COMPOSITION AND STRUCTURE OF AN OLD-GROWTH OAK-HICKORY FOREST IN SOUTHERN MICHIGAN OVER 20 YEARS[1]

William E. Hammitt and Burton V. Barnes[2]

Abstract.--A 150-year-old oak hickory forest in southern Michigan was surveyed vegetatively in 1968 and again in 1988. Composition, density, and stand structure were determined for all tree species above 1-in dbh. Woody stems less than 1 in dbh were identified and abundance was determined. In 1968, 85% of the canopy species consisted of Quercus rubra, Q. alba, and Q. velutina, with Q. alba comprising 44% of the oaks. Acer rubrum, Q. alba, Prunus serotina and Ulmus americana were most prominent in the subdominant canopy, and A. rubrum was most abundant in the understory. Acer saccharum was the most dominant ground cover species. Major changes after 20 years show less Q. velutina in the canopy, due to death and blow down, and less Sassafras albidum, Prunus serotina, and Q. alba in the intermediate canopy. Acer saccharum has been the most dynamic species in the understory during the period, and Fraxinus americana the most common ground cover species.

INTRODUCTION

Oak-hickory forests extend northward into the southern third of lower Michigan as part of the "Prairie Peninsula" section of the Oak-Hickory Forest region (Braun 1950). These forests were intermixed with prairie communities. Küchler (1964) shows widespread areas of oak-hickory forest as the potential natural vegetation of Southeastern Michigan. In addition, beech-sugar maple forests occupied the mesic sites of glacial moraine with their relatively heavy-textured soils (Albert et al. 1986). Oak-hickory forests occupied the fire-prone, dry and dry-mesic sandy sites on level to gently rolling glacial outwash and hilly ice-contact terrain. Much of the former beech-sugar maple forest has been cleared for agriculture leaving scattered, cut-over tracts of oak-hickory forest. Radrick Forest is one such remnant stand.

Old-growth forests--their composition, structure and management--are of increasing importance in forest management today (Crow 1988; McGee 1986; 1984; McCune and Cottam 1985; Romme and Martin 1982; Lorimer 1980). Although the literature on central hardwoods contains several detailed descriptions of forest stand composition and structure (Parker et al. 1985; Nigh et al. 1985; Della-Bianca 1983; Muller 1982), few studies are restricted to old-growth oak-hickory forests in Michigan.

The major purpose of this paper is to provide baseline information on the species composition and structure of a 150-year-old oak-hickory forest in southeastern Michigan, first sampled in 1968. The forest was re-surveyed in 1987-1988, using the permanent sample plots of 1968. Specific objectives of the paper are to: (1) describe the woody species composition, size classes, and forest types as they appeared in 1968 and (2) examine the major changes that have occurred in the forest over the last 20 years.

STUDY AREA

The Radrick Forest is in Washtenaw County (Ann Arbor and Superior townships) in southeastern Michigan. The forest is part of the Matthaei Botanical Gardens of the University of Michigan, located 5 mi east-northeast of Ann Arbor. The 35-acre upland oak-hickory forest is mostly on glacial-outwash and ice contact sandy soils (Boyer and Fox series), but about 10 acres occupy till soils of the Miami series. Texture of the soils are primarily sandy loams and sandy clay loams (Hammitt 1969).

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[2] Professor, Department of Forestry, Wildlife, and Fisheries, University of Tennessee, Knoxville, TN 37901 and Professor, School of Natural Resources, University of Michigan, Ann Arbor, MI 48105.

The General Land Office Survey for Radrick Forest was conducted in 1819. The original survey notes for a section corner within the study area described the vegetation as "black oak, red oak, white oak, hickory, and black walnut--undergrowth of hazel and sassafras." The diameters of the witness trees were: black oak--20, 24, 36, 40 inches, 20-in lynn (basswood), and a 13-in white oak. The land was described as being a little hilly. Radrick Forest was similar in 1968, except for smaller diameter trees and the presence of a few black walnut (Juglans nigra L.).

History of the forest suggests that it was logged in the 1820s, as tree ring counts made of seven dead trees logged[1] in the 1960s ranged from 129 to 140 years. An 1827-1829 map of the area also shows a road passing through the middle of the forest, and a sawmill on a stream within 1/2 mile of the study area. After the presumed initial logging of the forest, the area was owned by two families for over 100 years, with only a few selected trees being removed. Since 1939, the forest has been managed as a preserve.

METHODS

Field Measurements

The forest was type-mapped in 1968, based on a 20% strip cruise of dominant tree species. In addition, woody species were surveyed in 25-stratified randomly located plots, 10 by 20 meters (1/20 acre) . All tree species above 1 in dbh (diameter at breast height, 4.5 ft) were identified, measured, and recorded by 1 in diameter classes.

Nested quadrats of 0.5 by 8 meters (milacre) were located in each corner of the 25 plots for the purpose of sampling small woody plant saplings and reproduction under 1 in dbh. The amount of tree reproduction in two classes of woody ground cover was determined: (1) tall ground cover-plants under 1 in dbh but over 1 ft tall, and (2) short ground cover-plants under 1 ft in height.

In 1987-1988, the 25-permanent plots and nested quadrats were re-surveyed, using the same procedures and methods as in 1968. However, the 20% strip cruise could not be replicated, as the exact location of the strip cruise was not documented in 1968.

Data Analysis

Forest types were analyzed at two levels, overstory and understory. Dominant canopy and understory tree species were used to map the boundaries of the major forest types. Relative density and board foot volume (Scribner rule) were calculated to help define the forest types.

Frequency and density of tree species were analyzed by forest type and by five size classes: (1) trees $\geq$ 12 inches dbh (dominant canopy), (2) trees 4 inches to 11.9 inches dbh (subdominant canopy), (3) saplings 1 to 3.9 inches dbh (understory), and (4) woody plants less than 1 in dbh but over 1 ft tall (tall ground cover), and (5) woody plants under 1 ft in height (short ground cover).

Relative densities and frequencies of species were calculated using methods of Curtis (1959) and Curtis and McIntosh (1951). Relative density was computed as the number of trees of any species relative to the total number of trees in any sample. Relative frequency was equal to the number of plots a species occupied relative to the total number of plots it could have occupied.

RESULTS

Canopy Composition and Forest Types

Radrick Forest is dominated by three species of oak: white (Quercus alba L.), black (Q. velutina Lam.), and red (Q. rubra L.). Of trees 10 in and greater dbh in 1968, 85.8% consisted of white, black, and red oak (Table 1). These same three species made up 91.8% of the board foot volume. White oak was the most common canopy species (density), whereas black oak was the most dominant in terms of volume. Pignut hickory (Carya glabra Mill.) is the only other species of much occurrence in the canopy.

Three forest types, White Oak/Mixed Hardwoods, Black Oak/Mixed Hardwoods, and Red-Black Oak/Red Maple were distinguished (Table 2). The White Oak/Mixed Hardwoods type consisted of mostly white oak in the 12- to 18- in size class and a few pignut hickory (Carya glabra Mill.), black cherry (Prunus serotina Ehrh.), American elm (Ulmus americana L.), and sugar maple (Acer saccharum Marsh.).[1] The Black Oak/Mixed Hardwoods type contained about an equal number of white and black oak, but the black oak was much larger (dbh) and dominant (note board foot volume). Pignut hickory and black cherry were the most prominent other species. The Red-Black Oak/Red Maple type was characterized by a canopy of red and black oak and an intermediate canopy of red maple (Acer rubrum L.). The greater proportion of red oak present in the canopy and red maple in the subdominant canopy distinguishes this type from the other two. The Red-Black

[1] Seven trees were cut because they were dead and near roadways. They were primarily black oak (Quercus velutina Lam.).

[1] Black maple (Acer nigrum Michx. f.) was included with sugar maple.

Table 1.--Proportion of oak composition in Radrick Forest, based on trees 10 inches and greater in diameter at breast height, 1968.[1]

Species	Number of trees	Relative density (%)	Total relative density (%) of oak	Board foot volume[2]	Relative volume (%)	Total relative volume (%) of oak
Quercus rubra	65	14.7		17,471	23.4	
Quercus alba	195	44.0	85.8	18,716	25.1	91.8
Quercus velutina	120	27.1		32,310	43.3	
Other species	63	14.2		6,165	8.2	

[1] Based on a 20% (8 acre) strip cruise, 10 in. DBH limit.
[2] Board foot volumes (Scribner scale) are for the 8 acre sample, not entire forest.

Table 2.--Composition of Radrick Forest subtypes, based on trees 10 inches and greater in diameter at breast height, 1968.[1]

	White Oak/Mixed Hdwd.		Black Oak/Mixed Hdwd.		Red-Black Oak/Red Maple	
Species	No. of trees	Board ft. vol./acre[2]	No. of trees	Board ft. vol./acre	No. of trees	Board ft. vol./acre
Quercus rubra	4	537	6	1,844	45	4,491
Quercus alba	109	4,451	25	2,936	50	1,620
Quercus velutina	35	3,159	20	4,928	65	6,441
Carya grabra	7	348	3	289	14	431
Acer rubrum	-	-	-	-	10	367
Prunus serotina	4	233	3	54	6	300
Ulmus americana	3	32	1	43		
Acer saccharum	3	24	--	--	1	36
Juglans nigra	1	83	1	152	1	65
Carya ovata	--	--	--	--	1	65
Tilia americana	1	30	--	--		
Fagus grandifolia	--	--	--	--	1	18

[1] Based on a 20% (8 acre) strip cruise, 10 in. DBH limit.
[2] Board foot volumes (Scribner scale) per acre are based on the proportion of the total 8 acre sample within each subtype sample.

Oak/Red Maple type is on the till portion of the study area, and probably accounts in large part for its major difference in species composition compared to the other types.

Density, Frequency, and Size Classes

While the timber strip cruise conducted in 1968 does not allow for an exact replicate survey and data comparison in 1988, the permanent plot survey does permit a comparison of each type over time. Number of trees (density), frequency with which species occurred (number of plots), and distribution by the size classes of understory (1-3.9), subdominant canopy (4-11.0) and dominant canopy (12+), in dbh are reported in Tables 3 (1968) and 4 (1988).

The dominant canopy of the forest was dominated by about the same relative density of oak species in 1968 (88%) and 1988 (82%). However, there was a decrease in the number of red (40%) and black (37%) oaks in this size class and an increase (27%) of white oak trees. This change has resulted from the death and blow-down of some mature red and black oaks and the ingrowth of white oak from the 4-11.9 class into the 12+ in dbh class.

The subdominant canopy in 1968 was characterized by white oak at the larger diameters and black cherry, American elm, red maple, sassafras (Sassafras albidum Nutt.), and sugar maple at various diameters. Of particular importance is the absence of black oak and the near absence of red oak in this category and the presence of maple species. The most obvious changes in the last 20 years have been the reduction in relative density of white oak (55%), sassafras (59%), American elm (39%), and the increase in sugar (44%) and red (14%) maple. Of the decrease of 24 white oak trees in this dbh class, 8 moved up into the 12+ class and 16 died. During the 1987-88 survey, 4 dead white oaks could still be identified by their bark remains. Several dead stems of sassafras and American elm were also identifiable in the plots. Concerning the increase in maples, sugar maple increased in frequency in 3 plots, and red maple decreased in 2 plots.

Table 3.--Density and frequency by size class of tree species in Radrick Forest in 1968.[1]

Species	Understory		Subdominant Canopy		Dominant Canopy		Total Density N/%
	Density N/%[2]	Frequency N/%	Density N/%	Frequency N/%	Density N/%	Frequency N/%	
Quercus alba	--	--	44/19	18/72	30/45	15/60	74/13
Quercus rubra	6/2	6/24	2/0.9	1/4	10/15	6/24	18/3
Quercus velutina	--	--	--	--	19/28	14/56	19/3
Carya glabra	4/1	2/8	5/2	5/20	4/6	3/12	13/2
Carya ovata	11/4	8/32	6/3	5/20	1/2	1/4	18/3
Prunus serotina	23/8	13/52	39/17	12/48	2/3	2/8	64/11
Juglans nigra	1/0.3	1/4	--	--	1/2	1/4	2/.03
Acer rubrum	114/39	11/44	42/18	13/52	--	--	156/26
Acer saccharum	10/3	9/36	18/8	11/44	--	--	28/5
Acer nigrum	10/3	7/28	4/2	3/12	--	--	14/2
Ulmus americana	23/8	13/52	31/13	15/60	--	--	54/9
Sassafras albidum	17/6	7/28	29/12	8/32	--	--	46/8
Ostrya virginiana	37/13	12/48	3/1	3/12	--	--	40/7
Tilia americana	11/4	7/28	4/2	4/16	--	--	15/3
Fraxinus americana	6/2	2/8	6/3	5/20	--	--	12/2
Carya cordiformis	8/3	6/24	--	--	--	--	8/1
Cornus florida	6/2	4/16	--	--	--	--	6/1
Amelanchier sp.	2/0.7	1/4	--	--	--	--	2/0.3
Crataegus spp.	2/0.7	2/8	1/0.4	1/4	--	--	3/0.5

[1] Based on 25 plots, 10 x 20 meters.
[2] Numbers to right of slash bars are relative densities and frequencies, expressed as percentages within each size class sample.

Table 4. Density, frequency, and size class of tree species in Radrick Forest in 1988.[1]

Species	Understory		Subdominant Canopy		Dominant Canopy		Total Density N/%	% Change Density 1968-88
	Density N/%[2]	Frequency N/%	Density N/%	Frequency N/%	Density N/%	Frequency N/%		
Quercus alba	--	--	20/9	12/48	38/55	16/64	58/10	-22
Quercus rubra	4/1	3/12	--	--	6/9	5/20	10/2	-44
Quercus velutina	--	--	--	--	12/18	12/48	12/2	-37
Carya glabra	1/0.3	1/4	4/2	3/12	4/6	4/16	9/2	-31
Carya ovata	10/3	7/28	7/4	6/24	--	--	17/3	-6
Prunus serotina	32/9	11/44	29/17	12/48	3/7	3/12	64/11	0
Juglans nigra	--	--	--	--	1/1	1/4	1/0.2	-50
Acer rubrum	98/28	14/56	48/27	11/44	--	--	146/24	-6
Acer saccharum	41/12	14/56	26/14	14/56	1/1	1/4	68/11	+143
Acer nigrum	10/3	6/24	2/1	2/8	--	--	12/2	-14
Ulmus americana	51/15	15/60	19/11	11/44	1/1	1/4	71/12	+33
Sassafras albidum	3/0.9	3/12	12/7	7/28	--	--	15/3	-67
Ostrya virginiana	63/18	15/60	5/2	4/16	--	--	68/11	+70
Tilia americana	17/5	10/40	7/4	6/24	--	--	24/4	+60
Fraxinus americana	4/1	3/12	3/2	3/12	--	--	7/1	-42
Carya cordiformis	4/1	3/12	--	--	--	--	4/0.6	-50
Cornus florida	7/2	4/16	--	--	--	--	7/1	+17
Amelanchier sp.	1/0.3	1/4	--	--	--	--	1/0.2	-50
Crataegus spp.	1/0.3	1/4	1/0.6	1/4	--	--	2/0.3	-33

[1]Based on 25 plots, 10 x 20 meters.
[2]Numbers to right of slash bars are relative densities and frequencies, expressed as percentages within each size class sample.

In the understory class, red maple and hop-hornbeam (Ostrya virginiana (Mill.) K. Koch) were most dominant in 1968, and black cherry and American elm were frequent in over 50% of the plots sampled. During the last 20 years, density of stems increased 20%, due to the opening of the forest canopy by mortality among upper canopy oak species. Sugar maple increased in density by 310%, American elm by 122%, and hop-hornbeam by 70%. Sassafras showed the largest decrease in both density and frequency.

An examination of total density (all size classes combined) shows the major changes over the last 20 years to be a decrease in sassafras (67%), red oak (44%), white ash (Fraxinus americana L.) (42%), black oak (37%) and pignut hickory (31%). Red maple decreased by only about 6%. Increasing in density were sugar maple (143%), hop hornbeam (70%), American elm (33%), and basswood (Tilia americana L.) (Table 4).

Reproduction of Tree Species

Sugar maple was the most common seedling in Radrick Forest in 1968, in terms of both number of stems and frequency (Table 5). However, 85% of the plants were in the short ground cover class (less than 1 ft in height). Other most common species, in descending order, were red maple, American elm, black cherry, and red oak. In addition, the distribution of sugar and red maple reproduction in the three forest types of the forest were quite distinct. Although sugar maple[1] occurred in all three types, 79.5% of the plants occurred in the White Oak/Mixed Hardwoods portion of the forest. Red maple, in contrast, did not occur in the White Oak/Mixed Hardwood type. It was primarily in the Red-Black Oak/Red Maple type (91% density, 85% frequency).

The biggest change in woody ground cover during the last 20 years has been a large increase in white ash seedling density (2060%) and frequency (56%) (Table 6). White ash was present in only 9% of the milacre plots in 1968, compared to 65% in 1988. Most of the ash reproduction occurred in the western portion of the forest, where an adjacent 60-year old stand, with considerable ash, serves as an ample seed source. However, little of the white ash has advanced into the understory and subdominant size classes over the 20-year period (Table 4 shows a 42% decrease in density for the period). White ash can be a very transient species in the seedling class over time, due to abundant seed years. The only other species besides white ash to increase in density since 1968 has been bitternut hickory (Carya cordiformis (Wang.) K. Koch). The most noticeable decreases have been red maple (92%), sassafras (100%), and black cherry (64%). Red maple reproduction dropped from 244 specimens in 1968 to only 20 in 1988, and no sassafras seedlings were present in 1988. Although sugar maple and American elm are still abundant, both show density decreases of approximately 20% in 1988.

[1]Seedlings of Acer nigrum and Acer saccharum are considered together.

DISCUSSION AND CONCLUSIONS

Radrick Forest is old-growth in the sense that it's overstory is dominated by remarkably large and old oaks relative to those of the surrounding countryside. Having been heavily cut in the late 1820s, it is not an example of true pre-settlement old-growth. However, it's overstory composition is relatively similar to the old-growth oak-hickory forests of pre-settlement time.

Overall, the successional trend is toward mesophytic species not oaks--especially sugar and black maples. American beech is totally lacking in the understory and ground cover; only one beech (16 in dbh) occurs in the entire forest. McGee (1986) and Romme and Martin (1982) report a similar pattern in successional change due to tree fall in old-growth forests. More specifically, mature black and red oak in the 20+ in diameter classes are dying, and white oak in the 4 to 10 in dbh classes are showing a rapid decline. Whereas the loss of the mature black and red oak is expected, there is less of a reason for the decline of the white oak. It may be the intolerance of white oak in this size class, due to not occupying space in the canopy. Also showing a rapid decline over the last 20 years has been sassafras, a species intolerant to low light intensity below an upper canopy.

Sugar maple (including black maple) has been the most dynamic species during the period. It has shown the most rapid increase in density, frequency, and growth (diameter) of any major tree species. It is increasing in frequency in the subdominant canopy class (27%), whereas red maple seems to be decreasing slightly (15%). Also, the larger sugar maples showed more rapid diameter growth since 1968 than did the large red maples.

It is anticipated when Radrick Forest is re-surveyed again in 20 years that most of the black oak will be gone and that red and white oak, though reduced in number, will be the dominant canopy species, particularly white oak. Sugar maple will be the dominant in the subdominant overstory, except on the till soils (Red-Black Oak/Red Maple type), where red maple will continue to increase in density and dominance. Basswood should also become more common in the understory (1-3.9 in dbh) during the next 20 years (54% increase in density over last 20 years). Beech will probably not increase appreciably during the period due to lack of seed source.

Table 5.--Reproduction of tree species in Radrick Forest, by size class and frequency of occurrence, in 1968.

Species	Short Ground Cover N	Tall Ground Cover N	Total[1] Density N/%	Frequency[2] %
Acer saccharum/A. nigrum	232	41	273/24	64
Acer rubrum	181	63	244/22	42
Ulmus americana[3]	97	125	222/20	42
Prunus serotina	122	84	206/18	49
Quercus rubra	36	15	51/6	27
Quercus alba	1	9	10/0.9	4
Sassafras albidum	11	31	42/4	17
Carya glabra	15	5	20/2	15
Carya ovata	5	14	19/2	15
Fraxinus americana	3	17	20/2	9
Tilia americana	5	7	12/1	10
Carya cordiformis	1	5	6/0.5	6
Juglans nigra	--	1	1/0	1
Morus alba	--	1	1/0	1

[1]Numbers to right of slash bars are relative densities, expressed as the proportion (%) of each species compared to the number of stems present for all species.
[2]Frequency defined as the percentage of milacre plots that a species occurred.
[3] Ulmus americana was not separated from Ulmus rubra at the seedling stage.

Table 6.--Reproduction of tree species in Radrick Forest, by size class and frequency of occurrence, in 1988.

Species	Short Ground Cover N	Tall Ground Cover N	Total[1] Density N/%	Frequency[2] %	% Change Density, 1968-88
Acer saccharum/A. nigrum	61	156	217/22	54	-21
Acer rubrum	10	10	20/2	9	-92
Ulmus americana[3]	96	86	182/18	45	-18
Prunus serotina	26	49	75/8	37	-64
Quercus rubra	14	2	16/2	13	-69
Quercus alba	4	0	4/0.4	4	-60
Sassafras albidum	--	--	--	--	-100
Carya glabra	7	4	11/1	9	-45
Carya ovata	7	5	12/1	11	-37
Fraxinus americana	253	179	432/44	65	+2060
Tilia americana	4	5	9/1	6	-25
Carya cordiformis	9	3	12/1	8	+100
Juglans nigra	--	--	--	--	--
Morus alba	--	--	--	--	--
Acer negundo	0	1	1/0.1	1	--

[1]Numbers to right of slash bars are relative densities, expressed as the proportion (%) of each species as compared to the number of stems present for all species.
[2]Frequency equals the percentage of milacre plots that a species occurred.
[3]Ulmus americana was not separated from Ulmus rubra at the seedling stage.

Concerning the woody ground cover, sugar and black maple are expected to continue their dominance. The role of white ash is uncertain. While a prolific reproducer, it does not seem to be recruited into the understory class in the mature oak stand.

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