on the west by the Ozark and Mississippi Bottomland Provinces which extend approximately ten miles into the state, and on the east by the Ohio River (Fig. 1). The region encompasses an area of about 398,000 ha (960,000 acres). From the southern edge of Illinoian glaciation on the north, elevation gradually increases from approximately 122 m to a general level of 160 to 210 m with hill tops extending above 244 m; a few peaks exceed 275 m. Along the southern edge lies the Coastal Plain that was once submerged by ancient seas.

The bedrock is composed of massive Pennsylvanian and Mississippian sandstone (Schwegman 1973). The soil overlying these strata is derived mainly from loess, ranges in texture from silt loam (A horizon) to silty clay loam (B horizon), and may vary in depth from a few centimeters to approximately 3 meters. A red and gray mottled fragipan or claypan is often present and effectively prevents significant root penetration beyond the surface of the zone. Large sandstone fragments are generally scattered through the soil profile, and horizons of some soils may be 50 or 60 percent rock by volume.

Topography is gently to steeply rolling but escarpments, cliffs, and overhanging bluffs are found where bedrock surfaces. Relatively deep, sheltered gorges have been cut by some of the larger rivers and are of sufficient width to permit development of forest communities on low slopes and small floodplains.

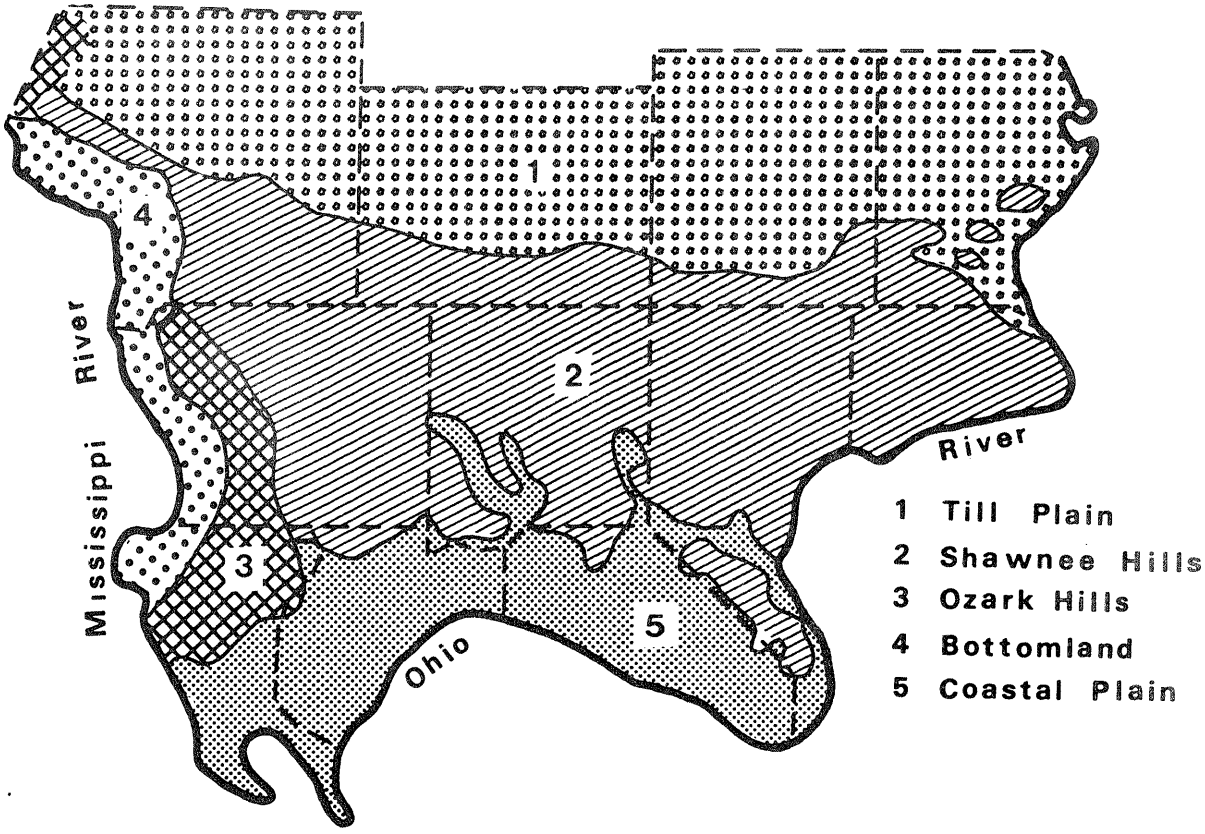


Figure 1. Natural divisions of southern Illinois (after Schwegman 1973).

The Region receives a yearly average rainfall of 1140 mm. Although approximately 760 mm falls during the 180-190 day growing season, summer droughts of up to four weeks during July and August are not uncommon. Recent investigations indicate that these prolonged hot, dry periods persist for a sizable portion of the growing season and cause soil moisture levels to drop below wilting point on some sites. This combination of climate, soil and topography has created a variety of physiographic site types (sensu Hills 1958) and has a profound influence on the distribution of forest species and communities.

Braun (1964) has classified the vegetation as western mesophytic forest although the border of the oak-hickory region lies a short distance to the north and west. On upland slopes forest stands are dominated by white oak (Quercus alba L.), post oak (Q. stellata Wangenh.), blackjack oak (Q. merilandica Muenchh.), and northern red oak (Q. rubra L.), with associated species of hickory (Carya spp.). In coves and small alluvial terraces, sugar maple (Acer saccharum Marsh.), American beech (Fagus grandifolia Ehrh.), hackberry (Celtis occidentalis L.), yellow poplar

(Liriodendron tulipifera L.), and bitternut hickory (Carya cordiformis (Wangenh.) K. Koch) predominate. Red cedar (Juniperus virginiana L.) is important on cliffs and rock outcrops, and in old fields and forests that have been disturbed. In general, the forests of the Shawnee Hills have been highly disturbed by fire, grazing, and cutting that occurred in the early decades of the 1900's. Farming eliminated forest from most relatively level land surfaces on broad ridges and hills; many of these areas are now abandoned fields in early successional stages.

METHODS

Site Selection and Sampling

The selection of study sites was based on physical characteristics and the condition of the forest stands. Uniformity was the important criterion for site selection. Characteristics considered for uniformity included soil depth, texture, and stoniness, aspect, slope, and slope position. In addition, the sites could not be less than 0.6 ha in size, the smallest area that would adequately enclose the sample quadrats; no sites were larger than 0.8 ha. If moderate variations in any one factor were present, the site was not used.

An acceptable forest stand on a uniform site could not (1) contain evidence of cutting, grazing, or fire, within the life of the canopy trees, (2) be younger than 75 years, or (3) have noticeable successional trends. The stands also had to be fully stocked for the conditions of the site. This last criterion, although it appears subjective, became quite meaningful after examination of large acreages of poorly stocked (high graded) stands. Finally the sites and their respective communities were selected to represent the complete range of environments and forest types found in the Shawnee Hills. A total of 30 stands were identified and sampled.

In each stand, five sampling points were randomly located but with a minimum of 24 m between points and 12 m between the point and the stand boundary. Each sampling point was used as the center of three nested, circular quadrats (0.0405, 0.0101, and 0.0004 ha). Stems >8.9 cm dbh were classed as trees on the 0.0405 ha plot and measured to the nearest 2.5 cm. Saplings between 1.25 and 8.9 cm dbh were recorded as 2.54, 5.08, and 7.62 cm stems on the 0.0101 ha circular quadrat. Seedlings on the 0.004 ha plot included stems less than 1.25 cm dbh but taller than 15 cm. All stems were recorded by genus and species.

Within each 0.0405 ha plot, the soil was probed to observe the range of soil characteristics. In a representative pedon, a soil pit was excavated to a depth of four feet or to bedrock if nearer the surface. Horizon designation, sequence, depth, stoniness, and texture, depth of rooting and presence of a fragipan was described for the profile. On alluvial sites, an auger was used to obtain samples to depths up to

nine feet. On one-half of the sites, two additional soil pits were dug. Samples of each horizon were taken for texture analysis and bulk density determination.

Other site data recorded included aspect (degrees azimuth), number of sides bounded by other forest communities and angle (°) to the ridge which affords some protection from west and southwest winds. Aspect was later transformed using the method of Beers, Dress and Wensel (1966). Stand position as a percentage of the distance between the ridge and the nearest permanent stream, and distance to the opposing slope were later obtained from topographic maps. These site factors were then integrated into a variable called site protection as outlined in table 1.

Table 1. Procedure for integrating site factors to estimate site protection. The actual values for slope position, number of sides adjoining stands, distance to opposing slope, protection ridge angle, and slope steepness are converted to index values. These values are then summed for all five factors and a rating (SPR) is then assigned to the site (after Jones 1974).

Slope Position (%)

Location	Index
Ridge	10
	20
High slope	30
	40
Middle Slope	50
	60
Low slope	70
	80
	90
Stream	100

No. sides with Adjoining Stands

Value (No.)	Index
0	0
1	25
2	50
3	75
4	100

Distance to Opposing Slope

Value (m)	Index
0	100
150	75
300	50
450	25
600	0

Protection Ridge Angle

Value (°)	Index
0	0
3	17
6	33
9	50
12	60
15	83
18	100

Slope Steepness

Value (%)	Index
0	100
5	85.7
10	71.4
15	57.1
20	42.9
25	28.6
30	14.3
35	0

Site Protection

Σ Index Values	Rating
0-50	1
51-100	2
101-150	3
151-200	4
201-250	5
251-300	6
301-350	7
351-400	8
401-450	9
451-500	10

Laboratory Analysis

Texture of each soil horizon was determined using the Bouyoucos hydrometer method described by Wilde, Voigt and Iyer (1964). Bulk density was determined using the Uhland Core Method (Black 1965). Soil texture, bulk density (BD) and horizon depth (HD) data were used to determine available soil water holding capacity (AWC) from the models suggested by Hill (1959) and Auclair and Cottam (1972):

1. AWC (%) = 6.5 + .26 (% silt)

2. AWC (cm horizon) = AWC (%) x BD x HD (cm/100)

Horizon AWC was then proportionally reduced according to the amount of rock present. The AWC values for all horizons above bedrock or fragipan were summed to obtain an estimate of AWC to effective soil depth.

The data for trees, saplings, and seedlings, were summarized by calculating density (# stems/ha), relative density, basal area (sq m/ha) and relative basal area. An importance value (IV 200) was calculated for each species by summing the values for relative density and relative basal area, and dividing by two to maintain a scale of 0 to 100 units. Models for predicting basal area were developed using multiple regression analysis.

Soil water levels were monitored in ten stands through the 1975 growing season (April to October), an average growing season from the standpoint of precipitation. An auger was used to obtain weekly soil samples from each horizon in the profile; water was measured gravimetrically. Soil samples for determining bulk density (saran resin method) and developing water retention curves (ceramic pressure plate method) were obtained from soil pits. Total available water stored was then calculated for soil depth to the fragipan or bedrock. Although the data on the soil water research will be reported elsewhere, occasional references to drought periods and water stored are based on the results.

RESULTS

The Red Cedar Community

The red cedar community is unique because it is one of the few evergreen forest types in the central deciduous forest ecosystem, and occurs on the most xeric sites in the Shawnee Hills. The criterion of uniformity in soil characteristics could not be closely adhered to in selecting stands of this community. Typically the substrate consists of soil lenses scattered over sandstone bedrock. They may cover 0.1 ha and have a thickness of up to 30 cm at the center but generally they are only 15 to 20 cm thick. Over the sampling area, soil depth averages about 10 cm. The means and ranges of site characteristics for this forest type are shown in table 2.

Soil texture is consistently a silt loam (15% sand, 67% silt, and 18% clay), and there is little horizon development. Because the lenses are uniform in texture and contain no rock fragments, it is felt that the soil was moved by erosion from adjacent upland areas and initially trapped by lichens and crevices. Broomsedge (Andropogon virginicus L.), the major understory species, probably invaded early in the development of the lenses and acted as a filter to trap additional soil as it washed onto the sites; it continues to be a common understory species.

Because of the overriding effect of the small amount of soil and limited water availability, the other site characteristics have little effect on the community. Stands are located in a variety of slope positions that range from exposed bluff edges facing a variety of directions, to protected valley positions adjacent to streams.

Extremes in moisture are characteristic of these sites. During the late fall, winter, and early spring months, the soil is saturated because for one to three days after a rain, water flows over the sites from higher elevations. In the late spring and summer, rainfall is sporadic and there may be droughts of several weeks duration. Soil water often drops below the permanent wilting point (Downs 1976), and therefore, only the most drought resistant tree species can survive.

Between the lenses is exposed sandstone bedrock covered with moss and lichens. A few scattered red cedar saplings along with broomsedge grow from cracks in the sandstone. Near crevices where a small amount of soil has accumulated, a few red cedar trees may be found. On the soil lenses, red cedar generally grows to tree size and along with post oak, blackjack oak, and winged elm (U. alata Michx.), forms stands with an average density of 197 trees per hectare and basal area of 5 sq m/ha. Red cedar dominates with maximum importance values of near 90 and a minimum of about 50 (Table 3). Post oak is only important in stands on the deeper soil areas and may have an IV as high as 15. These stands are, on some sites, transitional to the post oak forest type. Winged elm and blackjack oak are consistently minor species.

The Post Oak Community

On sites where the soil is somewhat deeper and covers the entire bedrock surface, the forest stands are generally dominated by post oak. Such areas of soil often are found between the sites where stands of red cedar and white oak are located, and, therefore, are quite narrow, but may also cover areas up to 10 hectares in the area known as "Old Stone Face". The total soil depth on such sites may be moderately deep (90 to 120 cm) but a well developed fragipan or clay pan is found at depths of 38 to 76 cm (Table 2) and restricts root development to the upper layers. Sandstone rock fragments often make up 35 to 60% of the soil volume and thus substantially reduce available water holding capacity. The profile is well developed with texture of the A horizon ranging from loam to silt loam, and the B2 from loam to silt loam and clay loam. On some sites

Table 2. Mean and range of site factors basal area and density for six forest communities in the Shawnee Hills Region.

	Red Cedar		Post Oak		White Oak	
	Mean	Range	Mean	Range	Mean	Range
% Sand A	14.6	10-20	35.6	26-56	29.7	15-52
% Silt A	67.6	67-70	52.2	32-58	56.6	40-71
% Clay A	17.8	13-23	12.2	11-14	13.7	8-22
% Sand B2			29.4	23-41	28.0	16-40
% Silt B2			47.6	39-54	46.0	20-56
% Clay B2			23.0	20-28	26.0	16-40
ESD (cm)	10.0	6-13	58	38-76	55	36-81
% Rock	0	---	50	35-60	27	15-40
AWC (cm)	3.3	2.0-4.0	7.2	4.4-10.1	12.8	8.6-21.8
SPR	5.2	3-8	3.8	2-5	6.0	3-7
Slope Pos.	5	3-8	3.2	2-5	4.9	3-6
Dist. Opp. Slope (m)	237	45-608+	548	304-608+	283	91-427
% Slope	20.8	10-35	32.8	22-50	24.9	15-27
Aspect (Azimuth)	231.3	180-255	232.4	200-290	221	180-285
Basal Area (sq m/ha)	5.09	2.19-11.06	14.97	12.46-17.71	20.76	18.08-23.76
Density (stems/ha)	197	113-291	393	350-424	415	330-563

Table 2. Continued.

	Northern Red Oak		Mixed Hardwood		Sugar Maple	
	Mean	Range	Mean	Range	Mean	Range
% Sand A	27.3	18-28	18	14-22	37	15-59
% Silt A	55.8	42-68	69	14-22	50.5	31-70
% Clay A	17	12-23	13	10-16	12.5	10-15
% Sand B2	22.0	10-40	31.8	16-52	44.5	14-75
% Silt B2	52.7	38-66	46.8	32-52	42.0	17-67
% Clay B2	25.3	18-38	21.4	16-26	13.5	8-19
ESD (cm)	72	51-86	92	76-106	198	152-244
% Rock	25	15-30	24	15-35	0	---
AWC (cm)	12.2	8.4-14.7	20.9	17.5-26.4	44.4	44.1-44.7
SPR	7.2	6-8	8.3	7-9	9.5	9-10
Slope Pos.	5.3	3-8	9	9-9	10	10-10
Dist. Opp. Slope (m)	354	75-600+	112	45-300	45	45-45
% Slope	25.5	17-40	35.4	20-65	0	---
Aspect (Azimuth)	3	340-65	27.4	0-49	---	---
Basal Area (sq m/ha)	26.44	19.34-31.19	28.43	21.62-34.43	29.87	27.67-32.1
Density (stems/ha)	377	3.30-429	345	192-405	311	281-340

Table 3. Average importance values for six forest communities in the Shawnee Hills Region.

Species	Forest Community					
	Red Cedar	Post Oak	White Oak	Northern Red Oak	Mixed Hardwoods	Sugar Maple
Juniperus virginiana	85.4	1.8	0.4			
Quercus stellata	4.5	39.5	12.2			
Ulmus alata	5.8	0.4	0.3	0.2		
Quercus marilandica	4.3	15.5	3.5			
Carya texana		11.6	0.6			
Quercus coccinea		1.7	2.1			
Quercus falcata		0.5	0.9			
Carya tomentosa			0.1			
Quercus alba		13.2	56.9	9.3	0.9	
Quercus velutina		7.8	10.0	5.9	0.8	
Fraxinus americana		0.4	0.4	6.2	6.1	0.8
Carya ovata		0.6	0.8	12.0	5.8	4.0
Carya ovalis + *C. glabra*		7.0	9.0	17.1	3.4	5.4
Quercus rubra			1.4	31.4	7.5	
Nyssa sylvatica			1.3	4.8	4.5	
Acer saccharum			0.1	6.5	43.9	51.2
Juglans nigra				0.5	0.8	0.8
Carya cordiformis				0.8	3.9	9.4
Liriodendron tulipifera				1.9	4.1	6.3
Fagus grandifolia				2.5	9.4	13.0
Ulmus rubra				0.2	3.0	1.9
Quercus muehlenbergii				0.3		
Sassafras albidum				0.4	0.5	
Celtis occidentalis					2.1	
Ostrya virginiana					0.3	
Prunus serotina					0.7	
Ulmus americana					1.6	2.4
Tilia americana					0.7	0.9
Liquidambar stryaciflua						0.9
Platanus occidentalis						2.1
Aesculus glabra						0.9
Total	100	100	100	100	100	100

the A is relatively thin possibly due to erosion on frequently steep slopes (max. 50%). The combination of restricted rooting, high rock content, and increased clay percentages in the B2 limits AWC to only 7.2 cm (range 4.4-10.1 cm); however, this AWC is substantially higher than the 3.3 cm average recorded for red cedar stands.

Other additional factors contributing to soil water depletion are the unfavorable south, southwest, and west aspects (200-290° az) of the sites that receive direct solar radiation during the hottest part of the day. The stands are often located on upper slope positions or near cliff edges overlooking wide valleys with the opposing slope averaging a distant 548 m (range 300-600 m); the effect of wind on water depletion is probably important. Individual site data indicates that the stands on the deepest soils are also the most exposed, the greater exposure counteracting the effect of the deeper soil. Since they are frequently located in high slope positions, there is often little lateral water movement to effect recharge on these sites. In two study stands, soil moisture during the 1975 growing season was below permanent wilting point for two extended periods (Downs 1976). The somewhat less severe but still harsh environment of these sites is indicated by the presence of twelve species compared to only four in red cedar stands.

The stands are dominated by post oak (average IV=39.5) with blackjack oak (IV=16), black hickory (Carya texana Buckl.) (IV=12), and white oak (IV=13) of secondary importance (Table 3). The density is only 393 trees per hectare with a basal area of approximately 12 to 18 sq m/ha. As in red cedar stands the openness of the canopy does not protect the site from wind and solar radiation so the small amount of moisture stored in the soil is rapidly lost through evapotranspiration.

The White Oak Community

Stands of white oak tend to dominate sites on south, southwest, and west slopes. In the study sites, average effective soil depth is approximately 55 cm but ranges from 36 to 81 cm (Table 2); all profiles contain a fragipan. Although there is considerable overlap in soil depth with sites where post oak stands dominate, soil available water holding capacity between the two communities is considerably different. Soils under the white oak stands average over 12.5 cm storage capacity, approximately 5 cm more than the post oak stands. The difference is due primarily to the lower rock content in the profile. Soil texture ranges from loam or silt loam in the A1 horizon to loam, silt loam, silty clay loam, or clay loam in the B2.

The sites are located in the middle slope position or on more gently sloping land surfaces near ridge tops. Compared to post oak stands, they were located in more narrow valleys with the opposing slope averaging about 280 m (range 90-425 m).

White oak dominated all stands (IV=33 to 76) by a wide margin over post oak, black oak (Q. velutina Lam.), and the red hickory (C. ovalis (Wang.) Sarg.), pignut hickory (C. glabra (Mill.) Sweet) complex (Table 3). The number of trees increased somewhat relative to post oak stands, and basal area increased to 18 to 23 sq m/ha, a reflection of improved site conditions. The more favorable site conditions are also reflected in the number of species (17) found on all sites as well as the increased productivity as indicated by basal area levels.

The Northern Red Oak Community

Northern red oak stands are found in middle slope positions but on sites that have northwest, north and northeast aspects. Average soil depth is 72 cm, about 13 cm deeper than in white oak communities. However, although the average of 12.2 cm AWC for these sites is not different from those supporting white oak communities (12.8 cm), the rate of water usage is probably considerably reduced because of the northern aspect and increased protection of the site: many of the sites were directly below small vertical cliffs (~20-30 ft); or if not below vertical cliffs, they were in the more narrow valleys (minimum distance to opposing slope = 75 m) where wind velocities may be lower. During the 1975 growing season, soil water through the profile was never reduced below permanent wilting point in two study stands (Downs 1976).

The importance value of red oak ranges from 18 to 32, averaging 31. However, in stands where low importance values occur, red oak remains the leading dominant because the large number of species (17) present on the sites. Other relatively important species include white oak, red and pignut hickory, shagbark hickory (C. ovata (Mill.) K. Koch), white ash (Fraxinus americana L.), and sugar maple (Acer saccharum Marsh.), the latter two with IV not exceeding 10.0. Basal area is high averaging 26.4 sq m/ha with a maximum of 31.2. These communities rapidly grade into sugar maple communities in lower slope positions.

The Mixed Hardwood Community

The 20 tree species that occur in this community rank it first in species richness among those studied. This mixture of relatively mesophytic hardwood species is designated "mixed hardwood" to distinguish it from the sugar maple community that occurs on stream terraces in the Shawnee Hills. The stands sampled are located in middle to low slope positions on northwest, north, northeast, and east facing sites. They are frequently in coves, and in these narrow valleys (distance to opposing slope = 45 to 300 m), the type often extends 10 or 20 m up the south facing slope. The soil is deep averaging slightly over 100 cm to bedrock; a fragipan is usually absent but a distinct textural B occurs below the A2 in most profiles. Soil AWC is substantially higher, averaging over 20 cm for the profile.

Sugar maple dominates all stands with an average IV of 43.9. American beech is weakly important (IV=9.4) as is northern red oak (IV=7.5). The 17 remaining species within the community have importance values below 6.0. Basal area level peaks in this community at 28.4 sq m/ha with one stand having 34.4 sq m/ha (Table 2).

The Sugar Maple Community

This community is located on level terraces that are scattered along some of the larger streams such as Lusk Creek, Little Lusk Creek and Bay Creek. These terraces are small, usually not exceeding one or two hectares in size; many are smaller. The sites are highly productive and readily accessible, thus most forest stands have been heavily cut over; only two stands met the criteria for selection.

Soil texture and depth are considerably more variable because of the nature of the initial material (alluvial); the soils are usually classed as part of the Sharon series. In one stand the texture is sandy loam and soil depth is approximately 3.0 m; during the spring months a water table is present at about 2.7 meters. In the other stand, the silt loam soil has a depth of 2.0 m; a water table, as indicated by a gleyed horizon, is also present at depth of 1.5 m during the spring months. After periods of heavy rain, the sites may be inundated for several hours, two or three times during the spring. During the remainder of the growing season, the soils are substantially below field capacity particularly in July and August. If heavy rain occurs during these months, the water recharges soil moisture within the watershed, thus flooding is rare in summer.

Sugar maple is the major dominant species with approximately 40 percent of the basal area and 63 percent of the stems (IV=51.2). American beech (IV=13.0), bitternut hickory (*C. cordiformis* (Wang.) K. Koch) (IV=9.4), and yellow poplar (IV=6.3) are other important components in the overstory (Table 3). There is some decrease in number of species to 14 but basal area remains nearly equal to the mixed hardwood community on north slopes (29.9 sq m/ha).

Multiple Regression Analysis

A large number of multiple regression models were tested primarily to (1) provide information on the biological response of forest tree species to site factors, and (2) predict basal area using site factors that can be easily observed in the Shawnee Hills ecosystem. The difference between these two objectives lies primarily in the inclusion of AWC in the models developed for examining biological response. The factor AWC integrates effective soil depth (ESD) with texture, percent stone, and bulk density changes through that depth. These variables have a strong effect on soil water which ultimately determines site potential and tree growth. However, data for estimating AWC are not easily obtained, and thus, for predicting basal area on disturbed sites where it is often below potential levels, it is necessary to use other site factors that can be rapidly observed in the field.

All 30 stands were used to develop models for examining possible biological response and for field use. An examination of basal area (BA) as a function of AWC (Fig. 2a) or ESD indicated an exceptionally strong curvilinear relationship (r=0.78 and 0.68 respectively). In order to obtain a more linear relationship, a log transformation was applied to AWC (Fig. 2b) and ESD values. The result was a substantially strengthened linear relationship in each case (r=0.90 and 0.81 for AWC and ESD, respectively).

The most parsimonious model using the natural logarithm of AWC, accounts for 87 percent of the variation in basal area:

$$BA = 2.71 + 4.97 \text{ (ln AWC)} + 0.70 \text{ (SPR)} + 2.80 \text{ (Aspect)}$$

where AWC is measured in centimeters, SPR is a coded value for site protection (Table 1) and aspect transformed according to Beers, Dress and Wensel (1966). F-ratios indicate that ln AWC, SPR and Aspect are significant at the .01 level. The components of SPR (distance to opposing slope, angle to protection ridge, percent slope, or number of sides protected by adjacent stands) were not significant when individually added to model 1 in place of exposure.

Model 2, designed primarily for field use, includes ln ESD as a predictor variable. The most parsimonious model is:

$$BA = -10.94 + 5.68 \text{ (ln ESD)} + 1.14 \text{ (SPR)} + 2.48 \text{ (Aspect)}$$

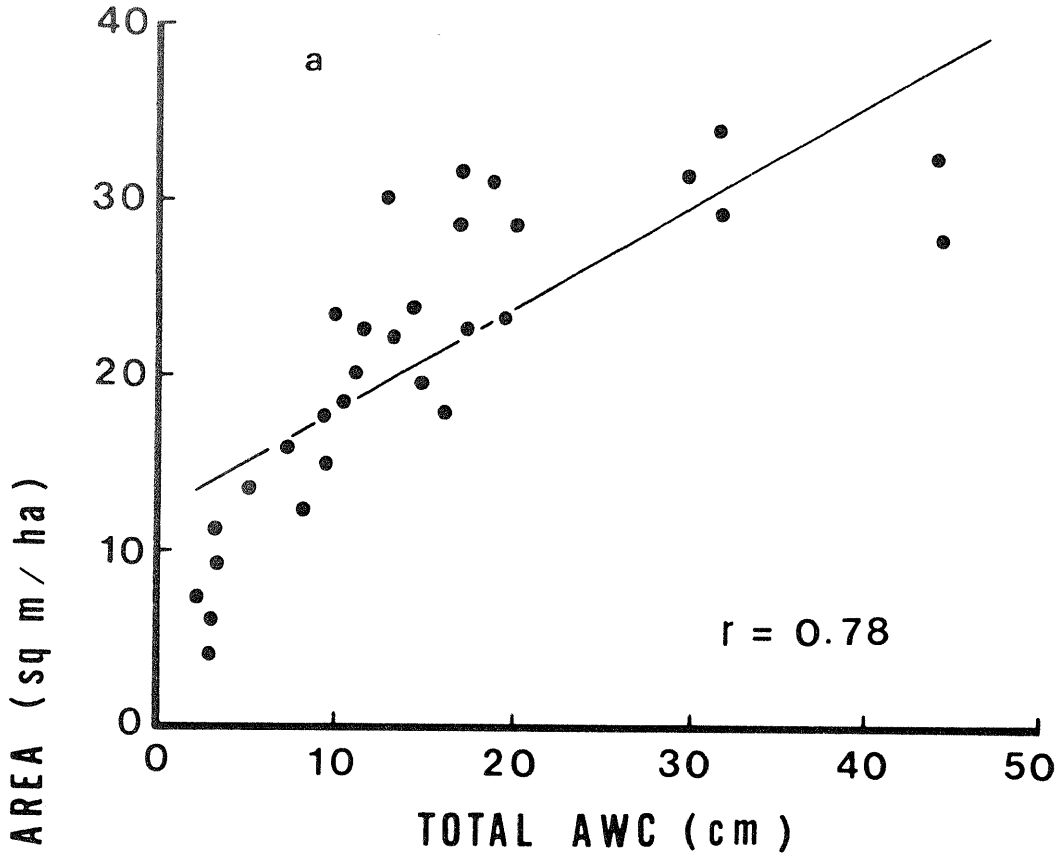
where ESD is measured in centimeters. The model accounts for 84 percent of the variation in basal area. Effective soil depth and SPR are significant at the .01 level while aspect is significant at the .05 level.

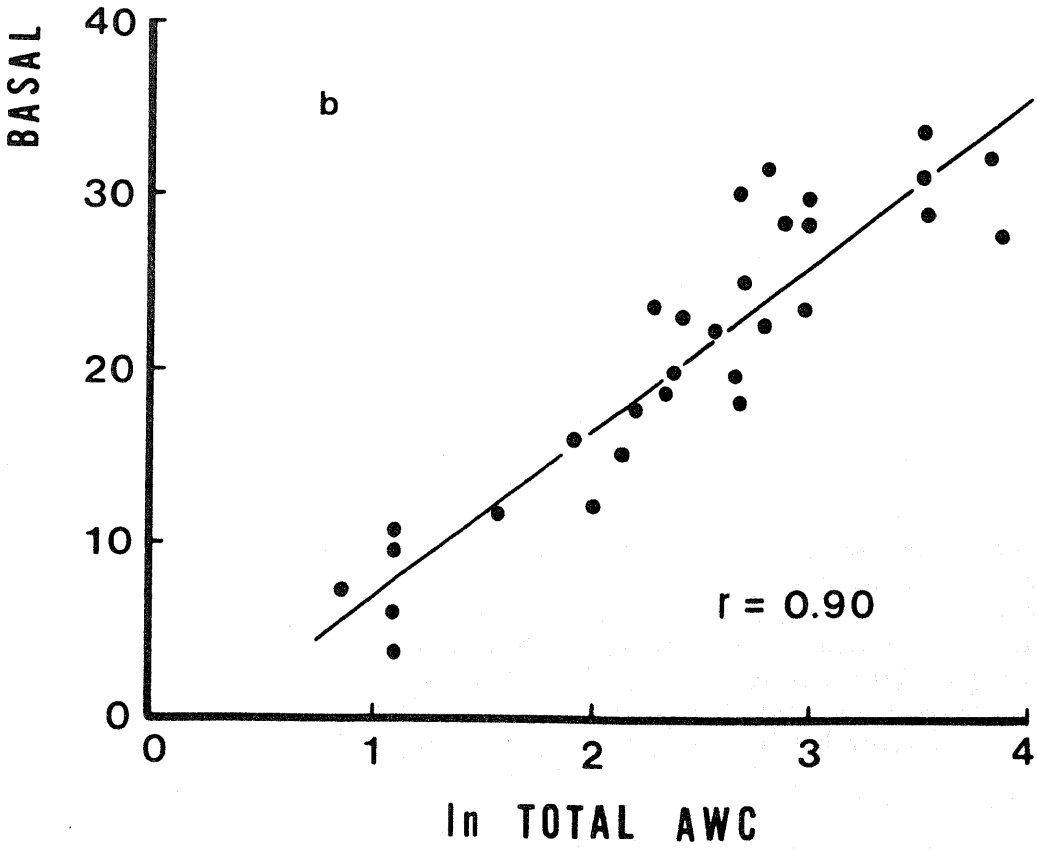
Foresters generally do not carry equipment for determining soil depth, and determining ESD in this region becomes tedious because of the high rock content of many soils. Moreover, foresters are not concerned with managing forest stands (for timber production) on sites that have extremely low productivity such as red cedar stands on rock outcrops. When these five cedar stands are removed from the analysis, ESD becomes statistically less important. The correlation between ESD and basal area (r=0.55) is substantially lower than between basal area and SPR (r=0.81), slope position (r=0.80) or aspect (r=0.76); the correlations between basal area and the latter three factors are substantially higher than those for 30 stands shown in table 4. Therefore, it appears that when the cedar stands are excluded, an adequate model need not include ESD as a predictor variable.

Shown on opposite page:

Figure 2a. Graph of stand basal area and total soil available water capacity.

Figure 2b. Graph of stand basal area and log total soil available water capacity.


a
r = 0.78
BASAL AREA (sq m / ha)
TOTAL AWC (cm)
0
10
20
30
40
50


b
r = 0.90
BASAL AREA
ln TOTAL AWC
0
1
2
3
4
10
20
30
40

Using 25 stands in the analysis, models 3 and 4 were developed. Models 3 and 4, which account for 71 and 75 percent of the variation in basal area respectively, are:

$$BA = 12.62 + 1.34 \text{ (slope position)} + 2.95 \text{ (Aspect)}$$

$$BA = 10.85 + 1.52 \text{ (SPR)} + 3.12 \text{ (Aspect)}$$

The site protection rating, because it integrates a number of site variables, accounts for a high amount of variance. Effective soil depth is not significant when added to either model.

Table 4. Correlation coefficient (r) matrix for variables in multiple regression models (30 stands).

	Basal Area	ln ESD	ln AWC	SPR	Slope Position	Aspect
Basal Area	1.00	0.81	0.90	0.68	0.67	0.70
Log ESD		1.00	0.94	0.40*	0.40*	0.50
Log AWC			1.00	0.57	0.57	0.62
Exp				1.00	0.86	0.59
Slope Position					1.00	0.66
Aspect						1.00

*Significant at the .05 level, all others significant at .01 level.

Models 3 and 4 account for a high proportion of the variation for reasons related to the characteristics of the Shawnee Hills ecosystem. The relationship between ESD and basal area is curvilinear with the stands on rock outcrops having extremely low basal area levels. The effect of little or no soil on these sites generally neutralizes the effect of substantial site protection and/or favorable slope position or aspect. With the red cedar stands removed, the impact of the effects of other site factors becomes more apparent, thus basal area is more strongly correlated to site protection, slope position and aspect.

In addition, the effect of AWC and ESD on site productivity is, in part, taken into account because of moderately strong interaction with SPR, slope position, and aspect (Table 4). Shallow rocky soils of low AWC are found on exposed bluff edges and deep soils of high AWC in low slope positions or valley bottoms that are substantially protected. In general, thinner soils are found on sites with south facing aspects compared to those on north aspects. The massive sandstone bedrock which forms the structure of the Shawnee Hills is inclined to the north so that the south slopes are generally steep with many cliffs, escarpments, and overhanging bluffs because of surfacing bedrock (Schwegman 1973).

The north slopes are more gentle and consequently have deeper soil. There is a strong likelihood that soil depth could be easily predicted from other site factors.

Because of a limited number of study stands, it was felt that removing stands prior to analysis (for purposes of testing the models) would substantially weaken the models. However, the models were examined using data from 10 stands in advanced stages of recovery from disturbance (Table 5). The trees in these stands were generally mature but fire scars and an occasional decaying stump indicated past perturbation. Some stands had been heavily cut approximately 40 or 50 years previously as basal area was low because of small stem size. In nearly all the test stands, the models predict a greater potential basal area than presently on the sites. In some stands (2, 6 and 8) the predicted and actual values are quite close because (1) sufficient time has passed to allow basal area to build up and many trees were close to maturity or (2) the initial disturbance was probably not severe. In other stands (1, 4 and 9), there were occasional openings in the canopy and the trees were generally small. In particular, stand 9, on an alluvial site, was largely pole-sized stems of sugar maple. This stand probably developed after a clear cut.

Table 5. Comparison of actual and predicted basal area (sq m/ha) for 10 disturbed stands. Stand 3 is composed of red cedar; such stands were excluded from the analysis when models 3 and 4 were developed. Therefore, the models should not be used to predict basal area in red cedar stands.

Stand Number	Actual Basal Area	Model Number 1	2	3	4
1	17.64	27.23	27.19	28.97	27.48
2	20.08	22.22	23.50	19.32	24.33
3	3.63	10.11	9.70	-	-
4	18.86	27.70	25.99	27.63	26.13
5	20.70	25.14	25.18	25.82	26.95
6	18.01	21.48	23.66	20.66	22.81
7	23.92	32.31	30.77	30.20	30.36
8	30.82	32.18	31.51	28.97	29.17
9	12.37	30.17	30.35	31.71	30.55
10	21.62	29.33	28.93	30.58	29.25

DISCUSSION

Each forest type in the Shawnee Hills region appears restricted to a specific range of site characteristics when the type is found in undisturbed and relatively steady-state stands. There is, however, overlap

in site characteristics between community types. The distribution of steady-state communities, as diagrammatically presented in figure 3, very likely approaches the pre-settlement vegetation condition.

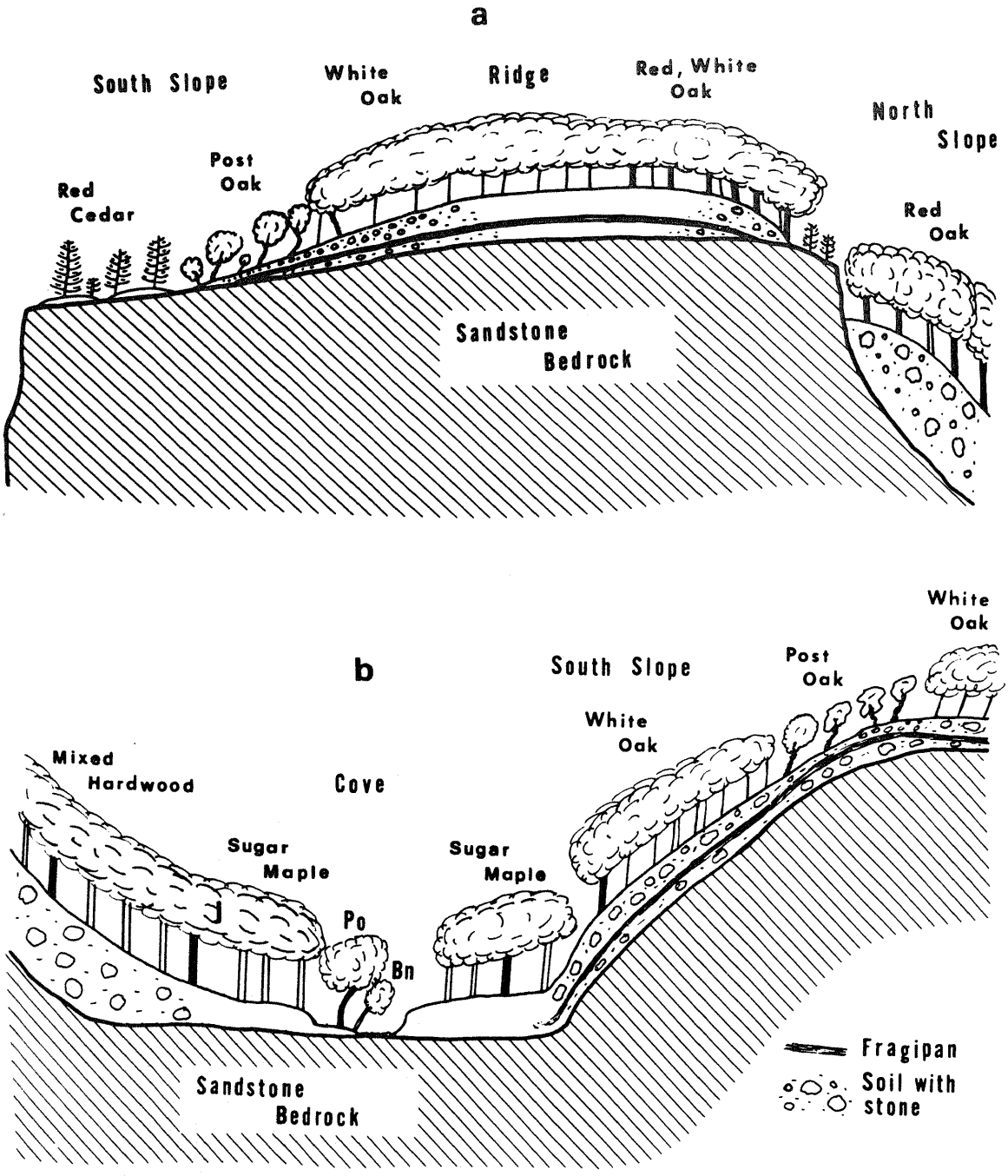


Figure 3. Diagrammatic presentation of the presettlement vegetation patterns in the Shawnee Hills Region, southern Illinois. The two species designations are: Po, Platanus occidentalis and Bn, Betula nigra.

Stands of red cedar are found generally on scattered soil lenses covering portions of bedrock along the edges of cliffs (Figure 3a) and occasionally on low slopes near streams where the bedrock is exposed. Few other trees grow on these xeric sites thus the importance values of red cedar are often near 90. Apparently, red cedar is not a strong competitor as only scattered individuals occur in post oak stands in which the canopy is still relatively open but where the basal area is much higher; these stands occur on sites where a continuous rocky layer of soil up to 76 cm deep covers the sandstone. These stands are frequently adjacent to the red cedar stands but also occur near ridge tops where the exposure to wind is more severe and thinner soils are found.

Primary differences between post oak and white oak sites are in the depth and rockiness of the soil both of which directly influence available water storage. White oak stands generally have deeper soil or soil with less rock in the profile. During the summer of 1975, post oak stands had two periods (June and August) when soil water stored in the profile was zero while white oak stands had zero water stored only during the August drought. Thus, it appears that post oak is often found in high slope positions and on thinner soils because the species is more adapted to extended drought conditions. However, it is not as drought tolerant as red cedar, stands of which also encountered two drought periods about equal in length to those in post oak stands. The apparent stability of red cedar on the thin soil lenses may be related to a generally lower amount of soil water stored through the growing season or to nearly continuous soil drought during dry years or both.

Differences in AWC between white oak and red oak sites appear small and there is substantial overlap, thus other site factors probably influence the character of the site. Red oak stands are found on the north or east facing aspects where the impact of solar radiation and velocity of the prevailing west and southwest wind are reduced and higher soil water levels are maintained. During 1975, soil water levels in the red oak stands were never below permanent wilting point at any level in the profile.

Although white oak is a member of red oak stands, the reverse does not appear to be true. Red oak is seldom found on sites that have a southern aspect. Presumably the environment is too severe for the species to survive although white oak stems seem to be sufficiently shade tolerant to survive in red oak stands.

The type of sites not investigated in this study were those located on broad ridges. These areas were under cultivation for many years and are now mostly abandoned fields in early stages of succession; many have been planted to shortleaf or loblolly pine which are nearing maturity. Based on the evidence presented and the site conditions of the broad ridge tops, the original vegetation appears to have been a mixture of white oak and red oak with additional minor species including white ash and shagbark, red and pignut hickory. The effective soil depth (depth

to the fragipan) is approximately 50 to 60 cm which is an intermediate depth between white oak and red oak sites. The topography is gently rolling (0-15% slope); relatively level sites are intermediate between the steeper south facing slopes of white oak sites and the steeper north facing slopes of red oak sites.

The red oak community may have reached full development on the more northern aspects of these broad ridges. Relative to other species in the study stands, it is not a strong dominant (IV=30), but on the deeper soil of these broad ridges particularly on more north-facing sites, red oak could have had much greater dominance in the community.

Both mixed hardwood and the stream terrace sites are dominated by sugar maple (Figure 3b). From sites high on north-facing slopes to low slope positions to stream terraces, sugar maple becomes increasingly more dominant particularly in coves or narrow valleys where environmental conditions are similar to sites of more northern regions. The high bordering ridges substantially shorten day length, and due to cold air drainage, the sites average as much as 5 to 7°C cooler than sites on south slopes as determined by max-min thermometers.

There are some definite physical differences between the soil under white oak stands and soil under red oak and mixed hardwood stands. Because of higher soil moisture levels on the north and east facing sites, leaching probably occurs at increased depth and may be the reason for fragipans and claypans being located deeper in the profile if present at all. The soils of north slopes are darker in color, appear softer and have better structure, the result of an improved moisture regime and less fluctuation between extremes. Research on soil moisture has shown that during a growing season with average precipitation, the soils on northwest to east facing slopes are not totally depleted of moisture while the soils on southeast to west facing slopes have at least one and often two periods during the growing season when moisture at all levels in the profile is below permanent wilting point (Downs 1976). Fluctuations between field capacity and permanent wilting point tends to break down structure and the generally lower moisture levels indicate lower site productivity; the lower basal area levels are a reliable index of reduced productivity. Probably less soil organic matter is present due to reduced productivity. On north-facing sites, the A1 horizon is frequently an earthworm mull and very friable. Earthworms are absent on south-facing slopes and the A1 horizon lacks the cohesiveness of the earthworm casts; when dry these soils are relatively hard but become powdery when broken.

The multiple regression models for basal area provide some insight into the possible effects and interactions of site factors. Soil AWC appears to be the major factor influencing site potential as variance accounted for by this variable is about 80 percent. Effective soil depth is also important because it largely determines soil water capacity. Site protection and aspect are important because these factors directly determine the impact of solar radiation and temperature, cold air drainage

and wind movement. These factors influence the amount of moisture lost from a site due to evapotranspiration. There is a weak interaction between SPR and aspect because the mixed hardwood and sugar maple stands are located in low slope (protected) positions on north aspects, while red cedar and post oak stands are generally in high slope (exposed) positions on south aspects.

Effective soil depth and available water capacity are strongly related; AWC is primarily a function of soil depth and percent stone. The loess deposit forms a rather shallow layer over the sandstone bedrock which has undergone only minimal weathering. Where the loess is several feet deep, there may be a fragipan, so that root penetration is often limited. In some soils, rock may lower water holding capacity by 50 percent. Soil texture differences have a very narrow range and thus little effect on soil water; the B2 horizons vary from a silt loam to a silty clay loam. Only infrequently will a sandy loam to loam soil be found on an alluvial site.

Aspect and soil depth are also interrelated because the thinner soils are found on southern aspects. Apparently, the west and south facing sites receive the full impact of storms that generally move from west, southwest to east, northeast. The communities on the sites are more open and thus erosion may have created thinner soils by removing much of the surface layer. As previously mentioned, the A1 horizons are much thinner or nearly absent, as in post oak stands, compared to relatively thick A1 horizons of the north facing sites. The soil of red cedar stands appears to be primarily A1 material. However, it is possible that differences in depth occurred when the loess material was originally deposited.

The data presented in figure 2a indicate a maximum basal area of approximately 33 sq m/ha that can be found on soils having as little as 20 to 25 cm of stored water within the profile. Although alluvial sites frequently have nearly 45 cm AWC, the basal area remains at about 30 sq m/ha indicating that species like sugar maple, beech, white ash, hackberry, yellow poplar and bitternut hickory cannot take advantage of the large amount of stored water as well as the generally sheltered conditions (low evapotranspiration rates) of such sites. Outside the Shawnee Hills, it is not uncommon to have basal areas of 78.7 sq m/ha on very wet sites (Anderson and White 1970). The problem is that the appropriate bottomland species are absent within the region. If such species were present the potential basal areas on alluvial sites probably would be much higher.

The mathematical models for predicting site potential in terms of basal area are a departure from previous models for predicting site index in the central hardwood forest region (Carmean 1965, 1967; Hannah 1968; McQuilkin 1974). The models may be an improvement over actual site index which is, to a large extent, density dependent; that is, the amount of competition from surrounding trees will influence the height of a given tree. Basal area levels are strongly affected by age and

disturbance (i.e., cutting) but not by density. The trees will continue to increase in size and withdraw increasing amounts of water until the lengthening soil water deficits (if any) match the drought tolerance of the species on the site. On sites where disturbance has occurred, changes in the species dominating the stand may change (succession) because water levels are adequate for the replacing species, and the higher level of shade (associated with increased basal area) is such that stems of the less shade tolerant overstory species do not survive in the understory.

These models are based on data obtained from fully stocked stands and there is an immediate opportunity to utilize them. In a disturbed ecosystem such as the Shawnee Hills, basal area levels on most sites are below optimum stocking. With the use of a computer, these models along with stand and site data from 225 permanent plots on the Shawnee National Forest, a comparison of actual and potential stocking levels could be obtained for each plot, or the information could be extrapolated to the forest as a whole. Certainly, it would be progress in forest land management planning and in step with the Renewable Resources Planning Act.

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