A Phytosociological Study of a Relict Hardwood Forest in Barren County, Kentucky

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Abstract

Analysis of a hardwood forest at Bonayer in Barren County, Kentucky, revealed a mature forest system with high tree species diversity and an age in excess of 150 years. The forest may be characterized as an oak forest, primarily due to the importance of *Quercus alba* in the stand. Accessory species are *Nyssa sylvatica*, *Carya ovata*, *Liquidambar styraciflua*, and *Liriodendron tulipifera*. *Cornus florida* is prevalent in the understory. A high degree of similarity is evident between the tree composition and the younger growth in the forest indicating a relatively stable forest system. Comparison with second and third growth forest stands in the surrounding area reveals that the same species are dominant in the younger developing stands. This suggests that the Bonayer Forest represents the climax vegetation of the area. The mature forest shows a mean dbh of 7.0 inches (17.8 cm), density of 289 trees per acre (713 trees/ha), and a basal area of 138.5 square feet per acre (31.8 m^2/ha).

Introduction

Although general information is readily available concerning the structure and composition of deciduous forests, especially in the eastern part of the United States, there seems to be little specific information concerning forest composition in the Commonwealth of Kentucky. The lack of phytosociological studies prior to the development of the land, and the extent of land development of Kentucky, has led to the paucity of information regarding the natural forest vegetation of the Commonwealth. To the authors' knowledge, there are few publications dealing with the vegetational composition of relict or virgin forests in Kentucky. It is apparent that there is a special need for studies of natural areas that have been relatively undisturbed by man. A small wooded area in Barren County, Kentucky, referred to as Bonayer Forest, was chosen for a detailed phytosociological analysis in 1971 after a preliminary investigation indicated that the forest might be representative of the natural vegetation of south central Kentucky.

This study was undertaken to describe the vegetational composition of the forest, to gain some insight into the successional development of the stand, to compare the tree composition of the forest with that of representative woodlots in the surrounding area, and to establish a record of Bonayer Forest as a basis for possible future studies of a structural or functional nature. An underlying aim of this investigation was to determine whether or not this small forest is indicative of the vegetational composition that would be present in the region if it were undisturbed by man.

The study area consists of approximately 14.5 acres (5.9 hectares) of mature hardwood forest in Barren County, Kentucky, 25 miles (40.25 km) east of Bowling Green and 6 miles (9.7 km) west of Glasgow on U.S. Highway 68 at the village of Bonayer. This woods was part of a Revolutionary War Grant to the Read family of Glasgow. To the knowledge of the last 3 Read generations (approximately 125 years) there has been no timber removed except for dead chestnut trees after the epidemic of chestnut blight in the late 1930's. Prior to 1971, the forest covered some 30 acres (12.1 ha), but during that year, a part of the Cumberland Parkway was cut through the woods, leaving less than half of the former stand.

Barren County is within the eastern and western Pennyroyal physiographic regions of Kentucky, which are parts of the Mississippian plateau (McFarlan 1943). The plateau is underlain by sedimentary rocks primarily of Mississippian age, with Devonian rocks in some areas. The topography of the county is predominantly that of a dissected plateau, and varies greatly. Bonayer Forest is on a nearly level section of land within an area of gently rolling topography.

According to a soil survey of Barren County (Latham 1969), the soils underlying Bonayer Forest have been classified as Dowellton and Taft silt loams. Both are nearly level, poorly drained, acid soils on upland flats. These soils were developed in residual or alluvial material derived chiefly from limestone and partly from sandstone or shale. The natural fertility of Dowellton and Taft silt loams is moderately low; organic matter is low.

The area now known as Barren County was settled following an order of the Virginia Convention in 1789, which declared that all the lands between the Barren and Green rivers would be given to soldiers of the Continental Army. Barren County was formed from Warren and Green counties in 1789 and originally included all of Metcalfe County, large parts of Hart and Monroe counties, and a part of Allen County. The name of Barren County was derived from the term "barrens" given by the early settlers to a treeless grassland roughly corresponding to the area of karst topography in central Kentucky. According to Shaler (1884) the early settlers considered these lands to be worthless and unproductive since they did not support the magnificent forests expected of fertile land. The lack of trees may have been due to periodic fires set by the Indians to burn off old grass, thus providing better forage for buffalo and other large game. When the Indians no longer made regular hunting expeditions into Kentucky (about 1790), the grassland known as the Barrens was quickly restored (Shaler 1884).

It is impossible to determine whether the present study site was a part of what was then the Barrens, or if it was part of the originally forested region which surrounded the Barrens. Franklin Gorin (1876), commenting on the appearance of Barren County in 1798, said:

> "The country north, northwest, and northeast of Glasgow was mostly barrens, poorly watered and lightly timbered, but the rest of the country . . . was heavily timbered with oak, black and white walnut, ash, sugar maple, hackberry, cherry, poplar, chestnut, beech, buckeye, etc."

Bonayer Forest is west and slightly north of Glasgow, so it would have been near the borderline between the wooded and barren regions as presented by Gorin. However, even if the study site was within the Barrens, it may have been reforested following 1790 (Shaler 1884, Hussey 1876). The history of Barren County, then indicates that the study site may have been covered with forest vegetation for 180 or more years.

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MATERIALS AND METHODS

The quadrat method (Oosting 1956) was used to determine species composition, relative density, and relative frequency of all size classes of vegetation as well as relative dominance (based on basal area) of tree species. At Bonayer, 23 quadrats of 10 m × 10 m dimensions were placed on 4 transect lines with a 30-m interval between each quadrat. Seven additional 100-m^2 quadrats were placed at random in the remaining area. The diameter

breast height (dbh) of each tree species greater than 2 inches (5 cm) dbh was recorded for each 100-m^2 quadrat. Saplings and shrubs less than 5 cm dbh and greater than 1 foot (30 cm) in height were sampled in 2 20-m^2 quadrats (2 × 10m) placed within each 100-m^2 quadrat. Seedlings less than 30 cm in height were counted and identified to genus in 4 1-m^2 (1 × 1 m) quadrats placed within each corner of the 100-m^2 quadrats.

In order to determine whether or not Bonayer Forest was different in tree composition than other forest stands in the locality, tree species were also sampled outside the Bonayer Forest. However, since no one forest of sufficient size for comparative purposes was found, we chose 6 wooded sites of similar topography and within a 5-km radius of the Bonayer Forest. All of those stands had obviously been disturbed and appeared to consist of second or third growth woods. This composite of 6 sites, referred to as the Surrounding Area, was sampled by 20 quadrats randomly placed among the 6 sites. Within each of the 10-m × 10-m quadrats, species greater than 5 cm dbh were recorded.

To check the adequacy of sampling at Bonayer, species–area curves were determined for trees, saplings and shrubs, and seedlings (Oosting 1956). Sampling was considered adequate when a 10 percent increase in area sampled yielded additional species equal to only 5 percent of the total present. This point indicated the minimum number of quadrats which should be used to obtain a representative sample of the vegetation.

Tree data were analyzed to provide mean diameter at breast height, mean density per hectare, and mean basal area per hectare of Bonayer Forest and of the Surrounding Area. Relative density, relative frequency, and relative dominance were calculated and summed to give importance values for each tree species (Curtis and McIntosh 1951). Relative density plus relative frequency values were determined for saplings, shrubs, and seedlings.

Collections were made of all tree and shrub species found in the study area. Specimens have been deposited in the Herbarium of Western Kentucky University. Plant nomenclature follows that of Gleason and Cronquist (1963).

To determine the approximate height of the canopy in the Bonayer stand, several random tree height measurements were taken using an Abney level.

When the State Department of Highways cut through a section of the woods in 1971, stumps provided a record of annual growth rings. A random sample of the cutover area was made and 18 tree stumps were analyzed to give an approximation of the age of the stand.

A soil sample of the first 8 cm of soil was obtained from the center of each 100-m^2 quadrat in the Bonayer woods. A LaMotte Soil Test Kit was used to measure soil pH. Soil texture was analyzed by the hydrometer method of Bouyoucos (1936).

To gain some insight into the total productivity of the forest stand, falling leaves, stems, and fruits were collected from October through February. Nearly all annual litter fall was expected during that period. At the midpoint of each transect line, a 0.5-m square box with a wire mesh bottom was placed to catch falling debris. Litter was periodically removed from the boxes, dried in a drying oven, and weighed to the nearest 0.1 g.

Diversity values for trees in both Bonayer Forest and the Surrounding Area were calculated using the Shannonn–Weaver diversity formula (Wilhm and Dorris 1968) which was programmed into a PDP8 computer. For the Bonayer Forest data, 3 groups of 20 randomly chosen 100-m^2 quadrats were analyzed and the mean of these 3 diversity values was then comparable to that based on the 20 quadrats in the Surrounding Area. Another expression of diversity is the slope (b) of the regression $\log Y = bx$ where Y is the number of individuals and x is the number of species (Williams 1964). The

TABLE 1.—THE NUMBER (N), RELATIVE DENSITY (RD), RELATIVE FREQUENCY (RF), RELATIVE DOMINANCE (RDo), AND IMPORTANCE VALUE (IV) OF TREES OVER 2 INCHES (5 CM) DBH IN BONAYER FOREST

Species	N	RD	RF	RDo[1]	IV
Quercus alba	24	11.2	11.2	38.9	61.3
Nyssa sylvatica	27	12.6	9.8	6.7	29.1
Carya ovata	24	11.2	10.5	5.1	26.8
Liquidambar styraciflua	18	8.4	8.4	5.3	22.1
Liriodendron tulipifera	9	4.2	6.3	9.8	20.3
Cornus florida	18	8.4	7.7	1.1	17.2
Fagus grandifolia	8	3.7	5.6	7.7	17.0
Sassafras albidum	15	7.0	4.9	1.5	13.4
Carpinus caroliniana	13	6.1	6.3	.6	13.0
Quercus velutina	8	3.7	3.5	5.4	12.6
Acer rubrum	8	3.7	4.2	4.2	12.1
Carya tomentosa	8	3.7	3.5	1.0	8.2
Ulmus alata	6	2.8	3.5	1.3	7.6
Acer saccharum	6	2.8	2.8	.8	6.4
Carya glabra	5	2.3	2.1	2.0	6.4
Quercus spp.	1	.5	.7	5.1	6.3
Fraxinus americana	4	1.9	2.1	.4	4.4
Fraxinus nigra	4	1.9	1.4	.7	4.0
Quercus coccinea	2	.9	1.4	1.0	3.3
Prunus serotina	2	.9	1.4	.4	2.7
Ulmus rubra	1	.5	.7	1.0	2.2
Fraxinus pennsylvanica	1	.5	.7	.1	1.3
Amelanchier arborea	1	.5	.7	.0	1.2
Oxydendrum arboreum	1	.5	.7	.0	1.2

[1] Basal area equals 138.5 ft², 12.9 m².

regression coefficient or slope (b) was determined for trees in Bonayer Forest.

RESULTS

Species–area curves for trees, saplings and shrubs, and seedlings demonstrated that, in all cases, samples were more than adequate for analysis of the vegetational composition of the forest. A minimum number of 18 of the 100-m² quadrats was necessary to characterize the tree species present at Bonayer Forest; an additional 12 quadrats were used. Saplings and shrubs were sampled in 60 of the 20-m² quadrats whereas 24 quadrats would have been sufficient. The 120 1-m² quadrats used to sample seedlings were in excess of the minimum number of 52 quadrats for this stratum of vegetation. A species–area curve for trees in the Surrounding Area showed that the minimum number of 100-m² quadrats needed was 12, so the 20 quadrats placed in the Surrounding Area also constituted an adequate sample for analysis.

TABLE 2.—DIAMETERS (IN CENTIMETERS) OF THE 10 MOST COMMON TREE SPECIES IN BONAYER FOREST, SHOWING THE NUMBER OF TREES IN EACH CLASS, BASED ON 214 TREES

	5.0–12.6	12.7–27.7	27.8–42.9	43.0–58.2	58.3+
Quercus alba	2	8	3	6	5
Carya ovata	15	7	2		
Nyssa sylvatica	17	7	3		
Liquidambar styraciflua	12	3	2	1	
Cornus florida	18				
Liriodendron tulipifera	1	4	3		1
Fagus grandifolia	4	2			1
Carpinus caroliniana	13			1	
Sassafras albidum	12	3			
Acer rubrum	5	2			1

In the Bonayer Forest, 24 tree species are included in the sample of 30 quadrats. When tree species at the Bonayer Forest are ranked according to importance values (Table 1), the 4 most predominant species (and their importance values) are *Quercus alba* (61.3), *Nyssa sylvatica* (29.1), *Carya ovata* (26.8), and *Liquidambar styraciflua* (22.1). *Q. alba* has a much greater relative dominance (38.9) than any other tree species. *Cornus florida* is the most abundant understory tree with a relative density of 8.4.

The total of 214 trees recorded at Bonayer Forest correspond to a density of 713 per hectare. The trees have a mean dbh of 17.8 cm, and a total basal area of 31.8 m² per hectare. Diameter size class distribution of the 10 most common tree species in the Bonayer Forest (Table 2) shows a generally even distribution of trees over several size classes. *Quercus alba* is present in all 5 size classes and is the only species so evenly distributed. *Liquidambar styraciflua*, *Liriodendron tulipifera*, and *Fagus grandifolia* are each distributed over 4 different size classes. Only 2 species, *Cornus florida* and *Carpinus caroliniana* are restricted to the smallest size group of 5–12.5 cm dbh. In these data, 8 individuals of 4 different species show dbh's of 23.0 inches (58.4 cm) or greater.

TABLE 3.—THE NUMBER (N), RELATIVE DENSITY (RD), RELATIVE FREQUENCY (RF), AND RELATIVE DENSITY PLUS RELATIVE FREQUENCY (RD&RF) VALUES FOR SAPLINGS AND SHRUBS IN BONAYER FOREST. DATA GATHERED FROM 60 2 × 10-M QUADRATS

Species	N	RD	RF	RD&RF
Saplings				
Cornus florida	142	4.3	7.1	11.4
Carpinus caroliniana	128	3.9	6.2	10.1
Fraxinus spp.	108	3.3	6.7	10.0
Acer spp.	67	2.0	6.2	8.2
Nyssa sylvatica	90	2.7	5.4	8.1
Carya spp.	62	1.9	6.0	7.9
Sassafras albidum	66	2.0	5.1	7.1
Liquidambar styraciflua	58	1.8	4.2	6.0
Prunus serotina	34	1.0	3.8	4.8
Fagus grandifolia	30	.9	3.6	4.5
Quercus velutina	28	.8	3.3	4.1
Liriodendron tulipifera	45	1.4	2.5	3.9
Quercus alba	31	.9	2.7	3.6
Ulmus spp.	17	.5	2.0	2.5
Castanea dentata	7	.2	1.3	1.5
Morus rubra	6	.2	.7	.9
Juniperus virginiana	2	.1	.4	.5
Cercis canadensis	1	.0	.2	.2
Ostrya virginiana	1	.0	.2	.2
Shrubs				
Euonymus americanus	1883	57.2	10.7	67.9
Smilax spp.	218	6.6	7.8	14.4
Corylus americana	83	2.5	3.6	6.1
Lindera benzion	56	1.7	3.8	5.5
Asimina triloba	68	2.1	1.6	3.7
Aralia spinosa	36	1.1	1.8	2.9
Vaccinium stamineum	10	.3	1.1	1.4
Vitis spp.	6	.2	.5	.7
Amelanchier arborea	5	.2	.5	.7
Rhamnus carolinianus	1	.0	.2	.2
Lonicera japonica			.9	

TABLE 4.—THE NUMBER (N), RELATIVE DENSITY (RD), RELATIVE FREQUENCY (RF), AND RELATIVE DENSITY PLUS RELATIVE FREQUENCY (RD&RF) VALUES FOR TREE AND SHRUB SEEDLINGS IN BONAYER FOREST. DATA GATHERED FROM 120 SQUARE METER QUADRATS

Species	N	RD	RF	RD&RF
Tree Seedlings				
Quercus spp.	238	28.9	14.1	43.0
Acer spp.	105	12.8	13.1	25.9
Liquidambar styraciflua	103	12.5	11.3	23.8
Liriodendron tulipifera	73	8.9	8.6	17.5
Nyssa sylvatica	31	3.8	6.0	9.8
Carya spp.	29	3.5	6.0	9.5
Carpinus caroliniana	30	3.6	5.3	8.9
Sassafras albidum	30	3.6	4.8	8.4
Fraxinus spp.	28	3.4	4.5	7.9
Cornus florida	26	3.2	4.0	7.2
Ulmus spp.	15	1.8	3.5	5.3
Prunus serotina	14	1.7	2.8	4.5
Amelanchier spp.	2	.2	.5	.7
Morus rubra	2	.2	.2	.4
Fagus grandifolia	1	.1	.2	.3
Unknown seedlings	6	.7	1.0	1.7
Shrub Seedlings				
Smilax sp.	43	5.2	7.0	12.2
Lindera benzion	27	3.3	5.3	8.6
Corylus americana	10	1.2	.5	1.7
Aralia spinosa	8	1.0	.5	1.5
Vaccinium stamineum	2	.2	.5	.7

When saplings and shrubs are ranked according to relative density plus relative frequency values, 3 genera appear as important understory trees in Bonayer Forest (Table 3). These are *Cornus florida* (11.4), *Carpinus caroliniana* (10.1), and *Fraxinus* spp. (10.0). *Euonymus americanus* is by far the most important shrub in the woods due to its high density of 6,357 individuals per acre (15,701/ha) and its frequency of 98.3 percent. Other common shrubs are *Smilax* sp., *Corylus americana*, *Lindera benzion*, and *Asimina triloba*. It is interesting to note that a few *Castanea dentata* root sprouts are present in the woods.

Relative density plus relative frequency values for seedlings in Bonayer Forest (Table 4) show that *Quercus* spp. (43.0), *Acer* spp. (25.9), and *Liquidambar styraciflua* (23.8) are the most dominant tree seedlings, while *Smilax* sp. (12.2) and *Lindera benzion* (8.6) are the most common shrub seedlings.

Woody vines present at Bonayer Forest and their frequencies in the seedling stratum are *Parthenocissus quinquefolia* (36.7), *Lonicera japonica* (10.8), *Rhus radicans* (10.8), and *Vitis* spp. (3.3). Herbaceous plants noted in the Bonayer woods are *Aralia racemosa*, *Ariseama triphyllum*, *Athyrium thelyteroides*, *Boehmeria cylindrica*, *Chimaphila maculata*, *Commelina communis*, *Desmodium* sp., *Houstonia* sp., *Impatiens biflora*, *Mitchella repens*, *Onoclea sensibilus*, *Osmunda regalis*, *Panicum*

TABLE 5.—THE NUMBER (N), RELATIVE DENSITY (RD), RELATIVE FREQUENCY (RF), RELATIVE DOMINANCE (RDo), AND IMPORTANCE VALUE (IV) OF TREES OVER 5 CM DBH IN THE SURROUNDING AREA

Species	N	RD	RF	RDo[1]	IV
Liriodendron tulipifera	32	15.6	8.9	24.4	48.9
Cornus florida	44	21.5	14.8	7.1	43.4
Quercus velutina	16	7.8	8.9	17.8	34.5
Nyssa sylvatica	20	9.8	9.9	9.9	29.6
Acer rubrum	14	6.8	7.9	9.3	24.0
Liquidambar styraciflua	13	6.3	6.9	5.1	18.3
Carya ovata	11	5.4	8.9	1.2	15.5
Quercus alba	9	4.4	4.0	3.0	11.4
Sassafras albidum	10	4.9	4.0	2.4	11.3
Prunus serotina	8	3.9	5.9	.9	10.7
Quercus borealis	3	1.5	2.0	6.4	9.9
Carya tomentosa	4	2.0	3.0	4.4	9.4
Carya glabra	3	1.5	2.0	3.9	7.4
Fagus grandifolia	6	2.9	2.0	.8	5.7
Carpinus caroliniana	4	2.0	3.0	.6	5.6
Juglans cinerea	1	.5	1.0	2.2	3.7
Cercis canadensis	2	1.0	2.0	.3	3.3
Fraxinus americana	1	.5	1.0	.1	1.6
Ulmus alata	1	.5	1.0	.1	1.6
Acer saccharum	1	.5	1.0	.0	1.5
Morus rubra	1	.5	1.0	.0	1.5
Rhamnus carolinianus	1	.5	1.0	.0	1.5

[1] Basal area equals 11.85 m^2.

sp., *Podophyllum peltatum*, *Polystichum acrostichoides*, *Sanicula canadensis*, *Smilacina racemosa*, *Thelypteris hexagonoptera*, and *Uvularia perfoliata*.

Tree data from 6 stands in the vicinity of Bonayer Forest (Table 5) give the total of 22 species which are included in the sample of the Surrounding Area. Of these, 17 species are common to both Bonayer Forest and the Surrounding Area. Surprisingly, *Cornus florida*, an understory tree, has the second highest importance value (43.4) in the Surrounding Area. This is due to its high relative density (21.5) and frequency (14.8) within the stands. The most important overstory trees in the Surrounding Area are *Liriodendron tulipifera* (48.9), *Quercus velutina* (34.5), *Nyssa sylvatica* (29.6) and *Acer rubrum* (24.0). *Liriodendron tulipifera* has the greatest relative dominance (24.4) of any species in the Surrounding Area. In comparing the 4 most important overstory species in the 2 forest areas only *Nyssa sylvatica* is among the most important canopy species in both Bonayer Forest and the Surrounding Area.

TABLE 6.—DIAMETERS (IN CENTIMETERS) OF THE 10 MOST COMMON TREE SPECIES IN THE SURROUNDING AREA SHOWING THE NUMBER OF TREES IN EACH CLASS. DATA BASED ON 205 TREES

Species	5.0–12.6	12.7–27.7	27.8–42.9	43.0–58.2
Cornus florida	32	13		
Lirodendron tulipifera	12	12	6	2
Quercus velutina	7	3	2	4
Nyssa sylvatica	7	9	4	
Acer rubrum	8	4		2
Carya ovata	10	1		
Liquidambar styraciflua	6	5	2	
Prunus serotina	8			
Quercus alba	7	1	1	
Sassafras albidum	5	5		

For the Surrounding Area, 205 individuals with a mean dbh of 15 cm are included in the sample quadrats. These figures give a density of 1,025 stems per hectare and a total basal area of 11.9 m^2 for trees in the Surrounding Area. Diameter class distribution of the 10 most common tree species in the Surrounding Area (Table 6) shows a less even distribution over the various size classes than did the data from Bonayer Forest. No trees are present in the 58.4 cm or greater classification, and only 2 species, *Liriodendron tulipifera* and *Quercus velutina* are represented in 4 different size classes. *Cornus florida* is represented by 44 individuals, but they are restricted to the 2 smallest size classes, 5–12.5 and 12.5–27.7 cm dbh.

Both forest areas show high Shannonn–Weaver diversity values for tree species. A value of 3.685 was computed for the Surrounding Area; a diversity of 4.057 was found for the Bonayer Forest. Linear regression analysis of tree species data from Bonayer Forest yielded a regression coefficient of slope (b) of 0.0759, which is another measure of diversity. When used in this manner, the smaller the slope the greater the diversity or the more species encountered per given number of individuals.

TABLE 7.—GROWTH RING ANALYSIS OF 18 WHITE OAK STUMPS

Diameter (cm)	Number of Rings
26.7	69
30.5	80
34.3	71
36.8	63
39.4	147
43.2	108
50.8	163
54.6	158
61.0	81
71.2 (double trunk)	84
72.4	132
73.7	136
76.2	184
78.7	156
88.9	139
99.1	172
104.2	181
116.9	207

The diameter and number of annual rings counted for 18 *Quercus alba* cut from Bonayer Forest during highway construction (Table 7) indicate a great variation in the number of rings counted for similar sized trees, but provided information as to the age of the trees. Of the 18 white oaks cut during highway construction, 8 had stump widths ranging from 50 to 79 cm and showed from 81 to 184 years of growth. The largest stump analyzed was 116.8 cm in diameter with 207 annual rings.

Among the 24 white oaks that fell within the 10- × 10-m quadrats, the range of dbh was 5.3–79.2 cm. Of these, 8 (33%) were of the size class 5.3–24.0 cm; 8 (33%) measured 25.7–47.8 cm; 7 (29%) showed dbh's of 52.8–71.1 cm; and 1 white oak measured 79.2 cm. A few large white oaks measured outside the quadrats gave dbh's of 83.8, 74.9, 67.3, 62.2, and 49.0 cm.

Eleven random tree height measurements gave an average of 28.5 m for an approximation of canopy height. The dbh was recorded for 7 of the trees, but not for the remaining 4. The species, dbh, and height of the 7 trees were: 1 *Fagus grandifolia* dbh of 39.8 cm and a height of 22.7 m, 2 *Liquidambar styraciflua* with dbh's of 53.3 and 59.2 cm corresponding to heights of 24.8 and 24.2 m, 2 *Liriodendron tulipifera* with dbh's of 37.8 and 35.6 cm corresponding to heights of 28.5 and 26.5 m, and 2 *Quercus alba* with dbh's of 71.1 and 78.7 corresponding to heights of 36.6 and 26.4 m. The 3 remaining *Liriodendron tulipifera* had heights of 29.9, 30.8, and 31.7 m. One *Quercus alba* measured 30.8 m in height.

The productivity of Bonayer Forest, as determined by collection of litter, seemed to be low, with very little organic matter being added to the forest floor annually. Collections from the 4 litter boxes averaged 251 g of leaves, stems, and fruits per square meter of forest floor. Of that total, leaf litter accounted for 229 g; stems, 15 g; and fruit material, 8 g.

Soil analysis of 30 soil samples gave a range of pH from 4.5 to 5.8 with a mean of 5.1. The average sand, silt, and clay content of the first 8 cm of soil was 11.3, 59.8, and 28.9 percent, respectively. The majority of the soil samples (22) fell within the silty clay loam texture class, 7 samples were classified as silt loam, and 1 sample was sandy clay loam (Foth and Jacobs 1964). There are no apparent differences in vegetation which may be correlated with differences in soil texture or soil pH within the Bonayer stand.

DISCUSSION AND CONCLUSIONS

Data in Table 1 indicate that Bonayer Forest may be characterized as an oak forest, primarily due to the importance of *Quercus alba* in the stand. *Q. alba* has the second highest density as well as the highest frequency and dominance of any species there. Other oaks included in data from the Bonayer Forest are *Q. velutina*, *Q. coccinea*, and an individual of an unidentified species. Together, the oaks have an importance value of 81.9 which makes up 27.3 percent of the total importance value (300) for all species. Accessory species which follow oak in importance in the Bonayer Forest stand are *Nyssa sylvatica*, *Carya ovata*, *Liquidambar sty-*

TABLE 8.—COMPARISON OF THE 6 MOST IMPORTANT TREE, SAPLING, AND SEEDLING GENERA IN BONAYER FOREST

Trees		Saplings		Seedlings	
Genus	IV	Genus	RD&RF	Genus	RD&RF
Quercus	83.5	*Acer*	8.2	*Quercus*	43.0
Carya	31.4	*Nyssa*	8.1	*Acer*	25.9
Nyssa	29.1	*Carya*	7.9	*Liquidambar*	23.8
Liquidambar	22.1	*Quercus*	7.7	*Liriodendron*	17.5
Liriodendron	20.3	*Liquidambar*	6.0	*Nyssa*	9.8
Acer	18.5	*Prunus*	4.8	*Carya*	9.5

raciflua, and *Liriodendron tulipifera*. The understory of the Bonayer Forest is characterized by the presence of *Cornus florida*.

Diameter size class distribution of the 10 most common tree species in the Bonayer Forest (Table 2) indicated that reproduction is taking place since canopy species are also present in the smaller size classes. The generally even distribution of trees over several size classes is evidence that the forest has not been disturbed in the recent past. *Cornus florida* and *Carpinus caroliniana* are both restricted to only the smallest size class, but this is to be expected, since they are typical understory species.

When overstory tree species present in in each size class (tree, saplings, seedlings) are grouped into their respective genera and subsequently compared, a high degree of similarity is evident between the composition of the canopy and the younger growth in Bonayer Forest (Table 8). Genera which are typically restricted to the understory (*Cornus*, *Carpinus*, *Fraxinus*, and *Sassafras*) and would not be expected to replace dead or dying canopy trees have been omitted from these data. The 6 most important genera in the canopy of Bonayer Forest are *Quercus*, *Carya*, *Nyssa*, *Liquidambar*, *Liriodendron*, and *Acer*. Of these genera, 5 are present in this relative position in the sapling layer, and all 6 are present in the seedling layer. In the sapling stratum, *Liriodendron* is not among the 6 most important genera since both *Prunus* and *Fagus* have higher relative density plus relative frequency values (Table 5). It is not unusual for *Liriodendron* to be less important in the sapling stage than in the canopy because it is shade intolerant and does not survive well under a closed canopy. The relative importance of the different genera is not the same throughout the seedling, sapling, and tree stages, but many factors affect the numbers, growth, and survival of seedlings so that the relative importance of different genera often changes over time. Nevertheless, it is obvious from an examination of the seedling and sapling composition at Bonayer Forest that the same genera are present in these younger stages as in the canopy, indicating that the tree composition of Bonayer Forest probably will be much the same in the future.

Euonymus americanus (strawberry bush) has a greater relative density plus relative frequency value (67.9) than any other sapling or shrub in Bonayer Forest (Table 5). Its unexpected density of 6,357 individuals per acre (15,701/ha) and frequency of 98.3 percent cannot be explained by reference to the literature, since little research has been published on this species. *Euonymus americanus* deserves further study to determine the reason for its great abundance in Bonayer Forest.

Tree data from the Surrounding Area (Table 5) show both similarities and differences in composition when compared to that of Bonayer Forest. In the Surrounding Area, *Liriodendron tulipifera* and *Quercus velutina* are the most dominant tree species in contrast to Bonayer Forest, where *Quercus alba* is the most dominant. When all the oaks in the data of the Surrounding Area (*Q. velutina*, *Q. alba*, and *Q. borealis*) are grouped, their collective relative domi-

TABLE 9.—COMPARISON OF THE IMPORTANCE VALUES OF THE 7 MOST IMPORTANT TREE GENERA IN THE BONAYER FOREST AND THE SURROUNDING AREA

Bonayer Forest		Surrounding Area	
Genus	IV	Genus	IV
Quercus	83.5	*Quercus*	55.8
Carya	31.4	*Liriodendron*	48.9
Nyssa	29.1	*Cornus*	43.4
Liquidambar	22.1	*Carya*	32.3
Liriodendron	20.3	*Nyssa*	29.6
Acer	28.5	*Acer*	25.5
Cornus	17.2	*Liquidambar*	18.3

nance value (27.2) and importance value (55.8) are higher than those of *Liriodendron*. The Surrounding Area, then, may be characterized as oak–tulip poplar with *Cornus florida*, *Nyssa sylvatica*, *Acer rubrum*, *Liquidambar styraciflua*, *and Carya ovata* as accessory species. It is apparent that oaks are dominant in both Bonayer Forest and the Surrounding Area; *Nyssa sylvatica*, *Liquidambar styraciflua*, and *Carya ovata* are accessory species common to both. Comparison of the 7 most important genera in the Bonayer Forest and the Surrounding Area (Table 9) shows that the same 7 genera (*Quercus*, *Carya*, *Nyssa*, *Liquidambar*, *Liriodendron*, *Acer*, *Cornus*) are the most important in both areas. This similarity in fundamental composition is to be expected of 2 forest areas in the same locality.

Two primary differences in composition between Bonayer Forest and the Surrounding Area seem to indicate that Bonayer Forest is a more mature and less disturbed forest stand than any stand in the Surrounding Area. One difference is that the importance values of *Quercus alba* and *Q. velutina* are approximately reversed in the 2 areas. In the Bonayer Forest data, *Q. alba* has an importance value of 61.3 and *Q. velutina* one of 12.6; in the Surrounding Area *Q. alba* has an importance value of 11.4 *Q. velutina* one of 34.5 (Tables 1, 2). A second difference between the areas is that *Liriodendron* is much more predominant in the Surrounding Area than in the Bonayer Forest. Among the 7 most important genera in the Bonayer Forest data, *Liriodendron* ranks fifth with an importance value of 20.3; in the data of the Surrounding Area, *Liriodendron* approached *Quercus* in status with an importance of 48.9 (Table 10). Both these differences probably are the result of selective cutting in the Surrounding Area, removing the larger *Q. alba*, and opening up the canopy so that shade intolerant *Liriodendron* and *Q. velutina* have become more prominent. Bonayer Forest shows no indication of previous disturbance by cutting. The composition of the Surrounding Area, in the absence of further disturbance, probably will approach that of the Bonayer Forest in time.

Distribution of diameter size classes for the 10 most common trees in the Surrounding Area provides further evidence that the stands in the Surrounding Area are younger and more disturbed than those in the Bonayer Forest (Table 6). This is obvious since no trees in the 58.4 cm or greater size class were present as in the data from Bonayer Forest (Table 2). The Surrounding Area shows a less even distribution of trees over the various size classes. In the Bonayer Forest sample, *Quercus alba* was represented in all 5 size classes, but it was present in only the first 3 classes in the sample of the Surrounding Area. This suggests that the larger *Q. alba* have been cut out of the Surrounding Area.

Growth ring analysis of *Quercus alba* trees cut during highway construction gives an estimation of the age of Bonayer Forest. From 81 to 184 annual growth rings were counted for 8 white oak stumps with dbh's of 50–80 cm. One-third of the white oaks included in the sample data showed dbh's within this same range, implying an equal age for these living trees. It follows, then, that Bonayer Forest has been in existence for more than 150 years.

According to ecological theory, quality, larger size, high diversity, and stability are typical of mature systems, while the

opposite characteristics, quantity, small individuals, low diversity, greater production are typical of young systems. Comparison of trees from the Surrounding Area, from Bonayer Forest, and from a virgin forest in Indiana support the statement that numbers of individuals decrease and size of individuals increase as a system matures. Lindsey et al. (1958) found that in an impressive virgin forest called Donaldson's Woods, some trees reached up to 132 cm (52 inches) in dbh, the mean dbh was 29 cm (11.4 inches) there were 294 stems per hectare, and there was a basal area of 28.7 m^2/ha. Going from younger to more mature, the Surrounding Area, Bonayer Forest, and Donaldson's Woods show increasing mean dbh's of 15.2, 17.8, and 29.0 cm (6.0, 7.0, and 11.4 inches), respectively. Similarly, the 3 forest areas exhibit decreasing numbers of individuals, of 1,025, 713, and 294 stems per hectare (415, 289, and 123 stems per acre), respectively. It seems that basal area of a stand is not necessarily correlated with maturity since the basal area of the Surrounding Area of 29.4 m^2/ha is almost identical to that of Donaldson's Woods, while the basal area of Bonayer Forest is greater than either being 31.9 m^2/ha. This comparison of the 3 forest areas suggest that although Bonayer Forest is more mature than the Surrounding Area, it does not exhibit a mean dbh and density which are characteristic of a virgin forest.

In general, high species diversity is considered characteristic of mature systems. According to Shannonn–Weaver diversity index, Bonayer Forest shows a slightly higher tree species diversity (4.057) than does the Surrounding Area (3.685). Since an almost equal number of species was present in both samples, the lower diversity value for the Surrounding Area is due primarily to less evenness in the apportionment of individuals among the species. Linear regression analysis of species data from the Bonayer Forest gave a slope (b) of 0.0759, where lower slope values signify higher diversity. Monk and McGinnis (1966), in a study of forest community types in Florida, found that known successional communities such as sandhills, cypress heads, and flatwoods gave slopes ranging from 0.1275 to 0.2262, while known climax communities such as the southern mixed hardwoods gave slopes of 0.0554 to 0.1160. The slope of 0.0759 calculated for the Bonayer Forest falls within the range of slopes which Monk and McGinnis found characteristic of known climax types. This indicates that Bonayer Forest has a high diversity typical of climax communities.

The small amount of litter deposited on the forest floor could be used to support the idea that the Bonayer Forest is a stand that has neared homeostasis. Although the litter samples were limited in number, the amount collected in the litter traps seemed consistent with the appearance of litter on the forest floor. The value of 251 g/m^2 of litter in 1972–1973 is much less than the 600 g/m^2 of litter deposition obtained by Bray and Gorham (1964) for warm temperate forests between 34 and 38 degrees North latitude. This is evidence that the Bonayer Forest has low productivity, or that the community energetics are such that the gross production to biomass ratio (P/B ratio) is low. A low P/B ratio is typical of a mature system, one which is approaching homeostasis.

A species list compiled by Hussey (1876) from collections in the western part of Barren County, in the cave region, and in Edmonson County contains all of the tree species present in the Bonayer Forest data, as well as 22 of 32 different species of genera of shrubs, woody vines, and herbs. Hussey stated that on the more level parts of Barren County, trees were still small in size and few in species, which he felt was evidence of the recent introduction of forest growth into the region. He noted that the largest trees in this section of Barren County were oaks 15 inches (38 cm) in diameter. This may be contrasted to white oaks which attained enormous development along the Green River, forming "immense trunks, reaching to a height

of eighty feet, where they still seem to be three feet in diameter." Most of the species present in the Bonayer Forest, then, are identical to those found in the region nearly 100 years ago. The difference in size between trees in Barren County and elsewhere at that time may explain why trees in the Bonayer Forest do not approach the tremendous size expected of a virgin forest.

Bonayer Forest is included within the Mississippian Plateau of the Western Mesophytic Forest Region by Braun (1964), which she designated as a transition region characterized by a "mosaic pattern of climax vegetation types" rather than a single climax type. Braun indicated the dominance of oak forest over much of the Mississippian Plateau. Accessory species which vary from place to place may include sugar maple, beech, tulip tree, chestnut, hickories, white ash, and occasional other species. In sampling the canopy trees at one location in Barren County, Braun found that oaks formed half of the canopy with maple and beech the next most frequent. If all trees greater than 30 cm dbh in the Bonayer Forest data are considered, oaks form 51.5 per cent of the canopy with tulip tree as the next most frequent. The designation of Bonayer Forest as an oak forest is therefore consistent with generalizations and specific data presented by Braun.

This study has provided evidence that Bonayer Forest is typical of what the vegetational composition would be in south central Kentucky if this area were left undisturbed by man. The composition of the forest is oak, with black gum, shagbark hickory, sweetgum, and tulip poplar as accessory species. Bonayer Forest is similar in composition to stands in the Surrounding Area, but is a more mature forest system. The same genera of trees are present in the younger growth stages as are present in the canopy, indicating that the canopy trees are replacing themselves and that the Bonayer Forest represents a climax vegetation type.

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